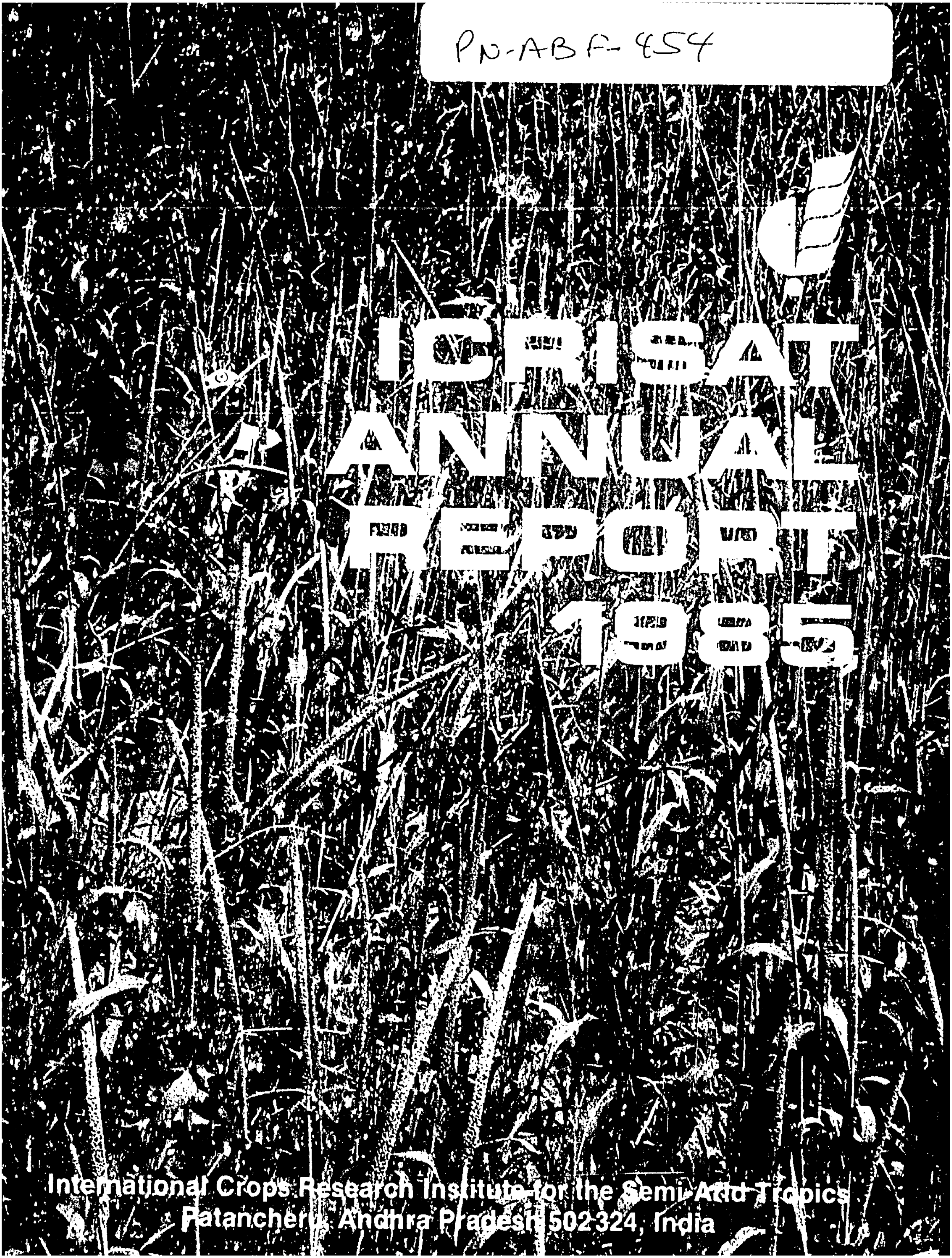


ICRISAT ANNUAL REPORT 1985

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

Cover: A well-managed field of the high-yielding pearl millet, CIVT, at ICRISAT Sahelian Center, Niger, shows the potential of research to improve crop production in the region.

ICRISAT
ANNUAL REPORT 1985

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O., Andhra Pradesh, India

1986

Published by
International Crops Research Institute
for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India

The International Crops Research Institute for the Semi-Arid Tropics is a nonprofit scientific educational institute receiving support from donors through the Consultative Group on International Agricultural Research. Donors to ICRISAT include governments and agencies of Australia, Belgium, Canada, Federal Republic of Germany, Finland, France, India, Italy, Japan, Netherlands, Nigeria, Norway, People's Republic of China, Sweden, Switzerland, United Kingdom, United States of America, and the following international and private organizations: Arab Bank for Economic Development in Africa, Asian Development Bank, International Development Research Centre, International Fertilizer Development Center, International Fund for Agricultural Development, The European Economic Community, The Ford Foundation, The Leverhulme Trust, The Opec Fund for International Development, The Population Council, The Rockefeller Foundation, The World Bank, and the United Nations Development Programme. Information and conclusions in this publication do not necessarily reflect the position of the aforementioned governments, agencies, and international and private organizations.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

ISSN 0257-2478

ICR 86-0029

AY

ICRISAT's Objectives

ICRISAT's mandate is to:

1. Serve as a world center for the improvement of grain yield and quality of sorghum, millet, chickpea, pigeonpea, and groundnut and to act as a world repository for the genetic resources of these crops;
2. Develop improved farming systems that will help to increase and stabilize agricultural production through more effective use of natural and human resources in the seasonally dry semi-arid tropics;
3. Identify constraints to agricultural development in the semi-arid tropics and evaluate means of alleviating them through technological and institutional changes; and
4. Assist in the development and transfer of technology to the farmer through cooperation with national and regional research programs, and by sponsoring workshops and conferences, operating training programs, and assisting extension activities.

About This Report

This Annual Report covers the 1985 calendar year. It includes work done at ICRISAT Center near Hyderabad, India, at research stations on the campuses of agricultural universities in different climatic regions of India, and at national and international research facilities in nine countries of Africa, Mexico, Syria, and Pakistan where ICRISAT scientists are posted. Pertinent agroclimatic information is presented in a new section entitled Agroclimatic Environment.

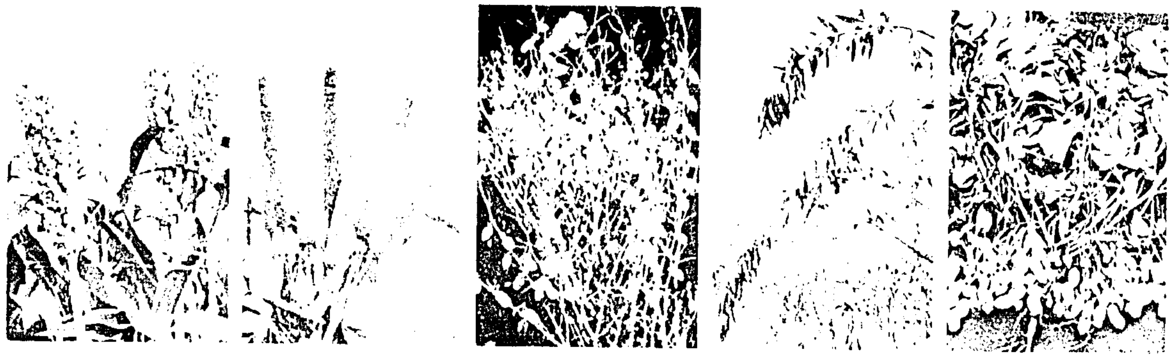
The crop improvement programs are presented as interdisciplinary reports on problem areas to better reflect the interactive nature of our scientists' work. For the first time the work of our Farming Systems and Economics programs is presented as a single section on Resource Management following their merger towards the end of 1985. Research by our scientists and cooperative programs outside India is reported with the relevant crop or discipline. Detailed reporting of the extensive activities of ICRISAT's many research support units is beyond the scope of this volume, but a comprehensive coverage of ICRISAT's core research programs is included. More details of the work reported here are given in individual program publications, available from the research program concerned. Offprints of individual sections of this Annual Report also are available from the programs.

ICRISAT now uses Systeme international d'unites (SI) in its publications. Throughout this Report, the variability of estimates is shown by including standard error (SE); on graphs representing the mean of several observations, the standard error is shown by a bar (I). In discussing levels of probability in the text, significance is generally mentioned at the 5% level; where the level differs, it is indicated parenthetically. Levels of probability are shown in tables by asterisks: * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$. Unless otherwise specified, available phosphorus (P) refers to the amount of phosphorus extracted from soil by Olsen's method, using 0.5 M $NaHCO_3$ as the extractant.

A listing of ICRISAT plant materials named by ICRISAT Plant Material Release Committee appears at the end of this Report.

Contents

ICRISAT's Five Crops



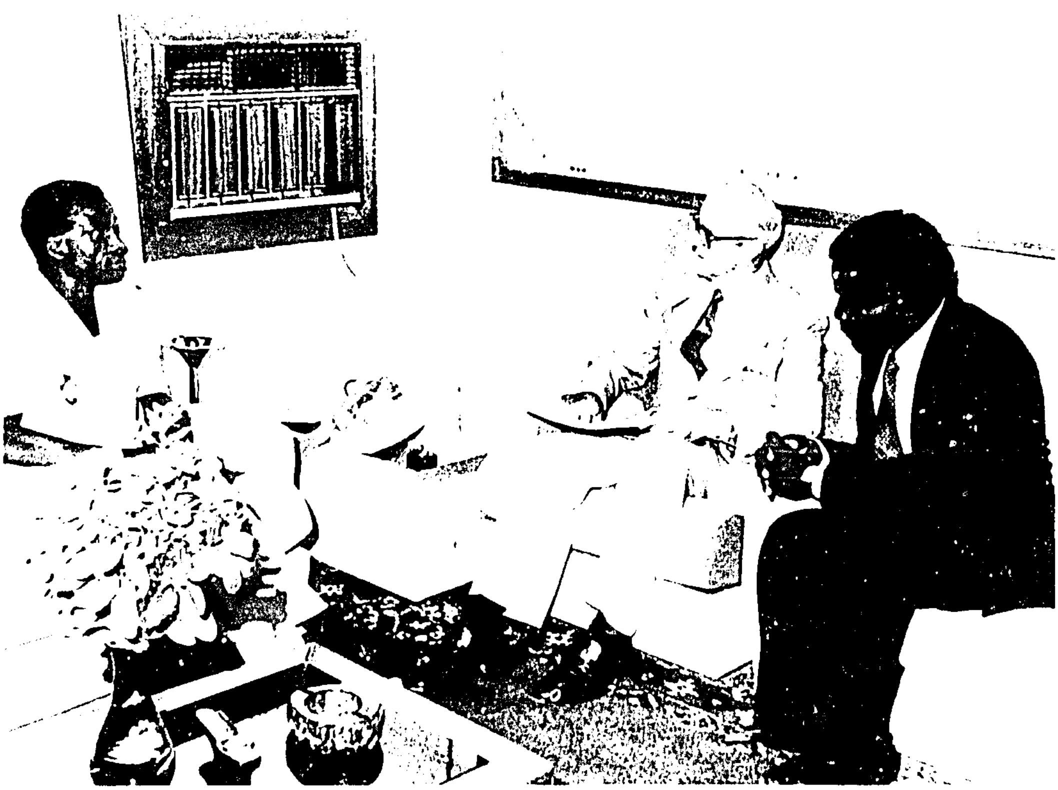
Latin	*Sorghum bicolor* (L.) Moench	*Pennisetum americanum* (L.) Leeke	*Cicer arietinum* L.	*Cajanus cajan* (L.) Millsp.	*Arachis hypogaea* L.
English	Sorghum, durra milo, shallu, kafir corn, Egyptian corn, great millet, Indian millet	Pearl millet, bulrush millet, cattail millet, spiked millet	Chickpea, Bengal gram, gram, Egyptian pea, Spanish pea, chestnut bean, chick, caravance	Pigeonpea, red gram	Groundnut, peanut
French	Sorgho	Petit mil	Pois chiche	Pois d'Angole, pois cajan	Arachide
Portuguese	Sorgo	Painco, perola	Grao-de-bico	Guando, feijao-guando	Amendoim
Spanish	Sorgo, zahina	Mijo perla, mijo	Garbanzo, garavance	Guandul	Maní
Hindi	Jowar, jaur	Bajra	Chana	Arhar, tur	Mungphali

Introduction

For ICRISAT, 1985 was a year of consolidation and progress. Suggestions from two external reviews in 1984 were implemented. Research on all five ICRISAT mandate crops was given a more strategic and sharper focus. Efforts to support national programs through training and long-term research were strengthened, at ICRISAT Center and at our regional programs and projects, particularly in Africa.

We moved further toward a cooperative network involving national, regional, and international institutions. The ICRISAT Sahelian Center (ISC) in Niger and the regional cereals improvement project in Zimbabwe stepped up cooperative research activities in western and southern Africa.

A successful meeting was held in September to explain to donors' representatives ICRISAT's work in West Africa and obtain support and assistance for



The President of Niger (left) discusses the problems relating to agriculture in Niger with the ICRISAT Director General (center) and Acting Director, ISC (right).

An ICRISAT Center scientist (kneeling) explains to donors' representatives his research on symbiotic fungal effects on crop growth in the Sahel.

funds to build the ISC. The meeting focused on the harsh environmental conditions of the Sahel and the prospects of improving agriculture there. The donors' representatives met again in October and several donors came forward with positive responses to fund ISC.

ICRISAT received further encouragement when the Director General and the Acting Director, ISC, were received in audience by President Seyni Kountché of Niger. The President expressed his great concern for improving the production and productivity of agriculture in his country. He expressed his appreciation of ICRISAT's efforts to establish ISC and assured the Director General of his Government's strong commitment to the efforts. He hoped the ISC would be able to increase production of pearl millet, cowpea, and groundnut in Niger by exploiting the country's underground water resources.

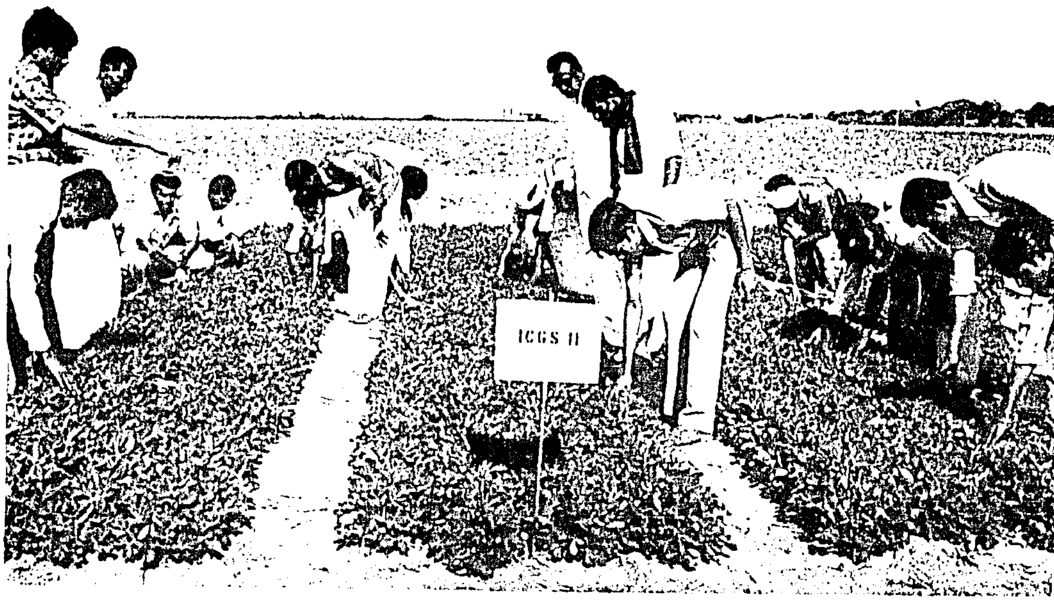
On the research front, ICRISAT continued to combat the major yield reducers—drought and other physical stresses, diseases, and insect pests—of its mandate crops. We confirmed that techniques developed earlier for screening resistant materials were efficient, identified new resistant materials, and better understood the mechanisms of genetic transfer. We also studied bacteria and symbiotic fungi that can aid crop growth and showed how they can be used to benefit crop yield.

Three scientists working at ICRISAT Center spent 4-6 weeks individually in Africa, relating the problems there with their experience in India. One scientist established a downy mildew field nursery in Mali, drawing upon his experience in reducing the losses due to the major crop disease of pearl millet in India, and trained Malian technicians for this work. Another scientist, exploring the relevance of mycorrhizal symbiosis in improving crop production and agroforestry in the semideserts of Rajasthan, India, has projected the importance of mycorrhizal symbiosis in improving crop production in the Sahel, through field studies of the low-phosphatic soils of Niger. Because West Africa abounds in phosphate-ore deposits, the use of vesicular arbuscular mycorrhizae combined with rock phosphate might be an economical alternative to commercial fertilizer for increasing pearl millet production. A third scientist, with considerable knowledge on the problems of seedling emergence in drought-affected areas of Andhra Pradesh and Rajasthan, India, employed similar methods to study the effect of soil temperature on survival of pearl millet after seedling emergence in the Sahel. This helped us better understand some causes of poor stand establishment in the Sahel.

Crop lines developed or improved by ICRISAT scientists were released or recommended for release to farmers in many parts of the semi-arid tropics. Prominent among them was ICGS 11—the first ICRISAT groundnut to be released in India. In earlier trials, ICGS 11 yielded 25-40% more than the local varieties. Another ICRISAT cultivar, ICCC 32—the first kabuli chickpea resistant to fusarium wilt and released in India's Central Zone in 1984—outyielded the control cultivar by 30% this year in farmers' fields in Madhya Pradesh, India. This year, ICCC 32 was also identified for release in India's Northwest Plain Zone. An ICRISAT pigeonpea line ICP 8863 (ICPV 1), with a high degree of wilt resistance was released in Karnataka, India. ICP 7035, another ICRISAT pigeonpea line, with utility as a vegetable, was released under the name Kamica in Fiji. Yet another ICRISAT pigeonpea line ICPH 8, the first short-duration hybrid, accepted by AICPIP for all India coordinated trials, yielded 25% more than the control in multilocational testing.

Many other crop lines reached advanced stages of prerelease testing, and we continued to provide breeding materials to scientists in the national programs. Taken together, they can contribute substantially to improved crop production in the semi-arid tropics.

The impact of ICRISAT-developed crops is being acknowledged. In India, the Secretary, Union Ministry of Agriculture and Rural Development, in a



An ICRISAT scientist briefs visiting farmers at ICRISAT Center on ICGS 11, the first ICRISAT groundnut recommended for release in India.

public meeting praised ICRISAT for the release of its downy mildew resistant pearl millet variety WC-C75 (ICMV 1), which he said had saved India's pearl millet crop from disaster in 1985. This variety, a product of population improvement breeding at ICRISAT, was released to farmers in 1982, and is now being grown by farmers in all millet-growing areas of India. It yielded as much grain as hybrid BJ 104 and gave 15% more fodder. It also has excellent resistance to downy mildew, and has not been seriously attacked by smut or ergot.

Similar efforts were made to increase crop production in West Africa by ICRISAT scientists. A sorghum breeder went from ICRISAT Center to screen a large amount of ICRISAT material, including germplasm accessions, elite varieties, preliminary hybrids, and male and female parents, at three locations in Burkina Faso for sources of resistance to various stress factors. He found material that exhibited potential disease resistance and good agronomic traits in the West African environments. He collaborated there with an ICRISAT Center sorghum pathologist in selecting disease-resistant material for further testing in West Africa.

Research progressed on ways to improve management of available resources. Some practices evolved at ICRISAT can be quickly transferred, and other findings gave useful insights for long-term planning. Analysis of data from socioeconomic studies in India and countries of Africa led to valuable inferences. Work on farming systems and socioeconomics was merged in 1985 into a new program called Resource Management to infuse a better perspective into these related areas of research.

The gene bank at ICRISAT Center added 3505 new accessions of its five mandate crops and 105 of minor millets and distributed 54 434 packets of seed samples all around the world in response to requests. Over 85 000 germplasm accessions of our five mandate crops and minor millets, representing 119 countries, are now well maintained and conserved in the ICRISAT gene bank. They are readily available to all crop improvement scientists.

Training activities by scientists at ICRISAT Center and those stationed in various African countries touched a new peak in 1985. As many as 195 trainees were at ICRISAT Center in programs designed to match individual needs

Trainee economists from Africa try out a blade harrow in a Maharashtra village, where ICRISAT conducts village-level studies, as part of their in-service training.

A soil scientist at the ISC explains the capability of instruments used to determine soil moisture levels to participants of the international symposium on agrometeorology of groundnut.

within the Institute's mandate. In addition, more than 15 students from four countries worked with ICRISAT scientists in Burkina Faso, Mali, and Niger.

Our research perspectives were improved during 1985 through five international conferences, symposia, and other meetings, sponsored or cosponsored by ICRISAT. For instance, the first major international symposium held at the ISC, on the agrometeorology of groundnuts, helped ICRISAT scientists working on groundnuts as well as on resource management to review their understanding of agrometeorological factors that influence the growth and development of groundnuts. Cosponsored by the WMO, FAO, Peanut CRSP, and ICRISAT, in cooperation with INRAN, the discussions gained importance as changes in the climate and weather over the past two decades, particularly in West Africa, have led to changes in varietal recommendations.

Another conference held in collaboration with IBSRAM focused on improving crop productivity through better management of Vertisols. International meetings were held on agroforestry research in the semi-arid tropics, on collaborative research on groundnut rosette disease, and on Asian grain legumes. Apart from these, seven regional workshops relating to specific regions of the semi-arid tropics were held. Field days were organized at ICRISAT Center on pearl millet, sorghum, and groundnut to benefit scientists who came from all over the world.

Seven senior agricultural scientists and research officials from eastern and southern Africa visited ICRISAT as part of an Indian tour of agricultural research institutions sponsored by ICAR and ICRISAT.

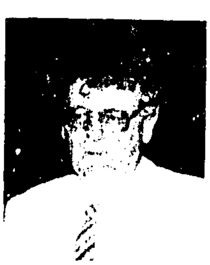
More than 12000 persons visited ICRISAT Center during 1985. The ISC received more than 350 visitors in the same period. A special farmers' day organized at ICRISAT Center benefited a group of nearly 500 farmers from Andhra Pradesh, while a similar occasion at ISC brought together 150 farmers from four ICRISAT study villages. Prominent among visitors to ICRISAT Center were the Indian Union Minister of Agriculture and Rural Development, Agriculture Ministers of Andhra Pradesh and Karnataka, and Ambassa-

Senior scientists and officials from eastern and southern Africa, on a tour cosponsored by ICAR and ICRISAT, listen to an ICRISAT International Intern (extreme right) describe his work on insect pests of stored groundnuts.

Visiting farmers at ISC show interest in intercropping trials with sesbania/cowpea (left) and millet/cowpea (right) on Farmers' Day.

dors to India from Japan and the Federal Republic of Germany. Prominent visitors to ISC included the Swiss Ambassador and the Director of the Swiss Development Cooperation and Humanitarian Assistance, the Ambassadors of Belgium and China, and the delegate of the European Economic Community.

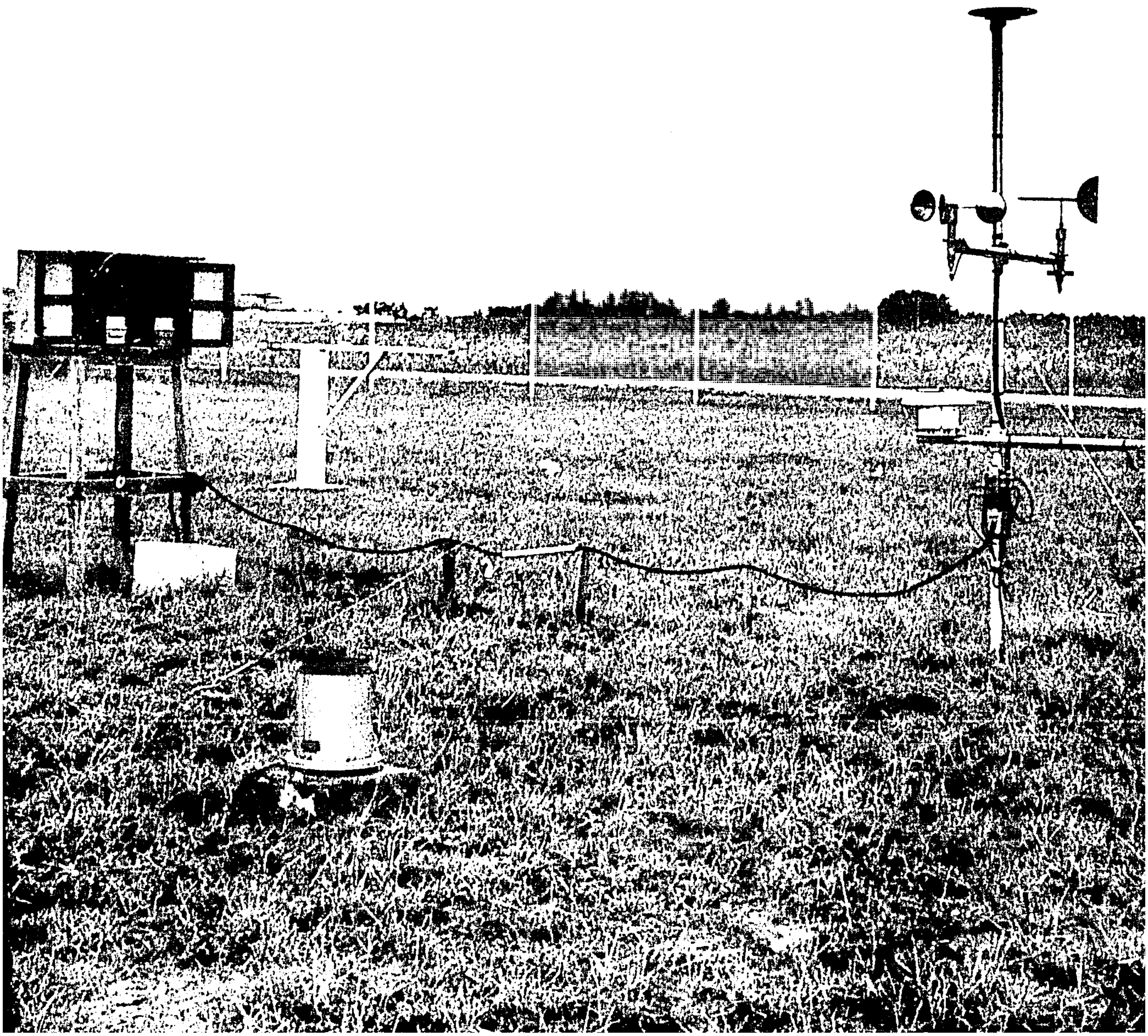
Encouraged by our research achievements in 1985, we look forward to further assisting farmers in improving crop production in the semi-arid tropics in the years to come.



J.L. Dillon
Chairman, Governing Board

L.D. Swindale
Director General

AGROCLIMATIC ENVIRONMENT



Semi-arid tropical regions of the world (shaded). Numbers indicate locations where ICRISAT staff worked in 1985.

Agroclimatic Environment

Most of the research reported in this volume was carried out at ICRISAT Center, the Institute's main research facility in south-central India, and at ICRISAT Sahelian Center in Niamey, Niger with important contributions from ICRISAT scientists posted at cooperative stations in India, in eight other African countries, and in Mexico, Syria, and Pakistan. As a background to our research reports, this section presents a brief description of the environments where our research is conducted and includes rainfall and temperature data for most of those locations.

India

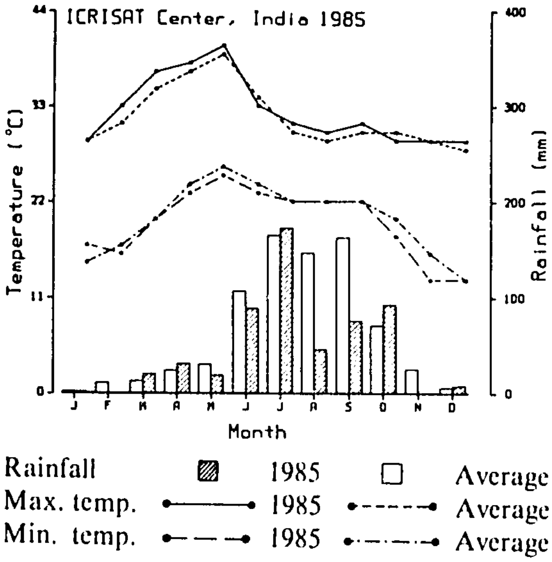
ICRISAT Center

The Institute is located at 18°N, 78°E near Patancheru village, Andhra Pradesh, 26 km northwest of Hyderabad. The experimental farm, extending over 1394 ha includes two major soil types found in the semi-arid tropics: Alfisols (red soils), which are light and drought-prone, with an available water-holding capacity (AWHC) of 60-100 mm, and Vertisols (black soils), which have high AWHCs of 180-230 mm. The availability of both soil types provides an opportunity to conduct experimental work on our five mandate crops under conditions representative of many SAT areas.

Seasons. Three distinct seasons characterize much of India. In the Hyderabad area the rainy season, also known as the monsoon or kharif, usually begins in June and extends into early October. More than 80% of 764 mm average annual rainfall falls in those months, during which the rainfed crops are raised. The postrainy winter season (mid-October through January), also known as the postmonsoon or rabi, is dry and cool and days are short. During this period crops can be grown on Vertisols on stored soil moisture. The hot, dry, summer season lasts from February until rains begin again in June, and any crop grown in that season requires irrigation.

Crops. The five ICRISAT crops have different environmental requirements that determine where and when they are grown. In the Hyderabad area, pearl millet and groundnut are sown on Alfisols during June and July at the beginning of the rainy season; at ICRISAT Center, additional generations are grown in the dry season under irrigation. Pigeonpea is generally sown at the beginning of the rainy season and continues to grow through the postrainy season; to provide additional genetic material for our breeding program, we plant an irrigated crop of short-duration pigeonpea in December. As in normal farming pratice, two sorghum crops a year can be grown at the Center, one during the rainy season and the other on Vertisols in the post-rainy season. Chickpea, a single-season crop, is grown during the postrainy season on residual moisture on Vertisols. At ICRISAT, as in normal farming practice, intercropping and relay cropping of our mandate crops is common.

Weather. Annual rainfall in 1985 was 557 mm, 27% less than the average 764 mm. The rainy season total (June to October) was 477 mm against the normal 653 mm. Rainfall in August was only 46 mm, the least since 1972. The drought affected all the ICRISAT crops this year, low rainfall reduced yields in both medium duration and rainfed short-duration pigeonpeas, groundnut yields were low in the rainy season trials at ICRISAT Center and most other sites. Daily maximum temperatures were below average in July and October, while daily minimum temperatures were above average in January.

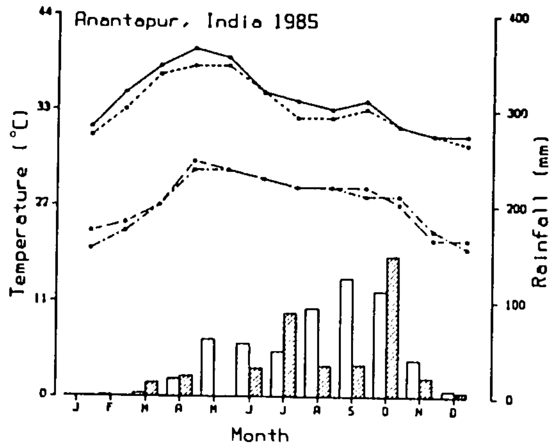


Other Research Locations

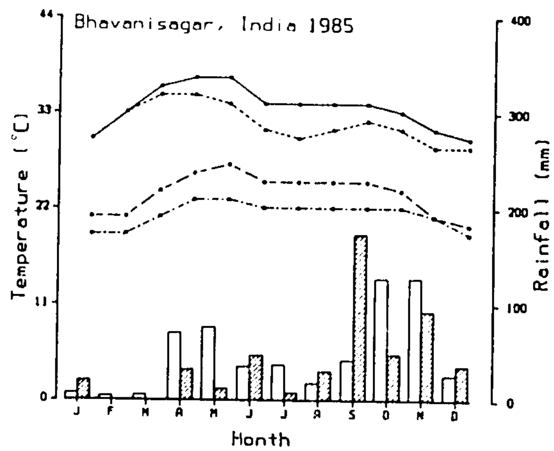
India

In cooperation with five agricultural universities in India, ICRISAT has established stations and carries out research on their campuses to test the performance of breeding material under various climatic conditions and latitudes.

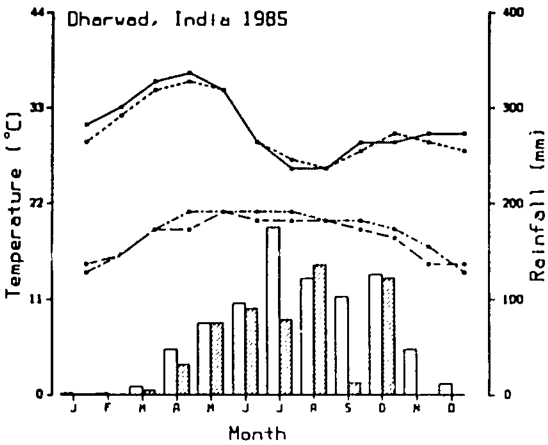
Anantapur (15° N, 562 mm rainfall)—a drought-prone area where we screen pearl millet, sorghum, and groundnut under low rainfall conditions in the rainy seasons on Alfisols (AWHC 50 mm). The 1985 weather conditions were ideal for testing responses to mid-season stress. Annual rainfall was 394 mm, 30% below the average. Severe stress occurred in our June-sown pearl millet trial. Because of the very low August and September rainfall trial yields averaged only 300-400 kg ha^{-1}. There was good rainfall in October, 147 mm, 34% above the monthly average of 110 mm, so the late (September) sown pearl millet trials yielded well (1400 kg ha^{-1}) even though little rain fell after flowering. Daily maximum temperatures were generally higher than the average while daily minimum temperatures were lower than the average only in October and November.



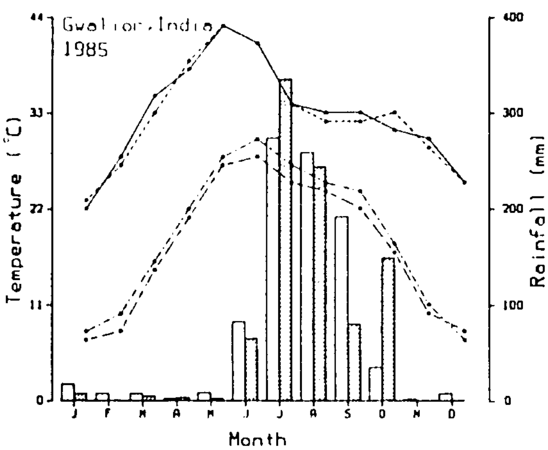
Bhavanisagar (11° N, 574 mm rainfall)—where we screen sorghum for diseases and pests and test pearl millet on Alfisols (AWHC 80 mm), at a daylength analog similar to the Southern Sahelian bioclimatic zone of Africa. Annual rainfall in 1985 was 499 mm, 13% below average, and 34% percent of the annual rainfall fell in September. Both daily maximum and minimum air temperatures were above average.



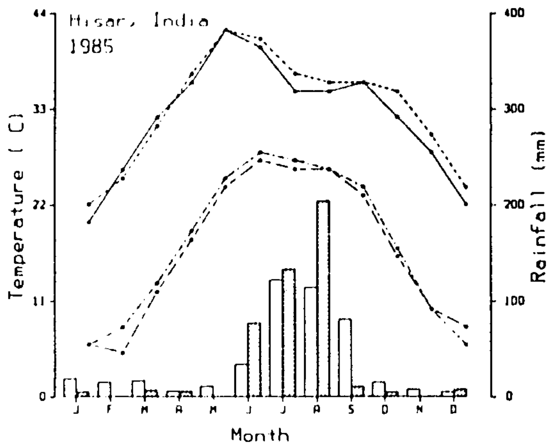
Dharwad (15°N, 818 mm rainfall)—an especially good Vertisol (AWHC 150 mm) site for pest and disease screening, e.g., screening sorghum for downy mildew. The annual rainfall in 1985 was 552 mm, 33% below the average, 47% of it fell in August and October. September rainfall was only 13 mm against the monthly average of 103 mm. Daily maximum temperatures were below average only in July and October.



Gwalior (26° N, 899 mm rainfall) - an area on Inceptisols (AWHC 150 mm), where most of India's long-duration pigeonpea crop is grown. Rainfall received during the rainy season (June-October) in 1985 was 873 mm, 4% above the average 843 mm. Daily minimum temperatures were lower than average.



Hisar (29° N, 447 mm rainfall) where chickpea and pearl millet are tested under the climatic conditions in which they are mostly grown, and short-duration pigeonpeas are tested in a region where they are increasingly being grown in rotation with wheat. The soils are Entisols with 150-200 mm AWHC. Annual rainfall in 1985 was 456 mm, of which 45% fell in August. This heavy rainfall caused considerable waterlogging and damage to the pigeonpea crop. As a result many trials were abandoned. Daily maximum and minimum temperatures were generally lower than average.



Niger

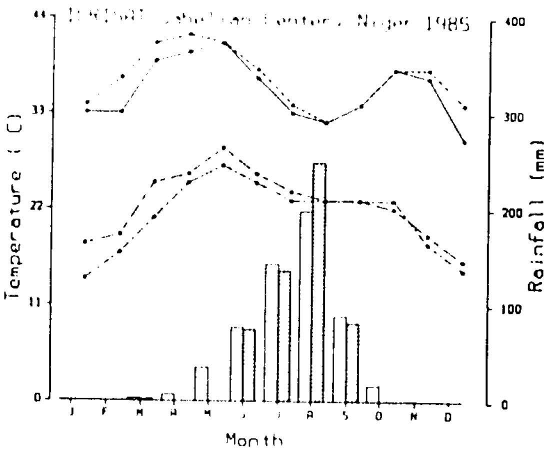
ICRISAT Sahelian Center

The ICRISAT Sahelian Center (ISC) is our principal research base for millet and groundnut and the farming systems associated with these crops in the Southern Sahelian bioclimatic zone of West Africa. The ISC is located at 13° N, 2° E near the village of Say, 45 km south of Niamey. The experimental farm, extending over 500 hectares is covered by reddish colored, friable, sandy soils (AWHC 50-75 mm) with low native fertility and low organic matter.

Seasons. The climate of the area is characterized by a June to September rainy season and a dry season throughout the remainder of the year. The average annual rainfall (570 mm) at Niamey is irregular and normally comes in the form of convective storms. The rainy season is short (about 90 days) during which periodic droughts are not uncommon. During the dry season periods of "harmattan" winds bearing dust from the north and east occur. The temperatures are warm year round and average 29° C.

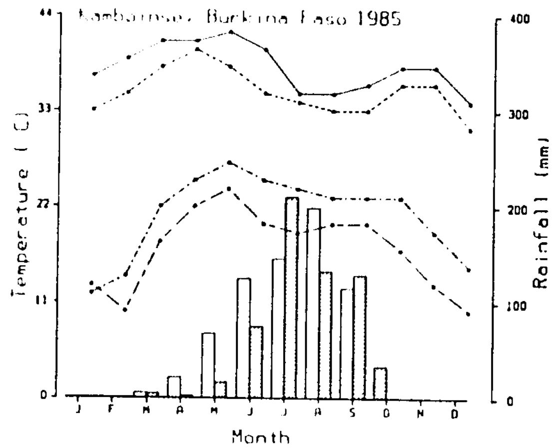
Crops. The main crop grown in the Niamey region is short-duration millet (90 to 110 days duration) which is sown with the first rains towards the end of May and June. To advance generations and to help in seed multiplication, an irrigated off-season nursery is grown from January to April. Intercropping millet with cowpea is common. Cowpea is normally sown between the millet rows 2 to 3 weeks after the millet emerges by which time the rains occur more frequently in this region.

Weather. Rainfall in 1985 was 545 mm, 4% below the average of 570 mm, but 26% above average in August. Daily maximum temperatures were generally lower than average, while daily minimum temperatures were above average except in October.



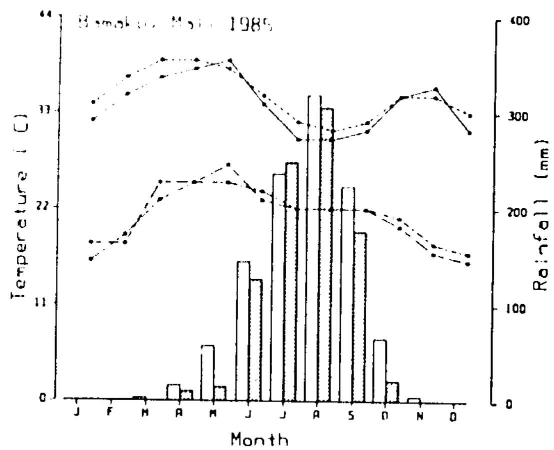
Burkina Faso

Kamboinsé (13° N, 2° W, 716 mm rainfall) in the Sudanian bioclimatic zone, where ICRISAT's principal work is on sorghum with particular emphasis on *Striga* resistance, millet, and socioeconomic studies in villages. The length of the cropping season is about 120 days from June/July to October/November. Sorghum, millet, maize, groundnuts and cowpea are the major crops in the region. Soils vary from gravelly sandy loams to silty loams depending on their position in the toposequence. The depth of the soil profile over laterite ranges from 0.3 m to 1.2 m on the lower slopes. The AWHC of the soils varies from 30 to 100 mm. The annual rainfall in 1985 was 573 mm, 20% below the average. Eighty-two percent of the annual rainfall was received in July, August, and September. Daily maximum temperatures were (1-5°C) above average and daily minimum temperatures were (1-6°C) below average except in January.



Mali

Sotuba near Bamako (13° N, 8° W, 1075 mm rainfall) where we are evaluating different crops and cropping systems to identify efficient land-use systems for the Sudanian bioclimatic zone. The length of the cropping season is about 140 days from May/June to October/November. Sorghum, maize, groundnut, and millet are major crops. Soils are tropical ferruginous,



leached to hydromorphic types (loam and clay loam), with AWHC 150-200 mm. This year the total annual rainfall (907 mm) was 16% below the average.

Cinzana (13° N, 6° W, 700 mm rainfall)—in the Southern Sahelian bioclimatic zone, where we conduct research on sorghum, millet, and agronomic practices associated with these crops. The length of the cropping season is about 120 days from June/July to September/October. Millet, cowpea, groundnut, and sorghum are major crops. Soils are tropical ferruginous, some humus-bearing hydromorphic loams and sandy loams (AWHC 120-150 mm). Rainfall in 1985 was 566 mm, 19% below the average.

Nigeria

Samaru (11° N, 8° E, 1133 mm rainfall)—where our breeder posted at the Institute of Agricultural Research works on pearl millet.

Senegal

Bambey (15° N, 16° W, 634 mm rainfall)—where the emphasis is on developing improved millets.

Sudan

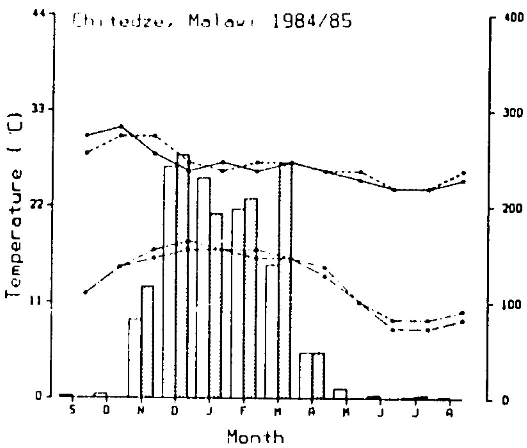
Wad Medani (14° N, 33° E, 373 mm rainfall)—where the major emphasis has been on developing sorghums that can withstand drought, and El Obeid (13° N 30° E, 418 mm rainfall), where our millet research is being carried out.

Kenya

Nairobi—(1° S, 37° E, 1066 mm rainfall), the center of an ICRISAT regional network testing sorghum and millet in four major agroecological zones: high, intermediate and low elevations, and very dry lowlands. Because of the large number of network locations it is not pertinent here to give their agroclimatic details.

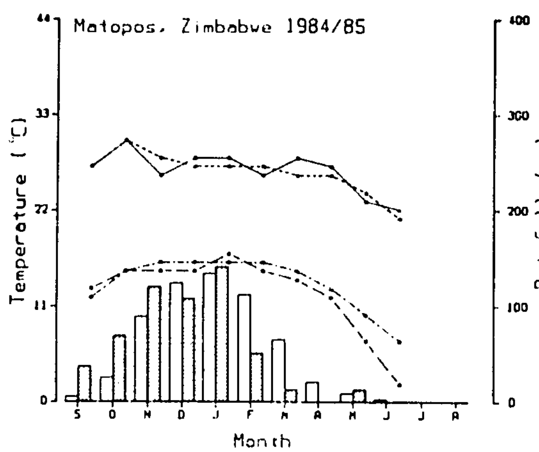
Malawi

Chitedze (14° S, 34° E, 957 mm rainfall)—where our Regional Groundnut Improvement Program for Southern and Eastern Africa is based. Chitedze, located on the Lilongwe plain, has a tropical continental climate with one rainy season from October/November to March/April. Maize, tobacco, groundnut are some of the important crops. Rainfall during the growing season (November 1984 to April 1985) was 1063 mm, 16% above the long-term average (920 mm) and 53% higher than that recorded in 1983/84 (683 mm). There were no dry spells and consequently daily sunshine hours (5.7 h) were lower than those during the previous season (6.6 h).



Zimbabwe

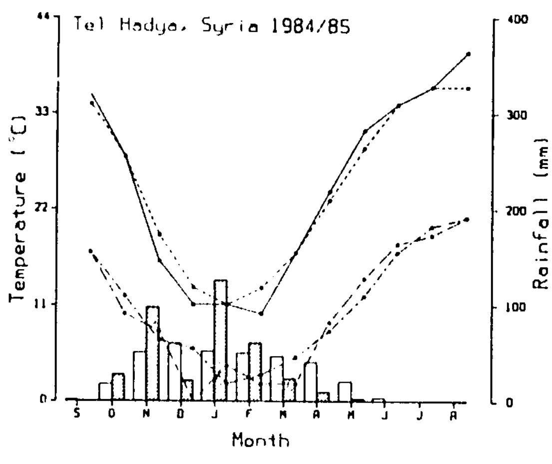
Matopos near Bulawayo (20° S, 29° E, 588 mm rainfall)—where our cereals improvement program for the nine African countries of the SADCC region is based at Matopos Research Station. Sorghum, millets, maize, and cowpeas are important crops in the region. The growing season is from October/November to March/April. Soils range from sandy soils with AWHC 60 mm, to deep clayey soils, with AWHC 180 mm. Rainfall from September 1984 to August 1985 was 552 mm, and 67% of the total fall was received in November, December and January.



Syria

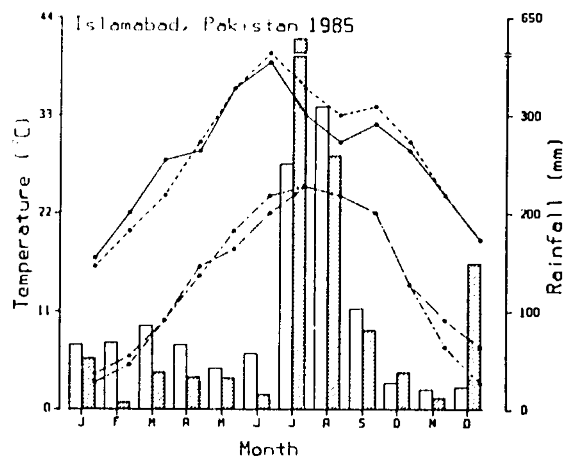
Tel Hadya near Aleppo (36° N, 37° E, 340 mm rainfall)—where our staff work with ICARDA on kabuli type chickpea for spring or winter sowing in the Mediterranean region, and South and Central America. The crop season is from November to June. Soils are deep red to heavy black (AWHC 80-120 mm). Wheat, barley, chickpea, lentil, and faba bean are important crops in the region.

Rainfall from September 1984 to August 1985 was 372 mm, 10% above the normal of 340 mm. This was the coldest year in the last 50 years. Forty-one nights had temperatures below 0° C the lowest being -9.8° C. The most severe cold spell was between 20 February and 15 March. After the cold spell the weather was dry and unusually hot. These conditions were very unfavorable for the development and spread of chickpea ascochyta blight, the development of *Orobanche*, and leaf miner populations, so many screening trials did not produce useful results. However, the extreme cold meant that a great deal of chickpea material could be screened for cold tolerance.



Pakistan

Islamabad—(34° N, 73° E, 1116 mm rainfall), where the emphasis is research on developing chickpeas resistant to ascochyta blight. Annual rainfall in 1985 was 1347 mm, 21% above the average, with a very high rainfall in July, 631 mm against the average 250 mm.



Mexico

El Batan—(19° N, 99° W, 750 mm rainfall), where our breeder and agronomist based at CIMMYT, work on high altitude, cold tolerant sorghums and material adapted for low and intermediate elevations in Latin America and the Caribbean. Because trials are grown over a wide area it is not pertinent here to give data for any single location.

GENETIC RESOURCES UNIT

Contents

Cover photo. Collecting chickpea in Bangladesh in the company of some enthusiastic helpers 1985.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Genetic Resources Unit, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

17

GENETIC RESOURCES UNIT

The diversity in genetic resources is basic to the improvement of existing crops and for the development of new crops. It is essential that this important natural resource be collected and preserved. Once landraces or their wild relatives are lost, they can never be restored. It is the responsibility of gene banks throughout the world, national and international, to collect, maintain, evaluate, catalog, preserve, and distribute germplasm before it is lost. The best possible methods of preservation must be employed in order to preserve seed viability as long as possible before growing the accessions again because genetic drift can, and does occur during each increase. It is essential to maintain the integrity (original genotype) of each accession as much as possible during each seed increase.

Figure 1. Checking accessions in medium-term storage in ICRISAT gene bank. When the new long-term storage facility is operational these accessions will be transferred.

ICRISAT has this responsibility for its five mandate crops. During 1985, we made germplasm collections in certain parts of the world, including the Caribbean, eastern, southern and western Africa, and South Asia, where no previous collections had been made. These expeditions resulted in adding valuable accessions to our collections, and also provided an opportunity to observe at first-hand the available genetic diversity, and the extent of the threat of genetic erosion in these areas.

In order to preserve collected material, the Genetic Resources Unit (GRU) employs the best currently known techniques, and researches on new ones for pollination control to prevent outcrossing. We are describing our assembled accessions, computerizing the information, providing optimum seed storage conditions to preserve viability. The ICRISAT gene bank provides medium-term storage at 4°C and 20% relative humidity (Fig. 1). We monitor seed viability of our stored accessions, and make them freely available to plant scientists throughout the world.

Present and Future Areas of Collection

The priority areas for collecting our mandate crops were identified, in collaboration with the International Board for Plant Genetic Resources (IBPGR), and national scientists in resource areas, according to their representation of number of accessions in the collection, the threat of genetic erosion, and known information about genetic diversity in the area. Countries where the germplasm has yet to be collected, for each crop, are listed below in order of priority:

Sorghum — People's Democratic Republic of Yemen, Somalia, Central African Republic, Nepal, Chad, Ghana, Turkey, Uganda, Mozambique, Syria, Burma, Ivory Coast, Australia (for wild species), and India (Bihar State.)

Pearl millet — Niger, Chad, Cameroon, Angola, Egypt, Mauritania, Pakistan, Togo, Namibia, Zaire, Central African Republic, Tanzania, and India (Rajasthan and Tamil Nadu States.)

Chickpea — Malawi, Burma, Syria, Turkey, Tanzania, Pakistan, Algeria, Morocco, Tunisia, Ethiopia, Iran, Afghanistan, and India (Madhya Pradesh, Rajasthan, Gujarat and Bihar states).

Pigeonpea — Caribbean Islands, South and Central America, Philippines, Indonesia, Bangladesh, Australia (for wild species), Burma, Uganda, Bhutan, Southeastern China, India (Gujarat, Rajasthan, Assam and Tamil Nadu states), Zaire, Angola, Zambia, Thailand, Sierra Leone, Ivory Coast, Burkina Faso, and Mali.

Groundnut — Brazil, Burma, Mali, India (Haryana, Rajasthan, Tamil Nadu and Madhya Pradesh states), Venezuela, Peru, Ecuador, Malagasay Republic, Niger, Ghana, Sudan, and Zambia.

The total numbers of germplasm accessions assembled to date for each mandate crop are shown in Table 1 together with the numbers of countries represented in the collection. We have also assembled 5097 accessions of minor millets from 34 countries (Table 2). There is much collecting yet to be done, including wild species and wild relatives of our mandate crops.

Germplasm Assembly and Maintenance

To facilitate easy access for our cooperators and to broaden the genetic base for plant breeders, efforts are being made to establish regional gene banks.

West Africa

The ICRISAT Sahelian Center (ISC) has plans to establish a regional gene bank for West Africa by collecting and conserving pearl millet and groundnut from West Africa. The construction of a medium-term cold storage facility is underway and when it is operational, duplicate samples of all the germplasm accessions from West Africa available with the GRU at ICRISAT Center will be transferred. ISC will maintain genetic stocks with known sources of resistance to pests, diseases, and environmental stresses. The ISC will also help as a backstop for the world collection of the Institute's germplasm assembly.

Southern Africa

SADCC Regional Sorghum and Millet Improvement Project based at Matopos near Bulawayo, Zimbabwe is maintaining germplasm accessions of sorghum, pearl millet, and finger millet in short-term storage conditions in plastic bottles. The sorghum accessions include introductions from ICRISAT Center and the USA, the Karper's Nursery, and local collections from Botswana, Lesotho, Swaziland, Zambia, and Zimbabwe.

The pearl millet accessions include collections made by ICRISAT/IBPGR from 1980 to 1985. In addition, all the accessions from SADCC countries available at ICRISAT Center, and a

Table 1. ICRISAT gene bank accessions in 1985 and to date, showing crop and numbers of countries represented.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Accessions in 1985	1960	540	543	362	100	3505
No. of countries	13	10	7	12	3	27
Total to date	26564	17621	14361	10466	11588	80600
No. of countries	83	42	41	41	89	119

working collection of long heads, thick heads, and large grains will be conserved at Matopos.

Finger millet accessions include those collected from Zimbabwe during 1982 and 1985.

Latin America

ICRISAT Sorghum Breeding Program at CIMMYT had introduced working collections from the GRU at ICRISAT Center. The sorghum genetic resources assembled in Mexico include accessions with known genotypes possessing sources of resistance to a specific disease, insect, or environmental stress. Each sample is maintained by selfing to obtain a stock of about 3 kg, except for the male-sterile lines that are maintained by hand pollination between corresponding male-sterile (A) and maintainer (B) isogenic lines. A small medium-term cold storage facility has been developed to conserve the germplasm with sufficient security to provide seed to regional cooperators in Latin America on request.

Table 2. Additions to minor millets collection in 1985 and cumulative totals, 1976-1985.

Species	Accessions in 1985	Cumulative total
Eleusine coracana (finger millet)	93	1956
Setaria italica (foxtail millet)	-	1260
Panicum miliaceum (proso millet)	1	754
Panicum sumatrense (little millet)	11	302
Echinochloa crusgalli (barnyard millet)	-	517
Paspalum scrobiculatum (kodo millet)	-	308
Total	105	5097

Germplasm Distribution

A very important component of GRU's activities is to provide ICRISAT scientists with germplasm accessions that are used in their attempts to improve all the mandate crops. These accessions are screened for their reactions to many yield-limiting factors. Table 3 shows the distribution of each crop's germplasm accessions to the various disciplines in other ICRISAT programs in 1985. The results of this screening work and other cooperative projects involving GRU botanists and crop programs are reported elsewhere in this Report in the Crop Improvement Program section. During 1985, in addition to the 32469 samples distributed to scientists at ICRISAT Center, 8222 samples were sent to scientists in India, and 17890 samples to scientists in other countries (Table 4).

Sorghum

This year 1960 new accessions were rejuvenated and added to our gene bank, raising the total to 26564. The new accessions, assembled by collection and correspondence, came from 13 countries (Table 5).

In May 1985, collection expeditions were

Table 3. Seed samples supplied to ICRISAT Crop Improvement Programs in 1985.

	Program					
Discipline	Sorghum	Pearl Millet	Chickpea	Pigeonpea	Groundnut	Total
Physiology	543	388		75	5	1011
Pathology	298	560	1246	119	2923	5146
Entomology	18354	203	1168	575	134	20434
Microbiology			1		57	58
Breeding	762	93	306	100	128	1389
Biochemistry	1004	1102	783	788	708	4385
Cytogenetics					14	14
Agroforestry			5			5
Plant Quarantine		2		1		3
Training	18				4	22
Total	20979	2348	3504	1663	3973	32467

organized in Lesotho and Swaziland in collaboration with the respective Ministries of Agriculture through the Southern African Development Coordination Conference (SADCC)/ICRISAT Sorghum and Millet Improvement Project based at Bulawayo, Zimbabwe. Sorghum landraces in both the countries are being replaced by maize and sorghum hybrids introduced from South Africa. We collected 130 accessions from Lesotho and 96 accessions from Swaziland. These include a good number of native kafir landraces with wide variation for panicle shape, seed color, and seed size (Fig.2). Sorghum germplasm collected from the highlands of Lesotho is reported to possess genes for cold tolerance. The collection from Swaziland contained sorghums claimed to be bird-resistant by farmers and a few roxburghii sorghums, which are on the verge of extinction. One complete duplicate set of this collection has been handed over to the SADCC/ ICRISAT project in Zimbabwe for use in the southern Africa breeding program.

To meet increasing requests for seed, we rejuvenated 5552 accessions by selfing during the postrainy season. During the rainy and postrainy seasons, 1955, newly assembled accessions were characterized and evaluated at ICRISAT Center using IBPGR/ICRISAT sorghum descriptors. Several sorghum scientists including the sorghum breeders from the All India Coor-

Table 4. Germplasm samples distributed in 1985.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (1+2+3)	No. of countries
Sorghum	20979	1816	12376	35171	39
Pearl millet	2348	426	2039	4807	20
Chickpea	3504	2766	2042	8314	21
Pigeonpea	1663	1597	532	3792	26
Groundnut	3973	1623	901	6497	16
Total 1985	32469	8222	17890	58581	
Cumulative total to date	351914	113210	158332	623456	

Figure 2. Collecting agronomically elite kafir sorghum landraces in the highlands of Lesotho, May 1985.

dinated Sorghum Improvement Project (AICSIP) visited GRU and selected sorghum lines for use in their breeding programs (Fig. 3). Computer printouts of sorghum evaluation data have been supplied to sorghum scientists working in AICSIP, and agricultural universities at Tamil Nadu, Rahuri, and Hisar in India, and to various research institutions in the People's Republic of China, the Federal Republic of Germany, Mexico, UK, and USA.

We supplied 3202 accessions for use as base material to the SADCC/ICRISAT project, and 2670 accessions to ICRISAT scientists working in Burkina Faso. We also supplied 3357 accessions to national programs of Belgium (1165), India (823), Iran (621), Zambia (321), Uganda (161), Chad (141), and Sierra Leone (125) for use in their breeding programs. Two kafir sorghum landraces from South Africa, IS 9302 and IS 9323 from ICRISAT gene bank have been approved for release by the National Variety Release Committee, Ethiopia, as ESIP 11 and ESIP 12.

Pearl Millet

During the year, we added 540 accessions from 10 countries to the gene bank raising the total pearl millet accessions to 17621 (Table 5).

In collaboration with the Institute of Agronomic Research (IAR), Ministry of Agriculture, we visited Cameroon in November and December and collected 888 samples of pearl millet (Fig. 4). The wild form *Pennisetum americanum* ssp *monodii* (Fig. 5) introgresses naturally with the cultivated forms and produces intermediate weedy forms called 'shibras' (*Pennisetum americanum* ssp *stenostachyum*). During the collection mission it was interesting to observe these wild, weedy shibras, and cultivated forms of pearl millet growing in the same fields at many places in Cameroon.

We rejuvenated 1714 accessions, for which the seed quantity was depleted, by cluster bagging and selfing during the postrainy season. During the rainy season, 3155 accessions were evaluated at ICRISAT Center using the IBPGR/ICRI-

Table 5. Additions to ICRISAT germplasm collection in 1985.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
AFRICA					
Burkina Faso	311	-	-	-	-
Cameroon	101	-	-	-	-
Cape Verde Islands	1	1	-	-	-
Ethiopia	5	-	361	3	-
Kenya	7	-	1	74	-
Malawi	-	-	1	217	-
Mali	-	3	-	-	-
Morocco	5	3	-	-	-
Niger	-	1	-	-	-
Nigeria	-	435	-	11	-
Senegal	-	1	-	-	-
Sierra Leone	97	55	-	3	-
South Africa	68	31	-	-	-
Zimbabwe	226	-	-	-	-
ASIA					
Bangladesh	-	-	-	13	-
China	14	-	-	1	22
India	-	-	134	4	-
Indonesia	-	-	-	8	-
Sri Lanka	-	-	-	-	4
Yemen Arab Republic	1060	-	-	-	-
EUROPE					
German Democratic Republic	-	-	10	1	-
Hungary	62	-	-	-	-
Italy	-	-	-	7	-
USSR	-	2	-	-	-
THE AMERICAS					
Antigua	-	-	-	20	-
Mexico	-	-	30	-	-
USA	3	8	6	-	74
Total	1960	540	543	362	100

Figure 3. Scientists from the All India Coordinated Sorghum Improvement Project (AICSIP) Rajendranagar, during a visit to GRU when they selected elite lines from the sorghum genetic resources accessions for use in their breeding programs.

SAT pearl millet descriptors. These included accessions collected by ICRISAT scientists from the Yemen Arab Republic in 1983 and Zimbabwe in 1985. Passport and evaluation data from IP 10 001 to IP 11 762 have been entered into the computer, and are available for distribution as printouts to millet scientists on request.

Chickpea

The chickpea germplasm collection now consists of 14 361 accessions originating from 41 countries including the 543 accessions from 7 countries acquired in 1985 (Table 5). We had a collecting venture in Tamil Nadu (India) in collaboration with Tamil Nadu Agricultural University (TNAU), Coimbatore in February 1985. A joint-exploration by an ICRISAT scientist, and representatives of the Plant Breeding Department of the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Bangladesh, collected germplasm material from northern and western regions of Bangladesh in April 1985. During this expedition we noticed early-maturing desi types in all chickpea fields. Some of the large-seeded desi

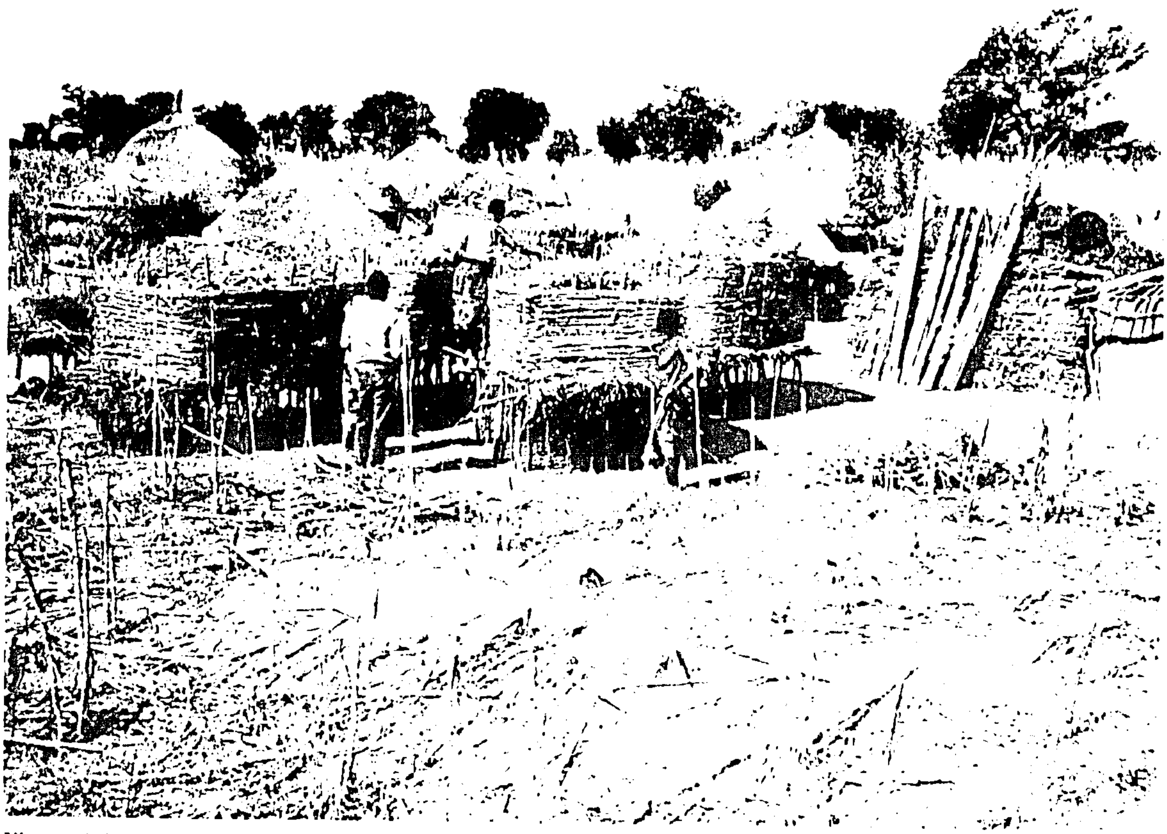


Figure 4. In northern Cameroon pearl millet stalks are used to build elevated stores for harvested millet. In the foreground are stalks left standing after harvest.

samples collected in the Coimbatore area are valuable additions to our gene bank.

During the year, we grew 1814 accessions for evaluation as per the ICRISAT IBPGR descriptor at Hisar, and 1937 for evaluation and 3200 for seed increase at ICRISAT Center.

The chickpea germplasm data base in the computer has been refined following statistical analyses to identify accessions with specific desirable characteristics or character combinations. We intend to publish this information as a catalog.

We studied the genetics of a natural mutant that is polycarpous and produces two flowers per axil (Fig. 6). These two apparent characteristics are the pleiotropic effect of a single recessive gene. We have concluded our studies on the genetics of leaf shape, and found that the simple and multipinnate leaf types are governed by supplementary gene action. When parents of these types are crossed, they produce normal (unipinnate, compound leaf), multipinnate, and simple-leaved plants in F_2 in a ratio of 9:3:4 (Fig. 7). The genetic constitution of parents in respect to leaf shape being, normal leaf: $M_1M_1S_1S_1$; multipinnate leaf: M_1S_1; simple leaf m_1S_1 or m_1S_1.

Pigeonpea

A collection expedition in the Caribbean Islands, in January and February 1985, where local farmers achieve the worlds' highest yields of

Figure 5. ***Pennisetum americanum*** **ssp** ***monodii*** **the wild progenitor of pearl millet collected during an expedition to northern Cameroon, 1985.**

pigeonpea, resulted in securing traditional landraces from Puerto Rico, the Dominican Republic, Trinidad and Tobago, Grenada, Barbados, St. Vincent, and St. Lucia. A total of 271 representative accessions were collected and the majority of them have already been cleared through Plant Quarantine. The new accessions have widely diverse agronomic traits, and are a rich source of material that can be used to improve long-duration vegetable-type pigeonpea. The Caribbean accessions are mostly of medium-late to late-maturing lines, with semi-spreading to spreading plant habit, with high biomass. Numbers of seeds pod^{-1} ranged from 3 to 8, and their 100-seed mass from 7.08 to 22.23 g with a mean of 13.93 g. A striking feature noticed was the occurrence of pigeonpeas with unusually broad pods (Fig. 8), that are popular in the local vegetable markets. Canned pigeonpeas are popular in Puerto Rico, Trinidad and Tobago, and other islands of West Indies. This product is exported and earns substantial foreign exchange for the Dominican Republic. Collected landraces include popular cultivars with superior agronomic traits. In addition, several locally bred lines/selections such as, '2-B-Bushy' and 'Kaki' were also collected from research stations and farmers' fields. During the expedition we observed

Figure 6. Polycarpy mutant in chickpea. Example of a natural mutant identified from cultivar K 850.

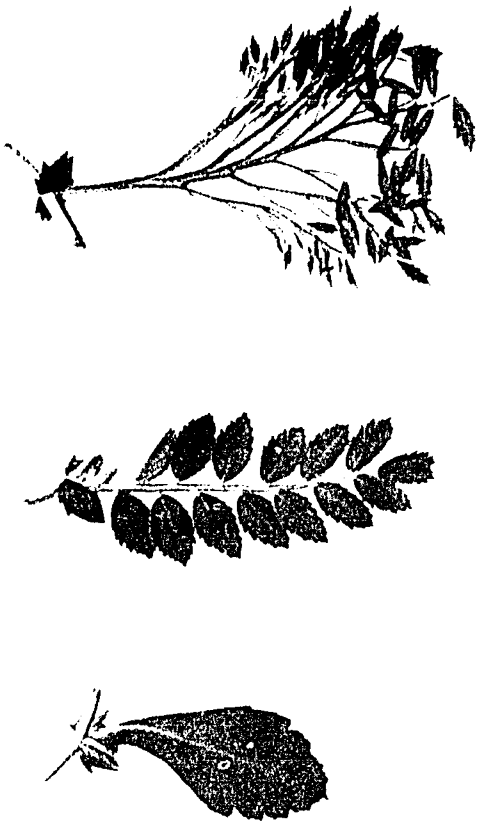


Figure 7. Examples of chickpea leaf shapes from top to bottom, multipinnate, unipinnate (normal), and simple.

that the Caribbean area is free from any serious disease problem except for witches' broom (Fig. 9) in the Dominican Republic.

A total of 362 new pigeonpea accessions were registered in the gene bank (Table 5) which consists of exotic lines recently released from the postentry quarantine isolation. These will be characterized in 1985/86. One of the highlights of these exotic accessions are several new accessions with high numbers of seeds pod^{-1}. Previously, we had only one source with this trait ICP 8504, an accession in great demand by pigeonpea breeders. The new sources include ICP 13253 and 13256 from Kenya, and ICP 13555 from the West Indies. Even within these lines, there is variation in other morphological traits so that the genetic base for pigeonpeas with large numbers of seeds pod^{-1} is now fairly wide. Our present collection now stands at 10466 accessions from 41 countries. A total of 61 lines, which were perennated from 1984 due to their late flowering, have flowered in 1985, and we hope to secure seed. It was interesting to note that 10 long-duration lines from the West Indies flowered in July when most other lines remained vegetative. These lines are being purified and will be tested for photoperiodic insensitivity.

In September 1985 we sowed 1000 lines for rejuvenation and seed increase. A total of 754 lines including 283 new accessions from Antigua, Bangladesh, Ethiopia, Indonesia, Kenya, Malawi, Mozambique, Nigeria, Philippines, and Tanzania were characterized, together with wilt-resistant and insect-tolerant lines bred at ICRISAT and our new collection from Tamil Nadu.

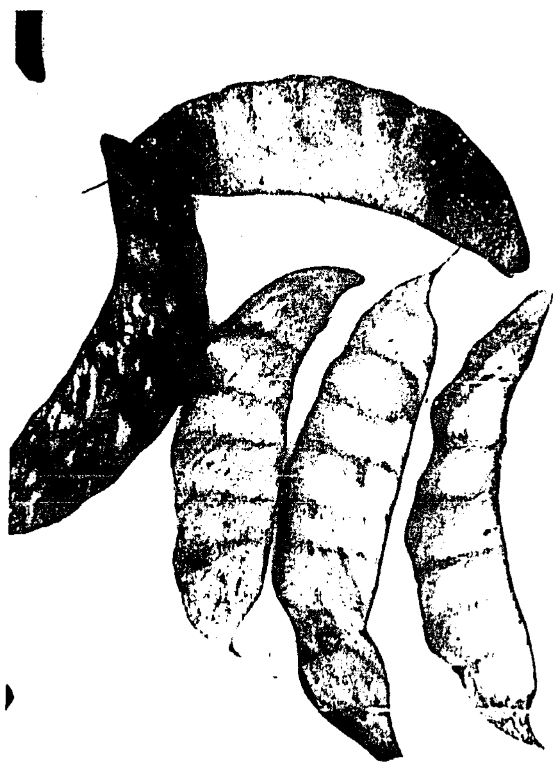


Figure 8. Pigeonpea pods that are unusually broad, from a sample collected in the Caribbean Islands, 1985.

Figure 9. Pigeonpea plant showing typical symptoms of witches' broom disease; note severe stunting, reduced leaf size and lack of pods.

We screened 400 accessions of pigeonpea for photoperiodic insensitivity. From these, selections were made and 20 were found to be moderately insensitive. We observed a marked increase in plant height, number of branches and leaf area in plants subjected to extended light (Fig. 10).

We started work on a new project that has been developed to evaluate germplasm accessions in their original habitat or area of adaptation. In 1985, a set of long-duration lines was evaluated at ICRISAT Center and Gwalior, India. Our future efforts will be to evaluate long-duration lines in East African and West Indian locations.

We have revised and edited the entire computerized database of 8582 accessions and carried out statistical analyses of evaluation data. The world collection is now classified into well-defined sets with specific combinations of desirable traits. This will eventually lead to the publication of a pigeonpea catalog, and substantially enhance the efficiency of germplasm use in pigeonpea improvement.

Groundnut

One hundred accessions from three countries were added during the year, raising the total to 11 588 (Table 5). Besides these, 89 accessions from the Tanzanian collection made in 1985 and 13 accessions from USA have been released through Plant Quarantine. These will be registered with ICG numbers after seed increase during the 1986 rainy season. Over 600 accessions from Texas A&M University and Georgia, USA, could not be transferred to ICRISAT because of new plant quarantine restrictions in India. Sixteen accessions from the Regional Station, Indian Agricultural Research Institute (RS-IARI), Rajendranagar, and one accession from Tamil Nadu Agricultural University, Vridhachalam, have also been received. These new accessions have contributed to a significant increase in the available variability in the ICRISAT gene bank (Fig. 11).

In collaboration with Tanzanian Agricultural Research Organization (TARO), we made a collection mission there from 24 April-19 May 1985. The mission aimed to collect local cultivars of groundnut and other ICRISAT mandate crops that matured during the period of the mission. The mission was timed to coincide with the groundnut harvest in most of the areas explored. In Tanzania, groundnuts are mainly grown by small farmers and there seemed to be no fixed time for sowing. As a result, we reached a few areas either well after the harvest, or before the crop matured. A total of 115 samples were collected, including 95 groundnut, 11 pearl millet, and 9 sorghum. The groundnuts were actually collected at 67 locations, but mixed types were subdivided later to make 95 distinct samples. There was significant variability in all the collected crops. We collected groundnut samples that differed in habit, botanical type, and seed color.

During the rainy season, we sowed 2279 accessions including 116 new acquisitions for seed increase and characterization of various morphoagronomic characters as per the ICRISAT/IBPGR groundnut descriptors. We also conducted a series of experiments on fresh seed dormancy (Fig. 11). In the postrainy season, we sowed about 1300 accessions, including 102 new introductions, mainly for rejuvenation. Out of 73 accessions of wild species (Fig. 12) sown in September 1984 for seed increase, because of an increased demand for evaluation and use, varying amounts of seed were harvested from 48 accessions.

Documentation has been further strengthened by computerizing passport data for 33 descriptors of 10000 accessions. Computerizing passport data for the remaining 1588 accessions, and the evaluation data on all the accessions in the gene bank is in progress. During the rainy season, a few modified descriptors were used for evaluation and found to be appropriate. We are preparing modified descriptors for cultivated groundnuts, and a sepa ate descriptor list for wild *Arachis* species.

Figure 10. Effect of extended hours of daylight on pigeonpea leaf size. Leaves from three genotypes (Above) grown in normal length days (12 h). Below the same genotypes grown in extended daylight (16 h) had much larger leaves. ICRISAT Center, rainy season, 1985.

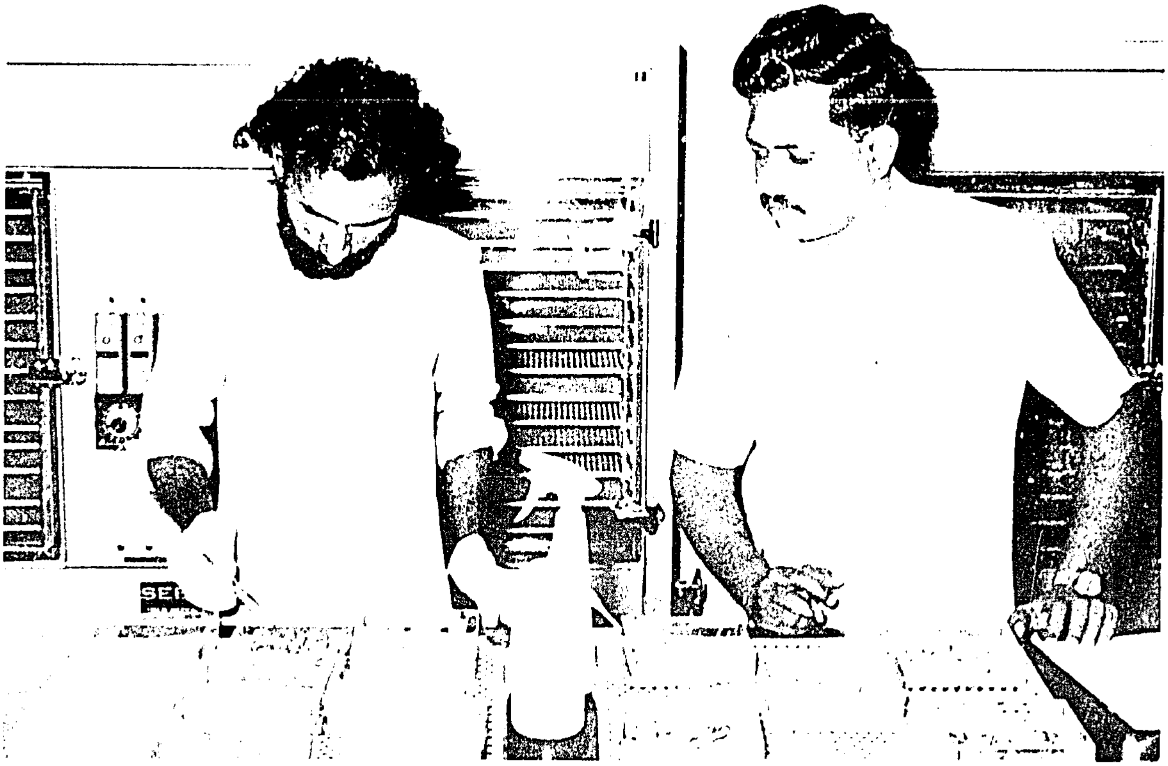


Figure 11. Testing fresh seed dormancy in groundnut germplasm accessions, in Genetic Resources Unit laboratories, ICRISAT Center.

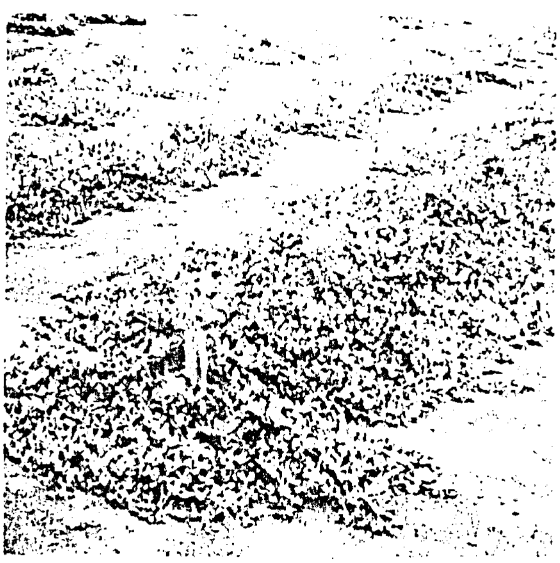


Figure 12. Wild *Arachis* accessions grown for evaluation and seed increase.

Minor Millets

A total of 105 new accessions of three crop species received from Hungary, India, Kenya, and South Africa were rejuvenated during the year raising the total gene bank holdings to 5097 (Table 2).

Using funds provided by IBPGR, we characterized and classified 1956 accessions of finger millet, *Eleusine coracana* and 302 accessions of little millet, *Panicum sumatrense* accessions held in our collection.

Looking Ahead

The collecting program will continue in high-priority areas. More emphasis will be placed on collecting wild species and wild relatives of all the mandate crops. This will not only add more new species to the collections but will provide currently needed broader genetic diversity. We hope that changes in Indian Quarantine restrictions will enable the transfer of more groundnut germplasm from the USA, which would include recent collections of wild species as well as cultivated groundnut from South America.

We will expand the regional evaluation of all crops, in West, eastern, and southern Africa. With the development of facilities at the ICRISAT Sahelian Center, the number of accessions of pearl millet evaluated there will be increased. Groundnut germplasm will also be evaluated at this location. Evaluation in southern Africa is now underway and further expansion of our work in evaluating pigeonpea in eastern Africa is planned. With the development of the Asian Grain Legume Program that will be coordinated from ICRISAT we will follow the recommendation of the Association for Science Cooperation in Asia (ASCA) workshop held in Tsukuba, Japan in November and will collaborate with ASCA member countries and international organizations in the region on effective collection and use of plant genetic resources.

Introgression work will expand in sorghum and chickpea. When conventional methods of introgression fail involving wild species', we anticipate that our cooperative work with ICRISAT cytogeneticists will develop and expand in the use of nonconventional methods for accomplishing wide crosses.

The transfer of seed from the old storage rooms into the new seed storage units, now in operation, will be completed in early 1986, and storage conditions in the new short-term storage will be implemented.

We will develop computer programs to record seed distribution and additional programs or data sets, to record viability tests and results, and for inventory control. From that information, a computer-assisted system of seed-increase management can be developed to avoid peaks and valleys in the number of accessions requiring increase each year.

Attention will be given to the expansion of monitoring seed viability. As much as possible, seed germination and testing equipment will be added to give us the capability of testing all new seed prior to storage. Results of later tests will then indicate the viability trend for each accession. Such information is essential to management of future seed increases.

Cooperative relationships between ICAR, NBPGR, and ICRISAT were initiated in 1985 by an exchange of visits, which resulted in a joint committee meeting in December. Future meetings are planned as well as cooperative work in areas of plant exploration and evaluation of ICRISAT mandate crops in India.

Publications

Journal Articles

Appa Rao, S., Mengesha, M.H., and Sharma, D. 1985. Collection and evaluation of pearl millet (*Pennisetum americanum*) germplasm from Ghana. Economic Botany 39(1): 25-38.

Pundir, R.P.S., Rao, N.K., and van der Maesen, L.J.G. 1985. Distribution of qualitative traits in the world germplasm of chickpea (*Cicer arietinum* L.). Euphytica 34: 697-703.

van der Maesen, L.J.G. 1985. Revision of the genus *Pueraria* DC. with some notes on Teyleria Backer (Leguminosae). Agricultural University Wageningen Papers 85-1. 132 pp.

van der Maesen, L.J.G. 1985. *Cajanus* DC. and *Atylosia* W. & A. (Leguminosae). A revision of all taxa closely related to the pigeonpea, with notes on other related genera within the subtribe Cajaninae. Agricultural University Wageningen Papers 85-4.

van der Maesen, L.J.G., Remanandan, P., Kameswara Rao, N., and Pundir, R.P.S. 1985. Occurrence of Cajaninae in the Indian subcontinent, Burma and Thailand. Journal, Bombay Natural History Society 82. 489-500.

Conference Papers

Mengesha, M.H., and **Prasada Rao, K.E.** 1985. World sorghum germplasm collection and conservation. Pages 90-104 *in* Proceedings of the Plant Breeding Methods and Approaches in Sorghum Workshop for Latin America, 11-16 Apr 1983, CIMMYT, Mexico. Part 1. Mexico City, Mexico: CIMMYT.

Ramanatha Rao, V. and **Sadasivan, A.K.** 1985. Wild *Arachis* genetic resources at ICRISAT. Pages 37-41 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Valls, J.F.M.. Ramanatha Rao, V., Simpson, C.E., and **Krapovickas, A.** 1985. Current status of collection and conservation of south American groundnut germplasm with emphasis on wild species of *Arachis*. Pages 15-33 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

SORGHUM

Contents

Cover photo: ICRISAT pathologist explaining sorghum trials at Dharwad to Governing Board members during their visit.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Cereals Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

γ1

SORGHUM

The main objective of the Sorghum Improvement Program continues to be the development of high-yielding, stable varieties and hybrids with acceptable food quality. To meet this objective, we concentrate on developing, or improving screening techniques for physical (abiotic) and biological (biotic) yield-limiting factors; screening germplasm accessions and breeding material for sources of resistance and other desirable plant and grain quality traits; and on using material identified in the breeding program. Our global activities are based at ICRISAT Center in India and at regional centers for West, eastern, and southern Africa, and for Mexico and Central America.

Our major research activities are concentrated at ICRISAT Center in India where we also use several locations where high stress factors regularly occur, to adequately screen germplasm accessions and breeding material for resistance to various stresses. The locations for stem borer and anthracnose disease are Hisar and Pantnagar, both in northern India; Anantapur in southern India for drought; Bijapur and Akola for *Striga asiatica*, Dharwad for sorghum downy mildew and midge, and Bhavanisagar (near Coimbatore) where we evaluate material for adaptation to latitudes near the equator and resistance to grain molds.

In West Africa the program operates from Ouagadougou, Burkina Faso, and Bamako, Mali and concentrates on the development of cultivars for two distinct zones: Sudanian (600-900 mm rainfall) and Northern Guinean (900-1200 mm rainfall). While frequent drought, poor seedling establishment, and the parasitic weed *Striga* sp are the major yield-limiting factors in the Sudanian Zone, leaf diseases, grain molds, and panicle pests pose serious problems in the Northern Guinean Zone. Soils with low fertility and poor water-holding capacity are common to both the zones. Accordingly, our breeding program evaluates germplasm lines and breeding material in the respective ecological zones and elite materials are systematically tested across a range of ecological conditions.

The eastern Africa regional program operates from Nairobi, Kenya, and concentrates on coordination of regional trials and nurseries conducted by national programs in the region.

The regional program for southern Africa (Southern African Development Coordination Conference (SADCC) countries) is based in Bulawayo, Zimbabwe. It has three fundamental objectives. Firstly, to strengthen the research capabilities of the national programs by providing genetic materials for a range of traits,

International Sorghum Variety Adaptation Trials, Kamboinsé, Burkina Faso, 1985.

research techniques, and assisting in formulation of their research programs. This objective encourages the development of regional cooperation among scientists of participating countries, organization of regional workshops to discuss the results and regional plans for the future. Secondly, training is at ICRISAT Center, in the SADCC region, and in overseas universities. Thirdly, service to national programs, includes upgrading facilities and conditions of field research, advancing generations and crossing in the off-season nursery, and assisting with items needed for field research.

The regional program for Mexico and Central America is based at the headquarters of Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) in Mexico, and works in close cooperation with the national programs in the region. Its main objectives are to develop cold-tolerant (6°-25°C) sorghum varieties and hybrids adapted to growing at high altitudes (1500-2500 m), and to improve the local cultivars adapted to low and intermediate elevations in the region. In both cases the improved genotypes should have high and stable yields, resistance to pests and diseases, and good grain quality.

This report integrates the work conducted by ICRISAT Center and regional programs, and gives research results from 1985 as well as those from previous years not included in earlier Annual Reports.

Physical Stresses

Drought

Resistance screening. We screened germplasm accessions and breeding lines for resistance traits under severe drought-stress conditions during the summer at ICRISAT Center, and the rainy season at Anantapur. The visual scores in 1983 and 1984 drought-resistance screening had clearly demonstrated that there were marked differences in the response of sorghum genotypes to high temperature and water deficit.

We therefore selected five 'susceptible' and four 'resistant' lines (Table 1) for a detailed examination of the physiological basis of resistance to midseason heat and drought stress. The lines were sown on 12 March 1985 in randomized blocks consisting of two treatments: drought-stressed and control. There were four blocks of the stressed treatment and two of the control. The plot size was 9 × 9 m^2. The four stressed plots

Table 1. Sorghum lines used in detailed drought stress, physiology experiment, ICRISAT Center, summer 1985.

Line	Origin	Elevation (m)	Rainfall (mm)	Taxonomic group	Time to 50% flowering (d)
Susceptible					
IS 17605	Yemen AR	1970	600	Durra	131
IS 12739	China	-[1]	-	Caudatum bicolor	50
IS 12744	Taiwan	-	-	Guinea caudatum	53
IS 21436	Malawi	75	800	Durra	56
IS 22253	Botswana	1250	514	Kafir	52
Resistant					
IS 20969	Kenya	1100	1500	Caudatum	115
IS 1347	Egypt	-	-	Caudatum bicolor	48
IS 13441	Zimbabwe	-	-	Caudatum	60
IS 22380	Sudan	600	450	Caudatum	85

1. - = data not available.

were not irrigated from 20 days after sowing (DAS) until the onset of the rains in June.

Control plots were irrigated weekly at a rate sufficient to replace evaporation. After emergence, the plots were thinned to a population of 120000 plants ha^{-1}. Instrumentation was installed in two replicates of each of the five genotypes in both stressed and control treatments. Further replication was restricted by the channels available on the two data-logging units. Also, comparable physiological measurements could only be made on a maximum of five lines per day.

The genotypes examined were IS 17605, IS 12739, IS 20969, IS 1347, and IS 13441 (Table 1) and represent an early- and a late-maturing susceptible line and two early- and one late-maturing resistant lines. Measurements of solar radiation, dry- and wet-bulb temperatures, leaf and soil temperatures, and wind speed were scanned every minute and readings were averaged for each hour. Measurements of wet- and dry-bulb temperatures and leaf temperature were made at heights corresponding to the top and middle of the canopy in each plot. Leaf temperature (°C) was measured at the tip, middle, and base of the underside of the first fully expanded leaf using copper-constantan (38 swg) thermocouples. Soil thermocouples (20 swg) were positioned at 30-cm depth. Solar radiation was measured using tube solarimeters. The fraction of total radiation intercepted by each crop was calculated by comparing the output of tubes placed beneath the canopy with that of a standard tube positioned above the crop. Wind speed was measured at the level of the top of the crop canopy using cup anemometers. Detailed physiological measurements were made twice weekly throughout the stress period on each of the five genotypes in the stress and control plots. On these 2 days, measurements were made at 0830 h, 1230 h, and 1530 h at the midpoint of the youngest fully expanded leaf and on a leaf in the middle of the canopy (usually three leaves lower).

Two days later, measurements were made only on the youngest fully expanded leaf, but in three positions: at its tip, middle, and base. The following measurements were made on these leaves: relative leaf-water content (RLWC) defined as the ratio of leaf-water content at sampling to that at full turgor, leaf-water potential (ψl—as measured with a pressure chamber), and stomatal conductance (gl, measured with a diffusion porometer). Measurements of light incident on the leaves (Si), was made with a quantum sensor and of the leaf temperature (tl), with an infrared thermometer at the time and site of measurement of conductance. Measurements of ψl, gl, Si, and tl were made on the same leaves. Immediately after the measurements of gl, Si, and tl, the leaf was excised and taken to a field laboratory for measurements of ψl. Soil-water content in plots was measured using a neutron probe. Detailed measurements continued until the onset of the rains at 84 DAS, after which only dry-matter production and grain yield were measured in kg ha^{-1}. Dry-matter production of shoots and roots and leaf areas were measured weekly throughout the experiment. We will report these findings in future Annual Reports.

Results shown in Figures 1a and 1b clearly demonstrate that, after a critical level of stress is reached (56 DAS), the resistant lines have a very different plant-water status to the susceptible lines, in terms of RLWC and ψl under both soil and atmospheric water stress. Noticeably, the trend for both traits is the same. A similar response, under atmospheric water stress for stomatal behavior measured by individual leaf conductance (gl) is shown in Figure 1c. The terminology requiring phrases such as 'resistant' and 'susceptible' was obviously subjective, based on the earlier visual scorings. Yet these data verify that these visual differences were based on measurable physiological traits and could be used effectively in an improvement program to identify 'resistant' lines. In addition to quantifying these visual differences, it is also possible to identify which traits are more suitable for field screening. From these data alone, it is clear that RLWC is a more sensitive measurement than either ψl or gl. These initial results are very encouraging and cooperators in the UK, Australia, USA, and Italy will look at additional factors that may consistently distinguish among these very contrasting genotypes.

At Anantapur, the following lines were sown

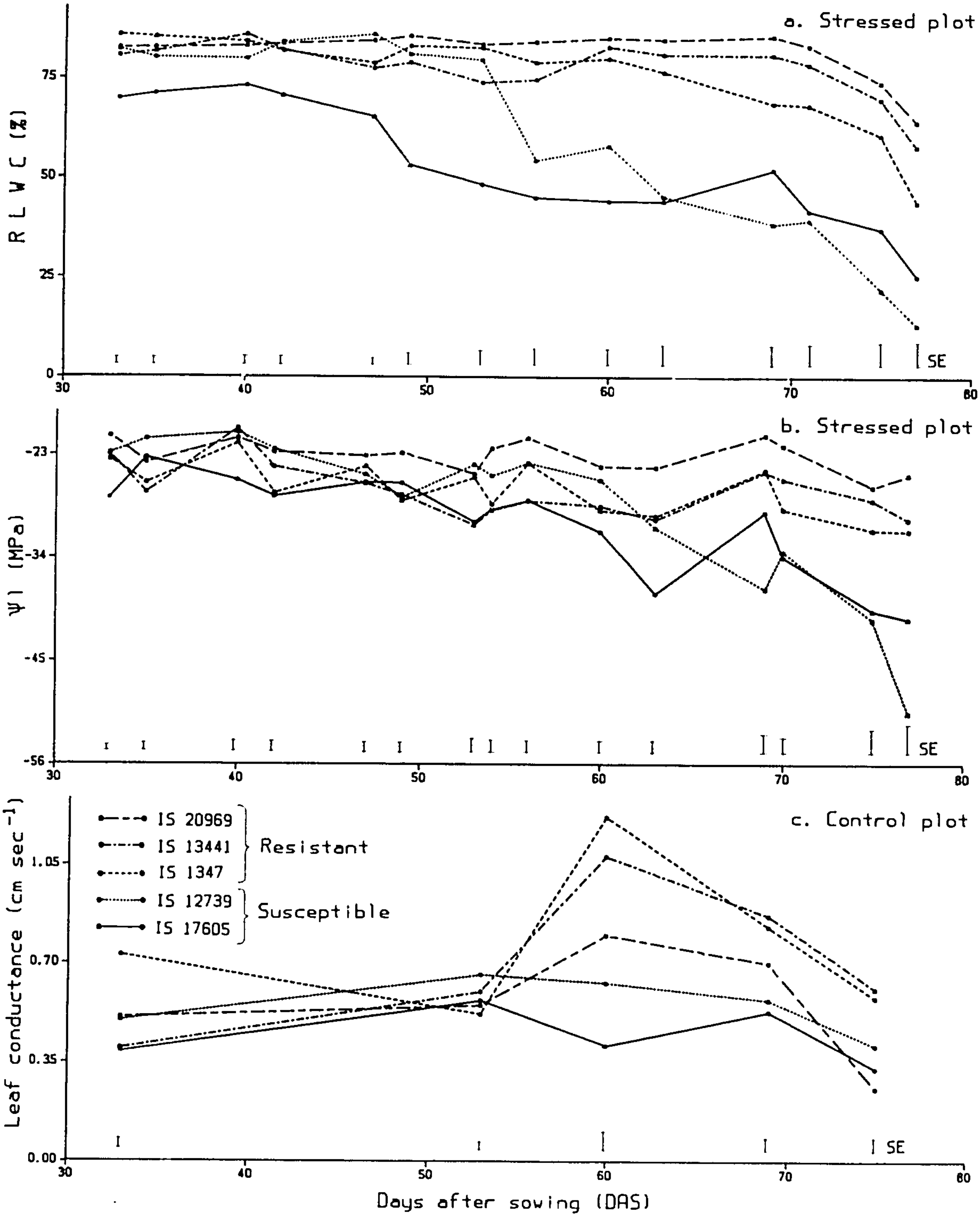


Figure 1. Measurements made at 1230 h on the midportion of the youngest leaves in five sorghum lines IS 20969, IS 13441, and IS 1347 (resistant), and IS 12739 and IS 17605 (susceptible) of (a) relative leaf water content (RLWC %) and (b) leaf water potential ψ 1 MPa in the stressed plots and (c) leaf conductance (gl cm sec^{-1}) in the control plot, ICRISAT Center, summer 1985.

on 23 July 1985: 71 germplasm lines selected from previous screening (ICRISAT Annual Report 1984, p.18), 26 lines from Botswana and Sudan, 122 ICRISAT-bred lines and 96 germplasm lines from the Cameroon. These included the nine germplasm lines that were examined in detail at ICRISAT Center. During the growing season, 321.6 mm of rain fell, but there was a characteristic midseason drought-stress pattern with 43 dry days in between the spells of rain. There was excellent correspondence between the performance of the lines screened at ICRISAT Center and those at Anantapur (Fig. 2). In addition, a number of ICRISAT-bred lines gave good grain yields under midseason stress, notably the varieties ICSV 213, 221, and 210, and hybrids ICSH 109, 199, and 200. For the 2nd year, SPH 263 was one of the top-yielding hybrids at Anantapur (Fig. 3).

Crop Establishment

Seedling emergence through soil crust. Soil crusts inhibit seedling emergence in sorghum. We reported earlier (ICRISAT Annual Report 1983, pp. 69-71) a technique to screen for seedling emergence through soil crust. The repeatability of this technique was assessed using 27 sorghum lines by comparing their performance in two summer trials in 1984 and 1985. Similarly, repeatability of emergence of different seed-lots of the same entries was tested using seeds produced in the postrainy seasons of 1983 and 1984.

The trials were conducted on broadbeds in an Alfisol field in plots 2-m long with a 0.5-m path between each broadbed. There were three replicates per entry in a randomized-block design. We sowed 50 seeds entry^{-1}, 50-mm deep using a John Deere 7100 planter with four planting

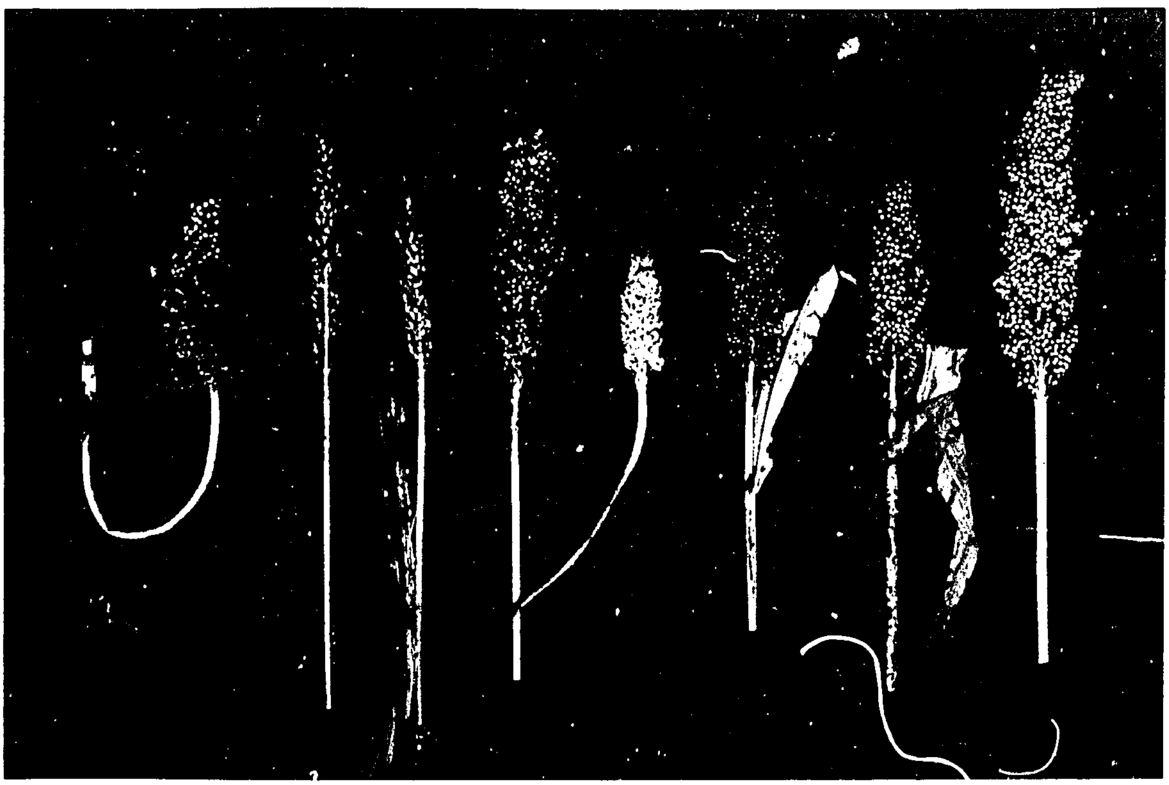


Figure 2. Sorghum panicles grown under midseason drought stress, (left to right); IS 17605, IS 12739, IS 12744, and IS 21436 (susceptible), and IS 20969, IS 1347, IS 13441, and IS 22380 (resistant), Anantapur, rainy season 1985.

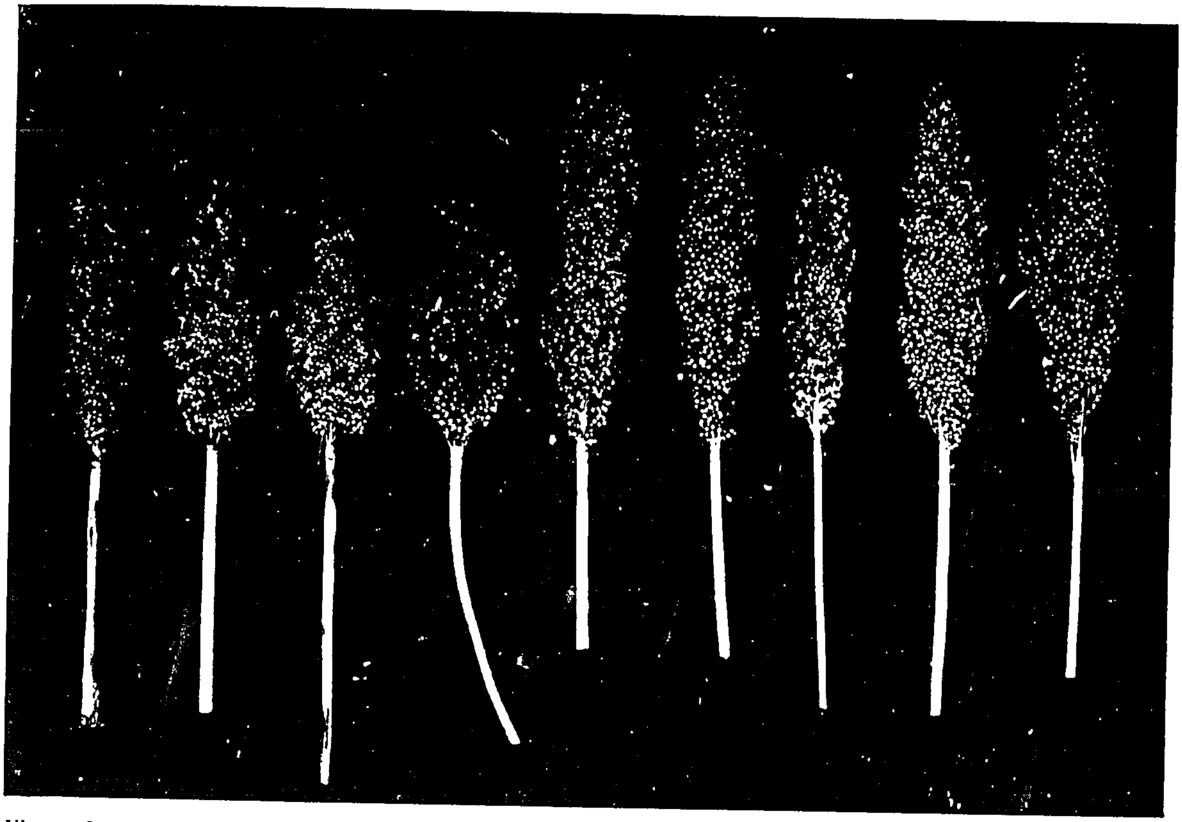


Figure 3. Sorghum panicles grown under midseason drought stress, (left to right): the highest-yielding breeding varieties ICSV 213, ICSV 221, and ICSV 210, Anantapur local cultivar, and hybrids SPH 263, ICSH 109, ICSH 134, ICSH 199, and ICSH 200, Anantapur, rainy season 1985.

units. The beds were again smoothed with a bed shaper, and 35 mm water was applied at 14 mm h^{-1} using two parallel sprinkler lines 15 m apart. The plots were then left to dry for 3 days. The crust in the control plots was then broken with a roller-type crust breaker.

The seedlings were counted 6 DAS. The ratio of the number of seedlings that emerged through crust to the number that emerged in the control (c:u) was used to characterize the emergence ability of each entry through a soil crust. Table 2 shows the c/u ratio of selected entries in both 1984 and 1985 trials for both seed lots. The close agreement of the c/u ratios of an entry between trials and between different seed lots was assessed. The correlation coefficients for the entry means in two trials with the same seed lot was 0.87, $P < 0.001$; 0.73, $P < 0.001$ for different seed lots in the same trial, and 0.82, $P < 0.001$ for different seed lots in different trials. The repeatability of the genotype performance over both years and seed lots suggests that differences between lines may be genetic in origin and of use in crop improvement by breeding or selection.

Plant Nutrition

Biological Nitrogen Fixation

Nitrogen-balance studies. In a long-term, nitrogen-balance field trial started in 1978, eight sorghum cultivars (Table 3) are grown each year on the same plot with the same rates of added nitrogen. During the 7th year of the experiment (rainy season 1984), a uniform crop of pearl millet cultivar ICMV 1 (WC-C75) was grown to overcome the problems associated with successive cropping of sorghum (ICRISAT Annual Report 1984, pp. 37-38). The total dry-matter yield across the cultivars during the 8th year of the experiment were 10730 kg ha^{-1} without nitrogen fertilizer application, 11310 kg ha^{-1} with 20 kg ha^{-1} of nitrogen fertilizer applied, and 11680 kg ha^{-1} with 40 kg ha^{-1} of nitrogen fertilizer applied (Table 3). These results show that the uniform cultivation of pearl millet in 1984 improved the yields of sorghum cultivars in comparison with 3350 kg ha^{-1} across the sorghum cultivars without nitrogen fertilizer application in 1983, 5460 kg ha^{-1} with 20 kg N ha^{-1} in 1983, and 6680 kg ha^{-1} with 40 kg N ha^{-1} in 1983. The total dry-matter yield of 11240 kg ha^{-1} across the cultivars and nitrogen levels was the highest as compared to yields obtained during any of the earlier years of the experiment. This year (the 8th year of the experiment) the total plant dry-matter yield of 10730 kg ha^{-1} was recorded with no application of nitrogen fertilizer for the last 8 years, and nitrogen fertilizer at 20 and 40 kg N ha^{-1} did not increase yield significantly over yield without nitrogen fertilizer (Table 3). The highest total plant dry-matter yield of 13580 kg ha^{-1} was produced by the cultivar Dobbs without nitrogen fertilizer application, followed by CSH 5 with 12130 kg ha^{-1}. The cumulative nitrogen uptakes in the above-ground plant parts from 1978-1984 (except in 1981) without nitrogen fertilizer application were 196 kg ha^{-1} by CSH 5, and 193 kg ha^{-1} by Dobbs, the highest amongst the cultivars without nitrogen fertilizer application.

Table 2. Emergence under crust (c) and under control (u) (c:u) ratios of selected sorghum entries tested in 1984 and 1985 from seeds produced in 1983 and 1984.

	c:u ratio		
Entry	1984 trial of 1983 seed	1985 trial of 1983 seed	1985 trial of 1984 seed
E 178-3	0.95	0.94	0.83
IS 17595	0.90	0.87	0.94
IS 3898	0.89	0.75	0.84
IS 22240	0.88	0.70	0.75
IS 22238	0.87	0.78	0.75
IS 17601	0.87	0.80	0.87
IS 7312	0.86	0.78	0.77
IS 22356	0.85	0.94	0.79
IS 3825	0.84	0.70	0.79
IS 7264	0.63	0.71	0.69
IS 9702	0.31	0.38	0.23
IS 22237	0.28	0.35	0.41
IS 10266	0.02(±0.01)[1]	0.30	0.21
SE	±0.031	±0.040	±0.044
Trial mean (27 entries)	0.769	0.710	0.710

1. Entry value not included in trial mean and SE.

Table 3. Total plant dry-matter yield (kg ha^{-1}) of sorghum genotypes with different levels of nitrogen in long-term nitrogen-balance trial[1], ICRISAT Center, rainy season 1985.

	Nitrogen applied (kg ha^{-1})			
Genotype	0	20	40	Mean
FLR 101	10650	10390	11830	10960
CSV 5	11250	12390	12450	12030
CSH 5	12130	13660	12500	12760
IS 2333	9580	10800	11680	10690
IS 889	6100	5560	6480	6050
Dobbs	13580	15000	15090	14550
IS 15165	11420	10610	10850	10960
Diallel 642	11130	12080	12550	11920
SE		±925		±481
Mean	10730	11310	11680	
SE		±499		
CV(%)		15		

1. Average of four replications, net plot area harvested 26.25 m^2. Basal dose of 9 kg P ha^{-1} applied.

Vesicular Arbuscular Mycorrhizae (VAM)

Colonization and phosphorus uptake. We had previously shown that positive correlations exist among VAM colonization, phosphorus measured in the bleeding sap, and total phosphorus uptake by the plant (ICRISAT Annual Report 1984, p. 40). In order to further standardize the technique, we examined the relationship between the free inorganic phosphorus translocated and total phosphorus content of the plant at different plant growth stages.

We inoculated the cultivar CSH 5 with three different VAM fungi (*Acaulospora* sp, *Glomus epigaeum*, and *Gigaspora calospora*) in separate pots, which included a noninoculated control in both sterilized and nonsterilized soil. We took samples of shoot, root, and bleeding sap at different growth stages to analyze the total phosphorus uptake, VAM colonization, and free inorganic and bound phosphorus in each treatment. Results showed that the free inorganic phosphorus in the bleeding sap was correlated with total phosphorus uptake by plants at 46 and 66 DAS, and was best on the 46th day. As phosphorus was found to be translocated in both inorganic and bound forms, we estimated total phosphorus in the bleeding sap by acid hydrolysis.

We found that the total phosphorus in the bleeding sap was also significantly correlated to total phosphate uptake by the plant at 46 and 66 DAS, but not at other growth stages. The estimation of free inorganic phosphorus in the bleeding sap of plants 46 and 66 DAS was therefore found to be a useful measure of VAM activity.

Biotic Stresses

Diseases

Grain Molds

Resistance screening. Sorghum lines previously identified as resistant under natural infection conditions were re-evaluated for resistance under artificial inoculation with grain mold-causal fungi in two trials comprising of 52 and 130 entries. We divided entries in each trial into early- (up to 65 days to 50% flowering) and medium- (66 to 80 days to 50% flowering) maturity groups. We sowed each maturity group separately in an augmented randomized-block design with two replications, two rows per entry in each replication, and with repeated systematic susceptible controls of similar maturity. At 50% flowering, we inoculated 10 panicles in one row with a spore suspension of *Fusarium moniliforme*, *F. semitectum*, and *Curvularia lunata*, then tagged and bagged them for 10 days. Panicles in the second row were tagged but not inoculated or bagged. To provide high humidity, overhead sprinklers were used on rain-free days from onset of flowering to postmaturity stages. We evaluated panicles 2 weeks after physiological maturity (black-layer formation) for grain mold incidence (termed panicle grain mold rating, PGMR), and later threshed grains were rated for mold severity (threshed grain mold rating, TGMR). Ratings were based on a 1 to 5 scale, where 1 = no mold and 5 = more than 50% grains in a panicle molded for PGMR, or more than 50% grain surface area molded for TGMR.

Mold scores of inoculated and noninoculated panicles and grain were similar and 156 entries out of 182 tested were resistant, i.e., had mold ratings of ≤ 3. Evaluation of bagged panicles was difficult due to severe earhead caterpillar and head bug damage and profuse saprophytic growth of mold fungi on dead pollen, insect excreta, and insect-damaged grain. To avoid these problems, screening for mold resistance under natural-infection conditions without inoculation and bagging is recommended, assuming that mist or sprinkler irrigation is provided on rain-free days to create the high humidity conditions essential for grain mold development.

All the grain mold-resistant lines identified so far have colored grain, mostly brown. However, 14 of them do not have the tannin-containing testa layer often associated with brown sorghums. These lines are IS 13885, IS 14375, IS 14380, IS 14384, IS 14390, IS 20708, IS 20884, IS 21509, IS 21599, IS 25017, IS 25064, IS 25070, IS 25098, and IS 25100.

Grain colonization and mold damage. Sorghum grains are often colonized by mold-causal fungi in the early stages of development. The routes of infection and colonization and, therefore, the nature of resistance are not well understood. We initiated studies to elucidate this. We standardized tissue-processing methods for the developing grain, and simple staining procedures to examine fungi in sectioned grains under a fluorescence microscope. Developing grains were cut, fixed in glutaraldehyde, dehydrated in methyl cellosolve, ethanol, *n*-propanol and *n*-butanol series, embedded in glycol methacrylate and then sectioned to 2 μm thickness. Sections were either stained with Cellufluor®, an optical brightener, or with malachite green, and then counterstained with acridine orange.

We observed the following as the route of colonization by mold-causal fungi. From anthesis onwards fungi colonized and sporulated on decaying stigmas and anthers; thereafter, glumes, lemmae, paleae, and stamen filaments were colonized, and ultimately the fungi reached and entered the base of the developing grain. The fungi then multiplied in the placental sac under the hilum before further colonization of other internal grain tissues.

The rate and extent of stigma, anther, and glume colonization, and the stage of grain development when infection occurred, determined whether mold damage was expressed as grain abortion, reduced grain size, or simply molding of normal-sized grains. When anthers and/or stigma failed to emerge fully from the floret, they were extensively colonized by mold fungi and as a result the developing grain was aborted or rotted within a week after anthesis. However, if fungi colonized the base of the developing grain before the soft-dough growth stage, grain maturity (black-layer formation) was hastened and grain size was reduced. Typical molding of normal-sized grains was expressed either as mold growth initially occurring under the glumes but gradually enveloping the grain, or as localized fungal sporulation on exposed grain surfaces.

Monitoring *Curvularia lunata* spores over a sorghum field. *Curvularia lunata* is one of the common mold-causal fungi and its spores are part of the air spora, the main source of inoculum that infects developing grain. We studied the temporal distribution of *C. lunata* spores to determine the potential amount of inoculum available in the air spora from flowering through grain development stages to grain maturity. We chose *C. lunata* for monitoring because its spores are easy to identify in spore trap catches.

We placed a 24-hour Hirst spore trap at 0.5 m above the canopy of a CSH 1 sorghum field measuring 24 m × 24 m. The trap was operated daily from Monday to Friday beginning on 29 July after full flowering and ending on 8 November. In the Hirst spore trap a pump continuously sucks air at constant rate inside a chamber through an orifice. On entry into the chamber, air strikes a greased slide that traps particulate matter in the air including spores. *C. lunata* spores were counted on each slide under a microscope and then the number of spores present calculated per unit volume (m^{-3}) of air. The results showed the number of spores of *C. lunata* in the air spora to range from 1 m^{-3} to 11 m^{-3} of air from flowering to grain maturity. Most spores were found in the daytime (peak at 0900-1100 h) and the least at night. The spore catch showed a gradual increase from prior to soft dough stage until maturity. After maturity there was nearly a sixfold increase in spore load over the sorghum field. The gradual increase in the level of *C. lunata* spores with grain development was due to the sporulation and further growth of earlier and later infections. These results confirm the availability of *C. lunata* in the air spora above a sorghum field from flowering to grain maturity as an inoculum source for grain infection.

Breeding for resistance. We screened, in a preliminary mold-screening nursery, 112 advanced breeding lines derived from crosses between mold-resistant, colored-grain sorghums and mold-susceptible, white-grain sorghums at ICRISAT Center and Bhavanisagar, a grain mold hot-spot location in southern India. Included in the nursery were mold-resistant, colored-grain and mold-susceptible, white-grain sorghums variable in days to 50% flowering as controls. We recorded the TGMR of grains from all entries 3 weeks after physiological maturity under conditions favorable for mold development.

We found 35 advanced breeding lines from ICRISAT Center to be resistant with TGMR of 3.0 or below as compared to TGMR of 5 for the mold-susceptible, white-grain sorghum controls. It is encouraging to note that 23 of these are white-grain types, selected entries of which are shown in Table 4. The results showed that mold-resistant lines had high grain density (low floater percentages) with high germination percentages, and hard and corneous endosperm that when dehulled gave high extraction rates with insignificant amounts of broken grains. However, the reverse did not appear to be true. There were a few breeding lines (Table 4) that were mold-susceptible but had high grain density with good germination percentage and good extraction rates when dehulled. It appeared that grain molding for these types was restricted to the surface of the grain with little damage to the endosperm. We will carry out detailed microscopic studies on the grains of these types, particularly their endosperm, to confirm this.

Table 4. Time to 50% flowering (days), threshed grain mold rating (TGMR), and other physical grain characteristics of selected advanced breeding lines derived from crosses between mold-resistant, colored-grain, and mold-susceptible, white-grain sorghum genotypes, ICRISAT Center, rainy season 1985.

Genotype	Time to 50% flowering (d)	TGMR[1]	Floaters (%)	Germination (%)	Dehulling recovery (%)
ICSX119K 19W1-6-1	73	2	8	97	88
ICSX119K 64W1-2-1	61	2	8	96	88
ICSX62K 140B$_3$-1	70	2	27	95	88
ICSX62K 140B$_2$-1	75	2	52	82	84
ICSX119K 19W1-4-1	70	3	11	97	88
ICSX119K 19W4-1	76	3	24	96	87
ICSX119K 53W-5-1	67	3	5	96	91
ICSX119K 15W3-1-1	72	3	25	95	85
ICSX132-28W1-2-1-1	75	3	21	92	86
ICSX132-28W1-2-7-1	73	3	25	88	87
ICSX119K 25W1-2-1	78	4	25	94	88
ICSX119K 165B$_1$-1	68	4	28	93	86
ICSX119K 67W5-4-1	61	4	8	93	88
ICSX132-48W1-8-1	67	4	19	93	86
ICSX119K 66W1-1-1	56	4	14	91	90
ICSX126-32W3-3-2-1	65	5	27	93	86
Resistant controls					
IS 14384	68	2	34	87	82
IS 14388	58	3	96	57	58
IS 14385	65	3	28	93	85
Susceptible controls					
SPV 351	61	5	56	68	78
SPV 104	63	5	100	60	52
ICSV 197	78	5	63	79	75
SE	±1.7	±0.4	±7	±5.5	±2.05
CV(%)	4	16	25	11.7	4.42

1. Based on a 1 to 5 scale, where 1 = no mold, and 5 = more than 50% grain surface area molded.

We also screened early-generation breeding lines derived from crosses between mold-resistant, colored-grain and moderately susceptible, white-grain sorghums, and identified 300 mold-resistant white-grain progeny with good levels of mold resistance for further screening. Some of these, which are more agronomically uniform and have high levels of mold resistance, will be included in the preliminary grain mold screening nursery.

Root and Stalk Rot Complex

Effect of soil fumigation and drought stress. We conducted an experiment at ICRISAT Center and Dharwad in the 1984 postrainy season to study the effect of soil fumigation to control soilborne root-infecting fungi, and drought stress on the incidence and development of root and stalk rot, plant senescence, and lodging. The experimental design was a split plot with six replications, with fumigation treatment as main plots and drought stress treatment as subplots. The subplot size was 8 m × 8 m. The soil was fumigated with Dazomet® (tetrahydro-3, 5-dimethyl-2H-1, 3, 5- thiadiazin-2-thione) at the rate of 80 g ai m^{-2} by mixing it with soil to a depth of 30 cm. The root and stalk rot-susceptible hybrid CSH 6 was sown and maintained at a population of 133-350 plants ha^{-1}. The crop was furrow irrigated until onset of flowering when irrigation was withdrawn to create drought stress. Altogether there were four treatments: (a) fumigation and drought stress, (b) fumigation and no drought stress, (c) no fumigation and drought stress, (d) no fumigation and no drought stress. We recorded data on green-leaf area, plant lodging, soft stalks, and visible root and stalk infection by *Macrophomina phaseolina* (one of the stalk rot pathogens), at six different grain development stages from early milky stage to physiological maturity (black-layer formation).

Results in Table 5 show that plant lodging in the nondrought-stressed treatments was low (2.8-8.3%) as compared to the drought-stressed treatments (26.2-74.1%). However, in the drought-stressed treatments, lodging was significantly higher in the nonfumigated soils than in the fumigated soils. At Dharwad, for example, lodging in the drought stressed and nonfumigated plots was 47.9% higher than in the drought-stressed, fumigated plots. Results of plant senescence and visible stem infection by *M. phaseolina* followed the same pattern as that of plant lodging. These results show that soil fumigation significantly reduced plant senescence and lodging in the drought-stressed plots and indicate that soilborne root-infecting fungi play an important role in plant senescence and lodging.

Fungal colonization of sorghum roots and stalks. We monitored fungal colonization of roots and stalks of the root and stalk rot-susceptible hybrid CSH 6 at different growth stages from seedling to grain maturity (black-layer formation) in both nondrought-stressed plots and in drought-stressed plots from onset of flowering to grain maturity. This was done by plating surface-sterilized pieces of roots, crown, and first internode on potato dextrose agar and czapek dox agar media. Seven *Fusarium* species (*F. moniliforme*, *F. moniliforme* var. *subglutinans*, *F. moniliforme* var. *intermedium*, *F. oxysporum*, *F. solani*, *F. semitectum*, and *F. chalamydosporum*), *Macrophomina phaseolina*, *Rhizoctonia solani*, *Phoma sorghina*, *Exserohilum rostratum*, and *Trichoderma harzianum*, were found to colonize sorghum roots and stems. Among these fungi we found *F. moniliforme* var. *subglutinans* and *F. oxysporum* to be early colonizers, which increased in abundance after the induction of drought stress from onset of flowering to maturity. *M. phaseolina* was not isolated during the early growth stages; it was isolated after the hard-dough growth stage and then only from drought-stressed plants. Further work is in progress to establish the primary causal fungi of root and stalk rots in drought-stressed plants.

Downy Mildew (*Peronosclerospora sorghi*)

Resistance screening. In preliminary screening in the field nursery at Dharwad (ICRISAT Annual Report 1982, p.28) we evaluated 1659

Table 5. Time to 50% flowering, green leaf area, lodging, soft stalk, and visible *Macrophomina phaseolina* incidence in sorghum hybrid CSH 6 under different treatments of fumigation and drought stress, ICRISAT Center (IC) and Dharwad (DH), postrainy season 1984.

Treatment	Time to 50% flowering (d)		Green leaf area (%)		Lodging (%)		Soft stalk (%)		Visible *M.phaseolina* incidence (%)	
	IC	DH	IC	DH	IC	DH	IC	DH	IC	DH
Fumigation and drought stress	56	54	0[3]	22.3 (-0.23)[1]	29.1 (32.6)[2]	26.2 (30.8)	19.9 (26.5)[2]	4.9 (12.8)	26.8 (31.2)[2]	8.3 (16.7)
No fumigation and drought stress	60	52	0	0	38.2 (38.2)	74.1 (59.4)	30.7 (33.7)	64.6 (53.5)	45.8 (42.6)	84.3 (66.6)
SE					(±5.65)	(±4.56)	(±5.49)	(±4.09)	(±3.15)	(±4.38)
Fumigation and no drought stress	56	55	72.3 (-0.91)	72.6 (-0.92)	8.3 (16.7)	2.8 (9.6)	0	0	0	0
No fumigation and no drought stress	60	52	54	41.1 (-0.61)	4.6 (-0.44)	3.4 (12.4)	0 (10.7)	0	0	0
SE	±0.8	±0.5	(±0.06)	(±0.07)	(±0.93)	(±1.44)				
CV (%)	1.0	1.0								

1. Figures in parentheses are log-transformed values using 0.5*log((100-p)/(100+p)).
2. Figures in parentheses are arc sine transformed values.
3. Zero values not used in SE calculation.

advanced-generation lines from various breeding projects and selected 594 for further testing. In advanced screening we evaluated 428 genetic resources accession lines and selected 124 lines as resistant, and evaluated 462 advanced generation-breeding lines and selected 142 lines as resistant. We made 82 single-plant selections from 42 resistant breeding lines for their agronomic desirability. We will evaluate these selections for yield in the disease nursery after seed increase.

In 4 years of resistance screening at Dharwad, 24 lines have consistently shown high levels of resistance (up to 5% systemic disease) to downy mildew. The best entries which have shown no downy mildew are IS 1032, IS 2204, IS 3443, IS 3547, IS 18757, IS 22227, IS 22228, IS 22229, IS 22230, IS 22231, and IS 27042.

Stability of resistance. In collaborative research at the USDA Plant Disease Containment Laboratory, Frederick, Maryland, USA, 75 sorghum lines, reported as resistant to downy mildew by various researchers, showed differential reactions to 16 isolates of the pathogen from Argentina, Brazil, Ethiopia, Honduras, India, Nigeria, and USA. Only 10 lines (IS 1032, IS 2473, IS 3545, IS 14332, IS 14387, IS 18757, IS 22227, IS 22228, IS 22229, and IS 22230) previously identified as resistant in our International Sorghum Downy Mildew Nursery were resistant to all isolates of the pathogen. These 10 lines with stable resistance are valuable for worldwide use in downy mildew resistance breeding. These results emphasize the importance of multilocational testing and collaborative research in the identification of stable disease resistance.

Anthracnose (*Colletotrichum graminicola*)

Resistance screening. In preliminary screening at Pantnagar in northern India, we evaluated 106 germplasm accessions and selected 24 lines for further screening, and we evaluated 684 advanced-generation breeding lines and selected 157 lines for further screening. In advanced screening, resistance was confirmed in 8 entries identified as resistant in 1983, and 128 entries identified as resistant in 1984.

We also evaluated in a replicated trial 14 lines selected from advanced-generation breeding lines and germplasm accessions for the 4th consecutive year. Results showed that one germplasm accession line (IS 17141) and three agronomically elite ICRISAT-bred lines (PYT 2 E1, PYT 2 E6, and TRL 74C 57) were highly resistant to anthracnose. The same lines were also resistant to anthracnose under severe natural incidence of the disease at Farako-Bâ in Burkina Faso, West Africa.

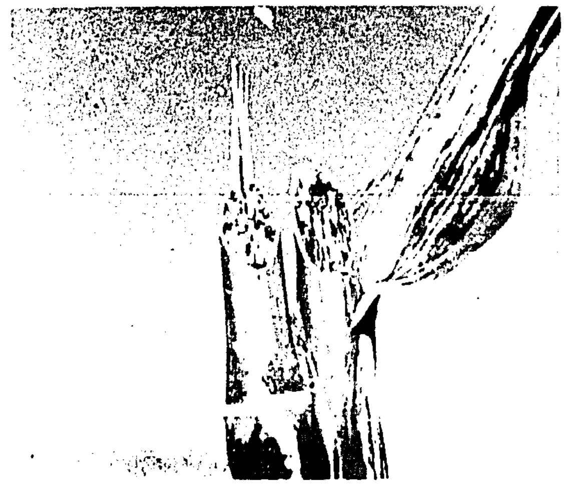


Figure 4. Stalk of acromonium wilt-infected sorghum plant cut diagonally to show xylem tissue necrosis. Note necrotic streaks in veins and intervenial desiccation of leaf, ICRISAT Center, 1985.

Acremonium Wilt (*Acremonium strictum*)

In July 1983 at Pantnagar in northern India, we observed a number of sorghum plants that had wilted. The most conspicuous symptoms of the disease were necrotic streaks on veins of the leaf sheath and lamina, followed by foliar desiccation and wilting. When stems of wilted plants were cut across, the xylem vessels or tissues were necrotic and colored red (Fig. 4). The grains of infected plants were considerably reduced in size. We isolated the fungus *Acremonium strictum* from stems of wilted plants and proved its pathogenicity in greenhouse experiments. The identity of the fungus was confirmed by the Commonwealth Mycological Institute (CMI), UK, and the Centraabweau voor Schimmelcultures, the Netherlands.

In another experiment, we inoculated potted plants at the fourth leaf growth stage by drenching the soil with a spore suspension of the pathogen after lightly injuring the roots with a scalpel. Disease symptoms appeared in most plants. At grain maturity (black-layer formation) we surface-sterilized different plant parts, plated them on potato dextrose agar medium, and reisolated *A. strictum* from root, stem, leaf, leaf sheath, peduncle, main rachis, rachis branch, rachilla, glume, and grain of diseased plants. This indicates that the pathogen colonized the plant systemically after its initial entry via the roots.

When seeds from infected plants were sown in a sterilized Alfisol, 59% germinated, and at maturity, 20% plants showed typical wilt symptoms. This suggests that *A. strictum* moved systemically from mother plant to seed and was further transmitted to the progeny internally through the seed. This is the first report of the seed transmission of the pathogen and of the occurrence of this disease in India.

Striga sp

Screening for resistance to *Striga hermonthica*. In Burkina Faso, we screened 26 cultivars including 7 landraces, 10 advanced-generation breeding lines derived from crosses with the resistant cultivar Framida, and 9 advanced-generation breeding lines from Institut de recherches sur l'agronomie tropicale (IRAT) in pot experiments laid out in a randomized-block design with 10 replications. A landrace variety from Sudan, IS 6961, exhibited the highest level of resistance compared to Framida, the resistant control. Six-hundred-and-fifteen germplasm lines identified to be low stimulant for *S. asiatica* in India were also screened for resistance to *S. hermonthica* in pot experiments. Eighty-six lines identified as resistant will be tested in *Striga* sick plots in 1986.

Breeding for resistance to *Striga asiatica*. At ICRISAT Center, 17 advanced-generation breeding lines, including two resistant lines (SAR 1 and N 13) and two susceptible lines (CSH 5 and CSH 1) as controls were tested in a checkerboard layout in a *Striga* sick field at Bijapur, India, in the 1984 postrainy season. The test entries exhibited varying degrees of resistance. However, SAR 29 was identified as highly resistant since it did not support any *Striga* plants.

Multilocational testing for *Striga* resistance. The 1985 International Sorghum *Striga* Nursery (ISSN) comprising 10 cultivars—5 sources of resistance, 3 breeding lines, and 2 controls—was grown by cooperators in *Striga* sick plots in eight African countries. Results received so far from two locations in Burkina Faso (Kamboinsé and Farako-Bâ) showed that *Striga* infestation level in the susceptible control cultivar CK 60 was satisfactory for meaningful evaluation of the entries. For the 4th year, the cultivar IS 6961 from Sudan was highly resistant to *Striga*. The cultivar Framida, previously considered resistant to *Striga*, was parasitized by significantly higher numbers of *Striga* at Farako-Bâ than at Kamboinsé.

Insect Pests

Sorghum Shoot Fly (*Atherigona soccata*)

Screening for resistance. In preliminary field screening, we evaluated 7000 germplasm accessions using the interlard fishmeal technique, and selected 793 accessions for further testing. In advanced screening of 225 lines in a replicated trial during the rainy season, 10 lines showed less than 40% shoot fly damage (deadhearts) as compared to 78.8% in the susceptible hybrid CSH 1 and 48.3% in a resistant line IS 18551. We also screened 290 breeding lines using a cage technique (ICRISAT Annual Report 1982, p.21). Fifty-one lines were selected as resistant under multi-choice conditions, of which 12 lines showed resistance under no-choice conditions.

The identified sources of shoot fly resistance in cultivated sorghums are not satisfactory because the levels of resistance are not high enough, and vary over seasons. We therefore screened wild sorghum species for better sources of resistance. We screened 345 wild sorghum accessions under no-choice conditions using the cage technique. Thirteen entries showed high levels of antibiosis and were rescreened in three replications. The results showed that no flies emerged from *Sorghum purpuriosericeum* (two accessions) and *Sorghum dimidiatum* (one accession) in spite of high egg-laying (average 5 eggs plant^{-1}) against the control CSH 1 that had 100% fly emergence. These resistant lines had high trichome density on the leaves that may have interfered with larval movement. Attempts will be made in future to transfer this resistance from the wild sorghums into cultivated ones.

Breeding for resistance. The sorghum population being developed for resistance to shoot pests (shoot fly and stem borer) was random mated for the fifth time under natural shoot fly and artificial stem borer infestations during the rainy season at ICRISAT Center.

We evaluated 136 experimental hybrids, resulting from three shoot fly-resistant male-sterile lines (PSA 14832, PSA 21459, and PSA 21453) for shoot fly resistance at ICRISAT Center during the postrainy season. Two hybrids with less than 40% deadhearts were selected as less susceptible than CSH 1, which had >85% deadhearts.

We screened 134 F_2 progeny segregating for shoot fly resistance, and selected 312 shoot fly damage-free plants. We also evaluated 1238 advanced progeny (F_6 and F_7) for resistance and agronomic desirability. The best progeny were PS 27655-3, PS 28060-2, PS 28060-3, PS 28062, PS 30706-1, PS 30715-1, PS 30723-3, and PS 30731. These lines will be included in the 1986 International Sorghum Shoot Fly Nursery (IS-

SFN) to test the stability of shoot fly resistance across locations and environments.

Multilocational testing. We sent the 1984 ISSFN comprising 13 germplasm accessions, 10 ICRISAT-bred lines, and 2 susceptible control cultivars (CSH 1 and a local entry) to cooperators in Asia and Africa for resistance evaluation. We received data from 11 locations (7 from India, and 1 each from Ghana, Mali, Pakistan, and Thailand). Twelve lines had less than 30% shoot fly damage across locations compared with 51% on CSH 1 and 56% on local control cultivars. The most resistant lines across locations were IS 2123, IS 2205, IS 2394, IS 3962, IS 5470, IS 5566, IS 18551, PS 20092, and PS 21318.

Chemical control. During the 1985 rainy season, we assessed the effectiveness of cypermethrin applied with an electrodyne sprayer in controlling shoot fly. Under severe shoot fly pressure, plots treated three times with cypermethrin at 6, 10, and 14 days after crop emergence showed 40% deadhearts against 100% in the nontreated control. Foliar applications of Oncol® and fenvalerate applied as high-volume sprays failed to control shoot fly.

Stem Borer (*Chilo partellus*)

Yield-loss assessment. We conducted a yield-loss trial by infesting plants with different numbers of stem borer eggs (0, 10, 20, 30, and 50 egg masses plant^{-1}; one egg mass contained 30-40 eggs) and larvae (0, 4, 8, and 12 plant^{-1}) at 5 different crop growth stages (15, 20, 30, 40, and 50 DAE) to determine pest density and plant-growth stage at infestation that result in grain yield loss. Early stem borer infestation (15 DAE) with either first instar larvae or eggs resulted in significantly higher death of the main shoot (deadheart) and subsequent yield reduction. Variation in larval infestation level at 15 DAE had no influence on the number of deadhearts or yield. However, plots infested 20 DAE with 12 larvae plant^{-1} showed significantly higher deadhearts than those infested with 8 or 4 larvae plant^{-1}. Plants infested at 30 DAE or later did not develop deadhearts. Egg mass infestation at 15 and 20 DAE resulted in fewer deadhearts than larval infestation.

Factors associated with resistance. In previous resistance screening trials, we observed that sorghum lines that grew faster during the vegetative stage were less susceptible to stem borer. To study the factors associated with this resistance, we monitored various growth parameters such as plant height, time of panicle initiation, internodal elongation, and number of internodes, on 20 lines with varying degrees of resistance during rainy and postrainy seasons. Results showed that early panicle initiation and faster internodal elongation were associated with resistance to stem borer.

Since time of panicle initiation and internodal elongation were not the only factors associated with resistance, we also examined biological parameters such as first instar larval establishment, time at which larvae enter the stem, larval mass, and duration of larval development, pupal mass, and survival rate on 20 lines during the 1985 rainy season. These lines were infested with egg masses and we recorded the number of eggs hatched on each plant. We found significant differences in number of larvae in leaf whorls and stems, larval mass, and survival rate (Table 6). The number of larvae in the leaf whorls was least in IS 12308 (25%), IS 13100 (39%), and IS 2269 (40%) compared to IS 18573 (77%) and ICSV 1 (51%). Fewer larvae were recovered in the stem 10 days after infestation in five lines (IS 1044, IS 2123, IS 4776, IS 5585, and IS 13100). Larval mass was significantly lower (<90 mg larva^{-1}) in six lines (IS 2309, IS 5585, IS 12308, IS 13100, IS 18333, and IS 18577) as compared to IS 18573 (140 mg larva^{-1}) and ICSV 1 (115 mg larva^{-1}). Survival rate as measured by total insect recovery was low in IS 2205, IS 2309, and IS 18333 (8-10%) as compared to 28% in IS 1044 and 24% in CSH 1. Further experiments are necessary to identify the important mechanisms and to quantify their role in overall resistance.

Resistance screening. In preliminary screen-

Table 6. Factors associated with stem borer resistance in sorghum, ICRISAT Center, rainy season 1985.

			Larvae in			
Genotype	DH[1] (%)	Time to PI[2] (d)	Leaf whorl 1 DAI (%)	Stem 10 DAI[3] (%)	Larval mass 21 DAI (mg)	Total insect recovery 28 DAI
IS 1044	24	53	54	9	92	28
IS 2123	9	33	54	7	93	15
IS 2205	33	39	57	16	103	9
IS 2269	-	33	40	17	127	22
IS 2309	18	30	53	35	85	8
IS 4776	20	40	44	10	109	20
IS 5469	8	33	57	11	98	25
IS 5538	-	56	56	12	99	22
IS 5585	49	33	41	9	85	15
IS 12308	36	17	25	31	89	21
IS 13100	30	25	39	7	88	18
IS 13674	41	28	64	24	101	26
IS 18333	54	53	58	21	85	10
IS 18551	25	38	62	10	109	23
IS 18573	23	56	77	10	140	20
IS 18577	33	51	41	21	84	21
IS 18579	29	40	42	13	92	15
IS 18580	38	40	57	12	99	19
ICSV 1	62	33	51	17	115	20
ICSV 2	38	28	42	13	94	24
SE			±6.5	±4.3	±6.5	±4.5
CV(%)			18	45	9	33

1. DH = Deadhearts (larval infestation 20 days after emergence).
2. PI = Panicle initiation.
3. DAI = Days after infestation.

ing, we evaluated 3000 germplasm accessions under natural infestation at Hisar during the rainy season, and selected 620 lines for further testing. In advanced screening of 121 lines tested in a replicated trial under artificial infestation at ICRISAT Center and natural infestation at Hisar, 13 lines (IS 2375, IS 2376, IS 4757, IS 5619, IS 9608, IS 21969, IS 22039, IS 22091, IS 22145, IS 22507, IS 23411, IS 23962, and IS 24027) were identified as resistant at both locations.

Breeding for resistance. Sixty-eight crosses were made between 5 stem borer resistant lines and 17 agronomically elite lines during the 1984 postrainy season. Forty-four agronomically desirable F_1s were selected and their F_2 progeny were screened for resistance under natural infestation at Hisar during the rainy season. Out of these, 163 stem borer-free plants were selected. We also screened 158 stem borer resistant advanced lines (F_6 and F_7), 91 F_4s, and 65 F_3s, under natural infestation at Hisar and artificial infestation at ICRISAT Center during the rainy season. Two lines, PB 10306 among the advanced progeny and PB 10688-2 among the F_4 progeny were identified as resistant to stem borer.

Sorghum Midge (*Contarinia sorghicola*)

Biology. Our studies on population monitoring and larval diapause continued at Dharwad and Bhavanisagar. At Dharwad, we observed maximum midge populations during the 2nd and 3rd week of November. Due to prolonged drought, the midge population peak was delayed by nearly 15 days. The midge incidence on germplasm and breeding lines was less than in the previous seasons. We screened a number of chemicals in combination with yellow traps for their usefulness in monitoring midge populations. Ethanol-baited yellow traps caught the maximum number of midges.

Resistance screening. We screened 2000 germplasm accessions for midge resistance at Dharwad, and selected 283 for further testing. We also screened 687 breeding lines, of which 46 were resistant under natural infestation conditions. Entries in the 1985 International Sorghum Variety Trial (ISVAT 85) and the 1985 International Sorghum Hybrid Trial (ISHAT 85) were also screened for midge resistance; only one line ICSV 197 (PM 11344) was resistant. In advanced screening, we evaluated 225 germplasm accessions and breeding lines at ICRISAT Center, Dharwad, Hisar, and Pantnagar, and selected 150 lines for further testing under no-choice conditions.

Breeding for resistance. We incorporated five improved midge-resistant breeding lines PM 6981, PM 7018, PM 7172-1, PM 7322, and PM 11344 into the midge and head bug-resistant population in 1984 postrainy season, and in the following summer season the population was advanced without screening for midge resistance. Subsequently, it was random-mated for the fifth time during the late rainy season.

Fifteen advanced-generation breeding lines were screened for midge resistance under natural midge infestation at Dharwad and artificial midge infestation at ICRISAT Center. PM 7017, PM 7018, PM 7032, PM 7104-1, PM 7172-1, PM 7499, PM 7526, and PM 11344 (ICSV 197) were resistant.

Multilocational testing. Data of the 1984 International Sorghum Midge Nursery from 10 locations (7 in India, and 1 each in El Salvador, Ghana, and Mali) showed that cultivars IS 3461, IS 7005, IS 8571, IS 15107, IS 18733, IS 19512, PM 6751, PM 7032, PM 7318-2, PM 7526, PM 8787-2, and PM 11344 (ICSV 197) were resistant to midge across locations (Table 7).

Head Bug (*Calocoris angustatus*)

Biology. We monitored head bug populations at ICRISAT Center by sampling sorghum panicles at the milky-growth stage at fortnightly intervals from January to December. The maximum number of head bugs were recorded during the second fortnight of September. The initial buildup of the head bug population was slow probably because of a prolonged period of drought during August. Head bug populations were also monitored in a sorghum crop using white sticky traps at heights of 1, 1.5, and 2 m. The highest number of bugs were trapped at a height of 1.5 m. During the off-season, no bugs were caught in the sticky traps.

We studied oviposition by head bug females on six sorghum cultivars by releasing 20 pairs of adults at panicle emergence onto each panicle enclosed in a cage. Panicles were sampled 5 days after adult release, and 500 randomly-selected florets were examined under a microscope for head bug eggs. We recorded the total number of eggs, and florets with eggs. The number of eggs laid (151 eggs 500 florets^{-1}) were significantly less in IS 17645, a less-susceptible cultivar compared to the highly-susceptible cultivar Swarna (562 eggs 500 florets^{-1}).

We studied the orientation behavior of adults towards light passed through different colored gelatins (green, yellow, blue, red, violet, and clear). More adults were attracted to light passed through clear gelatin, and least to light passed through red gelatin. Panicles of CSH 5 at the milky-growth stage were nonpreferred when they were illuminated with light passing through red gelatin, but preferred when illuminated with light passing through clear gelatin.

Table 7. Midge damage in 25 sorghum genotypes at 10 locations in the International Sorghum Midge Nursery, 1984.

Genotype	Locations[1] and damage rating[2]									
	1	2	3	4	5	6	7	8	9	10
IS 61	5.0	2.0	2.0	2.0	3.0	5.0	-	5.0	3.0	5.0
IS 2549C	2.5	2.0	2.0	3.0	3.0	1.0	3.5	4.0	1.0	1.0
IS 3461	1.0	1.0	2.0	2.0	3.0	1.0	1.0	3.0	1.0	1.0
IS 7005	1.0	1.5	2.0	2.5	3.0	1.0	1.0	3.0	1.0	1.0
IS 8571	1.5	1.5	1.0	3.3	3.3	1.0	1.0	2.0	1.0	1.0
IS 10712	2.0	2.5	1.0	3.0	4.0	1.0	3.0	3.5	1.5	1.0
IS 15107	1.0	1.5	2.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0
IS 18733	1.0	1.0	1.0	3.0	3.0	4.0	2.5	2.5	1.0	1.5
IS 19512	1.0	2.0	2.0	2.5	2.0	1.0	1.5	3.0	1.0	1.0
IS 21873	2.0	3.0	2.0	2.5	2.5	4.0	2.0	4.0	1.0	1.0
PM 6751	3.0	1.5	2.0	3.0	3.0	1.0	1.5	3.0	1.0	1.0
PM 7032	2.0	2.0	2.0	2.5	2.5	1.0	1.5	3.0	1.0	1.0
PM 7061	1.5	1.5	2.0	3.0	2.5	1.0	1.0	4.0	1.0	1.0
PM 7164-1	2.0	2.0	1.0	3.0	3.5	4.0	1.5	4.0	1.0	1.0
PM 7318-2	2.0	1.5	3.0	2.0	3.0	1.0	2.0	3.0	1.5	1.0
PM 7322	1.0	1.0	2.0	3.0	3.0	2.0	2.0	3.5	2.0	1.0
PM 7526	1.0	3.0	1.0	3.0	2.5	1.0	1.5	3.0	1.0	1.0
PM 8787-2	2.0	1.0	3.0	3.0	1.0	1.5	3.0	1.0	1.0	1.0
ICSV 197	1.0	2.5	2.0	2.5	3.0	1.0	1.0	3.5	1.0	1.0
Controls										
AF 28 (R)[3]	1.0	2.0	1.0	2.0	3.0	1.0	1.5	2.0	1.0	1.0
TAM 2566(R)	1.0	1.0	2.0	3.0	2.5	1.0	2.0	3.0	1.0	2.0
DJ 6514 (R)	1.0	2.5	2.0	2.0	2.0	2.0	1.5	3.0	2.0	1.0
Local cultivar	4.0	3.0	2.0	5.0	4.0	4.0	5.0	4.0	3.5	4.0
CSH 1 (S)[3]	4.0	2.5	2.5	5.0	4.0	5.0	5.0	4.5	3.5	5.0
SE	±0.18	±0.34	±0.87	±0.28	±0.36	-	±1.16	±0.44	±0.38	±0.26

1. 1 = Dharwad, Karnataka; 2 = Surat, Gujarat; 3 = Parbhani, Maharashtra; 4 = ICRISAT Center, I; 5 = ICRISAT Center, II; 6 = Kovilpatti, Tamil Nadu; 7 = Tolichowki, Hyderabad; 8 = Nyankpala, Ghana; 9 = Sotuba, Mali; 10 = San Salvador, El Salvador.
2. Damage ratings: 1 = <10% chaffy florets, 2 = 11-25% chaffy florets, 3 = 26-40% chaffy florets, 4 = 41-60% chaffy florets, and 5 = >60% chaffy florets.
3. R = Resistant, S = Susceptible.

In a feeding rhythm test, it was found that maximum probing and feeding occurred between 1300 and 1800 h, and least from 1900 to 2400 h. Probing was not observed from 0000 to 0500 h. The frequency and duration of probing and feeding was higher on CSH 5, a susceptible cultivar, than on less susceptible cultivars, IS 2761 and IS 17645.

Resistance screening. Using the infester-row technique (ICRISAT Annual Report 1984, p.35), we screened 2174 germplasm accessions for resistance, and selected 473 lines for further testing. In advanced screening, we evaluated 111 germplasm accessions under natural infestation and artificial infestation, by enclosing panicles in a headcage, and selected 67 lines for further testing. We screened 180 ICRISAT-bred varieties and hybrids and found all of them susceptible to head bugs.

Panicle-growth stage in relation to head bug susceptibility. We studied head bug population buildup and grain damage on 5 cultivars (IS 2761, IS 6984, IS 9692, Swarna, and CSH 5) at four panicle-growth stages in a split-split plot design with growth stages in main plots, cultivars in subplots, and head bug population in sub-subplots. Panicles enclosed in a cage were infested with head bugs at emergence, half-anthesis, postanthesis, and milky-growth stages with four levels of head bug populations (5, 10, 15, and 20 pairs of bugs panicle^{-1}). Head bug population buildup after infestation decreased with increasing panicle maturity (Fig. 5) probably due to difficulties in oviposition (generally the eggs are laid in florets before anthesis) and the inability of nymphs to feed on developing grain that hardens with age. At maturity, the susceptible cultivars CSH 5 and Swarna had supported more head bugs than IS 2761, IS 6984, and IS 9692.

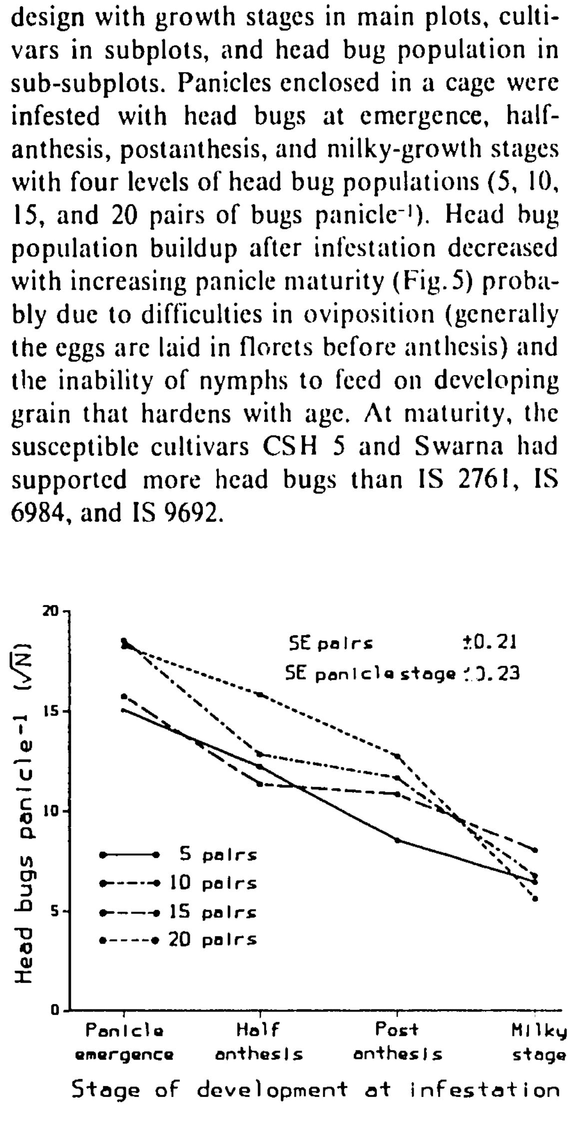


Figure 5. Head bug population buildup in sorghum panicles from five cultivars infested at panicle emergence, half anthesis, postanthesis, and milky stage under headcages, ICRISAT Center, rainy season 1985.

Chemical control. We tested six systemic insecticides for head bug control and found methyl demeton to be the most effective, although it did not differ significantly from carbaryl, a contact insecticide effective for head bug control. We also tested carbaryl at dosages of 250, 500, 1000, and 2000 g ai ha^{-1} and found that 500 g ai ha^{-1} was most effective for head bug control.

Head bug (*Eurystylus marginatus*)

Host-plant resistance. We studied host-plant resistance to the head bug *Eurystylus marginatus*, in Mali in 11 cultivars with different panicle and glume characteristics using a headcage technique whereby protective cages were placed on panicles at anthesis. We infested five randomly-selected panicles with 20 pairs of head bugs at the milky-growth stage, and counted adults and nymphs 20 days after infestation. Grain was threshed and separated for density in a sodium nitrate solution. The grain was also tested for germination and food quality. We found considerable varietal differences in head bug damage. The Guineense sorghums, CSM 388 and IS 14332, and Malisor 84-7 (83-F_6-225) had little grain damage compared to the other sorghums. Days to glume opening, glume length, and glume covering of the grain contributed towards head bug resistance. Head bug damage had a negative effect on germination. The keeping quality and color of *tô* made from nondamaged grain was better than that made from damaged grain.

In a second experiment, we studied the growth stage of the panicle and the numbers of head bugs that give the maximum grain damage. Headcages were placed on panicles of Malisor 84-7 at panicle exsertion. Panicles were infested with 5, 10, 20, and 40 pairs of head bugs at 3 grain development stages (post anthesis, milky, and post milky). The experimental design was a split plot with stage of panicle development as the main treatment. Panicles infested with head bugs at anthesis supported the maximum number of head bugs, and suffered more grain damage than panicles infested at milky and post milky growth stages. This indicated that the timing of infestation is critical in obtaining optimum damage for screening breeding material for resistance to *Eurystylus* sp.

Fall Armyworm (*Spodoptera frugiperda*) and Sugarcane Borer (*Diatraea saccharalis*)

Breeding for resistance. Sorghum yield losses in Latin America caused by the fall armyworm and the sugarcane borer can be quite high. The ICRISAT regional program for Mexico and Central America is breeding sorghums for resistance to these pests using insect-rearing facilities at CIMMYT to provide insects for artificial, uniform, and timely infestation of sorghum lines.

We made crosses between insect-tolerant lines, artificially infested their progeny, selected F_2 plants that showed resistance, and advanced them to F_3 and F_4 generations. Finally, we compared the F_5 generation with the original parents in a replicated yield trial using artificial infestation. Our results indicated that the pedigree approach to accumulate genes in order to obtain more resistant genotypes is not effective; i.e., there was no genetic gain in resistances to the two insects. Work now in progress aims to improve levels of resistance by population breeding.

Neem (*Azadirachta indica*) for Insect Control

In collaboration with the Regional Research Laboratories (RRL), Hyderabad, we continued to study the antifeedant properties of neem for insect control. We screened 75 formulations of neem fraction G and identified 11 formulations for further testing. We evaluated a formulation of neem fraction G for insect control on sorghum along with neem oil, the insecticide malathion, and a nontreated control. An oriental armyworm (*Mythimna separata*) damage rating of 2.7 (on a scale of 1-5, where 1=no damage and 5=most damage) and spotted stem borer (*Chilo partellus*) damage (stem tunneling) of 3.7% were significantly lower in neem-treated plots than in nontreated plots (3.8 oriental armyworm damage rating, and 13.7% stem tunneling, by spotted stem borer).

Plant Improvement

ICRISAT Center

Conversion of Tall,Photoperiod-sensitive Tropical Landraces

Conversion of Zerazera landraces. We completed the conversion of some photoperiod-sensitive and tall Zerazera landraces from Ethiopia and Sudan to day-neutral and short day backgrounds for use in ICRISAT and national breeding programs. One-hundred-and-fifty lines were finally selected from the converted Zerazera populations, selfed in the rainy season, and assigned International Sorghum Conversion (ISC) numbers.

Conversion of Nigerian Kaura and Guineense landraces. The second group of material chosen for conversion included highly photoperiod-sensitive Kaura and Guineense landraces from Nigeria. Selections from single cross F_2 progeny were advanced to F_3. We selected from 205 F_3 progeny of single crosses of 5 Kauras (IS 24704, IS 24737, IS 24750, IS 24881, and IS 27044) and 3 Guineense (IS 24885, IS 24886, and IS 27043) with 7 early and dwarf genotypes, 26 early dwarf landrace-type segregants for backcrossing to the landraces.

Multifactor Resistant Populations

We continued the development of five broad-based multifactor resistant (MFR) populations, each planned to have resistances to a set of diseases and insect pests important in priority geographical regions of the semi-arid tropics (ICRISAT Annual Report 1984, p.40-41).

We intermated 224 S_1s from Rs/R, 42 S_2s from US/R, and 174 S_1s from Indian Synthetic and obtained 2696 half-sibs to form the base materials for ICSP 1R MFR and ICSP 3R MFR populations. To form the base materials for ICSP 2B MFR and ICSP 4B MFR populations, 36 S_2s from US/B and 268 S_1s from Rs/B were intermated resulting in 1738 half-sibs. To develop the fifth population, ICSP 5BR MFR, 18 S_2s of the West African Early (WAE) population were intermated to give 900 half-sibs.

To ascertain restorability/nonrestorability of the R/MFR and B/MFR populations base materials, we evaluated the test crosses of the S_1/S_2s (that were involved in intermating in 1984 postrainy season) of the US/R, Rs/R, Indian Synthetic, Rs/B, and US/B populations for seed-set in bagged panicles. We observed R-allele frequencies: 0.95 in Rs/R, 0.84 in US/R, and 0.82 in Indian Synthetic; and B-allele frequencies, 0.79 in Rs/B, and 0.48 in US/B. We did not evaluate WAE for its restoration as the population ICSP 5BR MFR to be developed from this should contain both R- and B-alleles.

We made 967 S_1 selections from R/MFR half-sibs, 390 from B/MFR, and 408 from BR/MFR, after excluding those half-sibs from evaluation that have B-allele in R/MFR, and R-allele in B/MFR as determined by the testcross studies.

Introducing variability for resistances. Lines resistant to shoot fly (6), stem borer (9), midge (7), grain molds (2), downy mildew (6), leaf diseases (5), *Striga* (3), drought (6), and with seedling vigor (2) were crossed as females with R/MFR and B/MFR population base materials to introduce variability both for cytoplasms and genomes. Of the 46 resistant sources, only one good grain line with good emergence through a crust had the B-allele. Improvement for the resistances in the B-background would thus require additional efforts of testcrossing the resistant selections of the above R (resistant sources) × B (B/MFR) crosses in developing B/MFR.

Evaluation for resistances. In the advanced screening tests of lines including the S_2s of US/R and US/B, 14 lines were found resistant to downy mildew (< 5% plants infected), 16 to anthracnose (< 5% leaf area damaged), 9 moderately resistant to grain molds (< 3 TGMR, where 1 = no mold, and 5 = more than 50% grain surface molded), 3 to midge (< 3 score, where 1 = 10% grain damage and 5 = >60% grain damage), 16 to shoot fly (< 50% deadhearts), and 8 to stem borer (< 50% deadhearts under natural infestation at Hisar). Of these, 5 S_2 lines resistant to anthracnose, 11 to shoot fly, 2 to stem borer, and 2 to midge belonged to the US/R population. In the US/B population, one S_2 line was resistant to downy mildew, one to shoot fly, and 5 to stem borer (under artificial infestation). The resistant lines, thus identified from the populations, will be further crossed to the respective B/ or R/MFR population base materials.

Subpopulation evaluation. Six synthetics (ICRISAT Annual Report 1984, p. 42), hereafter referred to as subpopulations, in three levels of random matings were evaluated for yield, height, and DTF at three locations in India. These subpopulations were developed from the paired crosses made within US/R population and between US/R females and WAE males. These were separately random mated (C_0-once, C_1-twice, and C_2-thrice). Results showed that tall, medium, and short subpopulations had distinctly different heights as was expected, based on the intercrosses that were made to form the subpopulations.

Grain-yield performances of the subpopulations are presented in Table 8. Considering the deviations of C_0 from C_2 and of the mean of C_0 and C_2 from C_1, the levels of random mating did not show a significant effect on yield except in two comparisons (US/R × US/R short subpopulation for the former comparison under high fertility, and US/R × WAE-medium subpopulation for the latter comparison under low fertility). This suggested that through random mating, the subpopulations maintained similar gene frequencies and that there was little inbreeding depression. A similar analysis was made on the 36 comparisons to study the effects of height on yield. Two comparisions, tall vs short of C_0 and C_2 of US/R × WAE under ICRISAT's high-fertility conditions (see Table 8), showed distinct effects of height on yield. In all the other 34 comparisons, height did not significantly affect yield.

The inter- and intra-subpopulations were not significantly different at any location when judged either on the basis of paired-crosses bulks, or subpopulations.

Subpopulations were not superior to the best hybrid control SPH 221, at any of the locations and collectively they yielded 15% less than the control hybrid. However, contrary to our expectation, none of them had significantly higher yields than the best available varietal controls

Table 8. Mean grain yield (kg ha⁻¹) of sorghum subpopulations evaluated[1] at three locations in India, rainy season 1985.

Entry	ICRISAT Center			
	LF[2]	HF[3]	Dharwad[4]	Mean
US/R×US/R PC[5] Bulk	4620	3230	6760	4870
US/R×WAE PC Bulk	4880	3340	6900	5040
US/R×US/R C_0 Tall	4560	3370	7720	5220
US/R×US/R C_0 Medium	4940	3510	7320	5260
US/R×US/R C_0 Short	5030	3760	7600	5460
US/R×US/R C_1 Tall	4730	3240	6930	4970
US/R×US/R C_1 Medium	4910	3350	6890	5050
US/R×US/R C_1 Short	4450	3620	6860	4980
US/R×US/R C_2 Tall	4660	3210	7640	5170
US/R×US/R C_2 Medium	4690	3310	7180	5060
US/R×US/R C_2 Short	4760	2940	7180	4960
US/R×WAE C_0 Tall	4420	2850	6540	4600
US/R×WAE C_0 Medium	5000	3150	6910	5020
US/R×WAE C_0 Short	4680	3690	7190	5190
US/R×WAE C_1 Tall	4120	3020	6760	4630
US/R×WAE C_1 Medium	4200	3210	6360	4590
US/R×WAE C_1 Short	4670	3010	6920	4870
US/R×WAE C_2 Tall	4140	3370	7050	4850
US/R×WAE C_2 Medium	4940	3570	7320	5270
US/R×WAE C_2 Short	5080	3400	6970	5150
Controls				
SPH 221	4810	4750	8130	5900
CSH 6	2140	3900	6200	4080
SPV 351	4590	3820	6600	5000
SPV 386	4160	3770	7510	5150
ICSV 112 (SPV 475)	4280	3950	6760	5000
SE	±246	±271	±447	
CV(%)	9	14	11	
Efficiency(%)	94	120	91	

1. 5×5 tripple lattice, plot size 12 m² at ICRISAT Center and 7.2 m² at Dharwad.
2. LF = Low fertility (N 40:P 20:K 0)
3. HF = High fertility (N 80:P 56:K 0)
4. Dharwad (N 100:P 60:K 60)
5. PC = Paired crosses.

(SPV 351, SPV 386, or SPV 475) at any of the locations. This suggested that we need to develop synthetics; with lines known to have high levels of specific combining ability (SCA), and also with a relatively large number of SCA lines, in order to determine the feasibility of developing synthetics superior to the best varieties.

Male-sterile allele introgression. A genetic male-sterile allele (MS_3) is being introgressed into 24 postrainy season-adapted lines and 2 drought-resistant lines and they are in backcross $(BC)_2$ and BC_3 stages. These MS_3 isogenic lines, will be ready in another 2 seasons, and will be valuable to the national programs as they provide a ready means of creating genetic variability for post-rainy-season adaptation.

Derived lines. We made single-plant selections in advanced generations and continued to advance these by the pedigree method. From the evaluation of 80 selections in the 1984 postrainy and 124 in the 1985 summer seasons, 264 individual plant selections were made. We evaluated these, along with other derivatives of M 35-1 and drought-resistant materials, a total of 850 derivatives in various generations (F_3 to F_8), in the 1985 rainy season; and advanced 370 individual plants for further selections.

In addition, from earlier evaluations we provided 32 varieties and 6 experimental hybrids to common breeding trials for further testing in 1985. Also, 12 B lines were included in the common B-Line Observation Nursery.

Evaluating Advanced Elite Varieties

We yield tested 144 agronomically elite varieties from different projects at four locations in India during the rainy season. These varieties were derived from diverse parents known to have resistance to some yield-limiting factors. Yield data of selected high-yielding varieties are given in Table 9. The selected lines varied for plant height (173-239 cm) and days to 50% flowering (68-72 days).

We also evaluated our advanced elite varieties at five locations in India. Yield data for selected high-yielding lines are given in Table 10. Most of the lines were tall, varied in days to 50% flowering from 67 days (ICSV 209) to 77 days (ICSV 213). They also differed in height. For example, ICSV 221 was very tall (225 cm) while ICSV 202 was short (141 cm). At Anantapur, where the varieties experienced midseason drought, ICSV 221 and ICSV 213 gave the highest yields.

Female Parents (Male-steriles) for Hybrids

Milo cytoplasm. We continued to convert into male-sterile lines, those rainy-season adapted and postrainy-season adapted, nonrestorers of different heights and maturities, with good grain characteristics and resistance to leaf diseases. We made 58 nonrestorer × nonrestorer crosses to improve the nonrestorers; 250 agronomically superior plants were selected from the F_2 populations grown without protection from insect pests during the rainy season. We evaluated 126 new A and B pairs in BC_3, and selected 39 pairs of diverse types for height, maturity, and head types. In addition, from 117 A and B pairs of postrainy-season adapted materials with bold grain grown during the rainy season, we selected 77 backcrossed plants (for the 3rd and 4th time). The resulting plants were short (1-2 m), with bold (100-seed mass >2 g) semicorneous grain and good male sterility.

The shoot fly-resistant nonrestorers PS 21359 and PS 21747 were converted into male steriles and are now ready for hybrid production. Midge-resistant nonrestorers, PM 7061 and PM 7068, are in the BC_5 and BC_3 stages of conversion.

We supplied 45 male steriles selected for superior agronomic performance and resistance to leaf diseases (ICRISAT Annual Report 1984, p. 42) to 28 cooperators (outside India) and 6 breeders in India so that they could study their stability for male sterility and yield. In a three-locational (ICRISAT Center, Bhavanisagar, and Dharwad) testing of 64 nonrestorer lines, ICSB 55, yielded over all locations 5430 kg ha^{-1}, ICSB 3 yielded 5150 kg ha^{-1}, and ICSB 13 yielded 5130 kg ha^{-1}; significantly higher than the grain yield of the control BTX 623 (4610 kg ha^{-1}).

Table 9. Mean grain yield (kg ha⁻¹) of selected sorghum varieties evaluated[1] at four locations in India, rainy season 1985.

Entry	Pedigree	ICRISAT Center		Bhavani sagar[4]	Dhar-wad[5]	Mean
		Vertisol[2]	Alfisol[3]			
ICSV 233	[IS 9562×(IS 12611×SC 108-3)]-3-2-2-5-1	4030	5380	6990	7110	5880
ICSV 339	(PS 21143×E 35-1)-3-2-3-3	4120	5120	5970	7640	5710
ICSV 234	[IS 20509×(IS 12611×SC 108-3)]-1-1-2-4-3	3580	5220	6090	7820	5680
ICSV 332	(PS 21143×E 35-1)-2-2-4-1	3360	4830	6520	7630	5580
ICSV 230	(SPV 475×QL 3)-1-1-1-2	3340	5830	6310	6830	5580
ICSV 246	[IS 20509×(IS 12611×SC 108-3)-1-1-2-1]-2-1-4	3420	5000	6920	6640	5490
ICSV 296	[(M 35-1×M 1009)-3-2-1×6 F5]-5-1-4-2-1	2470	4910	7400	7140	5480
ICSV 272	[(M 35-1×M 1009)-3-2-1×F5-6]-5-2-3-1-1	2630	5530	6580	7160	5470
ICSV 338	(PS 21143×E 35-1)-3-2-2-3	3280	5200	6220	7100	5450
ICSV 295	[(M 35-1×M 1009)-3-2-1×6 F5]-5-1-4-1-1	2840	4360	7450	7100	5440
ICSV 330	(PS 21143×E 35-1)-2-2-2-3	3250	5340	6130	7030	5440
ICSV 247	(E 36-1×CS 3541)-3-15-1-2-2	4000	4410	6630	6620	5410
ICSV 273	[(M 35-1×M 1009)-3-2-1×F5-6]-5-2-3-1-2	3100	4310	6310	7890	5400
Controls						
ICSH 153[6]	296A×(SC 108-3×CS 3541)-27-2-1	3880	6540	7940	8400	6690
CSH 9[6]	296A×CSV 4	3470	6110	6310	7380	5820
ICSV 1	(SC 108-3×CS 3541)-19-1	3730	4810	5360	6380	5070
ICSV 112	[(IS 12522C×555)×(IS 3612C×2219B)-5-1×E 35-1]-5-2	2310	4000	6800	6800	4980
CSH 1[6]	CK 60A×IS 84	3210	2770	3150	6660	3950
SE		±440	±396	±715	±567	
CV(%)		26	14	21	13	
Efficiency (%)		93	107	117	100	

1. 12×12 lattice, plot size 6 m² at ICRISAT Center and 3.6 m² at Dharwad.
2. Vertisol (N 80:P 56:K 0)
3. Alfisol (N 80:P 56:K 0)
4. Bhavanisagar (N 80:P 30:K 30)
5. Dharwad (N 100:P 60:K 60)
6. Hybrid controls

Nonmilo cytoplasm. Fertility restoration on nonmilo cytoplasm is a major problem in making hybrids. The 471 F_1s made on A_2, A_3, and Maldandi male-sterile lines with nonmilo cytoplasm are being studied for their fertility restoration in crosses with germplasm lines.

Male Parents (Restorers) for Hybrids

More than 200 lines that restore fertility on milo cytoplasm were pooled from different breeding projects and observed in a common nursery at ICRISAT Center, Bhavanisagar, and Dharwad; 50 were selected for use in hybrid production.

Hybrid Evaluation

In India, we evaluated 156 experimental (preliminary) hybrids for yield in two separate trials at ICRISAT Center and Bhavanisagar. Yield data of some of the most productive hybrids are presented in Table 11. The highest-yielding hybrids, ICSH 281, ICSH 210, and ICSH 109, matured in about the same time as the hybrid control CSH 9, which took 64 days to 50% flowering. The hybrids, ICSH 266, ICSH 316, and ICSH 318 took less than 60 days to 50% flowering and are early maturers. Several of the selected hybrids were taller and had higher fodder values than the hybrid control, CSH 9 (160-cm tall). They were ICSH 228 (171 cm), ICSH 231 (178 cm), ICSH 319 (180 cm), ICSH 316 (172 cm), ICSH 301 (173 cm), ICSH 305 (183 cm), and ICSH 318 (188 cm).

We evaluated hybrids selected from the preliminary trials in 1984 for yield at five locations in India during the rainy season. The results are presented in Table 12. All the selected hybrids were about the same maturity as the control hybrid CSH 9 which grew to 163 cm, while several of the selected hybrids were taller. Taller hybrids include ICSH 205 (193 cm), ICSH 138 (186 cm), ICSH 109 (177 cm), ICSH 106 (198 cm), ICSH 117 (178 cm), ICSH 203 (181 cm), ICSH 199 (224 cm), ICSH 164 (183 cm), and

Table 10. Mean grain yield (kg ha^{-1}) of selected advanced sorghum varieties evaluated[1] at five locations in India, rainy season 1985.

Entry	Pedigree	Anantapur[2]	ICRISAT Center HF[3]	ICRISAT Center LF[4]	Bhavanisagar[5]	Dharwad[6]	Mean
ICSV 225	(PS 21143×E 35-1)-3-2-2-4	850	3550	4130	5670	7320	4310
ICSV 210	(SPV 350×SPV 475)-2-2-5	980	3290	3470	5230	8470	4290
ICSV 224	(PS 21143×E 35-1)-2-2-2-4	550	4000	3940	5460	7490	4290
ICSV 221	(E 35-1×IS 5604)-4-1-1-2-1	1310	2590	4190	4830	8210	4220
ICSV 202	(SPV 350×SPV 475)-2-2-7	750	3390	4090	5310	7490	4210
ICSV 219	(E 35-1×US R 703)-2-1-1-2-3	530	3260	4240	5120	7660	4160
ICSV 207	[SPV 475×(IS 12611×SC 108-3)]-4-4-8-27-2	910	2070	3990	5840	7470	4060
ICSV 211	(SPV 350×SPV 475)-7-1-2-1	700	3420	3460	5450	7200	4050
ICSV 200	[(148×E 35-1)-4-2-4×IS 17797]-1-2-5	570	2960	3810	5250	7000	3920
ICSV 214	(FLR 141×CSV 4)-1-2-4×Ind-Syn 3-3-4-6	970	2630	3520	5730	6210	3810
ICSV 212	(FLR 274×CSV 4)-6-2-1	940	2950	3950	4540	6470	3770
ICSV 209	[(148×E 35-1)-4-2-4×IS 17797]-3-4-4	640	3260	3800	5290	5380	3670
ICSV 213	(Rs/R×CSV 4)-1525-1-1-4-1	1790	1140	2340	4280	7000	3310
Controls							
CSH 9[7]	296A×CSV 4	980	3510	3650	6720	6550	4280
ICSV 1	(SC 108-3×CS 3541)-19-1	460	3640	3110	5420	7260	3980
ICSV 112	[(IS 12622C×555)×(IS 3612C×2219B)-5-1×E 35-1]-5-2	1220	2270	3640	5160	7190	3900
CSH 1[7]	CK 60A×IS 84	1830	2250	1500	2870	6930	3070
SE		±163	±365	±276	±375	±370	
CV(%)		42	25	14	14	9	
Efficiency (%)		121	101	144	114	96	

1. 6 × 6 lattice, plot size 12 m^2 at ICRISAT Center and 7.2 m^2 at Dharwad.
2. Anantapur (N 80:P 42:K 0)
3. HF = High fertility (N 80:P 56:K 0)
4. LF = Low fertility (N 40:P 20:K 0)
5. Bhavanisagar (N 80:P 30:K 30)
6. Dharwad (N 100:P 60:K 60)
7. Hybrid controls

Table 11. Mean grain yield (kg ha^{-1}) of selected sorghum experimental hybrids evaluated[1] at two locations in India, rainy season 1985.

Entry	Pedigree	ICRISAT Center[2]	Bhavani-sagar[3]	Mean
ICSH 281	296A×(SC 108-3×Diallel)-21-2-3-3	4500	9660	7080
ICSH 210	ICSA 4×(SC 108-3×CSV 4)-27-2-1	4170	8600	6380
ICSH 109	296A×[(SC 108-3×E 35-1)-5-1×CSV 4]-2-2-1	4750	7770	6260
ICSH 245	ICSA 16×[(SC 108-3×E 35-1)-5-1×CSV 4]-2-2-1	4330	7860	6100
ICSH 266	ICSA 22×(SC 108-3×GPR 148)-18-4-1	4000	8110	6050
ICSH 228	ICSA 9×(IS 9327×US/R Bulk)-6-1-2-1-1	4470	7680	6050
ICSH 231	ICSA 11×(SC 108-3×CSV 4)-11-2-3	3750	8030	5890
Controls				
ICSH 153	296A×(SC 108-3×CSV 4)-27-2-1	5580	7330	6460
CSH 9	296A×CSV 4	4670	6530	5600
SE		±383	±585	
CV(%)		15	12	
Efficiency (%)		96	103	
ICSH 319	ICSA 35×(SC 108-3×GPR 148)-18-4-1	3580	7240	5410
ICSH 304	ICSA 30×(SC 108-3×GPR 148)-18-4-1	3540	7250	5400
ICSH 316	ICSA 35×(SC 108-3×CSV 4)-27-2	4170	6560	5360
ICSH 301	ICSA 30×(SC 108-3×CSV 4)-27-2	3500	7180	5340
ICSH 296	ICSA 28×(IS 9327×US/R Bulk)-6-1-2-1-1	3170	7120	5150
ICSH 305	ICSA 30×(IS 9327×US/R Bulk)-6-1-2-1-1	3170	7070	5120
ICSH 311	ICSA 34×(SC 108-3×CSV 4)-27-2	3580	6490	5040
ICSH 318	ICSA 35×(SC 108-3×CSV 4)-11-2-3	4000	6060	5030
Controls				
ICSH 153	296A×(SC 108-3×CSV 4)-27-2-1	3920	6310	5110
CSH 9	296A×CSV 4	3080	6890	4990
SE		±502	±544	
CV (%)		24	13	
Efficiency (%)		90	123	

1. 9 × 9 lattice, plot size 6 m² at ICRISAT Center and 4 m² at Bhavanisagar.
2. ICRISAT Center (N 80:P 56:K 0)
3. Bhavanisagar (N 80:P 30:K 30)

ICSH 204 (177 cm). In addition to their yield advantage, these tall hybrids had higher fodder value. The hybrids, ICSH 205, ICSH 199, and ICSH 164 yielded significantly more than the control CSH 9 under midseason drought conditions at Anantapur. Their yields were almost double that of CSH 9. All these hybrids have superior grain quality with corneous endosperms.

West Africa

ICRISAT/Mali Cooperative Program

Crossing Program

The ongoing crossing program assures the gradual improvement of our breeding stocks through the recombination of our best materials. In the 1984 off-season nursery, we made bulk crosses of F_2 progeny of Malisor 84-7 (83-F_6-225) and genetic male-sterile plants in our hard grain population. That combination should provide excellent scope in 1986 for F_2 and F_3 selections of hard-grained, high-yield potential material with wide adaptation. During the rainy season, we realized that we had very little variability for high-tillering plants; so in the off-season nursery we made a large number of crosses between the best advanced progeny and sources of high-

Table 12. Mean grain yield (kg ha^{-1}) of selected advanced sorghum hybrids evaluated[1] at five locations in India, rainy season 1985.

Entry	Pedigree	Anantapur[2]	ICRISAT Center HF[3]	ICRISAT Center LF[4]	Bhavanisagar[5]	Dharwad[6]	Mean
ICSH 205	SPL 117A×(FLR 266×CSV 4)-2-2-2-1-1	3030	5250	4400	7400	9130	5840
ICSH 138	296A×(FLR 266×CSV 4)-2-2-2-3-2	1800	5260	4680	7830	8950	5700
ICSH 110	296A×(SC 108-3×CSV 4)-51-1	1400	5900	4750	7520	8940	5700
ICSH 109	296A×[(SC 108-3×E 35-1)-5-1×CSV 4] -2-2-1-1	2420	4820	4830	7360	8420	5570
ICSH 106	296A×(SC 108-3×CSV 4)-20-2-2	1780	4580	4600	7680	9020	5530
ICSH 117	296A×(FLR 101×IS 1082)-4-3-3	1450	4800	4860	6810	8880	5360
ICSH 203	SPL 180A×(CS 3541×GG 370)-2-1-1-6-1	2170	3860	4460	7640	8680	5360
ICSH 199	D 1A×(SPV 69×E 12-5)-28-4-1-1	2860	3900	3970	6950	8800	5300
ICSH 164	D 2A×[SPV 105×(SC 108-4-8×CSV 4)-1] -14-2-1	2570	4030	4920	7080	7810	5280
ICSH 195	MA 12×[(IS 12645×CSV 4)-45-1×CSV 4] -6-1-4	2170	4250	4660	6030	9260	5290
ICSH 137	296A×(Early Pop-5-1-1)	1780	4530	4160	5900	9690	5210
ICSH 182	MA 9×[(IS 12622×555)×(IS 3612×2219B) -5-1×E 35-1]-5	2130	4340	4940	6350	8190	5190
ICSH 204	SPL 204A×(CSV 4×Bulk-Y)-D 181-1-1-1	2100	4120	3720	6360	9630	5190
ICSH 197	MA 12×[(IS 10927×UChV 2)-16-1×CSV 4]-5	1970	3620	4950	6140	8910	5120
ICSH 187	MA 9×(SPV 99×E 35-1)-2 2 1	1610	4360	4570	6390	8560	5100
Controls							
ICSH 153	296A×(SC 108-3×CSV 4)-27-2-1	2320	4660	4660	7280	9110	5610
CSH 9	296A×CSV 4	1700	3680	3970	6530	8500	4880
ICSV 112	[(IS 12622×555)×(IS 3612×2219B)-5-1 ×E 35-1]-5-2	1120	3870	4370	5350	8310	4600
CSH 5	2077A×CSV 4	1740	1730	3720	5700	6450	3870
SE		±174	±307	±305	±544	±378	
CV(%)		16	13	12	15	8	
Efficiency(%)		108	103	106	125	90	

1. 6 × 6 lattice, plot size 7.2 m^2 at Dharwad and 12 m^2 at ICRISAT Center.
2. Anantapur (N 80:P 42:K 0).
3. HF = High fertility (N 80:P 56:K 0).
4. LF = Low fertility (N 40:P 20:K 0).
5. Bhavanisagar (N 80:P 30:K 30).
6. Dharwad (N 100:P 60:K 60).

tillering ability. We continued to backcross Malisor 84-2 (83-F_4-24) identified as a maintainer line to introduce cytoplasmic male sterility. We made about 100 crosses of F_4 progeny onto A lines to identify new R and B lines in 1986. We identified B lines in Malisor 84-3 (83-F_4-24) and are now working to obtain A line versions of this material.

Evaluation of Early-generation Selections

We evaluated 327 F_4 progeny and 67 F_6 progeny at four locations and selected from 88 families at harvest. We advanced these selections in our irrigated off-season nursery and will include the best progeny in further multilocational testing in 1986.

The majority of our selections are of medium height (150-200 cm). There is already a range of good early sorghums in the region, and we have recently identified Malisor 84-4 (83-F_4-183) and Malisor 84-5 (83-F_4-352) with earliness and good yield potential. Our present emphasis on medium- and medium-late maturing materials will make available a greater range of useful sorghums for the Sudanian Zone where most of the West African sorghum is grown. Sooty stripe damage scores are uniformly low in all our present selections. There are very few high-tillering plants among our present selections, the majority have one or occasionally two tillers. Yet the best local sorghums and the variety L 30, which is the top performer in intermediate yield trials throughout the region, have high tillering capacities under favorable conditions. We will enhance the useful diversity of high-tillering sorghums through crosses of high-tillering progeny with our hard-grain population. In future, we will continue to use recurrent selection and recombine high-tillering plants.

The majority of our present selections have vitreous endosperms, which assure longer grain storability, minimum bran loss, and excellent *tô* quality. The characteristic may also, in some cases, be associated with head bug tolerance. The high-yielding variety L 30 has a brown subcoat and soft grain. It is generally unacceptable to farmers in spite of its high yield potential.

Yield and Food Quality Assessment of Advanced Progeny

In balanced lattice square designs we sowed yield trials at nine locations in Mali. Medium-maturing materials were sown at five locations and early-maturing materials at four locations. The results are summarized in Tables 13 and 14. The rainfall of the five medium-maturing season sites was very well distributed throughout the season. At all locations except Longorola, average yield of the selected local variety CSM 388 was about the same as the highest-yielding improved varieties. However, the local variety matured at least 2 weeks later than most of the improved ones. In case of terminal drought, its yields would have been reduced. On a more droughty soil at Sotuba, the same local variety only yielded half the grain of Malisor 84-7 (83-F_6-225). In 1984, again on a droughty soil, Malisor 84-7's yield was more than twice that of CSM 388 at Sotuba.

The top-performing variety in the medium-maturing trials was L 30. This variety is the top performer in regional Comité Permanent Intérétats de Lutte Contre la Sécheresse dans le Sahel (CILSS) trials, but its poor grain quality makes it unpopular with farmers. Table 15 is a summary of the *tô* stability of grain harvested from four of the medium-maturing sites. The *tô* of L 30 was consistently unstable. In addition, the presence of a brown subcoat is an undesirable food factor for most West African consumers. Malisor 84-7 has high and stable yields and *tô* quality. As a result of 2 years' performance, we will recommend Malisor 84-7 for multilocational pre-extension testing in 1986. In addition, Malisor 84-7 has been used extensively in our population crosses. In 1986, we will evaluate over 100 F_5 progeny with Malisor 84-7 parentage.

The early-maturing trials experienced erratic drought spells. Consequently, the results are much more variable than the medium-maturing trials. Nevertheless, Malisor 84-5 (84-F_5-352) again yielded very well at Béma. The yield level and stability of that variety had also been

Table 13. Grain yields (kg ha^{-1}) of early- and medium-maturing sorghums sown late at five medium-season sites, Mali, 1985.

Genotype	Sowing date and location: 28 June Koula (640)[1]	15 June Longorola (1130)	28 June Katibougou (916)	1 July Sotuba (957)	2 July Kita (641)	Mean grain yield (kg ha^{-1})	Time to 50% flowering (d)
Malisor 84-2	1660	1170	2260	1100	919	1420	71
Malisor 84-3	1830	1810	2610	1900	1530	1940	72
83-F_4-477	1370	722	1670	1150	815	1150	72
83-F_6-222	1710	987	2350	1000	760	1360	72
Malisor 84-7	1930	1720	2330	1840	1360	1840	73
84-F_4-107	2060	1390	2410	1480	820	1630	67
84-F_4-53	1430	663	1040	996	220	869	65
84-F_8-111	1920	1540	2260	1900	1130	1750	69
84-F_4-89	1670	778	1650	1480	889	1290	66
84-F_4-11	1150	938	2500	998	777	1270	82
84-F_4-104	1320	1390	1850	1830	1090	1500	72
Controls							
S 6	1450	1080	2660	1160	1940	1660	81
A13120	2140	716	2690	1240	1120	1580	69
82 S 50	1500	1830	2350	1700	1340	1750	78
CSM 388	2310	184	2730	1740	1640	1720	86
L 30	2150	2400	2720	2430	1720	2280	71
SE	±165	±127	±142	±200	±106		
CV (%)	26	28	17	37	26		
Efficiency(%)		108	139		115	112	

1. Rainfall (mm)

demonstrated in both breeding and agronomy trials in 1984. We are recommending it for 1986 pre-extension testing in the Sahel region of Mali.

Burkina Faso

Germplasm Evaluation

The majority of local cultivars in the Northern Guinean Zone of West Africa mature in 135-150 days. In order to identify sorghums of diverse origin that could contribute to sorghum improvement in this zone, we sowed 2785 germplasm accessions from ICRISAT Center that flower in 85-100 days at Farako-Bâ in the 3rd week of July. We selected 79 accessions resistant to various leaf diseases, with good grain quality and adaptation, for further evaluation.

Observation Nurseries

We initiated work to identify and develop suitable sorghum cultivars that fit into existing and/or improved cropping systems of the Northern Guinean Zone. A large number of diverse breeding lines and parents (1100) and known stress-tolerant cultivars (120) were introduced and evaluated in observation nurseries at Farako-Bâ by considering days to 50% flowering, plant height, plot yield, disease resistance, and grain

Table 14. Grain yields (kg ha^{-1}) of early-maturing sorghums sown late at four short-season sites, Mali 1985.

Genotypes	Sowing date				Mean grain yield (Béma and Cinzana)	Mean grain yield (all locations)	Time to 50% flowering (d)
	18 July Béma (433)[1]	1 July Cinzana (560)	15 July Bmdg[2] (557)	22 July Massantola (486)			
83-F_4-95	2430	1790	-	602	2110	1600	59
Malisor 84-4	2450	1430	626	529	1940	1260	54
83-F_4-242	1920	1640	-	898	1780	1490	55
83-F_4-255	2020	1730	504	640	1870	1220	59
83-F,-268	2360	1520	-	520	1940	1470	64
83-F_4-286	2140	1820	-	-	1980	1980	72
83-F_4-291	2070	1660	-	541	1870	1430	56
84-F_4-352(Malisor 84-5)	3660	1440	644	689	2550	1610	60
83-F_4-353	2280	1900	422	615	2090	1310	61
83-F_6-171	2490	1680	-	384	2090	1520	63
83-F_6-222	2510	1410	-	689	1960	1540	64
83 SB Pop Keninké 37	1230	1530	-	615	1380	1130	61
CE 90	2110	1410	-	566	1760	1360	66
CE 151	2920	1380	325	573	2150	1300	63
CSM 219	1750	2090	-	750	1920	1530	61
Gumel	-	1050	-	-	1050	1050	77
SE	±268	±181	±34	±161			
CV (%)	32	31	42	72			

1. Rainfall (mm). 2. Bmdg = Baramandougou.

quality and by comparing these with local cultivars grown as controls. We selected 22 elite varieties for further tests. Most of these are advanced breeding lines from ICRISAT Center and they include: ICSV 2 IN (SPV 386), ICSV 297 IN (PM 11344), ICSV 230 IN, ICSV 234 IN, ICSV 247 IN, ICSV 242 IN, and ICSV 126 IN.

A- and B-line observation nursery. In Burkina Faso we evaluated an A- and B-line observation nursery comprising 45 recently developed female parents (A and B lines) at Kamboinsé and Farako-Bâ. All the lines maintained their sterility. Based on visual scores for agronomic characters and resistance to the leaf diseases anthracnose, grey leaf spot, sooty stripe, zonate leaf spot, and oval leaf spot, we retained 15 lines for further testing and use in hybrid production. ICSA 1, ICSA 2, ICSA 26, and ICSA 34 were highly resistant to leaf diseases.

Preliminary Variety Yield Trials

We tested F_4 and F_6 breeding lines in eight preliminary yield trials laid out in a balanced lattice design. Two of the trials comprised F_4 progeny derived from crosses of elite *Striga*-resistant breeding lines together with other desirable traits. We made 12 selections for further testing. The remaining six trials comprised 120 F_6 progeny derived from pedigree selections from a modified backcross program involving desirable exotic dwarf lines and established West African local cultivars. Past experience has shown that recovery of desirable recombinants from single crosses of exotic × photoperiod-sensitive local cultivars is very poor. In order to enhance the frequency of desirable recombinants, we have a backcross program involving the exotic as well as the local cultivars as recurrent parents; (ICRISAT Annual Report 1984). Desirable dwarf F_2

An ICRISAT scientist (right) with the sorghum breeder from the national program of Burkina Faso looking at the local sorghum genetic resources collection in Burkina Faso, 1985.

Pollination studies in the A-and B-lines observation nursery, Kamboinse, Burkina Faso, 1985.

Table 15. *Tô* stability of grain harvested in yield trials at four locations in Mali, 1985.

Genotype	Location				Mean *tô* score[1]
	Koula	Longorola	Katibougou	Sotuba	
Malisor 84-2	5.0	4.3	3.3	2.0	3.7
Malisor 84-3	4.7	3.0	2.7	1.7	3.0
83-F_4-477	4.7	2.3	2.0	1.0	2.5
83-F_6-222	4.7	1.3	2.0	1.7	2.4
Malisor 84-7	2.7	1.0	1.0	1.2	1.5
84-F_4-107	4.0	4.0	2.3	1.2	2.9
84-F_4-53	2.0	2.0	1.3	1.3	1.7
84-F_4-111	4.3	2.3	3.3	1.0	2.8
84-F_4-89	4.3	4.0	3.3	2.3	3.5
84-F_4-11	4.3	3.7	2.0	3.0	3.3
84-F_4-104	4.0	1.7	2.0	2.0	2.4
Controls					
S 6	3.3	2.3	2.3	1.8	2.5
A13120	4.7	2.3	3.0	1.7	2.9
82 S 50	4.0	2.7	3.3	3.7	3.4
CSM 388	1.7	2.0	1.0	1.0	1.4
L 30	4.7	3.0	3.0	3.0	3.5
SE	±0.59	±0.54	±0.42	±0.51	
CV (%)	26	35	21	47	

1. Measured on a 1-5 scale, where 1 = very stable, and 5 = very unstable.

segregants were backcrossed to the tall local parent and desirable tall F_2 segregants were backcrossed to the dwarf exotic parents. We evaluated the F_6 progeny from such backcrosses using local, exotic, and improved lines as controls. Several of the test lines had better seedling establishment, panicle exsertion and laxness, and grain quality than their exotic parents. Plant height was generally less than in the tall parents. However, the magnitude of yield superiority of these derivatives over the local cultivars was in general, insignificant, and many of them were also susceptible to leaf diseases.

Evaluating Advanced Elite Varieties

We tested 89 elite lines in six yield trials with balanced lattice designs at four locations: Kamboinsé, Gampela, Saria, and Farako-Bâ. At Kamboinsé rainfall was 565 mm and at Saria 592 mm, lower than the long-term average but was well distributed throughout the season. Rainfall at Farako-Bâ (1360.8 mm) was much higher than the long-term average, and flooding caused by excessive rains during the seedling stage resulted in uneven plant stands; nevertheless, the conditions were conducive to disease development.

In the medium-maturing cultivar trial ICSV 16-5 HV gave the highest average yield of 3130 kg ha^{-1} compared with 2790 kg ha^{-1} from the control cultivar Framida (Table 16). In the early-maturing (60-70 days to 50% flowering) trial the highest-yielding variety was ICSV 1014 HV (Table 17).

On-farm Testing

We selected six farmers' fields each in Kamboinsé and Pabre villages known to be infested with

Striga sp, to test eight breeding selections along with a local cultivar (S 29). Four 10-m rows were allocated to each cultivar in each of the six fields (replications), and we made observations on grain yield and number of *Striga* plants per 16 m^2. *Striga* emergence was low in Pabre but was very high in Kamboinsé. Therefore, we only summarized the results (Table 18) from Kamboinsé. ICSV 1007 HV and ICSV 1014 HV had significantly less *Striga* infection than the other five entries and the local cultivar. ICSV 1014 HV also combined *Striga* tolerance with good yield potential.

Hybrid Evaluation

We evaluated 162 preliminary hybrids bred at ICRISAT Center by using recently developed male-sterile lines and six restorer lines and compared them with varieties at Saria and Farako-Bâ in Burkina Faso. In general, hybrids exhibited good plant stand, flowered earlier, exserted panicles better and yielded more than the pure-line varieties. We selected 36 hybrids for further evaluation, including the advanced hybrids ICSH 153 IN (SPH 221) and ICSH 110 IN, bred at ICRISAT Center.

Southern Africa

Nurseries and Crossing Blocks

Nurseries. The first thrust of the ICRISAT/SADCC regional program has been to rapidly diversify variability useful for selection. A regional nursery of 375 entries (20 from the Zambia National Program) was distributed to 16 locations in 7 countries. Evaluation and selection was possible at 11 locations in 6 countries. Evaluation of most locations was undertaken by regional and national staff of several SADCC countries. A B-line observation nursery of 160 entries was evaluated in Botswana, Malawi, Tanzania, Zambia, Zimbabwe, and at the regional center near Bulawayo. A nursery of some 570 F_2s was evaluated in Zambia, Zimbabwe, and at the regional center. Scientists in the region evaluated these nurseries and were provided with seed of their selected lines.

Crossing blocks. A number of crossing blocks were sown at Mzarabani, Zimbabwe, in mid-April: one from the regional program and others from the programs in Botswana, Malawi, and Zimbabwe. This was an important beginning for this type of support activity. We made crosses

Table 16. Mean grain yields (kg ha^{-1}), time to 50% flowering (DTF), and disease scores of selected advanced elite sorghum varieties at four locations in Burkina Faso, 1985.

Variety	Location and grain yield (kg ha^{-1})					Mean	Disease score[1]				
	Kamboinsé	Gampela	Saria	Farako Bâ	Mean	DTF[2]	AN	GL	ZL	OL	GM
ICSV 16-3 HV	3740	2600	3230	1880	2860	80	3.0	4.3	1.7	1.5	3.2
ICSV 16-4 HV	3500	2300	3020	1410	2560	80	2.2	3.2	1.8	1.8	3.2
ICSV 16-5 HV	4590	2520	3520	1880	3130	80	2.5	3.2	1.7	1.3	3.0
Controls											
ICSV 1002 HV	2850	2680	3230	1530	2570	85	0.4	2.0	0.8	1.0	3.9
ICSV 1001 HV (Framida)	3640	2630	3010	1880	2790	85	2.7	4.2	1.7	0.7	2.4
SE	±370	±165	±200	±195							
CV (%)	25	17	16	30							

1. AN = Anthracnose, GL = Grey leaf spot, ZL = Zonate leaf spot, OL = Oval leaf spot, GM = Grain mold. Scored on a 1 to 5 scale where 1 = less than 5% leaf area infected, and 5 = 76-100% leaf area infected.
2. 5 × 5 balanced lattice, plot size 7.5 m^2 data analyzed as randomized-block design.

Table 17. Performance of selected early-maturing advanced, elite sorghum varieties at four locations in Burkina Faso, 1985.

Entry	Location and grain yield[1] (kg ha^{-1})				Mean seedling establ. (%)[2]	Mean DTF[3]	Disease score[4]				
	Kamboinsé	Gampela	Saria	Mean			AN	GL	ZL	OL	GM
ICSV 1014 HV	2420	2760	2960	2710	70	60	3.2	3.8	1.6	1.4	4.1
ICSV 94-1 HV	1920	2540	2790	2420	70	65	0.3	1.4	1.5	1.2	4.0
ICSV 85-2 HV	1830	2280	2830	2310	70	70	0.4	1.6	2.2	0.8	3.7
ICSV 94-3 HV	1840	2200	2520	2190	65	65	0.8	1.8	1.5	0.8	4.4
ICSV 95 HV	2150	1870	3340	2450	70	70	0.2	1.8	1.6	1.4	4.0
ICSV 2 HV	1950	1600	2360	1970	60	70	4.6	3.0	1.3	2.0	4.0
SE	±150	±165	±215								
CV (%)	20	22	22								

1. 5 × 5 balanced lattice, plot size 7.5 m^2, data analyzed as randomized-block design.
2. Mean seedling establishment (%) was estimated by the proportion of hills having at least one seedling over the total number of hills sown.
3. Time to 50% flowering (d).
4. AN = Anthracnose, GL = Grey leaf spot, ZL = Zonate leaf spot, OL = Oval leaf spot, GM = Grain mold. Scored on a 1 to 5 scale where 1 = up to 5% leaf area infected and 5 = 76-100% leaf area infected.

Sorghum hybrid ICSH 1 (foreground) with Kamboinsé local (background), Kamboinsé, Burkina Faso, 1985.

Sorghum scientists representing ICRISAT Center, the national programs of Lesotho and Zimbabwe, and the SADCC Regional Program, evaluating the sorghum nursery at Aisleby, Zimbabwe, 1985.

within and between crossing blocks. F_1 seed in the hard dough growth stage was harvested and immediately resown during the 1st week of August so that F_2 seed was ready for the 1985/86 rainy season.

We sowed 19 selected A lines and 78 R lines in early July to make experimental hybrids. Seed from 900 hybrids was harvested and sown in December for evaluation during the main cropping season at Matopos. Results will be reported in the 1986 Annual Report.

Mexico and Central America

Conversion of cold-tolerant landraces from eastern Africa. Thirty-two cold-tolerant, photoperiod-sensitive genotypes from the eastern Africa highlands were included in the conversion program for backcrossing to photoperiod-insensitive, cold-tolerant genotypes in order to diversify the local highland varieties. Advanced-generation material with a range of maturities (90-130 days to 50% flowering) and heights (140-250 cm) is available from this project.

Table 18. On-farm testing of promising sorghum varieties for grain yield (kg ha^{-1}) and *Striga* resistance, Kamboinsé, Burkina Faso, 1985.

Variety	Grain yield (kg ha^{-1})	*Striga* plants $16\ m^{-2}$
ICSV 1014	1250	505 (2.66)[1]
ICSV 1007	900	393 (2.55)
ICSV 1051	710	2911 (3.45)
ICSV 1005	1010	1348 (3.07)
ICSV 1036	650	1239 (3.08)
ICSV 1043	790	1561 (3.19)
ICSV 1052	630	1379 (3.08)
S 29 (local)	240	2857 (3.37)
SE	±140	±(0.134)
CV (%)	44	(8)

1. Figures in parentheses are transformed values.

Hybrids for the highland and lowland areas of Central America. In the highlands, cold-tolerant A, B, and R lines are required in order to successfully produce a fertile hybrid without risk of sterility. For this reason, in the breeding program, we have developed A and B lines now in the 6th backcross generation with cold tolerance using the cold-tolerant B line (1291 B, photoperiod-sensitive) introduced from Kenya. We have also identified cold-tolerant R lines.

This year we began to breed hybrids for the lowlands. We crossed our elite varieties to different cytoplasmic A lines to determine their reaction to fertility restoration (R) or sterility maintenance (B) in the F_1 hybrids. We identified six good hybrids using the following criteria: percentage of heterosis, plant height, days to 50% flowering, seed color, and general agronomic aspects. These hybrids will be evaluated in regional yield trials.

Evaluation of cold-tolerant elite varieties. We used 10 elite varieties at three elevations (2250 m, 1800 m, and 940 m) to study genotype and environment interaction. The design was a randomized complete block with four replications and plot size 5 m × 4 m. Grain-yield data (Table 19) indicated that the variety SA 5875 × BJ 216 was superior to all other varieties at all elevations. Data for plant height and days to 50% flowering indicated that average plant height increased as genotypes moved to lower elevations. On the other hand, average days to 50% flowering were reduced as genotypes moved to lower elevations.

Food Quality

Dehulling quality. We determined the dehulling quality of 10 cultivars that varied in grain hardness (from 6.3 to 8.8 kg) using the Tangential Abrasive Dehulling Device (TADD) and a barley pearler. Results (Table 20) show that recovery ranged from 65.8 to 93.7% for grains dehulled through the TADD and from 71.2 to 88.6% through the barley pearler. DKV 3 and the ICRISAT cultivar ICSV 112 (SPV 475) gave a higher recovery than other cultivars. Recovery of CSH 8 was lower by both methods. The softer endosperms of ET 3941 and SAR 1 yielded more (>12%) broken grains.

***Tô* quality.** *Tô* is a thick porridge commonly prepared from dehulled sorghum grains in Nige-

Table 19. Mean grain yield (kg ha⁻¹) of 10 cold-tolerant sorghum varieties evaluated at three different elevations, Mexico, 1985.

		Grain yield (kg ha⁻¹)		
Entry	Pedigree	El Batan 2250 m[1]	Tlayacapan 1500 m	Tlaltizapan 940 m
ICSCTV 1	P 74 AS 388 × Man 64	4560	5700	4200
ICSCTV 2	SA 5875 × BJ 216	7140	7740	5790
ICSVTV 3	SA 5875 × CT 37-1-2	4690	6310	5590
ICSCTV 4	76 BTP 96 × C4-F_9-3-10	5020	5070	4100
ICSCTV 5	Black Kafir × P 74 AS 67	5600	6860	5500
ICSVTV 7	(Black Kafir × P 74 AS 67) × ETS 3498	5450	5960	5300
ICSVTV 8	Pink Kafir × Man 84-1	4220	5430	5650
VA 110	Valles Altos 110 (INIA, Mex.)	3800	5160	4620
VA 130	Valles Altos 130 (INIA, Mex.)	4140	5390	4010
ICSCTV 12	SA 5875 × Man 64	3930	5780	5260
SE		±260	±379	±301
CV (%)		11	13	12

1. Elevation

A new photosensitive sorghum hybrid growing in a maize/sorghum cropping system, Guatemala, 1985.

ria, Mali, and Burkina Faso. It can be prepared by boiling flour with water (neutral *tô*), with lemon juice or tamarind (acid *tô*), or with wood ash (alkaline *tô*). We evaluated the *tô* quality of 10 dehulled sorghum samples (Table 20) by assessing their firmness, a very important quality criterion, subjectively, and by using the Instron food testing instrument to evaluate texture. The appearance and consistency of the *tô* samples was evaluated by three panelists. The *tô* produced from S 29 and DKV 3 was rated higher than that from other cultivars. *Tô* made from the ICRISAT cultivars ICSV 112 (SPV 475) and SPH 225 was of acceptable quality. The waxy-endosperm cultivar IS 158 produced poor-quality *tô*.

Digestibility. We estimated the protein digestibility of the ICRISAT-bred sorghum hybrid SPH 225 using the enzyme pepsin in vitro. The method involved incubating flour and cooked material with pepsin for 3 h at 37°C and estimating the protein digested. We compared sorghum with other cereal grains—wheat, rice, and maize. The digestibility of uncooked flour was higher than cooked from sorghum, wheat, and rice. However, in maize, cooking increased digestibility. The digestibility of the sorghum hybrid SPH 225 was as good as that of other cereals when determined by this method.

International Testing

Asian Regional Sorghum Variety Adaptation Trial (ARSVAT 84)

ARSVAT 84 consisted of 40 entries including a local control contributed by the cooperator at

Table 20. Dehulling characters and *tô* quality of sorghum genotypes, ICRISAT Center 1985.

		Recovery (%)							
	Grain	TADD[1]			Barley pearler				
Genotype	hardness (kg)[2]	Dehulled grain	Brokens	Total	Dehulled grain	Brokens	Total	*Tô* quality[3]	*Tô* texture[4]
M 35-1	7.3	87.0	2.1	89.1	69.6	6.2	75.8	2.8	14.3
S 29	7.0	87.5	0.5	88.0	84.5	0.5	85.0	1.8	12.2
DKV 3	8.1	93.0	0.7	93.7	87.6	1.0	88.6	1.5	13.0
ET 3491	6.3	67.0	12.8	79.8	52.0	19.2	71.2	2.3	16.0
SAR 1	5.4	67.0	13.2	80.2	67.6	12.0	79.6	2.9	15.8
ICSV 112	7.8	84.0	7.1	91.1	78.1	8.3	86.4	2.3	15.8
SPH 225	8.0	72.0	8.4	80.4	56.8	19.8	76.6	2.3	15.5
CSH 1	8.8	85.0	4.6	89.6	71.8	9.7	81.5	3.3	14.9
CSH 8	7.1	63.5	2.3	65.8	51.4	19.9	71.3	3.1	17.9
IS 158	6.9	80.0	4.9	84.9	71.2	7.2	78.4	5.0	4.7
SE	±0.29	±3.12	±1.39	±2.44	±3.79	±2.19	±1.80	±0.29	±1.21

All values are averages of two determinations.
1. TADD = Tangential Abrasive Dehulling Device.
2. Measured using Kiya hardness tester.
3. Measured on a 1 to 5 scale, where 1 = good and 5 = poor.
4. Expressed as Instron force (kg).

each location and 3 controls (variety ICSV 1 and hybrids CSH 6 and CSH 5). Data on selected entries from all 12 locations are presented in Table 21. The varieties ICSV 112, ICSV 162, ICSV 102, and ICSV 110 exhibited wider adaptability, yielding 2950-3230 kg ha^{-1} while the control hybrid, CSH 6 yielded 2830 kg ha^{-1} across the locations. The varieties differed in specific adaptation: for example, ICSV 110 yielded well in Thailand, while at Bhavanisagar in India the highest-yielding variety was ICSV 158.

Asian Regional Sorghum Hybrid Adaptation Trial (ARSHAT 84)

ARSHAT 84 consisted of 41 entries including a local control contributed by the cooperator at each location and 4 controls. Data on selected entries from all 12 locations are given in Table 22. The hybrid ICSH 180 (Fig. 6) showed the highest adaptability, yielding 3970 kg ha^{-1} across locations followed by ICSH 110, ICSH 174, and ICSH 162. The hybrids also differed in their specific adaptation. For example, ICSH 162 was the highest yielder in Thailand, while ICSH 120 gave the highest yield at Pantnagar, India.

Eastern Africa Cooperative Sorghum Screening Nursery (EACSSN)

The 1984 workshop of the Eastern Africa Sorghum and Millet Improvement Network recommended that an Eastern Africa Cooperative Sorghum Screening Nursery (EACSSN) composed of the most promising and advanced breeding lines from Ethiopia, Tanzania, Uganda, ICRISAT Center, and the Semi-Arid Food Grain Research and Development (SAFGRAD)/ ICRISAT Program in Kenya be organized for multilocational testing in Ethiopia, Kenya, Tanzania, and Uganda in 1985. It was further recommended that after the initial evaluation, the selected best entries from the EACSSN be

Table 21. Mean grain yields (kg ha^{-1}) of top-yielding entries in the Asian Regional Sorghum Variety Adaptation Trial (ARSVAT 84)[1], in 1984.

		India[2]						Pakistan[2]				Thailand[2]	Burma	
Entry	Pedigree	1	2	3	4	5	6	7	8	9	10	11	12[2]	Mean
ICSV 112	[(IS 12622C×555)×(IS 3612C×2219B)-5-1×E 35-1]-5-2	3540	3570	4350	3410	1670	4090	1330	4050	2280	1640	3240	4420	3230
ICSV 162	(CSV 4×GG×370)-2-1-4-4	3470	4490	5480	3190	880	3460	1050	1470	970	2340	4740	3190	3040
ICSV 102	(E 35-1×Rs/B 394)-1-1-2	3390	3740	4280	3200	1550	2920	1670	1990	1690	1060	4660	3870	2970
ICSV 110	[(SC 423×CSV 4)×E 35-1]-2-1	3480	3860	5580	2910	840	3560	1400	1790	1330	840	5610	2040	2950
ICSV 166	(20-67×SB 1067)-4-1-1-1B	3530	3930	3940	3730	970	3040	1280	2170	1580	1500	3060	2100	2810
ICSV 197	(IS 3443×DJ 6514)-1-1-1-1-1	3090	3810	5000	2580	1350	4370	1280	1630	1500	840	4040	3040	2800
ICSV 189	(E 35-1×US R 703)-2-1-1-2-2	3100	3350	4940	2210	1250	4470	1370	2930	970	1220	4350	2080	2790
ICSV 193	(148×Framida)-39-2-4-1-1-2-1	3300	3110	3300	2440	1780	3420	1480	3380	1940	2450	2930	1870	2790
ICSV 158	[(SC 108-3×Swarna)×E 35-1]-6-2	2800	4650	5170	2990	620	3810	1080	2040	1640	640	5250	2610	2780
ICSV 186	(SC 108-3×CSV 4)-14-1	3380	4070	3810	3270	1250	2680	1270	1970	1640	1530	3390	2270	2750
ICSV 108	(SC 108-4-8×CSV 4)-88	3320	3130	5920	2370	1020	2610	990	1170	2000	1610	4690	1900	2750
ICSV 188	(E 35-1×US R)-1-1-3-1-2-1	3300	2990	4240	2950	1250	3650	1250	2330	860	1860	2380	2740	2690
ICSV 175	CSV 4×IS 3922	3030	3890	2520	2830	1060	3610	1260	2010	2550	1890	2720	3210	2670
Controls														
CSH 5	2077A×CSV 4	4090	2750	4370	3000	1310	5410	2390	3350	1920	2530	4390	3090	3430
CSH 6	2219A×CSV 4	2960	1690	3900	3230	1730	4550	2020	3940	2810	1170	1400	4080	2830
ICSV 1	(SC 108-3×CSV 4)-19-1	3320	2630	4720	2550	1360	4100	1820	1870	1670	2230	2400	4410	2900
Local		3360	2980	4380	3470	1730	4910	1130	2660	1000	450	1220	4290	2810
SE		±140	±431	±371	±412	±127	±272	±346	±235	±116	±237	±580	±463	
CV(%)			24	15	26	20	13	44	19	14	27	32	30	
Efficiency (%)			94	115	97	104	94	103	129	100	91	169	181	

1. Locations: 1=ICRISAT Center, India, (5 tests); 2=Bhavanisagar, Tamil Nadu; 3=Dharwad, Karnataka; 4=Pantnagar, Uttar Pradesh; 5=Kanpur, Uttar Pradesh; 6=Surat, Gujarat; 7=Dera Ismail Khan, 8=Yousufwala, 9=Dadu, 10=Islamabad, Pakistan; 11=Suphanburi, Thailand; and 12=Yezin, Burma.
2. 6 × 6 lattice, plot size 3.6 m^2 at Dharwad, India and 11.25 m^2 at Yousufwala, Pakistan.

Table 22. Mean grain yield (kg ha^{-1}) of top-yielding entries in the Asian Regional Sorghum Hybrid Adaptation Trial (ARSHAT 84), 1984.

Entry	Pedigree	India							Pakistan				Thailand	
		1	2	3[2]	4	5	6	7	8	9[2]	10	11	12	Mean
ICSH 180	D 3A×[(SPV 105×SC 108-4-8)×CSV 4]-14-2-1	4000	6410	6390	4500	1590	5220	3120	1190	4440	1910	3710	5080	3970
ICSH 110	296A×(SC 108-3×CSV 4)-51-1	4440	4810	5980	3930	1540	4720	2390	1280	4440	2500	2700	5650	3880
ICSH 174	296A×(SC 108-3×E 35-1)-25-1	3970	4760	5820	4900	1370	4180	3300	2430	5060	2640	2980	4070	3830
ICSH 162	FLB 8963-2A×(FLR 101×IS 1082)-4-2	4100	5330	6260	5390	1460	3780	1890	1540	4940	1110	1500	7220	3810
ICSH 134	2219A×(UChV 2×GG×370)-4-2-3	4090	5750	4980	5300	1270	3600	3710	980	5530	2090	2700	3850	3760
ICSH 120	296A×(Diallel 475-746)-4-2-1-5	4150	5410	5290	5850	1460	4410	1060	1160	4140	2650	3390	3070	3660
ICSH 116	2219A×(UChV 2×GG×370)-2-1-2	3920	5750	4430	5480	1770	4860	2900	1610	5020	880	3140	2850	3640
ICSH 179	2077A×(SPV 69×E 12-5)-25-7-1-1-2	3910	5300	4780	4030	1640	5060	950	1120	4750	1870	2780	6090	3620
ICSH 164	D 2A×[(SPV 105×(SC 108-4×CSV 4)-1)]-14-2	4050	5200	5580	3680	1750	3640	2070	1320	4220	3990	1510	4140	3580
ICSH 159	296A×(FLR 266×CSV 4)-4-3-2-1	4300	5760	5580	4370	2150	3160	1200	1430	4160	1990	700	5140	3570
ICSH 176	US B 37-600-2A×(FLR 101×IS 1082)-4-2	3880	5790	5400	2930	1570	4120	310	1520	5340	1900	2620	5960	3550
ICSH 161	US R 50-398-2A×(FLR 101×IS 1082)-4-2	4130	4830	5290	4220	1600	4030	680	1610	4070	2140	3810	3720	3540
ICSH 156	2219A×(UChV 2×GG×370)-4-2-2	3990	4280	4220	4300	1070	4560	2500	1120	4540	1940	3290	4450	3510
ICSH 155	MA 10×(IS 12611×SC 108-3)-1-1-3	3590	5450	6200	3750	1260	4410	2780	480	3910	840	3590	5540	3510
Controls														
CSH 5	2077A×CSV 4	3700	4870	5190	3760	1520	4010	1860	2020	2490	1220	2310	5070	
CSH 6	2219A×CSV 4	2860	3040	4170	3230	1260	3200	1830	2040	3750	870	3870	2590	
CSH 9	296A×CSV 4	4170	6100	6350	2330	1210	4960	1580	1390	4990	2130	1080	3830	3550
ICSH 153	296A×(SC 108-3×CSV 4)-27-2-1	4140	5660	5740	4340	1140	4070	210	1190	4580	780	3570	5750	3610
Local		4200	4830	4500	2370	2220	5150	1930	740	3220	2640	620	8910	3630
SE		±133	±600	±449	±657	±294	±330	±347	±304	±449	±151	±321	±1222	
CV(%)			20	15	30	35	13	39	42	19	14	23	45	
Efficiency (%)			105	104	94	85	96	102	112	102	102	100	101	

1. Locations: 1=ICRISAT Center, India (5 tests); 2=Bhavanisagar, Tamil Nadu; 3=Dharwad, Karnataka; 4=Pantnagar, Uttar Pradesh; 5=Kanpur, Uttar Pradesh; 6=Surat, Gujarat; 7=Kovilpatti, Tamil Nadu; 8=Dera Ismail Khan, 9=Yousufwala, 10=Dadu, 11=Islamabad, Pakistan; and 12=Suphanburi, Thailand.
2. 6 × 6 lattice, plot sizes 3.6 m^2 at Dharwad, India and 11.25 m^2 at Yousufwala, Pakistan.

made available to the other national programs of the region for further testing. Accordingly, the EACSSN was organized with contributions from Ethiopia (180 lines), ICRISAT Center (196), SAFGRAD/ICRISAT/Kenya (224), Tanzania (200), and Uganda (200).

The main objective of the EACSSN was to identify sorghum lines for wide use in the national programs of eastern Africa. The 1985 EACSSN took entries suitable for, and concentrated only on the low elevation (<1500 m altitude) sorghum ecological zone of eastern Africa. The nursery was planted at Alupe (Kenya), Serere (Uganda), and Nazareth (Ethiopia). Single-plant rows, 5-m long with two replications were used for each entry at each location. A suitable local control was sown at regular intervals at each location. Nursery tours were organized and all EACSSN contributors travelled to each location as a team to evaluate and select the best entries. The Tanzanian location was not sown because the seed arrived too late for the season.

Based on the overall agronomic desirability score at one or more of the three locations, 150 entries were selected for further multilocational testing. Thirty-two entries were selected for advancing at Alupe, 68 at Nazareth, and 83 at Serere. Only two entries, (SC 108-3X C5 3541)-19-1 and 12 × 46/F_4/2/M/5, were selected at all three locations. However, 28 entries were selected at two sites. All the others were selected at one location only. It will be necessary to repeat the evaluation of the EACSSN over several seasons to establish the pattern of varietal adaptation in the low elevations of eastern Africa.

Arrangements have been made with the Ethiopian national programs to increase all the 150 selected entries of the 1985 EACSSN in the 1985/86 off-season for seed distribution to all national programs of eastern Africa in 1986. This activity should promote more active ex-

Figure 6. ICRISAT-bred hybrid, ICSH 180 obtained from the newly developed female parent (D 3A) and male parent, [(SPV 105 × SC 108-4-8) × CS 3541)] -14-2-1 ranked first for yield in the Asian Region Sorghum Hybrid Adaptation Trials 1984 (ARSHAT 84).

change of breeding lines among the national programs of the region.

Multilocational Yield Trial for the Lowland Areas of Central America

A multilocational yield trial was conducted to compare yields of the best hybrids and varieties available in Central America. The experimental design was a randomized complete block with four replications in 5 m × 4 m plots. A summary of the results is shown in Table 23. The hybrid (AT 623 × Tortillero) was the most stable and ranked among the highest yielders. However, this hybrid is very tall, not suitable for mechanical harvesting, and has lower grain quality than ICRISAT-bred varieties. In general, hybrid grain yields were superior when compared to variety grain yields. However, the ICRISAT-bred varieties, SPV 475 and SEPON 77, ranked among the five top-yielders.

Contribution to National Programs

India

The ICRISAT-bred hybrid, ICSH I (SPH 221/ICSH 153 IN) (Fig. 7) is to be formally released under the name of CSH 11 by the Central Subcommittee on Crop Standards, Notification and Release of Varieties (and Hybrids) for cultivation in all areas where rainy-season sorghum is grown. ICSV 112 (SPV 475) was evaluated in the All India Kharif (rainy season) Minikit Trials. Two other hybrids, ICSH 110 (SPH 296) and ICSH 138 (SPH 295), were promoted to the

Table 23. Average grain yields of sorghum varieties and hybrids at five locations in Central America, 1984.

	Location and yield (kg ha⁻¹)					
Genotype	Alanje (Panama)	San Salvador (El Salvador)	Jutiapa (Guatemala)	Asuncion (Guatemala)	La Lujosa (Honduras)	Mean
Hybrids						
Funk's G522 DR	5250	3975	2200	3950	3575	3790
BJ 83	5625	4125	2625	4275	4075	4145
BJ 84	6125	4950	3125	4700	3900	4560
ATX1623 × Tortillero	6025	4075	3575	4625	4150	4490
Varieties						
GWT 210	3700	2225	2000	4025	3100	3010
M 62492-2-3	4825	3000	2825	4200	2975	3565
Tortillero	4925	3025	2175	3975	2975	3415
ISIAP Dorado	4475	4500	2450	3675	3475	3715
SPV 475 (ICSV 112)	5825	4600	2300	3775	4000	4100
SEPON 77	5100	4300	2175	3825	3875	3855
M 62641	4325	3275	2175	3475	3100	3270
D 71444	4150	3900	2625	4325	3350	3670
M 90378	4925	4125	2525	3425	2850	3570
M 90812	4400	3700	2750	3775	3800	3685
7923K Red	4825	2825	2850	3800	2175	3295
R 6956 Red	4675	3375	2800	4050	2450	3470
M 90362	3675	3525	2425	3825	4175	3525
SE	±304	±433	±187	±274	±278	
CV (%)	12	23	15	14	16	

Figure 7. ICRISAT-bred hybrid ICSH 1 (SPH 221/ICSH 153 IN) released for general cultivation in all areas in India, ICRISAT Center, 1985.

AICSIP Kharif (rainy season) Advanced Trials in 1985. SPH 280 was recommended for evaluation in the 1986 87 All India Rabi (postrainy season) Minikit Trials.

The midge-resistant variety, ICSV 197 has been extensively tested by the AICSIP and by the University of Agricultural Sciences, Dharwad, in midge-endemic areas of Karnataka State. It was also used as an improved midge-resistant source by various national programs, e.g., El Salvador and Argentina, and by ICRISAT regional programs in Mexico and Mali.

West Africa

The program in Mali contributed five varieties to the regional CILSS trial, one variety, A 13120 (Malisor 84-1), was one of the top yielders in the intermediate trial in most countries in the region.

Since 1983, we have recommended the Malian sorghum collection entry, CSM 388, for general cultivation in 800-1100 mm rainfall zones. In preextension farmer trials conducted by SAFGRAD Mali this year, CSM 388 yielded, on average, 20% higher than local control varieties. This variety is produced nationally and is now being recommended for extension in appropriate areas.

Southern Africa

In Zimbabwe, two ICRISAT-bred sorghum varieties are under consideration for release; M

39335 (SPV 475) as Sorghum Variety 1 and A 6460 as Sorghum Variety 2.

Mexico and Central America

An ICRISAT-bred variety derived from a cross involving GPR 148 × E35-1 and CS 3541 as parents was released in Mexico under the name of Blanco 86. Mexico also released a variety called Variadad 110, which the national program received from the ICRISAT/CIMMYT program as early-generation breeding material and advanced through selection. Other ICRISAT-bred varieties released in different countries were (GPR 168 × SC 170-6-17)-1-1 (M 90975) in Guatemala under the name ICTA Mitlan 85, and (GPR 148 × E 35-1)-4-1 × CS 3541 as ISIAP Dorado in El Salvador and Venezuela. In Honduras, another ICRISAT variety, SPV 387, was released as Surano.

Seed Distribution to National Programs

We provided improved breeding materials to our cooperators in response to seed requests. We supplied a total of 2061 seed samples within India and 13186 outside India.

Seven-hundred-and-sixteen selections from the converted Zerazera populations were supplied on request to sorghum scientists in Ethiopia (87), India (115), Mozambique (142), Sierra Leone (243), Tanzania (37), and Uganda (91), for use in their breeding programs.

During our International Sorghum Scientists Field Day, 19 breeders from national programs selected 154 breeding lines for their use. Also, nine scientists from Tamil Nadu State, India visited our experiments at Bhavanisagar on 25 September and selected 266 improved lines for use in their programs.

Training

West Africa

Our training strategy is to help identify young researchers who have proven themselves in the national program, help find appropriate institutions and thesis advisors, and to facilitate their smooth transition back into the national program.

Three students from the Institut Supérieur Politechnique in Ouagadougou, Burkina Faso, prepared theses on sorghum breeding and *Striga* research for their Ingénieur Agronome degree under the guidance of ICRISAT scientists. A postgraduate student from France received training in aspects of *Striga* research.

During 1985, three ICRISAT/Mali sponsored students returned from graduate studies in the U.S. and India. All three have now been given positions of responsibility in the Malian National Program and continue to work closely with our program. Three other students are still completing graduate studies.

Mexico and Central America

Six scientists from the Central American regional programs, 2 each from Mexico and Guatemala, 1 from El Salvador, and 1 from Costa Rica received in-service training at ICRISAT/CIMMYT, Mexico for 5 months on sorghum improvement and production, bringing the total number of ICRISAT-trained scientists in the region to 38 to date. The course included work on sorghum breeding and agronomy. A training manual in Spanish on sorghum improvement was prepared in 1985 in association with the Faculdad Agronomica de Monterey, Nueva Leõn and is in use as an aid during these courses at CIMMYT. We intend to produce an English version in 1986.

Workshops, Conferences, and Seminars

ICRISAT Center

Sorghum Field Day

An International Sorghum Scientists Field Day was organized at ICRISAT Center from 17 to 19 September, to enable scientists from national programs to observe our improved screening techniques and breeding material, and to select varieties of interest to them. Participants came from Ethiopia, Gambia, India, Lesotho, Pakistan, and Tanzania.

West Africa

Second Regional Sorghum Workshop on Sorghum Research and Improvement in West Africa

The objective of this second meeting held in Bamako, Republic of Mali, 21-24 October, was to review progress made since the first workshop, to provide an opportunity for the regional sorghum research workers to hold in-depth discussions on research program development, especially on crop improvement and agronomy, and to obtain first-hand knowledge of all aspects of sorghum research activity of the Malian national program.

All national programs in West Africa except Benin, Burkina Faso, Cameroon, and Chad were represented. Representatives from SAFGRAD, L'Institut du Sahel, (INSAH), CILSS Intergrated Pest Management Project, INTSORMIL, ICRISAT Center and ICRISAT West African programs also participated. A number of scientists/administrators from the Malian national program took an active part in the workshop organization and scientific discussions.

The workshop was inaugurated and closed by the Minister of Agriculture of the Republic of Mali. A progress report on ICRISAT's regional work on sorghum was presented, followed by a number of presentations on sorghum research in Mali. A field and laboratory visit to research station and on-farm experiments was also organized.

At the workshop, an inventory of biotic and abiotic factors limiting sorghum production in each country was compiled, sorghum research currently in progress in each national program discussed, and proposed locations for different research activities in the region suggested. A number of possible areas of research in agronomy were discussed. Training of national researchers in all disciplines and at all levels was reemphasized. Weaknesses in infrastructures in the national programs that impair the quality of research were underlined. Four representatives from the national programs were unanimously elected to the network Advisory Committee. Finally, it was agreed that the Advisory Committee should meet in January 1986 to develop an action plan for the research network in the region.

Eastern Africa

Fourth Regional Workshop of the Eastern Africa Sorghum and Millet Improvement Network

This workshop was held at Soroti, Uganda, 22-26 July 1985. Of the 45 participants, 24 were from the host country, and others came from Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and the People's Democratic Republic of Yemen. Invited participants from outside the region came from Burkina Faso, India, UK, and USA. As in the past regional workshops, almost all the participants were active workers in sorghum and millet research. Of the 40 papers presented in the workshop, 20 dealt with different aspects of sorghum and millet research in Uganda. Fourteen papers covering the sorghum and millet work in the other eastern African countries were presented by national representatives. Invited speakers covered topics of special interest to the eastern Africa sorghum and millet workers, such as a retrospective review of the Serere sorghum and millet work, problems and methods of pearl millet breeding, sorghum nutrition and utilization, sorghum disease control, *Quelea* control strategies, stem borers, and intercropping.

In addition to paper presentations and discussions, participants visited the facilities and field work of the Serere Research Station, selected district variety trial centers, and seed-multiplication fields.

The main recommendations of the workshop were: other disciplines besides breeding/agronomy should be encouraged to participate fully in future regional workshops; initiatives should be taken to assemble and document the traditional knowledge on sorghum and millet use in eastern Africa; at the next workshop, invited speakers should cover *Striga*, sorghum entomology, and drought resistance; and the major thrust of the expansion of the eastern Africa sorghum and millet regional program should focus on strengthening the national programs of the region. The proceedings of this meeting are available from the SAFGRAD/ICRISAT Regional Office, Nairobi, Kenya. The Fifth Regional Workshop will be held in Burundi in July 1986.

Southern Africa

Regional Reporting and Planning Workshop

Hosted by the Department of Agriculture, Botswana in Gaborone, 22-27 September, the workshop was attended by scientists from six SADCC countries, the Regional Program, and ICRISAT Center. This is the overall coordinating meeting where plans for the next season are organized.

In addition, breeders from national and regional programs visited each others' research stations and programs and made selections of breeding material from trials.

Participants of the Second Regional Sorghum Workshop sampling sorghum food products, Bamako, Mali, 1985.

Participants of the Regional Reporting and Planning Workshop for Southern Africa, visiting a sorghum pearling and milling factory near Gaborone, Botswana, 1985.

Mexico and Central America

Fourth Annual Meeting of CLAIS

This meeting of the Latin American Commission of Sorghum Researchers (CLAIS) held at Guatemala City, 27-31 October, was attended by 46 coordinators and scientists from the national programs of Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Mexico, and Panama. Representatives of USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA) or INTSORMIL (Texas A&M University and University of Kentucky), United States Agency for International Development (USAID), Washington, and the USAID Regional office (ROCAP) were also present.

The first day was spent on presenting results from CLAIS and national program research projects; the 2nd on a field trip to see the released variety ICTA Mitlan 85 in farmers' fields, and the 3rd on reviewing future projects submitted to ROCAP for funding in 1986.

Copies of the proceedings, prepared in collaboration with the El Salvador national program, are available from the ICRISAT CIMMYT Sorghum Program Office at CIMMYT, Mexico.

Seed Production Workshop

This was held 14-18 October at CIMMYT, Mexico City, and was attended by 110 participants from Argentina, Colombia, the Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico, Panama, Peru, Sudan, USA, and Venezuela. The main objectives were to strengthen seed technology and production in Central America, to identify problems relating to seed production and to propose solutions. The main recommendations were:

1. Scientists in the national programs should be trained in seed technology and seed production-related issues.
2. Involvement of local private seed companies in seed production and training of national-program scientists should be encouraged.
3. Seed experts should participate in varietal description with the breeders in the region when new improved varieties and hybrids are released.
4. Future workshops in seed production should consider seed marketing in depth.

At the end of this successful meeting, the participants also recommended that a meeting should be held to discuss sorghum plant physiology and nutrition in 1986. The proceedings will be published by the ICRISAT/CIMMYT program in Mexico and will be available for distribution in 1986.

Looking Ahead

Physical stresses. We will continue to study the underlying mechanisms associated with factors affecting seedling emergence in collaboration with scientists at the Welsh Plant Breeding Station, Aberystwyth, UK. This work will now include studies on cold tolerance. At ICRISAT Center we will increase our activity in the identification of enzymes and proteins associated with environmental stress and will look more closely at the physiology and development of roots in relation to drought resistance. International nurseries of lines resistant to environmental stresses (seedling, midseason, and terminal drought stress) will be evaluated at locations where the appropriate stress occurs.

An interim nitrogen-balance sheet from the long-term nitrogen balance study will be prepared to provide information on the amount of nitrogen fixed by continuous cropping for 8 years in the same plot. The search for more efficient nitrogen-fixing plant genotypes and bacteria will continue, and inoculation-response trials using those genotypes and bacteria will be studied in the field.

Further investigations on better utilization of rock phosphate by exploiting VAM will continue, as will the assessment of plant genotypes for their response to VAM inoculation under field conditions.

Biotic stresses. We will complete studies on the histopathology of sorghum grain molds and begin similar studies on ergot. We will study the genetics of resistance to downy mildew, and the variability of the anthracnose pathogen.

A grain mold-resistant population will be composited and improved for mold resistance using recurrent selection methods. This will enable us to effectively use the various sources of grain mold resistance identified in colored-grain sorghums.

We shall use the identified sources of shoot fly resistance in wild and cultivated sorghums by incorporating it into agronomically elite cultivars. We will continue to identify and improve the sources of resistance to stem borer, midge, and head bugs. For stem borer and midge, the main emphasis will be on combining resistance with higher yield.

Plant improvement. In population improvement S_2s of the multifactor resistance base materials, F_2 bulks of crosses involving resistant parents and the base materials, and other selected parents will be evaluated for yield and resistance to *Striga*, diseases, and insect pests. In addition, variability for resistance to these stresses and for good grain and postrainy-season adaptation will be introduced into the base materials of the ICSP 5BR/MFR population.

The conversion of photoperiod-sensitive and tall landraces to day-neutral shorter plants will continue with the inclusion of more landraces with desirable traits in the crossing program.

We will continue the development of parents for hybrids and convert identified maintainer lines into female lines. New experimental hybrids will be produced using selected restorer lines and the newly developed A lines.

In addition to developing cold-tolerant varieties, emphasis in the Mexico and Central American Regional Program will be put on seedling cold tolerance combined with flowering cold tolerance in order to generate very early varieties. Using elevations of 1000 m, 1500 m, 1800 m, and 2200 m, we shall study the genotype × environmental interaction of our elite, cold-tolerant varieties. We will complete studies on the genetic inheritance of cold tolerance. We will continue backcrossing to develop A, B, and R lines to produce hybrids for highland areas, and will develop hybrids for the lowland areas.

The recent formation of a drought physiology research unit in Mali will greatly increase our ability to more accurately identify and select for drought tolerance at all phases of plant growth.

In the Regional Program for Southern Africa, populations will be developed. Four population progeny trials will be initiated in the 1986/87 rainy season. This will provide an opportunity to select lines to develop varieties for specific locations. Eventually, the 34 populations received and now under evaluation will be selectively pooled to form no more than three new populations.

Lines from the national and regional programs will be selected each year and intercrossed to generate genetic variability with broad adaptation across the region.

International testing. We will continue to expand and improve our international testing network in cooperation with national and other programs. In West Africa, improved varieties and hybrids from our research will be tested in the national programs through the auspices of on-going regional SAFGRAD programs.

Publications

Institute Publications

Book

House, L.R. 1985. A guide to sorghum breeding. 2nd edn. Patancheru, A.P. 502324, India: ICRISAT.

Information Bulletin

Vasudeva Rao, M.J. 1985. Techniques for screening sorghums for resistance to *Striga*. Information Bulletin no. 20. Patancheru, A.P. 502 324, India: ICRISAT.

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Plant Material Description

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Sorghum variety ICSV 1. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Bhola Nath, Omran, A.O., and House, L.R. 1985. Identification of a double recessive genotype for 'B' genes controlling presence and absence of pigmented testa in sorghum. Cereal Research Communications 13(2-3): 277-279.

Bhola Nath, Omran, Abbas O., and House, L.R. 1985. Genetic divergence among a non-restorer collection of sorghum (*Sorghum bicolor* (L.) Moench) and its relationship with heterosis. Euphytica 34(2): 441-447.

Cox, T.S., House, L.R., and Frey, K.J. 1985. Trait associations in introgressed populations of sorghum. Zeitschrift fur Pflanzenzuchtung 94(4): 265-277.

Kipe-Nolt, J.A., Avalakki, U.K., and Dart, P.J. 1985. Root exudation of sorghum and utilization of exudates by nitrogen-fixing bacteria. Soil Biology and Biochemistry 17(6): 859-863.

Leuschner, K., Taneja, S.L., and Sharma, H.C. 1985. The role of host-plant resistance in pest management in sorghum in India. Insect Science and its Application 6(3): 453-460.

Maiti, R.K., Raju, P.S., and Bidinger, F.R. 1985. Studies on germinability and some aspects of pre-harvest physiology of sorghum grain. Seed Science and Technology 13(1): 27-35.

Murty, D.S., Singh, U., Suryaprakash, S., and Nicodemus, K.D. 1985. Soluble sugars in five endosperm types of sorghum. Cereal Chemistry 62(2): 150-152.

Sharma, H.C. 1985. Strategies for pest control in sorghum in India. Tropical Pest Management 31(3): 167-185.

Soman, P., and Peacock, J.M. 1985. A laboratory technique to screen seedling emergence of sorghum and pearl millet at high soil temperature. Experimental Agriculture 21(4): 335-341.

Conference Papers

Agrawal, B.L. and **Abraham, C.V.** 1985. Breeding sorghum for resistance to shoot fly and midge. Pages 371-383 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Agrawal, B.L., Taneja, S.L., Sharma, H.C., Maiti, R.K., Leuschner, K., Mukuru, S.Z., and **House, L.R.** 1985. Sorghum Improvement for Pest Resistance at ICRISAT. Pages 7-9 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Guiragossian, V. and **Mihm, J.A.** 1985. Improving host-plant resistance to fall armyworm and sugarcane borer in sorghum. Pages 201-204 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Leuschner, K. 1985. Sorghum entomology research programs and need in the developing world. Pages 13-20 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Murty, D.S., Rao, N.S., and **Singh, U.** 1985. Evaluation of sorghum grain quality as influenced by milling methods. Pages 24-28 *in* Symposium of the Processing of Sorghum and Millets: Criteria for quality of grains and products for human food, 4-5 Jun 1984, Vienna, Austria. Eleventh Congress 1984 of the International Association for Cereal Science and Technology, 4-8 Jun 1984, Vienna, Austria. Vienna, Austria: International Association of Cereal Chemistry.

Nwanze, N.F. 1985. Sorghum insect pests in West Africa. Pages 37-43 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Sharma, H.C. 1985. Screening for host-plant resistance to mirid head bugs in sorghum. Pages 317-335 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Sharma, H.C. 1985. Screening for sorghum midge resistance and resistance mechanisms. Pages 275-292 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Taneja, S.L. and **Leuschner, K.** 1985. Resistance screening and mechanisms of resistance in sorghum to shoot fly. Pages 115-129 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Taneja, S.L. and **Leuschner, K.** 1985. Methods of rearing, infestation and evaluation for *Chilo partellus* resistance in sorghum. Pages 175-188 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, TX, USA. Patancheru, A.P. 502 324, India: ICRISAT.

Vasudeva Rao, M.J., Chidley, V.L., Mukuru, S.Z., and House, L.R. 1985. Screening methodology and breeding sorghum for resistance to *Striga asiatica* (L.) Kuntze at ICRISAT Center. Page 164 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

PEARL MILLET

Contents

Cover photo: Indian farmer with panicles of pearl millet ICMV 4 (ICMS 7703), an ICRISAT synthetic variety released by the All India Coordinated Millet Improvement Project for general cultivation.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Cereals Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

Pearl Millet

Phase III of the UNDP-funded ICRISAT cooperative research projects on pearl millet involving the national programs of five countries in the Sahelian bioclimatic zone, Burkina Faso, Nigeria, Niger, Senegal, and Sudan, concluded in 1985. During the 9-year course of these programs, all have produced a range of elite breeding materials, as well as varieties for national yield testing. In Niger, Senegal, and Sudan these varieties have already reached the farm level, following release by the concerned national governments. This represents an excellent beginning for ICRISAT's efforts in the Sahelian region, and we are grateful to the UNDP for the generous support it has provided for these activities.

UNDP support will continue for a further 3-year period, beginning January 1986, but the program's focus will change from national to regional. The regional millet team, consisting of six scientists, will operate from the ICRISAT Sahelian Center (ISC), Niamey, Niger, to serve the Southern Sahelian bioclimatic zone, where millet is the principal cereal crop. One breeder will be stationed at the regional sorghum program headquarters, to serve the Sudanian zone, (a longer-season, higher-rainfall area, that requires different varieties), and a seventh scientist will continue to work in the Sudan, which also requires different varieties from those for the western part of the Sahelian zone.

At the same time, the millet program has continued to build a base for a full-scale crop improvement program in the southern African region. This began with the assignment of a plant breeder and a pathologist to Zimbabwe for the 1985/86 crop season. In collaboration with the International Board for Plant Genetic Resources (IBPGR) and millet scientists in the various Southern African Development Coordination Conference (SADCC) countries, we evaluated more than 2400 breeding lines and genetic resources accessions during 1984/85 in multilocational trials across the region.

Collaboration between millet scientists at ICRISAT Center and the ISC was strengthened in 1985 when three Center scientists spent from 6 to 8 weeks each in Niger and in Mali working on crop establishment, mycorrhizal fungi, and downy mildew resistance screening. Several joint ICRISAT Center/ISC projects are planned for 1986. These include a new breeding population combining the best materials from India and West Africa, as a means of exchanging variability between Centers, joint work in breeding for crop establishment capability and disease resistance, and further research on mycorrhizae at ISC by scientists from ICRISAT Center.

In India, our research continued on a broad front in our effort to produce elite breeding materials with resistance to diseases and adaptation to the marginal environments in which a considerable part of the world's pearl millet is grown. The program at ICRISAT Center is gradually shifting emphasis from investigation of discipline-oriented problems (disease epidemiology, understanding the effect of drought, the role of soil microorganisms in crop nutrition, etc.) to using the knowledge obtained to breed new genetic materials. We now have more joint projects between plant breeders and discipline scientists, either actually breeding for adaptation, resistance, etc., or investigating the potential to do so regularly in the future. These changes should be reflected in the greater diversity and utility of the genetic materials we produce in the next decade.

Physical Stresses

Crop Establishment Problems

Field Studies on Crop Establishment in Niger

Poor crop establishment has frequently been cited as a major problem in the Sahel. In order to assess the problems of seedling emergence and survival in this zone, we conducted a survey of sowing practices, environmental conditions, and plant stands in farmers' fields in Niamey Department, Niger, during the 1985 sowing season, using a similar methodology to earlier studies in India (ICRISAT Annual Report 1981, pp.59-61).

Sowing begins following the first rain sufficient to wet the soil to a depth of approximately 15-20 cm. No presowing tillage is done; but individual sowing sites (hills) are prepared by opening a shallow hole with a long-handled hoe. Seeds are dropped into these depressions, covered with loose soil, and the soil compacted with the sower's foot (Fig. 1). The mean number of hills sown ha^{-1}, ranged from 3500 to 11 000, equivalent to approximately 1.7 m × 1.7 m to 0.9 m × 0.9 m hill spacing. The sowing depth (taken as the thickness of the soil pressed over the seeds) varied from 2 to 8 cm. This variation occurred in a single field as well as among different fields.

Farmers sowed only local landraces of pearl millet. Seeds were of good quality; their germinability ranged from 50 to 90%, and few had any kind of damage. Seeds sown $hill^{-1}$ ranged from 40 to as many as 300, giving estimated seed populations of 53000-1900000 ha^{-1}.

As sowing immediately followed rain, soil moisture and temperature conditions at sowing were generally favorable (Table 1). As a consequence, the initial establishment of hills (those with at least one emerged seedling) was good—between 3500 and 9500 hills ha^{-1}, or approximately an 80% success rate (Fig.2). However, in terms of emerged seedlings, the success rate was only about 25%, giving an estimated initial seedling population of 12000-450000 ha^{-1}. What the farmer actually requires, however, is a full population of hills, with 1-3 plants $hill^{-1}$. Therefore, the relatively low seedling emergence rate would not appear to be a problem, provided those seedlings that do emerge, survive, and produce grain.

The period following emergence was dry in most areas sampled, and surface soil temperatures began to rise rapidly, reaching as much as 50°C by 5 days after sowing (DAS) and 56°C by 12 DAS (Table 1). Surface soil temperatures generally remain moderate so long as there is evaporation of water from the surface soil. Once surface soil moisture evaporates—and is not replenished by subsequent rains—the intense

Figure 1. Sowing pearl millet seeds in a farmer's field in Niamey Department, Niger 1985.

Table 1. Changes in maximum diurnal surface soil temperature and seedbed moisture in 26 farmers' pearl millet fields, Niamey Department, Niger, rainy season 1985.

	Days after sowing (DAS)		
	2	5	12
	Temperature (°C)[1]		
Mean ± SD	36 ± 2.1	36 ± 8.5	51 ± 3.2
Range	34-42	27-51	43-56
	Moisture (%)[2]		
Mean ± SD	3.6 ± 0.95	-	1.6 ± 0.16[3]
Range	2.0-5.5	-	1.3-1.8

1. Measured at 2-cm depth on 2 DAS, and at 1 cm on 5 and 12 DAS.
2. Measured for 0-8-cm depth on 2 DAS and for 2-12 cm on 12 DAS.
3. Recorded on 6 of the 26 fields only.

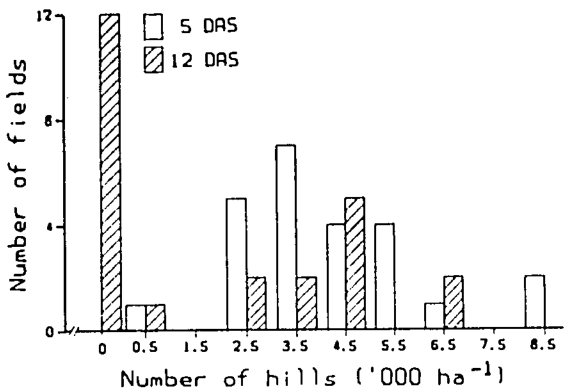


Figure 2. Frequency distributions of numbers of pearl millet hills emerged (5 DAS), and numbers of hills surviving, at 12 DAS, farmers' fields, Niamey Department, Niger 1985.

solar radiation at the beginning of the growing season will heat the surface soil to temperatures above those tolerated by most terrestrial plants.

The effects of these temperatures on the millet seedlings were disastrous; many seedlings dessicated and died during this period (Fig. 3). Estimated hill populations at 12 DAS reflected this; mean hill populations declined from 4900 ha^{-1} at 5 DAS to 2300 ha^{-1} at 12 DAS, and plant stands failed completely (0 hills alive) in nearly half the fields sampled (Fig.2).

Stepwise regression analyses were run to identify those factors related to final seedling number per hill, i.e., seeds hill^{-1}, percentage emergence, and environmental factors. Surface soil temperature at 12 DAS accounted for almost all the 56% variation in seedling number explained by the stepwise regression. We are aware that soil temperatures are a function of soil moisture, but both the regression analysis and our field observations suggest that even where there was moisture below the surface soil layer (i.e., below 8-10 cm, and within reach of the seedling roots, seedling death occurs if surface soil temperatures reach the values recorded in this study, i.e., exceed 50°C. Our results thus confirm the common observation that plant stand establishment in the Sahel depends largely upon the occurrence of rains following sowing, to prevent surface soil temperatures from rising to lethal levels. Work is

Figure 3. An individual pearl millet hill at 12 DAS, showing seedlings killed by high temperature (foreground) and the remaining live seedlings (background), farmer's field, Niamey Department, Niger 1985.

in progress both at ICRISAT Center and ISC (ICRISAT Annual Report 1984, pp. 84-85) to assess genetic variation for tolerance of such temperatures, at least for short periods of time.

Timing and Method of Sowing

Trials on farmers' fields in Niger in 1984 (ICRISAT Annual Report 1984, pp. 325-327) indicated that farmers frequently continued sowing for more than 4 days after the first rain, resulting in poor crop stands and reduced crop yields. We tested the effects on seedling establishment and growth of delayed sowings in controlled experiments at ISC in 1985, along with the possible benefits of two methods that could improve stands; dry sowing before the rains, and the use of presoaked seed for sowing.

Dry sowing prior to the rains was similar to sowing immediately after the rains. Both treatments produced seedlings with the highest root numbers per seedling and seedling dry mass in the experiment (Fig. 4). Delaying sowing for 1.5 to 3 days after the first rains significantly reduced both root and top growth of seedlings, but did not affect plant stands or grain yields (Fig. 4). The initial rains at ISC were regularly spaced in the 1985 crop season, however, and results of later sowing might have been different in years with inadequate early rains.

Delaying sowing to the second rain, rather than sowing 2-3 days after the first rain, resulted in better seedling root development at 21 DAS although seedling dry mass was not significantly different. Grain yields from delaying sowing to the second rain were significantly less than those from all sowings made with the first rain (Fig. 4).

Presoaking seeds for 7 hours before sowing had some influence on the rapidity with which seedlings emerged, but not on final hill stand (Fig. 5) or grain yield. The interaction of presoaking seeds with sowing time (Fig. 5) indicated that in a season where drought occurred immediately after the rains, some advantage may result from presoaking seeds, but the traditional practice of dry sowing still appears preferable to sowing presoaked seed.

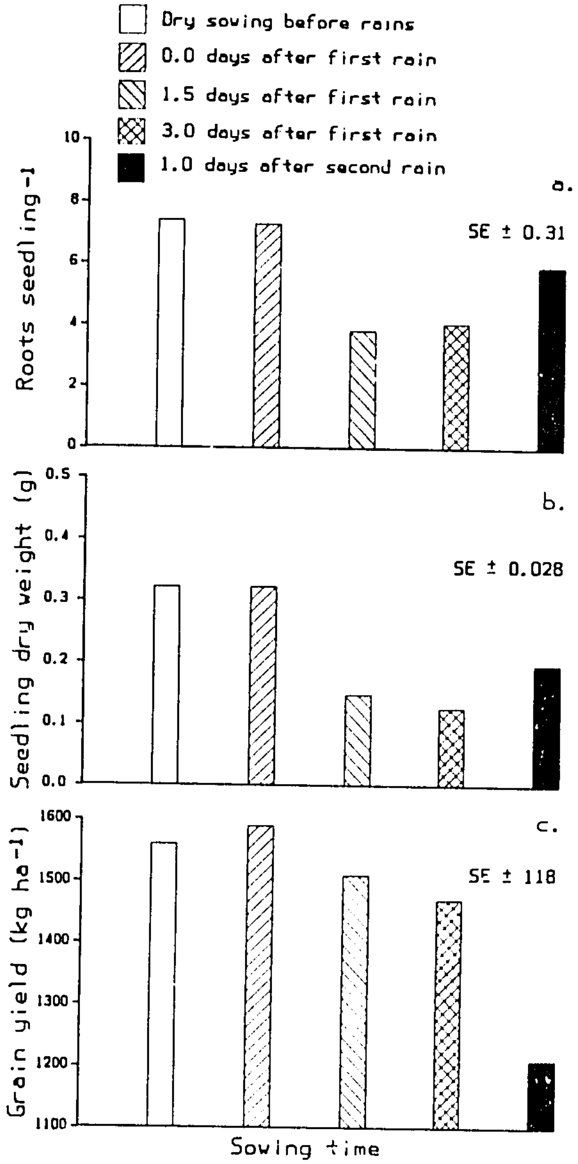


Figure 4. Pearl millet seedling root number (a) and top growth at (b) 21 DAS and final grain yield (c) for different times of sowing in relation to the first rain, ISC, rainy season 1985.

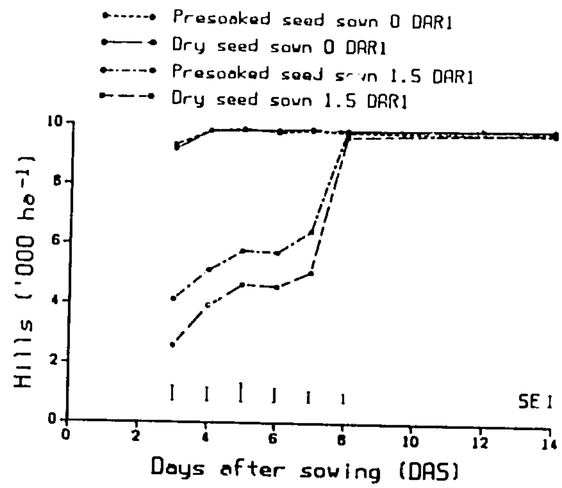


Figure 5. Number of hills established by dry and presoaked pearl millet seed sown immediately following the first rain (0 DAR 1) or 1.5 days later (1.5 DAR 1), ISC, rainy season 1985.

Seedling Establishment under Drought Stress

Research continued at ISC on a simple field-screening method for evaluating drought resistance during the seedling establishment phase, based on the hypothesis that two water levels (a regularly irrigated control and a nonirrigated stress treatment) would be sufficient to evaluate breeding materials (ICRISAT Annual Report 1984, p. 85). The relationship between percentage seedling survival and coefficient of variation was used to select the percentage survival at which to relieve the stress, such that differences in survival of 10% among entries could be detected statistically. Under the conditions of the method, the point at which the standard susceptible control genotype reached 40% stand loss (60% survival) fulfilled this criterion.

The seedling drought tolerance of 36 genotypes, including 24 synthetic varieties from the ISC Millet Breeding Program, was evaluated in irrigated and stressed plots at the end of October 1985. Control plots received 25 mm of irrigation every 10 days. Stressed plots received irrigations of 25 mm after dry seeding, and at the time when the stress was relieved (40 DAS). Because of residual moisture in the soil from the rainy season (June-September) and low soil temperatures in November, survival of the susceptible control genotype did not fall to 60%, even though the stress relief was delayed. Nevertheless, significant ($P<0.01$) genotypic differences were found among entries; 21 of the new synthetics have seedling stress tolerance equal to that of the local, and the improved local (CIVT) cultivars (Table 2). The good performance of these synthetics may be due to their Sahelian parental lines. Some of these better synthetics also have a higher grain yield potential than the local cultivars (see Plant Improvement section of this report).

Entries having poor seedling establishment originated in higher rainfall areas than ISC (>1000 mm vs 550 mm). Many of these lines are selections from material collected in northern Togo. This Togolese "Iniadi" population has been used by many millet breeders as a source of large seed size. Our study indicates that an early-generation screening of such selections is needed to eliminate lines that have poor seedling establishment in the drier zones. Our method for drought resistance screening is capable of identifying such genotypes.

Table 2. Seedling survival at 49 days after sowing in stressed and control treatments for selected ICRISAT West African pearl millet varieties, ISC, dry season 1985.

	Survival (%)	
Entry	Stressed treatment	Control treatment
ICMV 8524 SC	90	98
ICMV 8513 SC	90	98
ICMV 8506 SC	89	98
ICMV 8526 SC	88	99
ITMV 8001	87	99
ICMV 8532 SC	87	100
ICMV 8509 SC	87	99
ICMV 8533 SC	86	96
ICMV 8522 SC	85	96
ICMV 8523 SC	85	99
ITMV 8304	84	90
ICMV 8508 SC	79	100
ICMV 8511 SC	78	100
ICMV 8512 SC	76	99
ICNMV 121	74	91
Controls		
Local	93	100
CIVT	90	94
MBH 110	77	95
SE	±2.0	±4.9
Trial mean (36 entries)	87	99
CV(%)	11	12

Drought Stress

Timing and Intensity of Terminal Drought Stress

Investigations of genotype responses to drought stress over a number of years have indicated that except for stress during seedling establishment, stress during flowering and early-grain filling has far more serious consequences for pearl millet than at any stage prior to flowering. The effects of late-season stress were investigated in initial experiments conducted during the 1978 and 1979 dry seasons on medium-deep Alfisols when terminal drought stress treatments were begun at different times from 50% flowering. The combined analysis of 2 years' data showed that the time of onset of stress determined the extent of grain yield loss (Fig. 6a). Yield reductions were severe (70-80%) when the stress was initiated prior to flowering, but the effect declined rapidly as the onset of stress was delayed. Yield reductions were primarily due to the effect of time of initiation of stress on grain number per unit area (Fig. 6b), although grain size was also reduced by as much as 30% in the early stress treatments.

The timing of terminal stress is not the only factor affecting yields; intensity of stress may be equally important and may interact with timing. We initiated studies during the 1981 and 1982 dry seasons using the line-source sprinkler irrigation system, to investigate the simultaneous effects of timing and intensity of postflowering stress. The crop was initially furrow irrigated; the line-source treatments were begun 50 days after emergence (DAE) in 1981 and 58 DAE in 1982. The different stress intensity treatments created by the line source were quantitatively described as the percentage irrigation deficit, compared to the fully irrigated control treatment.

Since the genotypes (16 in 1981, and 32 in 1982) differed in time to 50% flowering, the phenological timing of onset of stress was different for each genotype. Therefore, the yield response of each genotype to increasing stress severity was expressed as a yield reduction ratio (yield loss as a fraction of the nonstressed control, per percentage irrigation deficit). This ratio provided a means of testing the influence of time to 50% flowering on yield reduction; there were strong linear relationships between time to 50% flowering and the yield reduction ratio in both the years (Fig. 7). This occurred because earlier-flowering genotypes partially escaped stress, resulting in

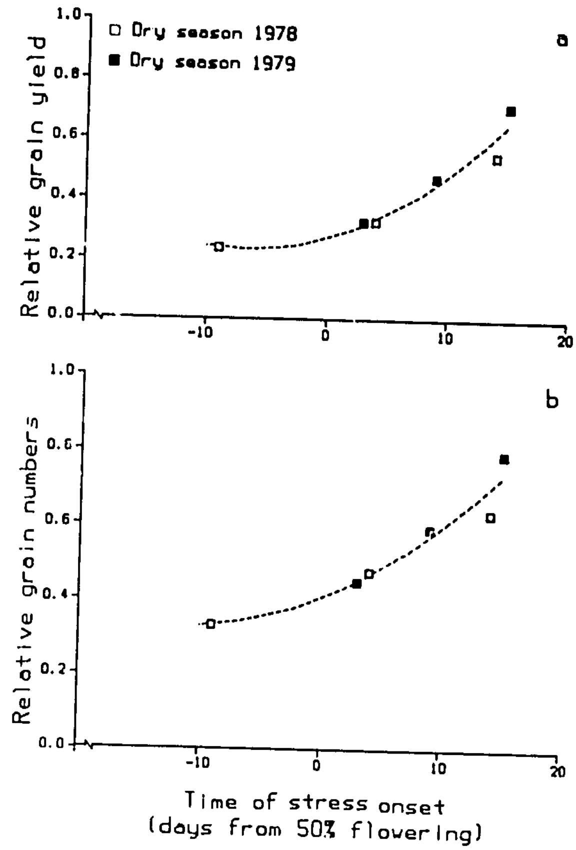


Figure 6. Effects of the time of onset of drought stress on pearl millet grain yield (a) and grain number (b) relative to nonstressed control. Data are means of eight genotypes, replicated four times; ICRISAT Center, dry seasons 1978 and 1979.

lower yield reduction ratios compared to the later-flowering genotypes, which encountered stress during the critical stages of flowering and early grain filling.

The time of line-source sprinkler irrigation treatment initiation (time of onset of stress) for each genotype was expressed as time from 50% flowering. For each stress intensity, each genotype's yield was plotted as a function of onset of stress for that genotype (Fig. 8). This method of expressing the data allows a simultaneous comparison of the effects of both stress timing and severity. At mild intensities (<20% irrigation deficit), timing of onset of stress had no serious

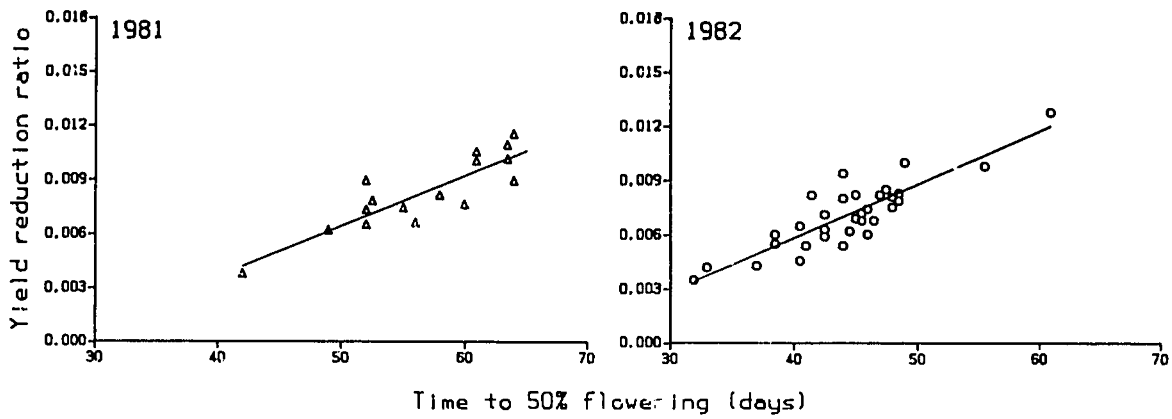


Figure 7. Yield-reduction ratios (reduction in pearl millet grain yield expressed as a fraction of the nonstressed control, per each percent irrigation deficit) in relation to genotype time to flowering, ICRISAT Center, dry seasons 1981 and 1982.

effect on grain yield. As the stress intensity increased, the time of onset of stress became more critical. The earlier the onset of stress, the more the yield reduction (Fig. 8). The effect of time of onset of stress on grain yield was mainly an effect on the grain number component, as a result of reductions in both panicle number per unit area and grain number per panicle. In comparison, the effect of stress intensity on grain yield was by a reduction in both grain number and size.

A very high percentage of the variation in grain yields in both years was accounted for by the combined effects of timing of stress onset and severity (86% in 1981, and 72% in 1982). The interaction of the two factors was not significant and the magnitude of the coefficients of determination suggested that genotypic differences other than in phenology were much less important than stress timing and intensity in explaining yield variation among the different treatments and genotypes.

The results also permit some quantification of the expected advantages of fitting cultivars of shorter duration to areas where terminal drought frequently occurs. For example, replacing a cul-

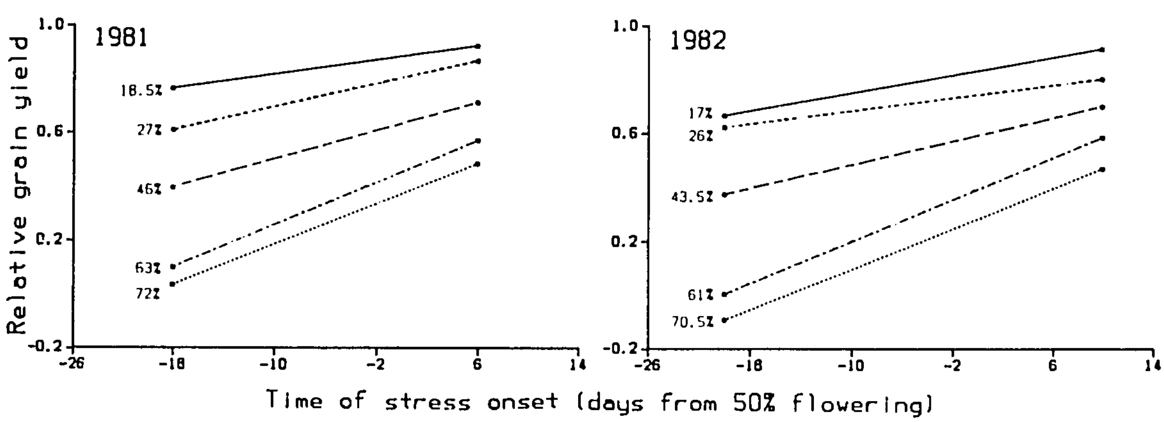


Figure 8. Relative pearl millet grain yields for selected intensities of drought stress, expressed as the percentage irrigation deficit, in relation to the onset of stress. ICRISAT Center, dry seasons 1981 and 1982.

tivar that flowers at the time of stress initiation with one that flowers 10 days before stress initiation would result in an 18% yield advantage in a mild stress year [30% deficient in potential evapotranspiration (ET) after flowering] and a 35% advantage in a severe stress year (70% deficient in potential ET after flowering). These relationships require testing in other locations/seasons, but the general principles should be useful in estimating the benefits of cultivars of shorter duration in areas prone to end-of-season droughts.

Selection for Adaptation to Drought

One alternative open to a plant breeder aiming to improve adaptation to drought stress conditions is to reselect promising, but variable, materials specifically for drought conditions. While this is most obviously done in open-pollinated varieties, the possibility also exists in hybrids, where there is residual variability in the pollen parent. A number of individual plants from such a variable pollinator [(T166-2 × 70594-2-6) 90] were selfed and crossed on 5141A, and both the S_1 progeny and test crosses grown under terminal drought in the dry season of 1982. Selected test crosses were reevaluated under rainy-season conditions in 1983 and one—EICH 8301—was selected for further testing in the 1984 Pearl Millet Advanced Drought Trial (PMADT) and the 1985 Pearl Millet Multilocational Drought Trial (PMMDT).

EICH 8301 outyielded ($P < 0.05$) the two standard control varieties WC-C75 and ICMS 7703 in three of the five trials subjected to terminal stress (ICRISAT Center Drought Nursery 1984, and rainy-season trials Anantapur 1984 and ICRISAT Center 1985, Table 3), and yielded as well as the control means in the other trial locations.

This approach of reselecting otherwise elite materials (the original hybrid made using the pollinator of EICH 8301 was entered in the All India Coordinated Millet Improvement Project trials) for better drought tolerance may have considerable possibilities, as it takes full advantage of disease resistance and yield potential

Table 3. Grain yield of pearl millet hybrid EICH 8301 in terminal stress environments, ICRISAT Center (IC) and Anantapur (A), 1984 and 1985.

	Grain yield (kg ha^{-1})				
	Drought nursery		Rainy-season trials		
	IC 1984	IC 1985	A 1984	A 1985	IC 1985
EICH 8301	980	1300	650	1500	2860
Controls					
WC-C75	630	850	470	1590	2100
ICMS 7703	740	940	470	1390	2320
SE	±112	±229	±66	±430	±279
Mean[1]	810	830	430	1400	2270
CV(%)[1]	28	28	27	31	12

1. Based on 48 entries at IC 1984, 20 at IC 1985, 14 at A 1984, and 20 at A 1985 and IC 1985.

available in elite materials. These results suggest that there may be useful residual variability for adaptation to stress in some elite materials. Several such reselection projects are now in progress and results will be evaluated in the future.

Biotic Stresses

Downy Mildew (*Sclerospora graminicola*)

Biology. We studied three aspects of downy mildew (DM) biology at ICRISAT Center: 1. the length of time required for asexual sporulation, 2. the effect of preinoculation storage temperature on sporangial infectivity, and 3. the effect of light on asexual sporulation. Studies on pathogenic variability in *S. graminicola* were continued at the University of Reading, UK, using isolates from India and African countries. A summary of this work will be reported next year.

To determine the minimum period of time required for production of sporangia on the surface of systemically infected leaves, we incubated excised leaves that had been appropriately pretreated for sporulation, at 20°C and 95-100%

relative humidity (RH) in darkness, conditions considered to be conducive for asexual sporulation by *S. graminicola*. Sporangiophores developed and sporangia began to form during the first 2 hours, and by the end of the 3rd hour mature sporangia were produced. With time, older sporangiophores collapsed, but new sporangiophores continued to develop and produce sporangia. No sporulation occurred on leaves maintained at only 70% RH. These findings suggest that given suitable temperatures and RH, sporangial production can continue for several hours in the field at night.

To determine the effect of storage temperature on sporangia in aqueous suspension (10^6 sporangia mL^{-1}), we placed 12 aliquots of a suspension of viable sporangia in petri dishes and held them at each of the eight temperatures: 10, 15, 20, 25, 30, 35, 40, and 45°C. One dish was removed from each temperature every hour for 12 h and used to inoculate 40-h-old seedlings of a downy mildew susceptible pearl millet cultivar, by immersing them in the sporangial suspensions. After 1 hour's immersion seedlings were transplanted into soil in pots. Counts of DM-infected seedlings showed that the infectivity of sporangia was greatly influenced by preinoculation temperature and length of storage (Fig. 9). Sporangia stored at 10 and 15°C for 12 h and also those stored at 20°C for up to 10 h, 25°C for up to 7 h, and 30°C for up to 4 h were able to infect a high percentage of inoculated plants. For other treatments, the frequency of diseased plants was either low or zero. The ability to maintain sporangial viability in suspension at a low temperature is important because it permits the use of sporangia collected in the early morning as inoculum for screening in the evening of

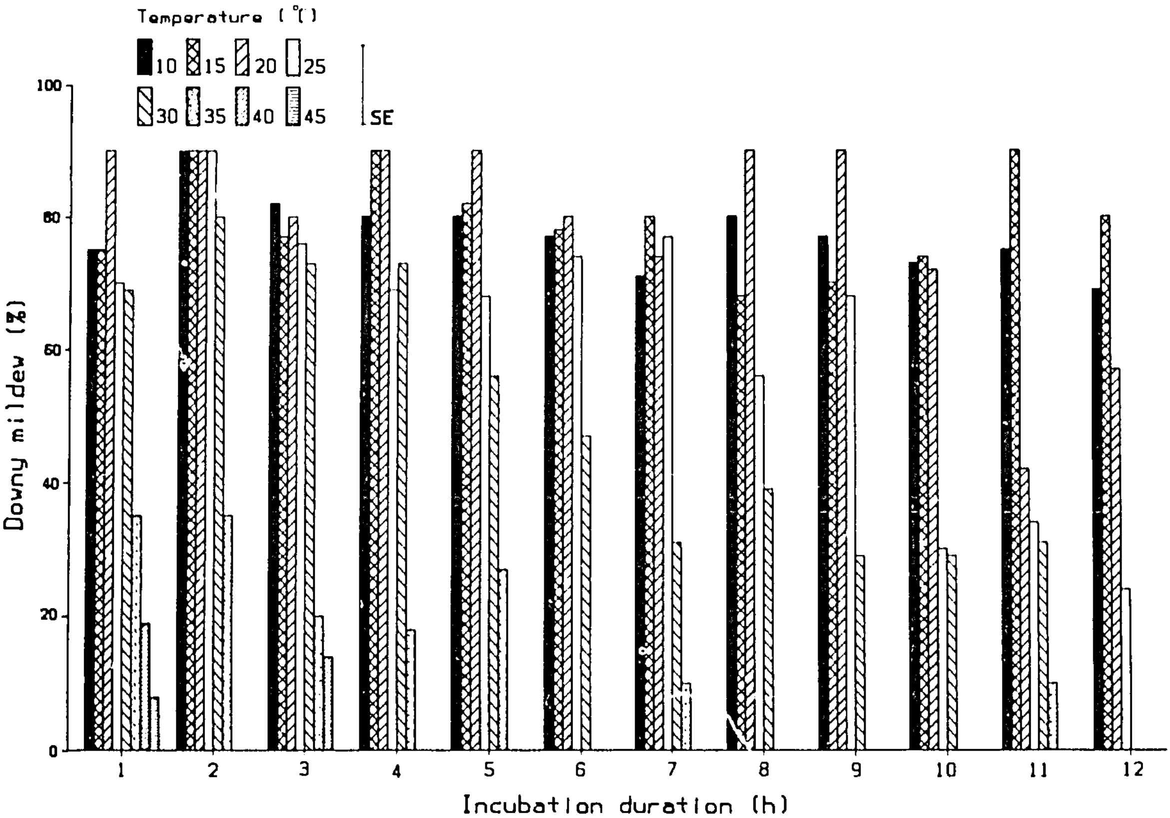


Figure 9. Effect of preinoculation storage temperatures on the infectivity of *Sclerospora graminicola* sporangia at different durations of incubation, ICRISAT Center, 1985.

the same day. Under field conditions, sporangia produced during the night lose their viability by midmorning or earlier.

To study the effect of light on asexual sp ulation of *S. graminicola*, we placed segments of systemically infected leaves, pretreated for sporulation, on moist blotting paper in open petri dishes in incubators, and exposed them to three treatments: near ultraviolet light (160 lux), fluorescent light (2000 lux), and darkness. The high RH required for sporulation was maintained in each incubator. Numbers of sporangia produced in the three treatments averaged 6.3×10^5 sporangia cm^{-2} leaf area, and did not vary significantly among treatments. We concluded that asexual sporulation in *S. graminicola* was not affected by these treatments.

DM Incidence at Selected Sites in Niger

At ISC, Tiaguirire, and Gaya, we planted four cultivars and one local variety of pearl millet to observe the natural incidence of DM. At ISC, only the ultrasusceptible variety 7042 became infected (Table 4). The overall highest level of DM for the nursery was found at Gaya, although the highest infection in 7042 occurred at Tiaguirire.

DM surveys of farmers' fields were conducted in the Gaya, Boboye, Samari, and Sadoré areas. No DM was observed at Samari and the mean level of DM was 3% at Sadoré and 4% at Boboye. The highest mean incidence of all the areas surveyed was at Gaya with 31%, confirming that this may be an appropriate environment for future DM screening.

Table 4. Natural incidence of pearl millet downy mildew at three locations in Niger, rainy season 1985.

	DM incidence (%)		
Entry	ISC	Tiaguirire	Gaya
7042	20	62	24
Sadoré Local	0	0	NA[1]
Gaya Local	NA	NA	29
3/4 HK	0	2	26
CIVT	0	2	7
Ex-Bornu	0	3	8

1. NA = Not applicable.

Figure 10. Pearl millet disease-resistance screening nursery, Bengou, Niger, 1985.

Establishment of DM Screening Nurseries in West Africa

Because it has been difficult to establish a DM-screening nursery at ISC, an agreement was made between ICRISAT and the Institut Nationale de Recherches Agronomiques du Niger (INRAN) to use land at the INRAN station at Bengou, near Gaya in southern Niger, for disease screening and agronomic evaluation of ICRISAT materials. Bengou has a mean annual rainfall of 800 mm, and pearl millet diseases, particularly DM, occur each year in farmers' fields in that area. We established a DM nursery at Bengou using the infector-row technique, successfully used for many years at ICRISAT Center (Fig. 10). A sprinkler irrigation system was not available for use in 1985, but we hope to have such a system in 1986 to help create, when necessary, the high humidity needed for infection.

A millet pathologist from ICRISAT Center spent 6 weeks at Cinzana, Mali, assisting the Malian national pearl millet improvement program to establish a DM screening facility (Fig. 11). High levels of DM were established in infector rows to provide DM pressure for testing breeding material.

Improvement in the Field-screening Technique at ICRISAT Center

The discovery that pearl millet seedlings are highly susceptible to DM at emergence (coleoptile stage) has led to a change in the system of inoculating infector rows in the DM nursery at ICRISAT. The old method of placing pots of infected plants at 10-m intervals in infector rows has been replaced by spraying infector rows with a sporangial suspension when plants are in the coleoptile stage. Infector rows are irrigated prior to inoculation to create high humidity condi-

Figure 11. ICRISAT pearl millet pathologist working with Malian national program staff, Cinzana Research Station, Mali, 1985.

tions, and plants are inoculated after sunset. This technique has given high levels of DM infection in infector rows and saves considerably on the expense of growing plants in pots.

Resistance Screening

With the availability of a large number of previously identified sources of DM resistance, our emphasis at ICRISAT Center has shifted to screening more breeding material. Resistance available in this type of material can be more readily used in the breeding program than that from genetic resources accessions.

DM incidence ranged from 1 to 10% in 12 composite populations evaluated in the field. We made single-plant selections from these populations and their progenies are being evaluated. We also evaluated more than 600 breeding lines, including those previously found to have stable resistance to DM and/or rust (*Puccinia penniseti*), plus hybrid seed parents and pollinators. Of these lines, 380 were either DM-free or had <10% DM. In addition, we evaluated 46 F_3 and F_4 progenies of crosses between the rust-resistant line, 7042-1-4-4, and 841B, 81B, and 68B.

Resistance Utilization

Several lines with stable DM resistance, including P 7, P 310, SDN 503, 700516, and 700651, are being used in the pollinator breeding project, and resistances from P 7 and 700651 are being transferred to several hybrid seed parents.

Ergot (*Claviceps fusiformis*)

Ergot Survey in Niger

We surveyed farmers' fields for ergot in 1985 in the areas of Boboye, Gaya, ISC, and Samari, but did not find any ergot. Only very low levels of ergot were found in surveys in 1982 and 1983, supporting earlier reports that ergot is relatively uncommon in such dry areas.

Resistance Screening

Very low levels of ergot infection were obtained in Niger following inoculation of ICRISAT materials; mean infection levels of 3% at Bengou and 1% at ISC were too low for reliable screening in Niger. However, as usual, ergot disease pressure was of sufficient magnitude to screen for resistance in India during both the dry and rainy seasons. About 3100 entries were screened for resistance at ICRISAT Center and Aurangabad in the continuing process of identifying, verifying, and using sources of ergot resistance.

Resistance Identification

We continued to identify and develop ergot-resistant (ER) lines with emphasis on concentrating resistance genes from diverse sources and selecting progenies with desirable agronomic traits. During the dry season we screened 377 progenies in F_2 to F_5 generations from ER × Togo selections, ER × DM resistant lines, and ER × ER crosses, and selected ER panicles from 84 progenies that had plants with high levels of resistance (≤5% severity) and desirable agronomic traits.

During the rainy season, we screened over 1200 entries, including selections from the dry season, plus new cross-bulks and inbreds. Of these, 193 entries were evaluated both at ICRISAT Center and at Aurangabad. Although a large proportion of entries (64%) showed high levels of ergot resistance (≤5% severity), only 216 entries (17%) were selected on the basis of ergot resistance and desirable agronomic traits (Table 5).

Resistance Utilization

We continued our efforts to transfer ergot resistance into hybrid seed parents. A large number of progenies from crosses ICP 220 × ER line, J 104 × ER line, 5054 B × ER line, and 81B × ER line were screened at F_3, F_4, BC_3, BC_5, and BC_6 generations, from which we selected ER segre-

Table 5. Summary of results from screening for ergot resistance in pearl millet, ICRISAT Center (IC) and Aurangabad (AB), rainy season 1985.

Material	Entries screened	Entries in the ergot severity (%) class[1] 0-5	6-10	11-20	21-30	>30	Entries from which ER[2] panicles selected
Togo × ER							
Cross/line bulk	73 IC	1	4	9	19	40	23
	73 AB	9	21	30	11	2	20
ICMPES[3]							
Cross bulk	193 IC	79	54	37	12	11	81
	27 AB	19	7	1	0	0	0
ER inbreds	946 IC	702	104	95	32	13	112
	93 AB	81	8	1	0	3	0

1. Based on mean of 6-80 inoculated inflorescences per entry.
2. ER = Ergot resistant.
3. ICMPES = ICRISAT Millet Pathology Ergot Sib-bulk.

gants. Results showed improvement in resistance of the successive backcross generations of 81A × ICMPE 134-6-9, from 17-31% infection in BC_1 to 3-11% infection in BC_6. However, the possibility of breeding ergot-resistant hybrids may be more difficult than was previously thought.

An ER composite has been formed using 52 ergot-resistant ICRISAT Millet Pathology Ergot Sib-bulk (ICMPES) lines, with desirable agronomic traits. Two random matings were completed, one at Bhavanisagar and another at ICRISAT Center. We will attempt to make this population flower earlier and improve its agronomic traits, to provide lines for use in breeding varieties and pollinators.

Smut (*Tolyposporium penicillariae*)

Resistance Screening

We screened more than 3150 entries for smut resistance at ICRISAT Center and Hisar, to identify or verify smut resistance in inbred lines and populations and in progeny of crosses involving at least one parent with resistance to smut.

In Niger, the level of smut in noninoculated, but bagged panicles was especially high in trials and nurseries at Bengou with 80% infection on some panicles. This suggests that Bengou may be a good location for screening for smut resistance in West Africa. The considerable variation in infection that occurred among panicles, even of the same entry, was probably partly due to differences in natural levels of inoculum in the air, and the suitability of the microenvironment of the bagged panicles for infection during the critical time period of vulnerability to smut infection. Artificial inoculation and use of sprinklers to better ensure high humidity during the critical infection period should make it possible to achieve more reliable smut screening at Bengou. High levels of smut infection were also observed on some selfed panicles at ISC. However, mean smut incidence was only 1% in farmers' fields in the Boboye area and 0.3% in the Samari area in 1985.

Resistance Identification

With a view to verifying resistance, we screened 1180 entries, including accessions, smut-resistant

Table 6. Summary of results from screening pearl millet smut-resistant (SR) inbred lines, ICRISAT Center, rainy season, 1985.

Material	Entries screened	Entries in the smut severity (%) class[1]				Entries selected
		0-5	6-10	11-20	>20	
SR Inbreds 1	118	118	0	0	0	29
SR Inbreds 2	115	108	5	1	1	8
SR Accessions	57	45	8	4	0	7
F_3 DWC Dwarf	61	61	0	0	0	20
F_3 DWC Medium	424	424	0	0	0	62
F_3 (F_6 × F_6) lines	203	199	4	0	0	48
F_4 (F_6 × F_6) lines	200	200	0	0	0	18
Total	1178	1155	17	5	1	192
Percentage		98	1.5	0.4	0.1	16

1. Based on 10-20 plants inoculated in each entry.

(SR) inbred lines, and F_3/F_4 lines, in the smut nursery at ICRISAT Center (Table 6). In each entry, 10-20 plants were inoculated. We selected 192 lines (16% of the total entries) that were highly resistant (<1% mean smut severity) and had desirable agronomic traits.

These lines will be evaluated for DM resistance and agronomic traits, and selected lines will be used in the breeding program.

Resistance Utilization

We screened more than 500 C_3, S_1, and S_3 progenies of the Smut Resistant Composite (SRC); about 85% of these had <5% smut severity. Many individual plant selections were made for recombination in the next cycle. Based on their resistance to smut and DM and their high grain yield, two of our experimental varieties, ICMV 82132 and ICMV 83118, and one synthetic, ICMS 8283, were entered in AICMIP trials in 1984.

As a continuation of our effort to improve different breeding populations for smut resistances, we screened 434 S_1 progenies of the Medium Composite (MC) and 496 S_1 progenies of the New Elite Composite (NELC). The frequency of resistance (<5% severity) was 48% in the MC and 53% in the NELC. We selected progenies with high levels of smut resistance and desirable agronomic traits for recombination.

Rust (*Puccinia penniseti*)

Resistance Identification

The incidence of pearl millet rust disease, caused by *P. penniseti*, in India is generally much higher than in West Africa, although rust was noted on some lines late in the season at Bengou, Niger. The natural incidence of rust at Bhavanisagar, Tamil Nadu, is generally high in pearl millet planted in September or October. Therefore, resistance screening for this disease is mainly done there.

In 1985, we evaluated 440 accessions for rust resistance at Bhavanisagar; all were infected and only five accessions showed <5% rust. All the entries in a 50-entry pollinator nursery, 49-entry population products nursery, and 32-entry 1985 International Pearl Millet Smut Nursery (IPMSN) developed >10% rust. In addition, 1380 single-plant progenies of three composites, New Elite, Medium, and Smut Resistant, were evaluated and although none were rust-free, 77 progenies showed 10% or less rust.

One-hundred-and-six entries, comprising lines possessing stable resistance to DM and rust, were again evaluated for rust at Bhavanisagar and ICRISAT Center. Of these, 43 entries were rust-free at both locations. Most of these entries are selections from 700481-21-8, P 24-1, P 1564, IP 2084, IP 1594, and IP 8695; P 24-1, P 1564, and IP 8695 also possess stable resistance to DM.

Resistance Utilization

Rust resistance from 7042-1-4-4 is being transferred into male-sterile lines 841A, 81A, and 68A. We evaluated F_3 and F_4 progenies from this project for rust resistance at Bhavanisagar and at ICRISAT Center. One hundred progenies of the 380 evaluated at ICRISAT Center, and the 470 evaluated at Bhavanisagar were rust-free at both locations, while plants of several other progenies were segregating for rust reaction.

Multiple Disease Resistance

We screened 808 entries for multiple disease resistance (DM, ergot, smut, and rust) during the 1985 rainy season at ICRISAT Center. These included AICMIP yield trials, the AICMIP disease nurseries, the ICRISAT 1985 international disease nurseries, and selected disease-resistant inbreds from ICRISAT (Table 7).

We evaluated test entries for all diseases except rust in the DM nursery. As in previous years, we inoculated for smut at the boot stage and for ergot at full stigma emergence. As far as possible, tillers of the same plant were inoculated, one with smut and another with ergot. In each entry, 10-20 panicles were inoculated. We

Table 7. Pearl millet lines screened for multiple disease resistance, ICRISAT Center, rainy season 1985.

		Entries found resistant (< 10% infection) to			
Trial/nursery[1]	Entries screened	Downy mildew	Ergot	Smut	Rust
AICMIP					
Yield trials	114	103	0	16	-[2]
Downy mildew nursery	56	26	0	-	-
Ergot nursery	24	7	12	-	8
Smut nursery	15	5	0	14	0
ICRISAT					
IPMDMN	45	43	0	18	-
IPMEN	32	31	23	28	-
IPMSN	32	23	0	28	-
ER inbreds	158	111	130	158	-
SR inbreds	211	182	-	197	-
DMR inbreds	40	35	0	15	-
RR inbreds	81	64	0	12	66
Total	808	630	165	486	74

1. IPMDMN = International Pearl Millet Downy Mildew Nursery.
IPMEN = International Pearl Millet Ergot Nursery.
IPMSN = International Pearl Millet Smut Nursery.
ER = Ergot resistant.
SR = Smut resistant.
DMR = Downy mildew resistant.
RR = Rust resistant.
2. Not screened.

counted DM infected plants 30 DAE and scored for ergot and smut severity 20-25 days after inoculation. We recorded rust scores only in three disease nurseries under natural rust pressure.

Among the AICMIP hybrid and population trial entries, 90% showed resistance to DM, 14% to smut, but none to ergot. In the AICMIP disease nurseries (DM, ergot, and smut), where more than 50% of the entries were contributed by ICRISAT, most entries showed resistance only to the disease that was the subject of the trial.

Among the international disease nursery entries, we again found most entries resistant to the target disease. In the International Pearl Millet Downy Mildew Nursery (IPMDMN), 18 entries had combined resistance to DM and smut; in the International Pearl Millet Ergot Nursery (IPMEN), 23 entries had combined resistance to DM, ergot, and smut; and in the International Pearl Millet Smut Nursery (IPMSN), 23 entries had combined resistance to DM and smut.

We also evaluated 490 individual, disease-resistant inbred lines for their combined resistance to two or more diseases. A large percentage (70%) of ergot-resistant inbreds were also resistant to DM and smut; 86% of the smut-resistant inbreds had combined resistance to DM and smut; 37% of DM resistant inbreds had combined resistance to DM and smut; and 15% of the rust-resistant inbreds had combined resistance to DM, smut, and rust.

In general, the frequency of combined resistance to DM and smut was adequate in the ICRISAT Center lines. The frequency of combined resistance to DM, ergot, and smut was high only in the ergot-resistant inbred lines. These inbred lines should be used in population breeding to incorporate multiple resistance in both the populations and their products. Many of these lines were supplied to breeders in India to be used in their breeding programs.

Striga hermonthica

To assess the infestation of *S. hermonthica* in each of the two sick plots initiated at ISC in 1982, we recorded the number of emerged *S. hermonthica* plants associated with each hill of pearl millet. One plot had a mean of nine *S. hermonthica* plants m^{-2} with a considerably more uniform infestation, than the other plot, which had a mean of five *S. hermonthica* plants m^{-2}. All the hills in each sick plot were sown on a carefully placed grid, and future sowings in these plots will be repeated on the same grid. Results from these plots can be evaluated in terms of the past history of *S. hermonthica* infestation in each 2 m^2 area of each plot.

In a small-scale survey of farmers' fields in Niger, *S. hermonthica* plants that had emerged from the soil were associated with 1.5% of millet hills in the Boboye area, 36% in the Samari area, and up to 70% in the Gaya area.

Insect Pests

Population Monitoring

At ISC, we monitored populations of the stem borer (*Acigona ignefusalis*) and the earhead caterpillar (*Raghuva albipunctella*), from October 1984 through September 1985. During the dry season, we recorded a drop in the numbers of diapausing stem borer larvae from 30 (100 stems)$^{-1}$ in November 1984, to 14 (100 stems)$^{-1}$ in May 1985. Lower numbers of adults were recorded in light traps during the crop season (May-October 1985) compared to previous years, and at the time of peak stem damage (September) we recorded 74 larvae (100 stems)$^{-1}$ in 1985. The corresponding figures were 106 larvae (100 stems)$^{-1}$ in 1984 and 339 larvae (100 stems)$^{-1}$ in 1983. These results thus indicate a declining trend in stem borer infestation at the ISC during the 3-year period, 1983-85.

Soil sampling for diapausing pupae of the earhead caterpillar also showed a decline in numbers during the dry season (November 1984 to May 1985). In 1985, adult moths were first recorded in light traps on 8 August, 3 weeks later than in 1984. This delay corresponded to a comparable delay in the arrival of good rains essential to break the diapause (ICRISAT Annual Report 1984, p.100).

Unusually high infestations of the cotton stainer (*Dysdercus volkerii*) were recorded in 1985. The most severe infestations resulted in complete head blasting on CIVT, an improved variety, where an average of 160 insects plant^{-1} were observed in early July.

Pest Management

Agronomic practices. In collaboration with the soil tillage scientist we initiated a study at ISC to investigate the effect of plowing at the end of the crop season (November) on the survival of diapausing *R. albipunctella* pupae. This study was conducted using 20 m × 20 m plots in a field where there had been considerable infestation in the previous year (mean of 85% infested panicles and an average damage score of 3.5). The study involved three replicated treatments: 1. crop residue removal and no plowing, 2. crop residue incorporation with deep plowing (30 cm), and 3. no crop residue removal and no plowing (control). We carried out monthly soil sampling in four 1 m × 1 m subplots in each plot, excavating and sieving the soil through 2 mm sieves to a depth of 30 cm at 5-cm intervals.

Our results indicate that deep plowing reduced the number of surviving diapausing pupae at all soil profiles sampled (Fig. 12). The effect was most pronounced in the top 10 cm of the profile. Overall, we recorded almost three times as many pupae in the control (86 out of 128) as in the plowed treatment (32 out of 77).

Survival was highest in the lower third (20-30 cm), although a higher proportion of the initial population of pupae (51%) was found in the middle third (10-20 cm) of the profile. An examination of the soil temperatures by profile layer indicated that temperature is an important factor in pupal survival. Mean temperatures for the hottest period (March, April, and May) were 52.0°C at 5 cm, 40.6°C at 10 cm, and 34.8°C at 20 cm.

Genetic resistance. A collaborative trial involving ICRISAT, INRAN, and the Institut du Sahel's Integrated Pest Management Project (IPM) was conducted at ISC, Magaria, and

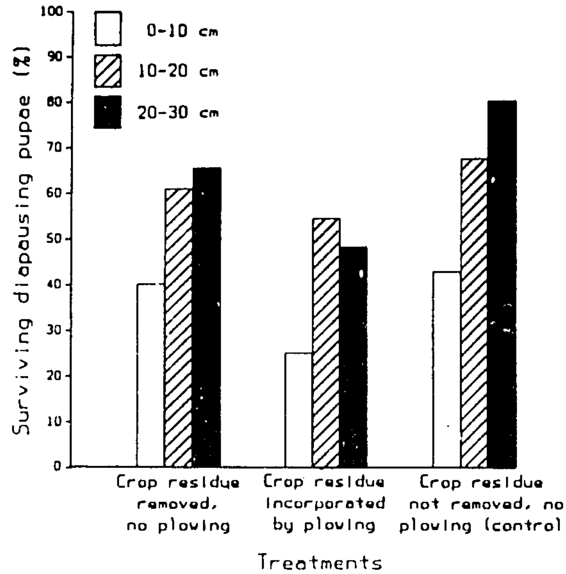


Figure 12. Effect of deep plowing at the end of the crop season on the subsequent survival of diapausing *Raghuva albipunctella* pupae at different soil depths, ISC, dry season 1984/85.

Maradi to evaluate pearl millet entries under natural infestations of *A. ignefusalis* and *R. albipunctella*. Test material consisted of five entries generated by the ICRISAT West Africa program and seven entries from INRAN. We used the recommended improved cultivar CIVT, and Sadoré Local as controls.

Infestations of *A. ignefusalis* sp were very low and uneven at ISC. *R. albipunctella* infestation was low to moderate, and data were obtained on the relative damage by this pest from 14 entries. On a 1-5 scale, where a score of 1 = 0 to low infestation and 5 = severe infestation, only one entry, 3/4 HK, had a rating as high as 3, and 6 entries were rated 1 (Table 8).

Microbial Associations

Biological Nitrogen Fixation

Ecological Studies

We studied the changes in populations of nitrogen-fixing bacteria associated with the field-

Table 8. Results of evaluation of *Raghuva albipunctella* infestation in pearl millet entries in an ICRISAT/INRAN/INSAH-IPM collaborative trial, ISC, rainy season 1985.

Entries	Damage severity score[1]	Infested hills(%)	Infested panicles(%)	Time to 50% panicle exsertion (d)	Grain yield (kg ha^{-1})
P_3 Kolo	1	66	36	56	1400
ITMV 8304	1	80	37	58	1360
Ankoutess	1	78	50	65	813
ITMV 8004	1	80	52	60	1300
ITMV 8001	1	79	53	60	1320
HKP	2	75	32	53	1130
IBMV 8004	2	80	34	55	1290
HKB-Tif	2	78	39	55	1170
ITMV 8303	2	72	39	56	1540
HKP_3	2	83	40	53	930
H 80-10 GR	2	59	41	54	1140
3/4 HK	3	83	51	55	1100
Controls					
Sadore Local	1	25	30	69	1280
CIVT	2	65	37	57	1360
SE	±0.6	±14.6	±13.1	±3.7	±320
CV(%)	31	20	32	6	23

1. Based on a 1-5 scale where 1 = zero to low severity and 5 = high severity.

grown cultivar WC-C75 during its growth cycle. Plants were grown in an Alfisol during the 1985 rainy season with 20 kg ha^{-1} N and P_2O_5 as a basal fertilizer. We collected rhizosphere soil and root samples at four stages of plant growth. We made counts of heterotrophic bacteria and estimates of the most probable number (MPN) of nitrogen-fixing bacteria by using a nitrogen-free combined carbon source (CCS) medium and a nitrogen-free malate medium (Tables 9 and 10). The counts of heterotrophs and MPN of nitrogen-fixing bacteria increased significantly up to the flowering stage (58 DAS), and were significantly higher at 30 DAS than at harvest (92 DAS). The MPN of nitrogen-fixing bacteria was higher in the CCS medium across sampling times and different samples than in malate medium. The MPN of nitrogen-fixing bacteria averaged over sampling times and media was highest in the root wash 1 sample, followed by root wash 2, rhizosphere soil, and root macerate.

The changes in populations of nitrogen-fixing bacteria were in agreement with changes in nitrogenase (C_2H_2 reduction) activity of the plants during the rainy season (ICRISAT Annual Report 1981, p.64-65).

Serological Relationships Amongst Nitrogen-fixing Bacteria

We studied the serological relationships amongst strains, species, and genera of nitrogen-fixing bacteria using the enzyme-linked immunosorbant assay (ELISA) technique. We raised antisera against strains of *Azospirillum lipoferum* (ICM 1001 and 4 ABL), *A. brasilense* (SL33, SM6M, and SP7a), *Azotobacter chroococcum* (ICM 2001), and *Enterobacter cloacae* (ATC 13047) in rabbits. We found that the three species of *Azospirillum* (*A. lipoferum, A. brasilense,* and *A. amazonense*) were serologically distinct from each other. Their antisera also did not cross-react with other species or strains, i.e., 7 strains of *Azotobacter*, 7 of *Derxia*, 6 of *Enterobacter*, 1 of *Erwinia*, 9 of *Pseudomonas*, 2 of *Klebsiella*, and 10 of *Rhizobium*.

The different strains of *A. lipoferum* formed a serologically homologous group, i.e., all 13 *A. lipoferum* strains tested cross-reacted with strain ICM 1001 antiserum. We tested 18 strains of *A. brasilense* against the antisera of *A. brasilense* strains SP7a, SL33, and SM6M, but did not observe cross reactions amongst the different strains. Antiserum of *A. chroococcum* (ICM 2001) did not cross react with antigens of other species of *Azotobacter*, or with other genera of nitrogen-fixing bacteria. Different strains of *E. cloacae* were serologically homologous with the antiserum of *E. cloacae* (ATCC 13047). These results indicate that the ELISA technique would be useful to study the persistence of various nitrogen-fixing bacteria in field or greenhouse inoculation trials.

Responses to Inoculation with Nitrogen-fixing Bacteria

During the 1985 rainy season we conducted five field trials at ICRISAT Center and four trials at other locations using different cultivars of pearl millet, different N fertilizer levels, and farmyard manure (FYM), to study the responses to inoculation with nitrogen-fixing bacteria. Data from seven trials have been analyzed and in three trials, two at ICRISAT Center and one at Aurangabad, we observed statistically significant increases in grain yield and total plant drymatter with inoculation. In one of the trials at

Table 9. Populations of heterotrophic bacteria associated with pearl millet variety WC-C75 at different growth stages, ICRISAT Center, rainy season 1985.

		Bacteria (log no. sample^{-1})[2]				
Crop age (d)	Culture medium[1]	Rhizosphere soil	Root wash 1	Root wash 2	Root macerate	Mean
30	M	6.89	7.08	7.03	5.95	6.69
	CCS	6.89	6.96	6.95	5.81	
58	M	7.28	7.47	7.38	6.29	7.01
	CCS	6.94	7.35	7.16	6.19	
73	M	6.94	7.91	7.63	6.06	6.98
	CCS	6.68	7.71	7.12	5.82	
92	M	6.70	7.75	7.31	6.29	7.02
	CCS	6.54	7.59	7.80	6.19	
SE			±0.048			±0.01
Mean		6.86	7.48	7.30	6.07	
SE			±0.019			

1. M = malate semisolid medium, CCS = combined carbon source medium.
2. Rhizosphere soil = The soil adhering to the roots after removing the bulk soil by gentle shaking was collected by shaking with wrist action.
   Root wash 1 = A root sample of 20 g washed once in 180 mL sterilized water.
   Root wash 2 = Once-washed roots transferred to a flask containing 180 mL sterilized water and washed for 15 min by thoroughly shaking with glass beads.
   Root macerate = Twice-washed roots sterilized for 30 min with 1% chloromine T, washed 10 times with sterilized water, and then macerated.

Table 10. MPN of nitrogen-fixers associated with pearl millet variety WC-C75 at different growth stages, ICRISAT Center, rainy season 1985.

		Bacteria (log no. sample⁻¹)[2]				
Crop age (d)	Culture medium[1]	Rhizosphere soil	Root wash 1	Root wash 2	Root macerate	Mean
30	M	4.45	4.40	3.56	2.18	3.45
	CCS	4.40	3.63	3.39	1.60	
58	M	5.40	5.63	4.99	4.16	5.18
	CCS	5.80	5.74	5.36	4.40	
73	M	4.62	5.17	4.63	2.86	4.67
	CCS	5.36	5.50	5.26	3.99	
92	M	3.63	4.49	3.63	2.36	3.69
	CCS	3.79	4.49	4.36	2.76	
SE			±0.291			±0.043
Mean		4.68	4.88	4.40	3.04	
SE			±0.106			

1. M = malate semisolid medium, CCS = combined carbon source medium.
2. Rhizosphere soil = The soil adhering to the roots after removing the bulk soil by gentle shaking was collected by shaking with wrist action.

Root wash 1 = A root sample of 20 g washed once in 180 ml. sterilized water.

Root wash 2 = Once-washed roots transferred to a flask containing 180 ml. sterilized water and washed for 15 min by thoroughly shaking with glass beads.

Root macerate = Twice-washed roots sterilized for 30 min with 1% chloromine T, washed 10 times with sterilized water, and then macerated.

ICRISAT Center, we compared effects of different levels of N and inoculation with nitrogen-fixing bacteria on WC-C75 (ICMV 1). Mean grain yield across the N levels was significantly ($P < 0.05$) increased by inoculation, as well as across the inoculation treatments by application of nitrogen (Table 11). Inoculation resulted in increases in grain yield of 21% with *A. lipoferum* (ICM 1001) and 24% with *A. chroococcum* (ICM 2001).

In another trial at ICRISAT Center, the grain yield of cultivar BJ 104 was significantly ($P < 0.05$) increased by addition of FYM at 5 t ha^{-1}, by 20 kg N ha^{-1}, and by inoculation with nitrogen-fixing bacteria. Mean increases in grain yield measured across the N and FYM levels were 7% with *A. lipoferum* (ICM 1001) and 11% with *A. chroococcum* (ICM 2001).

Mycorrhizae

Response of Genotypes to VAM Inoculation

We showed earlier (ICRISAT Annual Reports 1983, p. 89, and 1984, p. 103) that the extent of root colonization by vesicular arbuscular mycorrhizae (VAM) is partly dependent on the host genotype. In 1985, we screened a further 24 genotypes for response to VAM (*Acaulospora morroweae*) inoculation. At ICRISAT Center, ICH 220 responded to inoculation with a significant increase in biomass of 40%, and IP 5921 with an increase of 34%, compared to their noninoculated controls. At Bhavanisagar, IP 4937 showed a significant increase in biomass of 47%, IP 4362 of 47%, and IP 3120 of 20%, due to VAM inoculation.

Table 11. Grain yield (kg ha^{-1}) of pearl millet variety WC-C75 grown with different levels of nitrogen and inoculated with nitrogen-fixing bacteria, ICRISAT Center, rainy season 1985.[1]

	Nitrogen applied (kg ha^{-1})			
Culture	0	20	40	Mean
A. lipoferum				
(ICM 1001)	1810	1990	2350	2050
A. chroococcum				
(ICM 2001)	1820	2110	2330	2090
Noninoculated control	1500	1580	2010	1690
SE		±120		±70
Mean	1710	1890	2230	
SE		±70		
CV(%)		15		

1. Mean of 6 replications each with a net harvested area of 9 m^2. A basal fertilizer dose of 9 kg P ha^{-1} was applied. Each plot was inoculated at sowing, and at 20 DAS with 2.5 L of liquid inoculum prepared by suspending a 70 g peat culture (viable bacterial count of 10^8 cells g^{-1} of peat) in 70 L of water.

Symbiosis of Pearl Millet and VAM in Niger

During previous investigations at ICRISAT Center we also showed that VAM inoculation increases phosphorus uptake by pearl millet (ICRISAT Annual Report 1983, p.90). Since phosphorus is known to be the most limiting macronutrient in pearl millet growing areas in SAT West Africa, we initiated research on VAM at ISC in 1985. A survey of farmers' fields within a 200-km radius of Niamey, Niger, showed that VAM symbiosis on pearl millet is ubiquitous. Root colonization ranged from 17 to 71% (field means). This variation was related to differences in the VAM-propagule density in the soil. We found that *Gigaspora* sp (Fig. 13) was the most predominant VAM fungus, followed by *Sclerocystis rubiformis*, in contrast to India where *Glomus* spp are the most common.

We measured VAM colonization and phosphorus uptake on 14 genotypes sown at ISC. VAM colonization ranged from 17 to 49%, but the relationship of colonization and phosphorus uptake was not consistent (Table 12). IEMV 8502 and ITMV 8302, with high VAM colonization, had a high total phosphorus uptake. How-

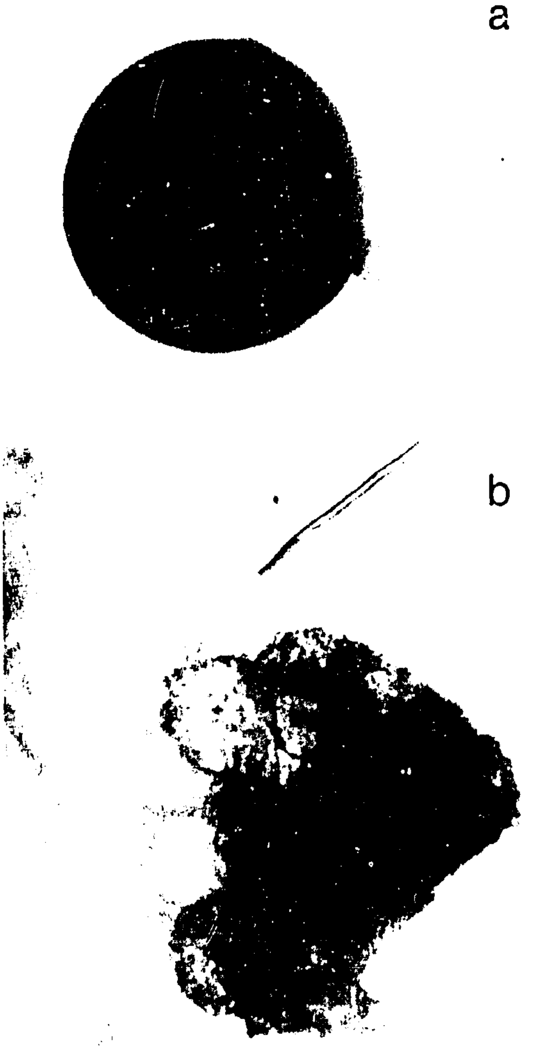


Figure 13. Extramatrical chlamydospore (propagule) (a), and echinulate vesicles (b), of the predominant VAM fungus *Gigaspora* sp found in soils of farmers' fields, Niger, 1985. (×400)

Table 12. Genotypic differences in VAM colonization and P uptake of pearl millet grown in a sandy soil, ISC, rainy season 1985.[1]

Genotype	VAM colonization (%)[2]	Shoot dry mass (g plant^{-1})	P uptake[3]	
			% dry mass	Total (mg plant^{-1})
IEMV 8502	49	92	0.22	200
ITMV 8302	40	112	0.22	254
IEMV 8501	34	103	0.21	221
ITMV 8303	31	419	0.19	792
IKMC 1	30	135	0.20	275
Sadoré Local	29	76	0.16	125
ITMV 8001	28	75	0.18	133
IEMV 8503	26	67	0.13	109
ITMV 8304	24	170	0.13	109
INMV 82141	22	84	0.15	128
CIVT	22	117	0.21	201
INMV 82076	21	83	0.18	151
INMV 82068	17	55	0.22	124
IKMV 8201	17	216	0.18	414
SE	±3.9	±34.8	±0.024	±57.4
CV (%)	19	38	17	43

1. Plants from IMZAT 1 were sampled at 90 DAS.
2. VAM colonization was assessed by the grid-line intercepted method.
3. Phosphorus was measured by the molybdenum-blue method.

ever, ITMV 8303 and IKMV 8201 also had very high shoot dry mass and total phosphorus uptake although they had medium to low VAM colonization.

We studied the effects of VAM inoculation on phosphorus uptake in a pot trial using ISC soil with 20 kg P ha^{-1} added. VAM inoculation increased dry matter and phosphorus uptake significantly ($P < 0.01$) compared to the non-inoculated control. Phosphorus uptake (118 mg P plant^{-1}) due to *Glomus monosporum* inoculation was nearly six times that of the noninoculated control (18 mg P plant^{-1}) and highest in comparison to the four other VAM fungi tested: *Gigaspora margarita* (106 mg P plant^{-1}), *Acaulospora moroweae* (95 mg P plant^{-1}), *Acanlospcra* sp (93 mg P plant^{-1}), and *Glomus constrictum* (62 mg P plant^{-1}). These results clearly show that pearl millet benefits from VAM inoculation.

Grain and Food Quality

Protein Quality

The nutritional quality of a cereal grain protein depends on the relative distribution of different protein fractions and their amino-acid composition. We determined the distribution of nitrogen in different protein fractions of two elite cultivars (ICMS 7703 and WC-C75) and three high-protein breeding lines (700112, WC 190, B 816). The albumin content was comparatively lower (18%) and the prolamine content was higher (40%) in high-protein lines than in elite cultivars. However, only marginal differences were observed in the distribution of the globulin and glutelin fractions among the elite and high-protein lines. High-protein lines contained adequate amounts of the most essential amino acids compared to the elite lines (Table 13). Lysine content (expressed as a percentage of protein content) was lower in the high-protein than in the elite lines.

Dehulling and Food Quality

In several countries of Africa, pearl millet food products are usually prepared from dehulled grains. Dehulling removes the seed coat and improves the color of the product. This is an important process in food preparation. We evaluated the dehulling quality and *tô* quality of nine cultivars that came from different geographic regions.

Dehulling Quality

Nine pearl millet cultivars were dehulled by the traditional method of hand-pounding (using a stone mortar and wooden pestle), using a barley pearler, and a tangential abrasive dehulling device (TADD) mill. The individual grain mass of the cultivars varied from 7.7 to 13.6 mg (Table 14). Grain hardness (measured by Kiya hardness tester) did not vary among the cultivars (3.0-3.8 kg), except for Fakiyabad, which had a significantly lower value (2.6 kg). The recovery of the dehulled product by the traditional method was highest for Mossi Local and lowest for Souna. Using mechanical dehullers, SAD 448 gave the highest and Fakiyabad the lowest recovery. The low recovery in the case of Fakiyabad may be due to its soft endosperm coupled with other grain characteristics like pericarp thickness, starch-protein interaction, etc.

We determined the chemical composition of whole grains and the dehulled grains obtained by the above methods. The loss in nutrients was calculated on a mg $grain^{-1}$ basis and as percent reduction on a whole grain basis. The dehulling process removed a considerable amount of crude fiber—39% by the traditional method, 54% by the barley pearler, and 56% by the TADD mill. In addition, dehulling resulted in the loss of important nutrients—sugars, fat, and ash (minerals) from the grain.

Tô Quality

Tô is a common food in Burkina Faso, Mali, and Niger. It is referred to by a variety of names like tou, tuo, tuwo, and asidah. *Tô* is prepared by boiling flour obtained from dehulled grain with water (neutral *tô*), with lemon juice (acid *tô*), or wood ash (alkaline *tô*). We evaluated the appearance and consistency of neutral *tô* made from nine millet cultivars from different geographic areas (Table 14). The *tô* quality was evaluated by a trained panel of three members and the ratings

Table 13. Essential amino-acid composition and protein content of five pearl millet genotypes, ICRISAT Center, 1985.

	Amino-acid composition [g (100 g protein)$^{-1}$]					
Amino acids	ICMS 7703	WC-C75	B 816	WC 190	700112	SE
Lysine	3.4	3.3	2.8	2.7	2.9	±0.13
Threonine	4.0	4.0	3.9	3.8	4.0	±0.04
Valine	5.7	5.6	5.8	5.7	5.9	±0.05
Methionine + cystine	2.4	3.2	3.4	2.4	2.9	±0.23
Isoleucine	4.8	4.6	4.9	4.8	4.9	±0.52
Leucine	10.5	10.4	10.7	11.1	10.8	±0.11
Phenylalanine + tyrosine	8.9	8.7	8.9	8.7	8.7	±0.52
Protein[1]	9.9	11.3	14.4	16.7	19.8	±1.79

1. Protein content expressed as g N × 6.25 (100 g flour)$^{-1}$.

Table 14. Grain characteristics, recovery by different methods of dehulling, and *tô* qualities of pearl millet cultivars, ICRISAT Center, 1985.

			Recovery (%) following dehulling by									
			Hand pounding			Barley pearler			TADD[2]			
Cultivar	1000-seed mass(g)	Grain hardness[1] (kg)	Dehulled grain	Brokens	Total	Dehulled grain	Brokens	Total	Dehulled grain	Brokens	Total	*Tô*[3] quality score[4]
Mossi Local	9.9	3.6	77.2	10.3	87.5	86.0	1.6	87.6	87.2	1.2	88.4	3.3
WC-C75	7.8	3.4	75.3	11.9	87.2	86.8	0.7	87.5	86.2	1.4	87.6	3.0
CIVT	9.6	3.4	72.0	12.0	84.0	86.6	0.7	87.3	85.5	0.6	86.1	2.3
SAD 448	8.5	3.0	71.7	14.3	86.0	89.5	0.6	90.1	88.3	0.6	88.9	2.3
DSA 74	13.6	3.8	70.3	12.7	83.0	83.2	1.5	84.7	85.8	2.5	88.3	2.7
Nigerian Composite	8.6	3.3	69.5	13.2	82.7	86.9	0.5	87.4	86.6	0.4	87.0	3.7
Fakiyabad	11.3	2.6	68.8	15.6	84.4	76.5	7.1	83.6	77.1	2.1	79.2	2.7
Togo	11.0	3.6	66.7	14.7	81.4	84.8	1.9	86.7	85.2	1.6	86.8	3.3
Souna	7.7	3.8	56.9	19.2	76.1	89.1	0.7	89.8	86.6	1.2	87.8	3.0
SE	±1.06	±0.13	±1.94	±0.87	±1.16	±1.30	±0.70	±0.70	±1.08	±0.23	±0.98	±0.16

1. Grain hardness was measured as kg force required to break grain using a Kiya hardness tester.
2. TADD: Tangential Abrasive Dehulling Device.
3. *Tô* prepared using the dehulled grains obtained from TADD.
4. Scored by a panel of 3 members using a 1-5 scale where 1 = good and 5 = poor.

were averaged. The cultivars SAD 448, CIVT, Fakiyabad, and DSA 74 received the highest ratings among the nine cultivars.

Plant Improvement

Genetic Diversification

The evaluation and use of large-seeded accessions from Togo and Ghana have recently received greater emphasis in the genetic diversification of breeding lines. Variety ICTP 8203, produced by intermating five S_2 progeny derived from Togo germplasm, continued to perform well; in 1984 it ranked second and yielded 1750 kg ha^{-1} [about 5% more than the control, WC-C75 (ICMV 1)] in the AICMIP Initial Population Trial. Studies have shown that among the leading varieties in advanced trials, it has resistance to terminal drought stress. Hybridization between breeding lines and S_2 progenies selected from accessions from Ghana and Togo has produced a wide range of F_5 progenies (about 1000 in a nursery of nearly 1300). These progenies have high panicle volumes, large seeds, and vary in height and maturity. More than 700 of them were selected, in the rainy season of 1985, and advanced to the F_6 generation for multilocational evaluation.

Evaluation of 41 S_3 progenies, derived from accessions from Ghana, identified some large-seeded progenies with a 1000-seed mass of 11 g yielding up to 86% of WC-C75. Ten progenies had very large white seeds with a 1000-seed mass of 14 g, and at present they provide the best source of both characteristics.

Several progenies derived from this project have proved useful in producing high-yielding hybrids. Five of these hybrids are now in advanced yield tests; four are in AICMIP trials, and one will be entered in AICMIP trials in 1986.

Previous studies comparing tall composites with their dwarf versions produced by a back-cross breeding program showed that, in general, dwarf composites had a yield potential equal to their tall counterparts, (see Yield Physiology Studies). Those comparisons, however, were not based on isogenic tall vs dwarf pairs as the dwarf composites had been derived using only three backcrosses. Twelve pairs of isogenic d_2 dwarf vs tall inbred lines from diverse genetic backgrounds (four from the Early Composite, seven from the Medium Composite, and one from the Nigerian Composite) were produced by nine generations of selfing heterozygous (D_2/d_2) plants. The comparison of isogenic tall and dwarf lines at two locations showed that, on average, dwarf lines did not differ significantly from the tall ones in any characteristic, including yield, at either location (Table 15).

At ISC, the use of genetic resources accessions to generate improved plant material with desirable attributes is a major activity. Work carried out during the year included evaluation of accessions and elite breeding material received from other programs, making crosses, and evaluating segregating populations and progenies. To diversify the genetic base of the breeding program, we evaluated 234 accessions originating from southern and West Africa, and retained 45 for reevaluation and use as parents.

We received elite breeding lines and composites from the millet improvement programs of Mali and Senegal. Among the three Malian composites evaluated, the Early Composite and the Souna-Sanio Composite appear promising. From the 400-entry inbred nursery from Senegal, we retained 97 agronomically desirable entries for use in breeding varieties and pollinators, and for conversion into male-sterile lines.

From a set of crosses, made using improved varieties and landraces from within the region as parents, 193 F_1s were selected as parents of a composite, and more than 70 for further evaluation. Twenty-seven F_2 populations from crosses between lines from Niger and Senegal provided 350 individual plant selections for further inbreeding, and 6 F_2 bulks for use as parents of varieties and composites. From 1200 F_3, F_4, and F_5 progenies we identified groups of lines for recombination to produce 16 varieties. From the backcross F_4 and F_5 nursery and the double cross F_2 populations, we made 160 plant selections with large panicle girth; these will be random mated to produce a source population for this trait.

Breeding Varieties

Pedigree Breeding

The term synthetic varieties is used in its broadest sense at ICRISAT. Our synthetics are the products of pedigree (or line) breeding, but the parental lines may not have been tested for combining ability, and the synthetics, once formed, are not reconstituted from their parental lines since these are often only partially inbred.

Table 15. Comparison of inbred lines of pearl millet isogenic for the d_2 locus, rainy season 1985.

Location	Height group	Grain yield (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	1000 seed-mass (g)	Effective tillers $plant^{-1}$	Time to 50% flowering (d)
ICRISAT Center	Tall	1620	157	17.8	6.7	1.3	56
	Dwarf	1120	84	19.3	6.4	1.4	55
SE		±193	±5.6	±0.9	±0.04	±0.2	±1.0
CV(%)		14	5	5	7	18	2
Bhavanisagar	Tall	1920	168	21.4	7.4	2.1	55
	Dwarf	1970	99	22.0	7.4	2.5	55
SE		±443	±10.8	±1.3	±0.07	±0.4	±2.7
CV(%)		22	8	6	9	17	5

Inbred lines, or partially inbred lines, are first derived by pedigree breeding from crosses between parents of diverse origin, that are often selections from other projects, e.g., inbreds or lines from the genetic diversification project, progenies from the population improvement project, and newly identified, disease-resistant lines. The inbreds derived from these crosses are then tested for phenotypic performance, and in some cases, are also tested for combining ability. In the past, this has been done by using diallel trials, but in order to test a larger number of inbreds, topcross testing is now being increasingly used. Sets of inbreds or partial inbreds selected on the basis of these tests are then used as parents of synthetics.

In 1985 at ICRISAT Center, we evaluated more than 7000 lines at various stages between F_1 and F_7, and 923 inbreds (i.e., lines beyond the F_7 stage of selfing). In addition, a 100-entry inbred nursery and a 325-entry preinbred nursery were evaluated at ICRISAT Center, Bhavanisagar, and Hisar. We also evaluated 186 selected inbreds for combining ability: 158 in topcrosses, and 28 in three diallel crosses. In the topcross trial the inbreds were crossed with five testers, WC-C75, ICMS 7703, ICMS 7704, Ex-Bornu, and ICTP 8203.

Among the synthetics ICMS 8010 and ICMS 8021 continue to do well in AICMIP trials (Table 16), and ICMS 7704 reached the 6th and final year of AICMIP testing in 1985. ICMS 7704 over the previous 5 years of testing has given 104% of the grain yield of the control variety WC-C75 and 114% of its fodder yield. ICMS 7704 can thus be regarded as a dual purpose (grain and fodder) variety. Hybrid ICMP 83401, whose pollinator was bred in the synthetics project, was the top-ranked entry over 11 locations in the 10th International Pearl Millet

Table 16. Performance of ICRISAT pearl millet entries in All India Coordinated Millet Improvement Project (AICMIP) trials, 1984.

Trial		ICRISAT entries performance 1984							Top-yielding entry 1984		
							% of WC-C75[1]			Grain yield	
Name	Locations	Entries	Entry	Years in test	Grain yield (kg ha⁻¹)	Rank	Grain yield	Fodder yield	Entry	kg ha⁻¹	% of WC-C75
Initial Pearl Millet Hybrid Trial I	21	28	ICMH 501	1	2190	3	126	119	MBH 142	2380	136
			ICMH 451	1	2140	4	123	112			
			ICMH 502	1	2110	5	121	112			
			WC-C75	-	1740	14	-	-			
Advanced Pearl Millet Hybrid Trial II	35	20	ICH 423	2	2020	5	120	100	MBH 131	2130	121
			ICH 415	2	1620	19	105	83			
			WC-C75	-	1760	14	-	-			
Initial Pearl Millet Population Trial III	17	16	ICMV 81111	1	1900	1	114	120	ICMV 81111	1900	114
			ICTP 8203	1	1750	2	104	94			
			ICMS 8010	1	1720	3	103	88			
			WC-C75	-	1680	4	-	-			
Advanced Pearl Millet Population Trial V	29	18	ICMS 7704	5	1710	3	104	114	ICMS 8021	1740	110
			IVS 5454	5	1600	10	102	104			
			ICMS 7835	4	1690	4	104	104			
			NELC-P79	4	1680	5	102	109			
			IVS-P78	3	1680	6	105	115			
			ICMS 8021	2	1740	1	107	106			
			NELC-H79	2	1660	7	107	121			
			WC-C75	-	1580	11	-	-			

1. Calculated over comparable years, i.e., over the number of years the entry has been under test.

Table 17. Performance of selected entries in the International Pearl Millet Adaptation Trial (IPMAT 10), across 11 Indian locations, rainy season 1985.

Entry	Grain yield (kg ha^{-1})	Rank	Time to 50% flowering (d)	DM[1] (%)
ICMH 83401	3010	1	51	0.7
ICMH 837129	2910	2	53	-
ICMH 837120	2840	3	51	-
ICMV 83117	2690	7	52	2.7
ICMV 83104	2520	9	52	-
ICMS 8102	2510	11	48	-
Controls				
MBH 110	2780	5	46	0.9
Local	2520	10	50	0.0
WC-C75	2450	14	52	1.4
ICMS 7704	2390	17	56	0.9
SE	±76		±0.3	-
Trial mean (21 entries)	2570		52	-

1. Data on DM incidence from ICRISAT Center Downy Mildew Nursery, rainy season 1985.

Adaptation Trial (IPMAT 10) in 1985 (Table 17).

At ISC, in the 1985 off-season, progenies identified over the last 3 years of evaluation were recombined to form 22 varieties. These were yield tested in two initial trials (PMIVT 1 and 2) at Bengou, ISC, and Maradi in Niger, and at Cinzana in Mali. The highest yields of the test entries at each location ranged from 107 to 112% of the control variety CIVT. From these two trials nine entries were retained for a second evaluation in 1986 (Table 18).

Population Improvement

Breeding methodology. At ICRISAT Center recurrent selection is used to improve composites, and produce a range of genetic products (Fig 14). An S_1 selection method, that takes four crop seasons (2 years) per cycle, and involves multilocational progeny testing is being used to improve all our composites except the Dwarf Composite (D_2C). This Composite is improved by a modified half-sib selection method (1 year per cycle) using phenotypic performance of individual plants as the selection criteria.

The S_1 selection scheme involves deriving progenies by selfing, testing these in a number of environments and nurseries, and selection of superior ones for recombination to produce the next cycle of the composite (Fig. 15). The selected progenies are also used to form varieties, and to derive pollinators of hybrids by selfing the progenies.

At the beginning of each cycle of selection at least 800 S_1 progenies are derived by selfing plants in the composite bulk. A two-stage selection procedure is then used to test the S_1 progenies, beginning with an initial trial of about 1000 progenies in a replicated dry-season nursery. In the following rainy season, the best 400-500 entries from the dry-season nursery are evaluated for yield at three locations in India, and for downy mildew, smut, and rust resistance in the appropriate disease nurseries. From these rainy season trials 50-70 high-yielding, disease-resistant progenies, are selected and recombined to produce the next cycle of the composite. Bulked seeds from selfed plants resistant to downy mildew and smut (obtained from the disease nurseries) are used for this intermating of the selected progenies. From the selected progenies groups of five to nine progenies are further selected on the basis of within-location or across-location performance, and are intermated to produce varieties.

All the selected progenies used to produce the next cycle of the composite are inbred for 4-5 generations to produce lines that are tested as pollinators of hybrids (see section on Breeding Pollinators).

In any cycle, the composite bulk can be mass selected to produce high-yielding, uniform varieties. The top-yielding entry, ICMV-F84400 in the Pearl Millet Advanced Variety Trial, (PM-AVT) 1985 (Table 19) was mass selected from spaced plants of the New Elite Composite (NELC) grown in a physiology experiment.

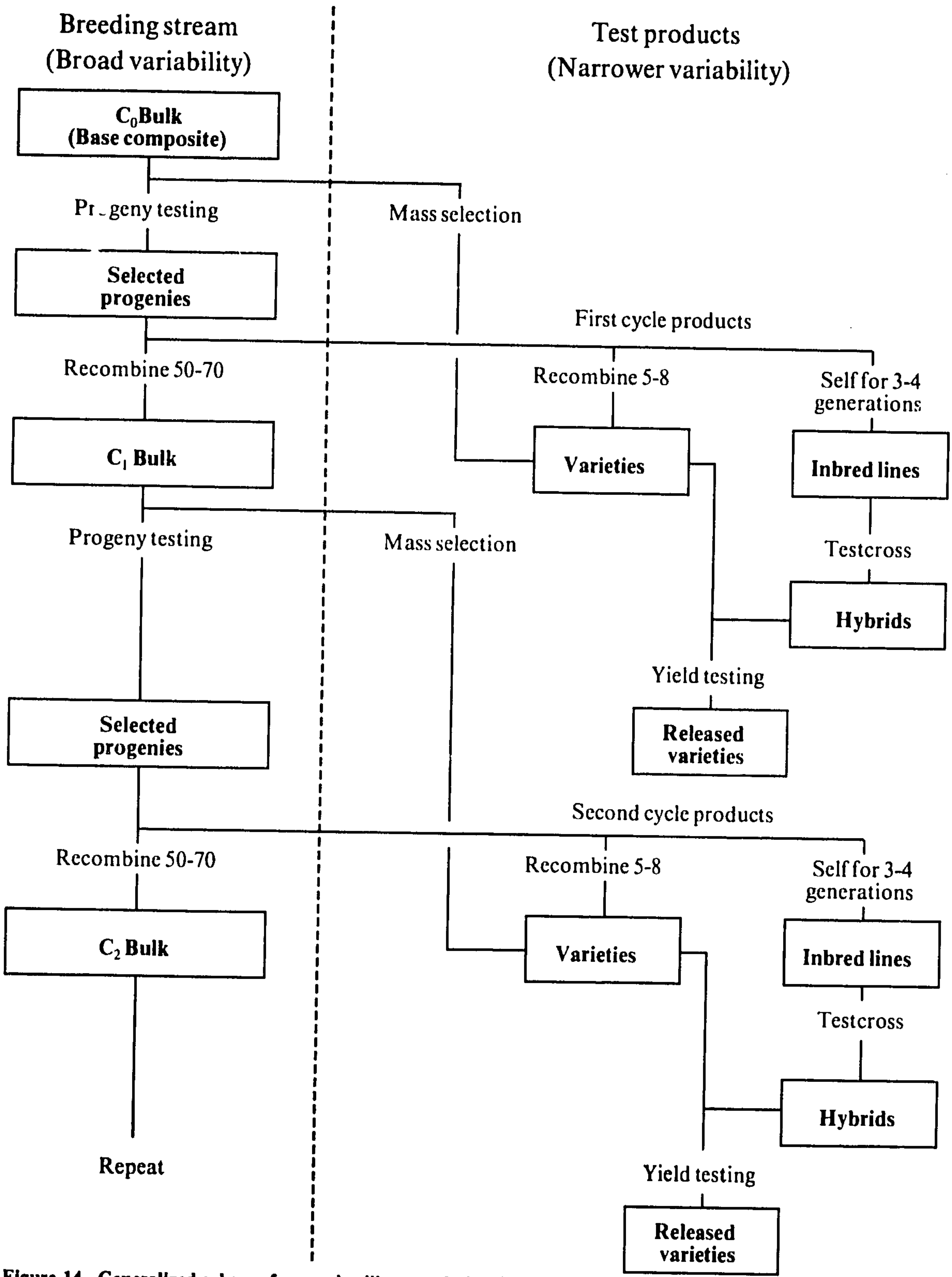


Figure 14. Generalized scheme for pearl millet population improvement.

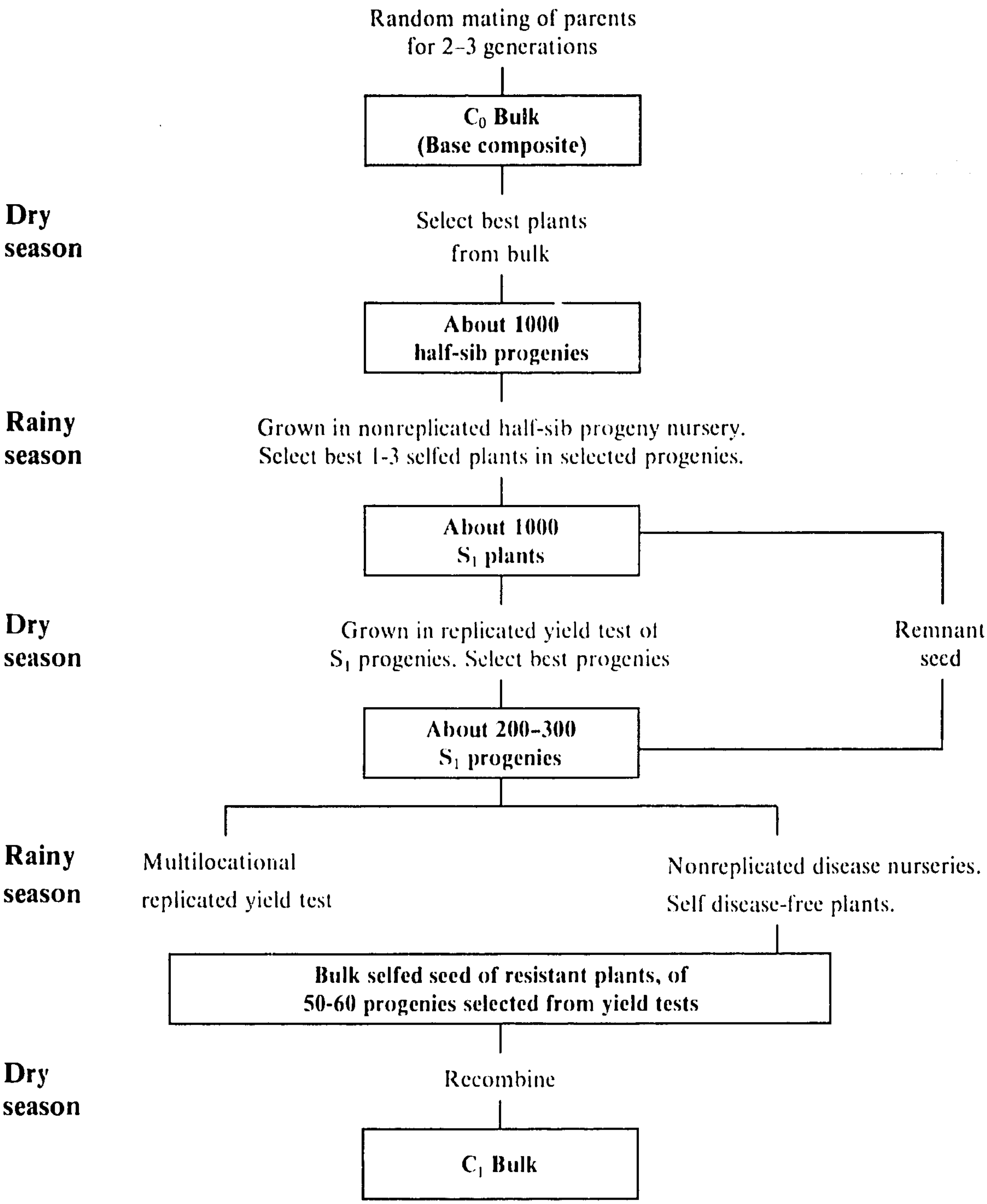


Figure 15. S_1 selection scheme for pearl millet population improvement.

Table 18. Grain yield (kg ha^{-1}) and rank of entries retained for further evaluation from Pearl Millet Initial Variety Trials (PMIVT) 1 and 2, Niger, rainy season 1985.

	Cinzana		Bengou		ISC		Maradi	
Entry	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
PMIVT 1								
ICMV 8506 SC	2340	2	1830	10	2000	2	1470	6
ICMV 8526 SC	1940	9	1970	6	2190	1	1290	13
ICMV 8529 SC	1580	14	1500	16	1900	5	1580	4
ICMV 8532 SC	2320	3	2030	4	1920	4	1380	10
ICMV 8533 SC	2230	6	2340	1	1840	6	1650	3
ICMV 8534 SC	2180	8	1930	7	1670	10	2110	1
Controls								
CIVT	2290	4	2090	2	1950	3	1980	2
Local	1390	17	2010	5	1820	7	1520	5
SE	±203		±130		±163		±295	
Trial mean	1910		1810		1610		1420	
CV(%)	21		14		20		29	
PMIVT 2								
ICMV 8509 SC	2180	2	1810	6	1780	7		
ICMV 8522 SC	2180	3	1730	8	1880	5		
ICMV 8523 SC	2020	7	2000	1	1800	6		
ICMV 8524 SC	2230	1	1510	13	2060	1		
ICMV 8527 SC	2160	4	1480	14	1890	4		
ICMV 8530 SC	2030	6	1860	3	1540	13		
Controls								
CIVT	2050	15	1810	5	1780	8		
Local	1920	16	1880	2	1990	2		
SE	±190		±138		±167			
Trial mean	1930		1680		1740			
CV(%)	20		16		19			

The major advantage of a population-improvement breeding method is that the population can be improved simultaneously for several characteristics. All our composites are subjected to selection for yield, maturity, height, and resistance to downy mildew. Recently, we have introduced selection for resistance to smut in composites other than the Smut Resistant Composite (SRC). Results on screening S_1 progenies from NELC and the Medium Composite (MC) for smut resistance are encouraging. There is a great deal of variability for smut resistance in these composites (Fig. 16), and in only a few cycles of selection we will perhaps be able to make all of our composites resistant to smut. We plan to introduce selection for additional traits in the future, including seedling emergence and early vigor.

Composites and varieties. Intrapopulation recurrent selection is continuing in five pearl millet composite populations: Inter Varietal (IVC), MC, NELC, SRC, and D_2C composites. By the end of the 1985 rainy season, two to seven cycles of selection had been completed in these five composites.

Table 19. Mean performance of selected pearl millet varieties in Pearl Millet Advanced Variety Trial (PMAVT 1) across three Indian locations, rainy season 1985.

Entry	Parental composite	Grain yield kg ha^{-1}	Grain yield Rank	Grain yield % of WC-C75	Time to 50% flowering (d)	Plant height (cm)
ICMV-F84400	NELC	3320	1	124	51	233
ICMV-F84108	NELC	3170	2	119	51	235
All varieties (6)	NELC	2950	-	110	51	232
NELC-C4[1]		2730	27	102	50	234
ICMV-E84425	MC	3140	3	118	49	225
ICMV-E84423	MC	3080	4	115	48	221
All varieties (5)	MC	2920	-	109	48	220
MC-C7[1]		2930	10	110	47	224
ICMV-H84409	SRC	2930	9	110	50	241
All varieties (4)	SRC	2820	-	105	50	237
SRC-C2[1]		2630	40	98	48	230
Control						
WC-C75		2670	35		50	228
SE		±192			±0.7	±4.7
Trial mean (49 entries)		2770			50	228

1. Composite bulk from which the varieties are derived.

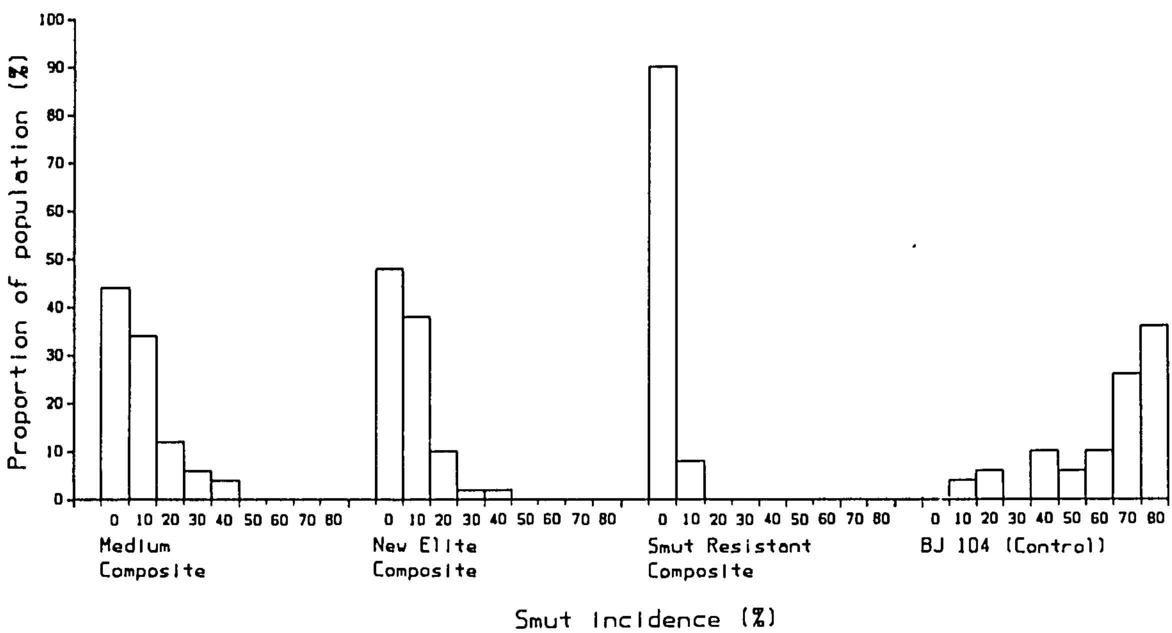


Figure 16. Smut disease incidence (%) in progenies of three advanced pearl millet composites, in comparison to susceptible control BJ 104.

The New Early Composite (NEC), which was not particularly high yielding, was replaced by the Early Composite II (EC II). This was formed by intermating in isolation for three generations, 230 genotypes selected across the entire breeding program that were high-yielding, early-maturing, resistant to downy mildew and, in many cases, to smut. Similarly, an Ergot Resistant Composite (ERC) has been formed by intermating 52 ergot-resistant lines. The first cycle of S_1 selection has started in both of these composites.

About 30 varieties are constituted annually from composites. A gradual improvement in grain yield and in resistance to diseases has been observed in the varieties formed from successive cycles of composites. In the PMAVT, 19 synthetics and 26 varieties from different composites were tested together with four controls. Two varieties from NELC and four from MC were the highest-ranking entries of the trial, with 110-124% of the grain yield of WC-C75 (Table 19). The highest-yielding synthetic ranked eighth in the trial, and gave 110% of WC-C75's yield.

At ISC, we evaluated over 950 S_1 or S_2 progenies derived from gene pools and varieties of the ICRISAT/INRAN cooperative program, and we selected from five varieties 41 progenies as parents to form new varieties.

Of the four varieties constituted on the basis of parental testing in 1984 and evaluated in two initial variety trials in 1985, three (ICMV 8532 SC, ICMV 8533 SC, and ICMV 8534 SC) were retained for reevaluation in 1986 (Table 18). From 407 new crosses, 193 were selected to constitute a broadbased and adapted composite. These selected crosses involved 40 varieties or adapted landraces from the region. The adapted composite, ISC Millet Composite 851, is undergoing its first generation of random mating, and recurrent selection in the composite will start in 1987.

Breeding Male-sterile Lines

The use of male-sterile lines 81A (ICMA 1) and 834A (ICMA 4) has considerably increased in various hybrid-breeding programs in India. In the 1985 AICMIP hybrid trials, there were at least 10 hybrids on 81A, and 3 hybrids on 834A. Both of these male-sterile lines have very high levels of field resistance to downy mildew, they are morphologically very different, and produce hybrids with distinct phenotypic characteristics.

Two additional male-sterile lines (833A and 852A) are likely to find increasing use in hybrid-breeding programs as they also are very highly resistant to downy mildew, and add to the phenotypic diversity of the ICRISAT bred, male-sterile lines. Preliminary tests indicate that 852A is additionally highly resistant to rust. Of these four male-sterile lines, 852A is most sensitive to photoperiod, and hence is likely to be more useful in central and southern India or in locations with a shorter day length. Although ICRISAT Center has contributed eight male-sterile lines so far to AICMIP for evaluation and use, four of them are not likely to be extensively used in India because of their relatively low downy mildew resistance. Male-sterile line 843A, however, is a d_2 dwarf (70-75 cm in height), early-maturing (42 days to 50% flowering), has a 1000-seed mass of 12 g, and produces very early hybrids with reduced height. It is therefore likely to be useful in areas with no endemic downy mildew problem and where early maturity is particularly desirable.

About 200 F_5/F_6 progenies from B×B and B×R crosses have proven to be maintainers of male sterility consistently for two seasons. As expected, the recovery rates of maintainer progenies from B×B crosses was much higher than from B×R crosses. We compared 85 F_5 progenies derived from B×B crosses on 81A, and 68 progenies on 843A. The recovery of maintainers on 81A was 81% as compared to 19% on 843A. In another test, 46 F_4 progenies derived from B×R crosses were tested on 81A, and 34 progenies on 843A. No F_4 progeny produced sterile hybrid offspring, so none were proven maintainers on either of the male steriles. This implies that there is, perhaps, multigenic inheritance of cytoplasmic male sterility. Investigations are underway to examine if 3-way crossing (or backcrossing) with the maintainer parent will improve the recovery rates of maintainer progenies from B×R crosses.

At ISC, 156 A/B pairs from the fourth to eighth backcross generations, from seven genetic backgrounds, are being converted into male-sterile lines. Among 270 pairs generated, we selected 96 and will assess them for uniformity and synchrony in flowering in the dry season of 1986, and for downy mildew susceptibility at Bengou in the next rainy season. By the end of 1986, we hope to have at least one male-sterile line available for use in West Africa. In addition, based on time to 50% flowering (52-65 d), height (100-170 cm), panicle length (30-45 cm), and good tillering, 30 lines were identified from various breeding nurseries for conversion into male-sterile lines. Initial testcrosses to identify maintainers will be made on 81A in the dry season of 1986.

Two scientists from the Institut français de recherche scientifique pour le développement en cooperation (ORSTOM) who are conducting studies on the genetic diversity of wild and cultivated *Pennisetum* species with reference to isozymes and male sterility are presently working at ISC. Their current research involves the transfer of *P. violaceum* cytoplasm into *P. americanum.* Over 250 accessions from the world collection were used to study the geographical distribution of maintainer genes for *P. violaceum* cytoplasm. They also initiated studies on the genetics of sterility and restoration in the A_1 system.

Breeding Pollinators (R lines)

To produce pollinators 174 S_2 progenies of the NELC, MC, NEC, and D_1 (D_1C) Composites were advanced to the S_6 generation using the pedigree bulk method. Using rapid generation advance (three generations a year) these inbred

A geneticist from ORSTOM examining an experimental plot of *Pennisetum* species at ISC, 1985.

lines were produced in less than 2 years. We have also used an equal-seed descent method to advance the generations of these composites, and we are comparing the progenies derived from both methods. The advanced cycle composites are among our highest-yielding populations, so we expect that their derived inbreds will be superior as pollinators. In the downy mildew nursery, in the 1985 rainy season, the S_6 progenies showed high levels of downy mildew resistance, reflecting the characteristics of the parental populations.

The S_6 bulk progenies were crossed onto two male-sterile lines, 81A and 852 A (Table 20). The NELC progenies produced superior hybrids on both lines and 852 A was superior to 81A in combination with these composite progenies. We are now making single cross hybrids on S_7 lines derived from the selected bulk progenies.

The restorer collection has now been increased to 1302 lines that are being selected for improved resistance to downy mildew and improved uniformity. A large number of restorer lines have been distributed to our cooperators (see section on International Trials and Nurseries). The restorers in the collection show a wide range of phenotypic diversity as do our new male-sterile lines; we should therefore be able to identify appropriate restorers for these lines.

Hybrid Testing

The Pearl Millet Advanced Hybrid Trial 1 (PM-AHT 1), consisting of 49 entries, was grown at seven Indian locations. Two hybrids from this trial, ICMH 84122 and ICMH 84913, were selected for promotion to IPMAT or AICMIP trials in 1986 (Table 21). In these two hybrids, the seed parent (81A in both cases) and the pollinators are resistant to downy mildew.

We also tested 44 dwarf hybrids in the Pearl Millet Advanced Hybrid Trial 2 (PMAHT 2). The best dwarf hybrids yielded about the same as the mean of the tall hybrid controls (ICMH 451 and MBH 110).

The top entries in IPMAT (Table 17) are, as in PMAHT 1, based on male-sterile line 81A. In the AICMIP initial trials, two hybrids, ICMH 451 and ICMH 501 have been released by AICMIP. ICMH 451 is based on male-sterile line 81A, and ICMH 501 on male-sterile line 834A.

At ISC we continued preliminary hybrid evaluation for a 2nd year. These trials tested two types of hybrids, inbred × variety, and male-sterile × variety hybrids in an unreplicated test-cross nursery and a preliminary yield trial. In the testcross nursery 5 of the 21 hybrids tested out-yielded the control CIVT (2050 kg ha^{-1}) by 6-58%. In the 24-entry Preliminary Hybrids Trial,

Table 20. Performance of pearl millet hybrids from composite-derived inbreds, ICRISAT Center, rainy season 1985.

	Male-sterile of hybrid					
	81A		852A			
Source composite	Grain yield (kg ha^{-1})	Rank	Grain yield (kg ha^{-1})	Rank	Mean grain yield (kg ha^{-1})	Rank
NELC	1790	1	2620	1	2205	1
D_1C	1710	3	2430	2	2070	2
NEC	1740	2	2270	3	2000	3
MC	1680	4	2100	4	1890	4
SE	±408		±457		±236	
Mean[1]	1730		2330		1890	
CV%[1]	24		20		22	

1. For all entries (including controls).

seven hybrids yielded 110-134% of the trial mean yield, while the control, CIVT, yielded 109% (Table 22). Results of these two tests indicate that hybrids may have a higher yield potential than improved and landrace varieties. Further hybrid combinations using new inbreds and male steriles need to be evaluated.

Yield Physiology Studies

Recent worldwide increases in the production of rice and wheat have been based on varieties with dwarfing genes. The protection against lodging afforded by the reduced height of such varieties allows the profitable use of higher levels of var-

Table 21. Performance of two selected pearl millet hybrids in the Pearl Millet Advanced Hybrids Trial (PMAHT), at seven locations[1] and DM incidence, ICRISAT Center Downy Mildew nursery, rainy season 1985.

Entry	Grain yield (kg ha^{-1}) Mean	Rank	IHF	ILF	BSR	HSR	Jalna	AB	Ludhiana	Time to 50% flowering (d)[2]	Plant height (cm)[2]	DM incidence (%)
ICMH 84122	3220	7	3970	1850	3990	3180	1750	5110	2720	51	189	0.0
ICMH 84913	3140	10	3770	2010	4420	3300	2270	4210	2020	51	185	0.0
Controls												
MBH 110	2930	26	3900	1870	3190	3010	1730	4590	2200	45	188	0.0
ICMS 7704	2580	47	3060	2290	2900	2500	1520	4710	1080	54	220	0.0
WC-C75	2580	46	3650	1760	3230	2870	1990	2700	1870	50	203	3.4
SE	-	-	±299	±276	±312	±218	±295	±508	±325	±1.7	±10.9	-
Trial mean (49 entries)	-	-	3620	2130	3550	3120	1550	4590	2260	50	199	-
CV(%)	-	-	17	26	18	14	33	22	25	-	-	-

1. Locations: IHF = ICRISAT high fertility (80 kg N ha^{-1}); ILF = ICRISAT low fertility (20 kg N, 9 kg P ha^{-1}); BSR = Bhavanisagar; HSR = Hisar; AB = Aurangabad.
2. Mean of all locations.

Table 22. Performance of selected pearl millet hybrids in Preliminary Hybrids Trial, Bengou, Niger, 1985.

Entry	Grain yield kg ha^{-1}	Rank	% of mean	Time to 50% flowering (d)	Plant height (cm)	Panicle length (cm)	DM incidence (%)
3/4 HK-B78 × ITMV 8305	2440	1	134	56	215	39	9
81A × Sadoré Local	2170	2	119	61	219	47	27
3/4 HK-B78 × DG P-1	2140	3	117	59	224	55	7
438 × Zanfarwa	2070	4	114	62	219	56	4
81A × P_3 Kolo	2060	5	113	53	196	40	25
IBMV 8401 × P_3 Kolo	2010	6	111	54	199	56	13
438 × Sadoré Local	2010	7	110	67	243	57	6
Control							
CIVT	1980	8	109	54	213	59	7
SE	±304			±1.9	±15.8	±4.2	±8.6
Trial mean (24 entries)	1820			58	215	50	17
CV(%)	17			3	7	9	50

ious inputs, leading to substantial yield increases. A similar dwarfing gene in pearl millet has been used by plant breeders since the 1960s, but dwarf varieties have never been widely grown by farmers in Africa or on the Indian subcontinent.

Work began in 1976 at ICRISAT to diversify the backgrounds in which the dwarfing gene was available, by creating dwarf versions of seven composites then under improvement (ICRISAT Annual Report 1977/78, p. 68). This was done by mating each composite to a dwarf source and then backcrossing the dwarf segregants thrice to their original composite bulks. The resulting tall (original) and dwarf versions of all seven composites were compared in field trials from 1982 to 1985 to evaluate the effect of the dwarfing gene on yield in a range of genetic backgrounds and environments. These included 2 years of yield trials at both ICRISAT Center and Bhavanisagar, using all seven of the composite pairs. A comparison of response to fertility and plant population/sowing arrangement at ICRISAT Center was then made, using four composite pairs. There was no effect of height class on mean grain yield or yield components in the first set of trials (Table 23), suggesting there were no pleiotropic effects of the dwarfing gene that affects yield ability. There were, however, significant interactions of height class and composite, indicating that the effects of the dwarfing gene were modified by the genetic background. Height × location interactions were small, but height × year interactions were large and approximately equal to the composite × year interactions.

The second trial was affected by drought stress during grain filling, resulting in poorly filled grains in both tall and dwarf version, but the dwarf versions of the composites yielded significantly less grain than the tall versions, as their grains were more poorly filled (Table 24). Grain numbers were not different between the tall and dwarf versions. There were significant interactions of height with both plant population and fertility, due to the tall versions filling grains better in a high-fertility, low plant-population treatment (high grain numbers, but spaced plants).

The potential yield of materials carrying the dwarfing gene is equivalent to that of their tall counterparts, but there is no evidence of any potential yield advantage to the dwarfs (as judged by grain numbers). Yield levels in none of the trials distributed were high enough to be affected by lodging, so the potential advantage of the dwarfs in lodging resistance was not measured. However the interactions of height with year, and the poorer seed filling of the dwarfs

Table 23. Comparison of tall and dwarf versions of seven pearl millet composites in multilocational yield trials, ICRISAT Center, rainy seasons 1982 and 1984; Bhavanisagar, rainy seasons 1983 and 1984.

	Grain yield (g m^{-2})	Grain number ('000 m^{-2})	1000-seed mass (g)
Means			
Tall	260	34.3	7.53
Dwarf	264	35.1	7.48
SE	±4.8	±0.70	±0.074
Significance of effects			
Height	NS	NS	NS
Height × composite	**	***	*
Height × location	NS	NS	*
Height × year (location)	***	***	***

Table 24. Comparison of tall and dwarf versions of four pearl millet composites at two different fertility levels and three plant population/sowing geometry treatments, ICRISAT Center, rainy season 1985.

	Grain yield (g m^{-2})	Grain number ('000 m^{-2})	1000-seed mass (g)
Means			
Tall	183	27.3	6.84
Dwarf	157	27.0	6.08
SE	±4.5	±0.80	±0.082
Significance of effects			
Height	***	NS	***
Height × composite	**	*	*
Height × population	NS	*	***
Height × fertility	NS	NS	**

under stress, raise questions about the yield stability of lines with the d_2 allele.

International Trials and Nurseries

ICRISAT distributes elite breeding materials to cooperators through a broad range of trials and nurseries and meets a large number of requests worldwide for seed of breeding materials, disease-resistance nurseries, etc., of pearl millet. ICRISAT also contributes to national and international yield trials in India and in West Africa, as well as coordinating its own international and regional trials, that are distributed from both ICRISAT Center and ISC.

Yield Trials

IPMAT 10 had 20 entries (7 hybrids, 5 synthetics, and 8 population varieties) and was sent to 26 locations in India, Korea, Niger, Pakistan, Zambia, and Zimbabwe. At 11 Indian locations, the hybrid ICMH 83401 was the top-ranking entry, followed by ICMH 837129, and ICMH 837120 (Table 17). All these hybrids are on male-sterile line 81 A, and are downy mildew resistant. The highest-yielding, open-pollinated varieties were ICMV 83117, derived from the Medium Composite, ICMV 83104, derived from the Inter Varietal Composite, and ICMS 8102.

Fifteen varieties, synthetics and hybrids from ICRISAT were tested in various AICMIP trials of 1984, with WC-C75 as one of the standard controls. ICRISAT varieties continued to perform well (Table 16). The best-performing variety, ICMV 81111, has a clear superiority over WC-C75 for both grain and fodder yield (Fig. 17). The performance of ICRISAT hybrids has improved, with ICH 451 on 81A, and ICMH 501 on 834 A ranking 3rd and 4th with yield levels close to the best entry. We also contributed five restorer lines and six A/B pairs of new male-sterile lines to AICMIP for evaluation.

During the year, the annual ICRISAT Pearl Millet Zone A Trial (IMZAT) for drier zones was conducted across the West African pearl millet growing zone, principally to evaluate the elite products of the ICRISAT cooperative programs in Africa. IMZAT contained 11 entries contributed by African national programs cooperating with ICRISAT; 2 entries from Burkina Faso, 3 from Niger, 3 from Nigeria, 3 from Sudan, and 3 control varieties. Sixteen sets of this trial were sent to nine countries in the region. Presently data are available from eight locations (Table 25). This year rainfall at almost all locations was normal or near normal according to the long-term average data available. The highest mean yield was recorded at Bengou, Niger (2110 kg ha^{-1}) and the lowest at Samaru, Nigeria (966 kg ha^{-1}). Over all locations, entries IKMV 8201, IKMC 1, and ITMV 8304 performed well.

In addition, two ICRISAT/INRAN cooperative trials containing prerelease varieties from Niger were conducted as part of a multilocational evaluation of varieties bred by INRAN and ICRISAT.

Breeding Materials

In 1985, the Uniform Progeny Nursery (UPN 85) was sent on request to 28 cooperators in 7 countries; Cameroon being added for the first time. Our Elite Products Nursery (ELPN 85) was also in great demand, being sent to 20 cooperators in 13 countries. The nursery consists of advanced ICRISAT products (13 open-pollinated varieties and 7 hybrids).

The largest number of seed requests came from cooperators who attended the Pearl Millet Scientists' Day at ICRISAT Center and Bhavanisagar. A total of 2980 requested breeding-material selections, were dispatched to 25 cooperators. This represents a large increase over previous years' requests (Fig. 18). Of these, 913 were from the restorer collection, and were sent to 20 cooperators in India, Pakistan, and southern Africa. From the genetic diversification project, 358 F_6 lines were sent, and 594 B lines from F_5 to F_7 were supplied from the male-sterile project.

Figure 17. ICRISAT-bred variety ICMV 81111, the highest-yielding entry in the 1984 IPMAT and 1985 AICMIP Initial Population Trial.

A further 1476 seed samples, mainly from our trials, nurseries, and our restorer collection, were sent to Zambia and Zimbabwe for the newly established ICRISAT/SADCC millet program.

The annual Pearl Millet Exchange Nursery (PMXN) that contained 19 varieties and 47 progenies contributed by ISC and ICRISAT/National Program cooperative projects in the region, was evaluated at nine locations in seven countries. Seed material of elite breeding lines was exchanged between ISC and five countries in the region.

International Disease Resistance Nurseries

With the help of many cooperators, multilocational nurseries were again conducted for each of the four major diseases of pearl millet. These nurseries include: the 50-entry International Pearl Millet Downy Mildew Nursery (IPMDMN) for which data were obtained from four locations in India and one in Niger; the 32-entry International Pearl Millet Ergot Nursery (IPMEN) for which data were obtained from three locations in India; the 32-entry International

Table 25. Grain yield (kg ha^{-1}) and rank of ICRISAT Pearl Millet African Zone A Trial (IMZAT85) entries at eight West African locations, rainy season 1985.

	Across locations		Maradi		Cinzana		Koporo		ISC		Gaya		Bambey		Nioro		Kamboinsé	
Entry	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
CIVT	2000	1	2320	5	2060	3	1580	1	2350	2	2550	1	1300	7	2200	5	1620	3
ITMV 8304	1910	2	2520	1	2040	4	1450	2	1530	6	2530	2	1530	4	2200	6	1470	7
ITMV 8302	1860	3	2480	3	1990	5	1220	7	1810	5	2110	10	1570	3	2130	9	1540	5
ITMV 8303	1820	5	2510	2	1550	11	1190	8	2010	4	2150	8	1580	2	2180	7	1380	9
IKMV 8201	1810	6	1770	8	1710	8	1440	3	1280	7	2470	3	1180	10	2750	1	1910	2
IKMC 1	1760	7	1950	6	1930	6	1290	6	1200	9	2230	6	1660	1	2330	4	1490	6
INMV 82076	1710	8	1760	9	1570	10	1390	4	1270	8	2070	11	1150	11	2490	2	1970	1
INMV 82068	1630	10	1760	10	1600	9	1360	5	1040	11	2240	5	1380	6	2150	8	1550	4
INMV 82141	1590	11	1560	11	1760	7	1170	9	1190	10	2180	7	1250	8	2370	3	1210	11
IEMV 8503	1350	12	1380	12	1530	12	1010	11	1000	13	1700	12	1190	9	1780	12	1230	10
IEMV 8502	1170	13	1200	14	1400	13	800	14	1020	12	1470	14	1110	12	1330	13	1030	12
IEMV 8501	980	14	1330	13	1040	14	950	12	600	14	1530	13	360	14	1300	14	690	14
Controls																		
Improved	1820	4	2320	4	2190	1	860	13	2070	3	2260	4	1400	5	2050	10	1460	8
Local	1670	9	1810	7	2090	2	1040	10	2590	1	2140	9	1080	13	1910	11	720	13
SE			±146		±206		±164		±226		±151		±205		±174		±132	
Mean	1650		1900		1750		1200		1500		2120		1270		2080		1380	
CV(%)			15		24		28		30		14		32		17		19	

Pearl Millet Smut Nursery (IPMSN) for which data were obtained from two locations in India and one in Niger; and the 50-entry International Pearl Millet Rust Nursery (IPMRN) for which data were obtained from four locations in India.

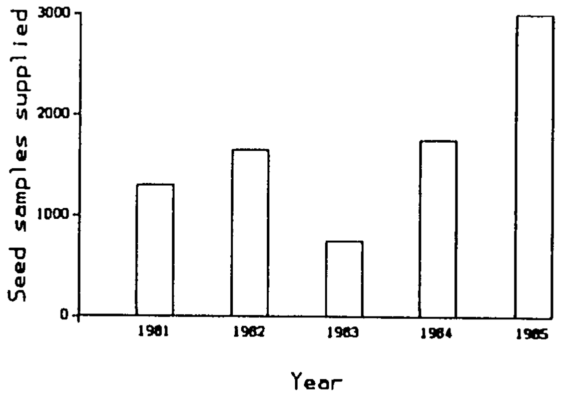


Figure 18. Numbers of seed samples sent to cooperators, resulting from requests made during the Annual Pearl Millet Scientists' Days held at ICRISAT Center, 1981-85.

As usual, each of the 1985 nurseries contained a number of entries that had been included in one or more previous years of testing, and a large number of entries had very low disease incidence at all locations, compared to the susceptible controls.

The purpose of these nurseries is to provide cooperators with an opportunity to evaluate under their own conditions entries believed to be elite sources of resistance, and to test promising materials for their resistance stability. A number of such elite sources of stable resistance to each disease have been found. The nurseries also provide limited information on the aggressiveness/virulence of pathogen populations, but as disease expression is environment-dependent, only indications of qualitative differences can be determined.

The number of locations where ICRISAT's international disease nurseries are grown has declined somewhat in recent years. In 1985, AICMIP began their own disease nurseries at several locations in India, including ICRISAT Center, and ICRISAT contributed many resistant entries to these trials. This new effort in multilocational testing for disease resistance by AICMIP, together with the fact that ICRISAT's many years of international disease nurseries have given little indication of pathogenic variability in the major pathogens, justifies a reduction in the number of disease-nursery sites in India. The extent and reliability of testing in Africa, however, has been much lower, and it is hoped that through the appointments of ICRISAT pathologists in 1985 in West and southern Africa, multilocational disease testing will in future become more extensive and reliable. A start was made with a 20-entry disease nursery sown at 10 locations in southern Africa in December 1985, to help identify the major disease problems of the region and to further expand our knowledge of resistance stability of some entries.

Cooperative Programs

Senegal

The objectives of the ICRISAT/ISRA (Institut Sénégalais de Recherches Agricoles) Cooperative Program are to improve grain yield, grain size, harvest index, resistance to diseases and pests, and the productive tillering ability of millet varieties for Senegal.

On 24 April 1985, the National Seed Service recommended the release of three varieties generated by this Program: IBV 8001 (ICMV 2), IBV 8004 (ICMV 3), and IBMV 8401. IBV 8001 and IBV 8004 were widely grown in the northern zone of Senegal in 1985. There is a plan to grow these two varieties throughout the whole northern zone as they are high yielding and resistant to drought. IBMV 8401 was grown on 2000 ha in the south-central zone in 1985, where farmers appreciated its dwarfness, high-tillering ability, long panicles, disease resistance, good food-quality, and good yields.

Plant Improvement

Inbreds and synthetics. We evaluated 400 inbred lines generated by crossing [illegible] materials with introduced lines in the 1984 and 1985 rainy seasons at Nioro and Bambey, for their useful characteristics before they are turned over to the National Program. During the 1984/85 dry season we made four new synthetics from selected lines but, in general, these inbred lines have not been fully exploited in generating synthetics and hybrids. They should serve as a strong genetic base for the future program.

Hybrids. We retested 23 selected hybrids in 1985 at both Nioro and Bambey, against three controls—IBV 8001, Souna III, and the farmers' local variety. Ten of these hybrids had already been tested for 2 years (1983 and 1984) and the remaining 13 for 1 year.

The highest-yielding hybrid in 1985 was ICMH 8512 SN, which yielded 2700 kg ha^{-1}, 30% more than the best control, IBV 8001, followed by ICMH 8414 SN, ICMH 8510 SN, and ICMH 8413 SN. Based on 3 years' results, the best hybrid is ICMH 8413 SN (81A × IBMI 8207), which produced 30-50% more grain than Souna III in each year. All these hybrids are shorter in height and panicle length than Souna III, but produced more panicles per unit area. The hybrids are highly resistant to downy mildew and moderately resistant to smut. Five hybrids—ICMH 8412 SN, ICMH 8413 SN, ICMH 8418 SN, ICMH 8510 SN, and ICMH 8512 SN—are now ready for evaluation in multilocational trials and farmers' fields to select the most-suitable hybrid for each region.

Synthetic improvement. Three cycles of recurrent selection in two synthetics, IBV 8004 and Souna III, were completed in the 1984/85 dry season. The most important criterion used in the selection was grain yield in IBV 8004, and resistance to downy mildew in Souna III. Final comparisons between the reselected and the original synthetics were made in the 1985 rainy season in trials at Nioro, Bambey, and Louga. Synthetic IBV 8004 C_2 gave the highest grain yield (1920 kg ha^{-1}), followed by Souna III C_3. IBV 8004 C_2 was 14-31% superior in grain yield to the other cycles bulks of IBV 8004 and was 14% superior to Souna III C_3. The germination in the original population (C_0) of Souna III was very poor at all the locations in 1985, and grain yields were low. During 1984, Souna III C_2 yielded 9% more grain than Souna III C_0. During the 1985 test, Souna III C_3 yielded 7% more than Souna III C_2. Downy mildew incidence at Bambey was reduced from 66% to 17% in Souna III in three selection cycles.

We initiated a project in 1984 to improve grain size in IBMV 8401, a dwarf variety, by crossing it with two high-seed-mass lines from Ghana, IP 16151 and IP 16152. We backcrossed 200 selected F_2 plants with large seeds, to IBMV 8401 and reevaluated the 200 BC_1 progenies evaluated at Bambey during 1985. It was possible to select 40 BC_1 progenies with 1000-grain mass greater than 11 g compared to 8.9 g for the recurrent parent. The BC_1 F_2 populations of these 40 BC_1s are now ready to be evaluated in larger plots to select several hundred plants of dwarf stature, and with 1000-grain mass above 11 g that have the panicle length, tillering ability, and disease resistance of IBMV 8401. The selected F_3 progenies can be recombined to form an improved IBMV 8401.

Trials and Nurseries

Synthetic trial. During 1985 we evaluated 16 of the best synthetics from previous yield tests at Nioro and Bambey. In 1984, the two highest-yielding synthetics were IBMV 8403 and IBMV 8406. These did not perform so well during 1985. The highest-yielding synthetic in 1985 was IBMV 8402 (2510 kg ha^{-1}, 18% more than the control variety, IBV 8001, and 36% more than Souna III), followed by IBV 8405, IBV 8501, and IBV 8502.

Regional trials. IMZAT 85, which included two Senegalese controls, IBV 8001 and Souna III, was grown at Nioro and Bambey. The highest-yielding entry was IKMC 1 (2000 kg ha^{-1}, 15% superior to the best control IBV 8001) followed by IKMV 8201, both from Burkina Faso.

In the exchange nursery, all the three top varieties, ICNMV 147, ICNMV 19, and ICNMV 122, were from Nigeria. It seems that the entries bred in this program have potential use in Senegal, either directly as varieties or as parents in the breeding program.

Burkina Faso

The objective of the ICRISAT/Burkina Faso Cooperative Program is to breed varieties for the 500-900 mm rainfall zone, including both photoperiod-sensitive, full-season (120-150 d) varieties that farmers can sow with the early rains, and photoperiod-less-sensitive/insensitive, early-maturing (80-110 d) varieties for late sowing (July) or very early sowing (May) conditions. The major thrust of our research activities is developing full-season, photoperiod-sensitive varieties, since these allow most flexibility in time of sowing.

Plant Improvement

Improvement of IKMP 4. IKMP 4, which was one of the best varieties in the multilocational yield trials, has shown some downy mildew susceptibility in 3 years of screening in the disease nursery at Kamboinsé. A total of 270 selfed progenies made in 1984 were screened in the downy mildew sick field in 1985, and 39 downy mildew free entries were selected to reconstitute the population.

Improvement of RP 1004. We derived synthetic variety RP 1004 by recombining selected progenies from a cross between the late-maturing local cultivar Kapelga (qualitative photoperiod-sensitive type) and GT 85, an early-maturing Iniadi millet introduced from Togo (quantitative, photoperiod-sensitive type). Kapelga has a hairy leaf surface (HLS) and Iniadi a smooth leaf surface (SLS). This cross was notable for transgressive segregation for increased panicle size in a Kapelga background.

Results of various trials showed that RP 1004 reached 50% flowering between 21-27 August for sowing dates that ranged from 12 June to 6 July, suggesting it has a qualitative photoperiod response, despite its earliness. It will be more adapted for general use if the time to 50% flowering can be increased by 10-15 days. Later-flowering plants in RP 1004 generally had a HLS. (Similar results were obtained from a genetic study of a cross between Kapelga and GT 79, suggesting a linkage between genes for HLS and lateness.) Since the leaf-surface type can be readily identified in the seedling stage, we used this characteristic to identify probable late-flowering plants in a nursery during the dry season, from which we selected 1025 seedlings (mostly HLS), which were transplanted and selfed. Progenies of selected HLS plants (247) and SLS plants (79) were evaluated in 1985 along with Kapelga and GT 85. In general, HLS lines tended to be late and SLS lines early. Average time to 50% flowering of the selected (late-flowering) HLS lines was 74 days compared to 64 days for the mean of all progenies. The parent lines required 84 days (Kapelga) and 52 days (GT 85) to 50% flowering. We selected a total of 48 lines on the basis of maturity, agronomic score, and disease ratings. They will be used during the next dry season to make six varieties with different maturities and leaf-surface types, and a composite from the top-performing 23 late, HLS progenies.

Trials and Nurseries

Full-season varieties. The ICRISAT Millet Multilocational Trial 2 (IMMLT 2) evaluated entries of 130-150 days duration. These include reselected landraces, made by recombining progenies selected as agronomically superior and less downy mildew susceptible (CVP series), and populations derived by mass selection. Controls included a local cultivar, an improved variety, and the medium-duration variety IKMP 2. IMMLT 2 was conducted at four locations (Kamboinsé, Saria, Gampela, and Farako-Bâ) in Burkina Faso, and at Bengou in Niger, covering average annual rainfall zones from 750 to 1100 mm. Yield data from Saria were not obtained due to severe infestation with the cantharid beetle (*Psalydollytta* sp) at flowering.

The superiority of IKMP 3 (CVP 417 selections) and IKMP 4 (CVP 480 selections) reported earlier (ICRISAT Annual Report 1984, p. 117) was again evident during the 1985 rainy season, at all locations in Burkina Faso (Table 26). The early control, IKMP 2, also outyielded the local controls at most locations in Burkina Faso, and the improved variety, CIVT, at Bengou. At Kamboinsé, IKMP 4, IKMP 3, and IKMP 2 had less downy mildew than the local control Kapelga. Improved varieties had 0-5% smut infection and no ergot. IKMP 3 will be proposed for on-farm trials in 1986 for normal sowing (early June onwards) in the 700-900 mm rainfall zone.

The second trial of full-season varieties, IMMLT 3, contained entries maturing in 120-130 d when sown at the start of the rainy season. IMMLT 3 was conducted at four locations (Kamboinsé, Saria, Ouahigouya, Aourema) in the 600-800 mm average annual rainfall zone of Burkina Faso. Rainfall in 1985 at Ouahigouya (600-mm zone) was 56% of the long-term average. Trial entries at this location and at nearby Aourema suffered severe drought stress during flowering and grain filling. Grain yield data from these locations could not be statistically analyzed because of extreme field heterogeneity due to drought. However, at Ouahigouya, estimates of the performance of some entries could be obtained on visual observation and consistent performance in all replications. Other locations had near- or above-average rainfall with reasonable distribution.

IKMP 5 (CVP 170 selections) and IKMP 2 were again the best varieties at Ouahigouya and were also among the best entries at Kamboinsé, where the IMMLT 3 trial was grown to evaluate medium-duration varieties for late-June sowing. At Kamboinsé, IKMP 2 yielded 1650 kg ha^{-1}, IKMP 5 yielded 1300 kg ha^{-1}, and the local control yielded 300 kg ha^{-1}. At Ouahigouya, IKMP 2 yielded 340 kg ha^{-1}, IKMP 5 yielded 280

Table 26. Grain yields and mean time to 50% flowering of selected entries in ICRISAT Millet Multilocational Trial 2 (IMMLT 2), Burkina Faso and Niger, rainy season 1985.

Entry	Grain yields (kg ha⁻¹)					Time to 50% flowering (d)
	Kamboinsé I[1]	Kamboinsé II[1]	Gampela	Farako-Bâ	Bengou	
IKMP 4	1190	1100	1810	1920	1270	82
IKMP 3	990	1140	2000	1830	700	85
IKMP 2	2160	890	1220	1010	1830	65
Control[2]	520	550	1490	430	1320	84
SE	±78	±68	±104	±146	±124	
Trial mean (14 entries)	1030	930	1420	1310	930	
CV(%)	18	18	18	27	33	

1. First and second dates of sowing.
2. Local cultivar 'Kapelga' at Kamboinse and Gampela, Farako-Bâ local at Farako-Bâ, and improved variety CIVT at Bengou.

kg ha^{-1}, and the local control yielded 70 kg ha^{-1}. Under the stressed conditions of Ouahigouya and Aourema, IKMP 5 remained green during the reproductive phase in all replications, an indication of its drought tolerance. Both improved varieties also had less than 5% incidence of downy mildew and smut. IKMP 2 and IKMP 5 will be proposed for on-farm trials for normal sowing (mid-June onward) in 500-700 mm rainfall zones. These varieties may also have a place for end-June sowing in the 700-900 mm rainfall zones.

Early-maturing varieties. Trial IMMLT 4, designed to evaluate early-maturing varieties for late-sowing conditions, was grown at Kamboin-

Table 27. Grain yields and mean time to 50% flowering of selected early-maturing varieties and controls in ICRISAT Millet Multilocational Trial 4 (IMMLT 4), Burkina Faso, rainy season 1985.

Entry	Grain yield (kg ha⁻¹)					Time to 50% flowering (d)[3]
	Kamboinsé		Ouahigouya		Aourema	
	2.7.85[1]	7.7.85	1.7.85	10.7.85	1.7.85	
IKMC 1	1090	1760	550	630	200	55
IKMV 8201	1100	1530	530	530	250	53
Controls						
IKMP 5	1900	1290	630	530	350	66
Local cultivar	750	460	90	160	90	-[2]
SE	±67	±100	±45	±47	±32	
Trial mean (10 entries)	1000	1220	430	440	190	
CV (%)	16	20	25	26	41	

1. Sowing date.
2. Less than 50% flowering at Ouahigouya and Aourema due to drought stress.
3. Mean of all locations.

sé, Aourema, and Ouahigouya. The results confirmed the superior performance of IKMV 8201 (Table 27), now in its 4th year of trial. IKMV 8201 was also grown in on-farm trials by the Regional Development Office in Ouahigouya, with encouraging results. IKMC 1 performed well for the 2nd year. Medium-duration entry IKMP 5, included as a control, was the highest-yielding entry in the trial.

Striga Control

A 3-year study of the effectiveness of hand pulling *Striga hermonthica* plants was initiated in Aourema village in 1983. We selected 10 m × 20 m plots at random in each of nine village millet fields infested with *Striga*. In half of each plot, *Striga* plants were counted (Fig. 19) and removed 10 days before they shed seed (*Striga*-removal treatments). In the other half, *Striga* plants were counted but not removed (control). Millet panicles were harvested and weighed in each treatment at maturity. The treatments were continued in the same plots in 1984 and 1985.

Mean *Striga* plant numbers were similar in 1983 in both treatments, but declined in the removal treatment to 35% of the number in the control in the 2 subsequent years (Table 28). Panicle yields in 1983 were 30% higher in the removal treatments than in the control in 1983 and increased to 67 and 107% in the 2 subsequent years. (The difference in 1983 is unlikely to be due to the *Striga* removal, as this was done late in the season; but the differences in 1984 and 1985 are consistent with the greatly reduced *Striga* infestation). The response in crop yield in 1984 and 1985 was both statistically and agronomically significant (Table 28).

Based on these results, the control of *Striga* by hand-pulling *Striga* plants before they produce

Figure 19. Counting *Striga* plants in experimental pearl millet plots, Aourema village, Burkina Faso, 1985.

Table 28. *Striga* incidence and panicle yields of pearl millet in nine farmers' fields with and without removal of *Striga* plants. Aourema village, Burkina Faso, 1983-1985.

	Striga incidence (plants 100 m^{-2})			Panicle yield (kg 100 m^{-2})		
	1983	1984	1985	1983	1984	1985
Treatment means[1]						
Removal (R)	3575	335	258	7.2	9.5	8.9
Control (C)	3195	964	735	5.5	5.7	4.3
R/C (%)	112	35	35	130	167	207
Treatment differences (R-C)						
Mean[2]	+0.18	-1.15	-0.59	+1.65	+3.75	+4.58
SE[2]	±0.094	±1.73	±0.95	±0.53	±0.505	±0.662

1. Removal (R) = *Striga* plants removed before seed maturity; Control (C) = *Striga* plants not removed.
2. In transformed data.

seed deserves further agronomic and economic evaluation. As it was done only once during the season, and at a time when labor supply is not limiting, the doubling of millet yields achieved in the 3rd year may make the practice economically attractive, even though it does not eradicate *Striga* from the fields.

Niger

The main objective of the ICRISAT/Niger Cooperative Program is to provide genetically broadbased varieties, populations, and breeding materials with higher yield potential, better yield stability, and resistance to biotic stresses, to the national program of Niger and other West African programs. The ICRISAT/Institut Nationale de Recherche Agronomique du Niger (INRAN) cooperative program has made a substantial contribution to the Niger national pearl millet improvement program. We have constituted 5 broadbased gene pools and have derived 10 varieties from them. It is hoped that these diverse gene pools will be used by the national program for further development of new varieties. In addition, a wide range of desirable genetic materials, at various levels of inbreeding, has been made available to the Niger national program and the ISC. Appropriate use of this material will greatly aid these programs in the development of stable and high-yielding varieties.

Three ICRISAT/Niger varieties, ITMV 8001 (ICMV 5), ITMV 8002 (ICMV 6), and ITMV 8304 (ICMV 7) bred in cooperation with the INRAN research station at Maradi were released to farmers in Niger in 1985. Following their excellent performance in the multilocational trials coordinated by the Institut du Sahel, varieties ITMV 8001 and ITMV 8003 are also being extended to farmers in other countries in the Sahelian Zone.

Plant Improvement

Pedigree breeding. In order to provide the Niger national program with genotypes having characteristics complementary to those of the local landraces, we have generated a large number of progenies and segregating populations originating from crosses between landraces from Niger and exotic lines with desirable characteristics, such as higher harvest index and shorter plant height. Many desirable segregants have resulted from these crosses. We are maintaining these with the Niger national program as a base of new but adapted breeding material. This base includes the working collection (297 lines), uniform (F_8) progenies from Niger × exotic crosses (58 lines), source material F_4s (68 lines), and F_5, F_6, and BC_1F_5 progenies from African × exotic crosses (176 lines). The important characteristics of this material have been cataloged, and seed has been stored in the seed store at the INRAN research station, Maradi. This material, mostly inbred lines, can be used as parental material to breed hybrids and synthetics. A duplicate set of all these materials has been sent to ISC.

Population improvement. In a project started in 1979 and completed in 1984, we formed five gene pools to maintain desirable variability and avoid inbreeding: African long-headed (named INMG 1), Indian D_1 (INMG 2), tall segregants from D_2 dwarf populations (INMG 3), bristled head (INMG 4) and thick head (INMG 5). The gene pools were formed by random mating genotypes of similar panicle length and maturity, that originated in similar agroclimatic zones across countries in Africa and in India. Two varieties were derived from each of these gene pools (Table 29) by mass selection in the advanced random mating cycles. These varieties have performed well in various national and regional trials. A trial to compare the base gene pools and the varieties derived from them was conducted at Maradi and ISC in 1985. Overall, the derived varieties yielded 4% better than the parent gene pools, with those from INMG 1 and 3 outyielding the parental pool by 15% (Table 29).

Breeder seed of all these gene pools and their associated varieties was produced during both the dry and rainy seasons and is maintained at the INRAN station at Maradi and at ISC, for distribution and future use. Seed of the gene

Table 29. Comparison of pearl millet basic gene pools and varieties derived from them. Means of trials at Maradi, and ISC, Niger, rainy season 1985.

	Grain yield (kg ha-1)	% of parental gene pool	Time to 50% flowering (d)	Panicle length (cm)	Panicle number[1] ('000 ha-1)
INMG 1	1560	-	61	46	42.3
ITMV 8001	1760	113	61	54	44.9
ITMV 8002	1780	115	60	41	45.8
INMG 2	1520	-	62	45	42.7
ITMV 8003	1650	108	59	44	43.5
ITMV 8302	1600	105	60	45	45.0
INMG 3	1570	-	63	47	40.6
ITMV 8303	1740	111	61	45	49.2
ITMV 8004	1870	119	60	54	48.0
INMG 4	1670	-	60	50	47.8
ITMV 8301	1470	88	60	49	36.2
ITMV 8306	1680	101	60	52	46.3
INMG 5	1690	-	62	40	51.8
ITMV 8304	1570	90	60	36	42.9
ITMV 8305	1470	87	61	36	47.0
SE	±170	-	±0.8	±1.3	±7.4
Mean	1640	-	61	47	45.1
CV (%)	11	-	1.3	2.8	17

1. Recorded at ISC only.

pools and the varieties developed by the ICRISAT/Niger project has been requested by national programs in West Africa and in India.

Trials and Nurseries

Two ICRISAT/INRAN cooperative trials were conducted during 1985: one at locations in the northern zone of Niger (annual rainfall <400 mm) and the second in the southern zone (rainfall >400 mm). The northern zone trial, which contained four promising varieties from INRAN and five from the ICRISAT/Niger cooperative program, was grown at seven locations (Table 30). Varieties ITMV 8003, ITMV 8002, and ITMV 8304 contributed by our program were the best entries in this trial, yielding 13-15% more grain than the control HKP, a released variety in Niger.

The southern zone trial, which contained six test entries from INRAN and five from ICRISAT, was grown at five locations. An INRAN variety, DG-P1, was top-ranked, followed by ITMV 8001 and ITMV 8301 (Table 30). ITMV 8001 maintained its superiority over the control CIVT.

In IMZAT 85 the grain yield of the ICRISAT/Niger variety ITMV 8304 was the highest of all the entries at Maradi, yielding 38% more than the control, a local variety.

Nigeria

The 1985 cropping season marked the completion of the ICRISAT/Institute of Agricultural Research (IAR) cooperative millet breeding program at Samaru. Emphasis was placed, therefore, on multiplication of breeder seed of the most advanced of the improved selections developed in the program. We also conducted two multilocation?[1] Advanced Millet Yield Trials (AMYT 1 85 and AMYT 2 85) and IMZAT 85 jointly with the IAR.

Plant Improvement

Ten of the most promising improved varieties have been compared for grain yield with two improved control varieties, Nigerian Composite and Ex-Bornu, for 4-5 years at Samaru and Kano (Table 31). Samaru is in the Northern Guinea bioclimatic zone and represents the wetter millet-growing areas (800-1200 mm annual rainfall). Kano represents the drier millet-growing areas (600-800 mm annual rainfall) of the Sudanian zone. Of a total of 85 comparisons, the yield of the INNV entries exceeded the yield of the control variety by a statistically ($P < 0.05$)

Table 31. Summary comparison of grain yields of best ICRISAT Nigerian millet varieties with controls at Samaru, 1981-1985, and Kano, 1981-1984.

Variety	Performance of INMV relative to control[1] Greater[2]	Equal	Less
INMV 2	1	8	0
INMV 6	3	5	0
INMV 10	3	4	1
INMV 12	3	4	1
INMV 20	3	4	2
INMV 36	2	5	2
INMV 37	3	4	0
INMV 40	3	5	1
INMV 42	3	6	0
INMV 55	2	6	1
Total	26	51	8

1. Statistical ($P < 0.05$) comparison of INMV entry and control variety.
2. Nigerian Composite in 1981, 1982, and 1984 and Ex-Bornu in 1983 and 1985.

Table 30. Three top-ranking pearl millet varieties at each location in ICRISAT/INRAN cooperative trials, Niger, rainy season 1985.

Location	Rank of entries 1	2	3	Trial yield range (kg ha^{-1})
North Zone Trial				
Magaria	HKB-Tif[1]	ITMV 8304[1]	ITMV 8003	1120-1720
Maradi	ITMV 8002	HKB-Tif	Ank. PI	1770-2560
Konni	ITMV 8002	ITMV 8303	ITMV 8304	960-1340
ISC	ITMV 8304	ITMV 8002	Ank. PI	1360-1850
Chikal	ITMV 8003	ITMV 8002	HKB-Tif	550-830
Ouallam	HKP 3	Moro PI	ITMV 8304	730-1030
Tillabery	ITMV 8003	ITMV 8304	HKP 3	1090-1780
Mean	ITMV 8003	ITMV 8002	ITMV 8304	
South Zone Trial				
Magaria	DG-PI	ITMV 8001	ITMV 8305	1150-1980
Maradi	ITMV 8302	ITMV 8001	DG-PI	1550-2160
Bengou	ITMV 8001	ITMV 8305	ITMV 8004	1040-1480
ISC	DG-PI	HKB-PI	ITMV 8305	1230-1850
Kolo	ITMV 8301	CIVT	ITMV 8001	1060-1550
Mean	DG-PI	ITMV 8001	ITMV 8301	

1. ITMV series bred by the ICRISAT/Niger Cooperative Program and others by INRAN.

significant amount 26 times, equalled the control variety 51 times and yielded less 8 times. Breeder seed of each of these varieties was multiplied and made available to the IAR who will continue to evaluate these varieties in multilocational trials.

Other promising selections over the period 1981-85 included the INMV series numbers 4, 9, 23, 32, 43, 46, 47, 49, 62, and 68. Seed of each of these varieties along with that of 45 others was multiplied and supplied to the Nigerian national program, ISC, and the ICRISAT/SADCC project based in Zimbabwe.

Yield Trials and Nurseries

Two ICRISAT/IAR trials (AMYT 1 85 and AMYT 2 85) were conducted with the national program at six locations within Nigeria. Only data from the Samaru location were available for this report. Four of the INMV selections: INMV 40, INMV 42, INMV 55, and INMV 36, significantly ($P > 0.05$) outyielded Ex-Bornu, the improved control variety.

We hope that a number of new selections will receive consideration from the national program as possible alternate varieties to the Nigerian Composite and Ex-Bornu. Most of the new ICRISAT varieties have the advantages of earlier maturity, shorter plant height, and more productive tillering than the current improved varieties.

Sudan

Rainfall during 1985 was higher than in 1984 in most of the pearl millet growing areas in Sudan. In 1985, pearl millet was grown over an esti- 1.58 million ha in Sudan, an increase of 20% over 1984. Total millet production this year was 472 000 tonnes, about thrice that in 1984. The national average grain yield of 300 kg ha^{-1} in 1985 was also the highest in the last 3 years.

The ICRISAT/Sudan Cooperative Program seeks to breed new genotypes with high grain yield potential and improved stability, which are responsive to moderate fertilizer application, and have resistances to drought stress, diseases, insects, and birds. We continue to emphasize on early-maturing lines (75 days to maturity) with compact, bristled panicles, and good grain quality.

Breeding work was carried out at Kaba, and the Western Sudan Agricultural Research Project (WSARP) farm, both at El Obeid. Multilocational yield trials were also grown at Kadugli and Nyertete.

Plant Improvement

Inbreds and synthetics. We crossed 130 inbreds developed in this program between 1977 and 1984, with the local variety Kordofani, the improved variety Ugandi, and the Bristled Population, to generate new breeding lines in more-adapted backgrounds. A total of 274 new crosses were made and will be advanced in the dry-season nursery 1985/86.

Of 159 new crosses made in 1984, 6 F_1s showed high degrees of heterosis and were selected for generation advance to derive synthetic parents. F_2 populations of these will be evaluated in 1986. We identified 70 plants representing 38 crosses from 152 F_2 populations for pedigree selection. We made 192 individual plant selections from 130 of a total of 918 segregating progenies (F_3 and F_4 generations) for further evaluation as progeny rows. Six lines that were found uniform, productive, and agronomically acceptable, were selected for use in national trials and the exchange nursery.

Hybrids. Eight male-sterile lines along with their maintainers were grown for maintenance and use as seed parents in new test crosses. We evaluated 63 hybrids, and selected 6 for further evaluation. Selections of male-sterile Ex-Bornu were found to be good combiners.

Population improvement. We continued to improve the Bristled Population for grain yield, panicle compactness, phenotypic uniformity, and grain quality. Approximately 1000 S_2s were made in Bristled Population-A (BP-A) and 543 in the Bristled Population-B (BP-B), in the dry-season nursery of 1984/85, and evaluated in the rainy season at Kaba and the WSARP farm. Single plants from 32 S_1 progenies of BP-A and 6 plants from 4 S_1 lines of BP-B were selected for recombination to complete the first cycle of recurrent selection in both populations. The mean panicle yield of selected progenies of BP-A was 2080 kg ha^{-1} at Kaba and 1080 kg ha^{-1} at the WSARP farm.

Germplasm evaluation. We planted 1005 accessions at two locations—Wad Medani (irrigated) and Nyertete (rainfed)—to record data on physiomorphologic characteristics. All the accessions are being classified on the basis of plant, panicle, and grain characteristics.

Figure 20. Seed-multiplication field of the ICRISAT-bred variety Ugandi, Sudan, 1985.

Trials and Nurseries

National trials. Two Pearl Millet National Trials (PMNT 9A and PMNT 9B) were conducted in four sites in 1985. In PMNT 9A, Ugandi was the highest-yielding entry at the Kaba and Nyertete locations, and the BP-A ranked first at Kadugli. Ugandi, with a mean yield of 1190 kg ha^{-1}, outyielded the best control, Bayuuda, by a 31% margin at Nyertete, while the BP-A yielded 47% more than the control variety, Kordofani, at Kadugli. In PMNT 9B, only ICMV 82111 was retained for reevaluation.

On-farm trials. We conducted trials using Ugandi, BP-A and various local varieties in 30 farmers' fields in North Kordofan Province in association with USAID Title XII Collaborative Research Support Program on Sorghum and Millets (INTSORMIL). Ugandi was earliest to flower and mature at all sites, and yielded 20% more (584 kg ha^{-1}) than the best control, Bayuuda (486 kg ha^{-1}). The BP-A was superior to Ugandi for panicle length and compactness. Seed of Ugandi was multiplied by a private seed company on 20 ha for the Ministry of Agriculture, North Kordofan, and should be available to farmers in 1986 (Fig. 20).

Regional trials and nurseries. Three population varieties were contributed by the ICRISAT Sudan program to IMZAT 85 and six new lines to the exchange nursery. At the Sudanian location of IMZAT 85, Ugandi and ITMV 8304 were rated most-promising. Varieties from Nigeria in the exchange nursery performed well at the WSARP farm, and three, ICNMV 147, ICNMV 212, and ICNMV 22, were selected for use in our program. We selected single plants from seven inbred lines from the exchange nursery. Three entries in the *Striga* Observation Nursery, 84 W181, 84 W684, and 84 W688, were agronomically good and selected for future use, although the incidence of *Striga* was very low.

International trials and nurseries. One international trial (PMAST 84) and a uniform progeny nursery (UPN 84) were sown in 1985. Two synthetics, ICMS 8265 and ICMS 8247, were rated better than Ugandi.

Southern Africa

A full-time pearl millet breeder joined the SADCC Regional Sorghum and Millet Improvement

Project based in Zimbabwe in November 1985, in time for the 1985/86 rainy season. His main assignment will be to breed a wide range of materials for use by national programs in the region, and to encourage regional cooperation in the breeding of improved pearl millet varieties for the nine countries which form the Southern African Development Coordination Council (SADCC). The assembly and initial evaluation of genetic variability for this effort began in the 1984/85 season, so crossing and selection could begin immediately.

Germplasm Evaluation

Pearl millet germplasm collected from Zimbabwe was evaluated at Gwebi, Aiselby, and Matopos, in collaboration with Food and Agriculture Organization of the United Nations/International Board for Plant Genetic Resources (FAO/IBPGR). Most of the accessions were very tall (3 m), flowered in approximately 70 days, and produced medium-sized panicles. Agronomically superior lines with good adaptation to SADCC conditions were selected for further testing and crossing with exotic material.

Nearly 650 pearl millet accessions from six SADCC countries and 720 accessions from the ICRISAT Genetic Resources Unit (GRU) working collection, representing 27 countries, were evaluated at Sebele, Botswana (Fig. 21); Ngabu, Malawi; Hombolo, Tanzania; and Kaoma and Longe, Zambia. Crop growth at Aiselby, Ngabu, and Gwebi was very good and differences in plant height, panicle length, and other characters were evident. At Ngabu, the Maiwa accessions produced panicles >100-cm long. Crop growth was poorer at Kaoma, Longe, and Hambolo, and the differences between accessions were not clear. Because of severe drought at Sebele, only the early accessions flowered and produced grain.

Among the SADCC countries, accessions collected from Botswana are the earliest, followed by those from Malawi. Accessions from Zambia, Zimbabwe, and Mozambique are late maturing, while those from Tanzania, the highlands of Malawi, and Zambia are photoperiod-sensitive. Based on their agronomic performance, height, and maturity class, we selected accessions to enter the base composites for the breeding program.

Plant Improvement

Based on the evaluations in the 1984/85 nurseries, we selected 456 lines and accessions to generate four composites:

Early—less than 100 days to maturity (184 entries)
Medium—100-125 days to maturity (174 entries)
Dwarf—plant height 120-165 cm (39 entries)
Bristled—panicles with long bristles (63 entries)

Figure 21. Scientists evaluating genetic resources accessions from 25 countries for possible use in breeding programs in the SADCC region, Sebele near Gaborone, Botswana, 1985.

The constituent lines of these four composites were sown at Mzarabani in April and August 1985, for the first and second generations of random mating, and at the Aiselby farm near Bulawayo in December 1985, for the third generation of random mating. These populations will be random mated for another generation before we start recurrent selection in the 1986/87 season.

Breeding Trials and Nurseries

During the 1984/85 rainy season, 12 yield trials and observation nurseries were sown at seven locations in five countries: Botswana, Malawi, Tanzania, Zambia, and Zimbabwe (ICRISAT Annual Report 1984, pp. 123-124). These trials and nurseries, provided by pearl millet breeders around the world, were grown to select a broad genetic base for the breeding program to begin in 1985/86. Crop growth was satisfactory at Ngabu, Malawi, and at the three locations in Zimbabwe (Gwebi, Matopos, and Aiselby). The crop suffered from drought at Sebele, Botswana; Kaoma, Zambia; and Hambolo, Tanzania.

Varieties from West African countries were medium maturing, tall, and had long panicles. Entries from India were generally early maturing (< 90 days), medium tall, and had small panicles. The material from eastern Africa was early maturing and had bold grains, while lines from the USA were short-statured, with small panicles, and many tillers. It is expected that the diversity in the introduction nursery will be of significant value to subsequent crop-improvement activities. Selections for various purposes were made jointly by scientists from the national programs, and regional programs, and from ICRISAT Center.

Selected varieties and inbreds from the 1984/85 rainy-season trials and nurseries, plus 1131 newly introduced lines and varieties (synthetics, hybrids, male-sterile lines, pollinators, and inbreds for specific traits) were grouped into 18 trials and nurseries for 1985/86. These trials and nurseries were sent to the same countries participating in the 1984/85 evaluation program.

Training

Two students from the Institut Pratique de Développement Rural (IPDR) at Kolo worked with pearl millet scientists at ISC from June to September on the influence of seed treatment on the germination and growth of millet, and the effects of agronomic and cultural practices on infestation by the major insect pests of millet and cowpea. Two trainees from ISC came to ICRISAT Center to participate in the in-service training course. In Burkina Faso four students preparing for their Ingénieur Agronome degrees worked with ICRISAT scientists on problems relating to *Striga* resistance.

Millet scientists from several disciplines were involved in programs for participants in the 8-month in-service training course at ICRISAT Center. In addition three trainees worked for longer periods during 1985, in millet breeding a research scholar worked on population selection studies, a research scholar in pathology worked on smut biology and resistance studies, and an international intern in physiology on relationships between development and growth in millet. A millet pathologist from the national program in Senegal spent two months with the pathologists studying screening techniques and biology of millet pathogens.

Workshops, Conferences, and Seminars

West African Regional Travelling Workshop on Pearl Millet

ISC hosted this Workshop from 11-17 September. The objectives of this annual workshop were to bring together pearl millet scientists from West Africa, to visit national and regional programs in the region, and to discuss important research topics. There were visits to the national pearl millet improvement program in Mali, ISC, and the INRAN Station at Kolo, Niger. Participants included 28 millet scientists from Burkina

Faso, Cameroon, Chad, Gambia, Ghana, Ivory Coast, Mali, Mauritania, Niger, Nigeria, and Senegal, as well as scientists from ISC and ICRISAT Center.

Sessions in the workshop focused on both basic and applied research on pearl millet. Participants expressed a need for further agroclimatological analyses to define drought probabilities for locations in the region, for information on experimental designs and methods to overcome problems of field heterogeneity, and for research to determine isolation distances for varietal multiplication. Participants also expressed satisfaction over the action taken by ICRISAT on the recommendations of the first Regional Workshop held in 1984.

Fourth Regional Workshop of the Eastern Africa Sorghum and Millet Improvement Network

This workshop was held at Soroti, Uganda, 22-26 July 1985. Of the 45 participants, 24 were from the host country, and others came from Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and the People's Democratic Republic of Yemen. Invited participants from outside the region came from Burkina Faso, India, UK, and USA. As in the past regional workshops, almost all the participants were active workers in sorghum and millet research. Of the 40 papers presented in the workshop, 20 dealt with different aspects of sorghum and millet research in Uganda. Fourteen papers covering the sorghum and millet work in the other eastern African countries were presented by national representatives. Invited speakers covered topics of special interest to the eastern Africa sorghum and millet workers, such as a retrospective review of the Serere sorghum and millet work, problems and methods of pearl millet breeding, sorghum nutrition and utilization, sorghum disease control, *Quelea* control strategies, stem borers, and intercropping.

In addition to paper presentations and discussions, participants visited the facilities and field work of the Serere Research Station, selected district variety trial centers, and seed-multiplication fields.

The main recommendations of the workshop were: other disciplines besides breeding/agronomy should be encouraged to participate fully in future regional workshops; initiatives should be taken to assemble and document the traditional knowledge on sorghum and millet use in eastern Africa; at the next workshop, invited speakers should cover *Striga*, sorghum entomology, and drought resistance; and the major thrust of the expansion of the eastern Africa sorghum and millet regional program should focus on strengthening the national programs of the region. The proceedings of this meeting are available from the SAFGRAD/ICRISAT Regional Office, Nairobi, Kenya. The Fifth Regional Workshop will be held in Burundi in July 1986.

ICRISAT Center Millet Scientists' Day

A pearl millet scientists' day was organized at ICRISAT Center during the 2nd week of September. Thirty-five scientists attended, including 26 from the Indian national program, 7 from private seed companies in India, and 2 from southern Africa. Ten ICRISAT trainees from various African countries also participated. This

An ICRISAT pearl millet breeder compares the panicle lengths of ICMH 501 and MBH 110 for the benefit of visiting scientists from Zambia and Zimbabwe during the ICRISAT Center Millet Scientists' Day, 1985.

was the first time that African scientists have participated in pearl millet scientists' days at the Center. The 2-day program included visits to the fields where research in breeding, pathology, physiology, and microbiology was in progress. The Genetic Resources Unit also organized visits to its fields where new and existing accessions were being evaluated and multiplied. Participants were invited to select materials from all the fields they were shown, resulting in a large number of requests for seed (see International Trials and Nurseries section). The program concluded with a discussion on ways of evaluating possible seed production problems with new hybrids under consideration for release by AICMIP.

ICRISAT/SADCC Regional Workshop

An ICRISAT/SADCC workshop took place from 21-27 September, at Gaborone, Botswana. This was the second such workshop; it brought together more than 30 scientists, working on sorghum and millet improvement in the SADCC region, to discuss their programs. There were participants from Botswana, Lesotho, Malawi, Tanzania, Zambia, and Zimbabwe, as well as scientists from ICRISAT Center and from the International Development Research Centre (IDRC), Canada.

The meeting featured reports by scientists from each country on results of both national and regional trials, including selected trials supplied from ICRISAT Center. Varieties originating from ICRISAT are in advanced tests in Zambia and Zimbabwe, and WC-C75 is in a prerelease stage in Zambia.

Looking Ahead

Physiology. We will begin to shift the work on selection for drought resistance from the status of an experimental project to a part of the regular ICRISAT Center breeding program, with an emphasis on selection for the ability to set and fill grain in a terminal drought situation.

The field technique to screen for seedling survival at the ISC will be further refined to increase screening precision and will be routinely used on promising breeding materials. We plan additional work on the infrared-lamp technique for seedling heat tolerance at both the ICRISAT Center and ISC, and will initiate selection for seedling heat tolerance in breeding materials.

Research on the consequences of the dwarfing character on growth, yield, and environmental response of pearl millet will continue, with experiments on reduced height and grain yield in hybrids, on the role of the modifier genes for height, and on interactions of height and drought stress.

Research on the consequences of time to flowering on growth and yield processes should be completed in 1986, and we will continue our studies on the genetics of photoperiod response and the predictability of time to flowering in hybrids from parental data.

Pathology. Studies on the pathogenic variability among populations of downy mildew and smut pathogens are in progress and will continue. We will initiate studies on the mechanisms of resistance for rust and continue those on downy mildew and ergot. Selected pearl millet lines will be used to study host variability to support production of oospores and sporangia of the downy mildew fungus in diseased tissue. Field measurements of environmental factors affecting the epidemiology of downy mildew will be made at ICRISAT Center and ISC in an effort to increase the reliability and efficiency of screening for resistance to this disease in the field. Studies on the biology and epidemiology of rust will continue.

Screening breeding materials for resistance to downy mildew, smut, ergot, and rust will continue at ICRISAT Center, as will screening for resistance to downy mildew and smut at ISC. In collaboration with breeders at ICRISAT Center, efforts will continue to transfer resistance to downy mildew, ergot, smut, and rust into specific breeding materials, as will our studies on the resistance heritability to these diseases.

Research efforts at ISC will be intensified to establish effective and reliable disease nurseries for resistance screening of breeding materials. Preliminary trials with a limited number of genotypes will be conducted to evaluate the degree of available resistance to *Striga hermonthica*. Collaborative linkages initiated in 1985 with several West African countries will continue, with the objective of establishing cooperative research projects in the future.

Entomology. Priority will be given to the development of appropriate diets for mass rearing the stem borer (*Acigona ignefusalis*) and the earhead caterpillar (*Raghuva albipunctella*); so that we can artificially infest plants in the field for varietal resistance screening. Survey studies initiated in 1985 for parasites and predators of both these pests will continue in collaboration with the Commonwealth Institute of Biological Control. Our studies on diapausing populations of *R. albipunctella* will also continue.

Microbiology. Inoculation trials with nitrogen-fixing bacteria will be continued under both greenhouse and field conditions. Since we have been able to standardize the ELISA technique in the laboratory, we will attempt to use this technique in pot and field experiments to study the persistence of inoculated, nitrogen-fixing bacteria.

We will continue selecting for efficient nitrogen-fixing associations between plant genotypes and bacterial strains in the laboratory, and those selected genotypes and bacteria will be evaluated for plant growth and nitrogen fixation in the greenhouse and the field.

Measurement of nitrogen fixation by pearl millet will continue by the Kjeldhal method and possibly by natural ^{15}N abundance methods.

We will continue screening plant genotypes and VAM strains for improved plant growth and phosphate uptake in response to inoculation with VAM.

We will begin work on the development of serological techniques to identify VAM by a less laborious method than the conventional method using morphological distinction.

Following our investigations of mycorrhizae in West Africa in 1985, we will conduct field experiments there to improve plant growth and phosphate nutrition by manipulating local VAM species.

Grain and food quality. Endosperm starch quality of several millet genotypes will be studied and the relationship between starch quality and *tô* quality determined. Studies on quality characteristics of other African foods such as uji (thin porridge) and couscous prepared from millet will be initiated.

Breeding at ICRISAT Center. Our genetic diversification project will look increasingly to Africa as a source of new variability. Improved lines, disease resistant and capable of surviving in hostile environments, with large panicle volume and seed size are being produced in large numbers by our colleagues in Africa.

In the male-sterile breeding project we will, in the next 2-3 years, be using rapid generation advance to produce the first male-sterile lines in which selection for combining ability is an integral part of the breeding scheme.

In the pollinator project we will continue to enlarge and improve the restorer collection. We expect an increasing number of lines in the collection will be derived from composites from the population improvement project.

In varietal breeding, the merging of old composites and the creation of new ones will actively continue. We expect that the smut resistance of all the composites will improve over the coming years. In the synthetics project, African as well as Indian elite material will be used as parents, and a range of breeding methods tried and tested.

We will continue to conduct IPMAT, participate in the AICMIP testing system, and distribute trials, nurseries, and breeding material worldwide.

Progress has been made in computerizing the documentation of the breeding program, and in the coming years we will increasingly use microcomputers to handle our data and aid selection, particularly in the population improvement and pollinator projects.

Breeding activity in the African programs. Two additional breeders will be added to the ISC Millet Improvement team in 1986. This will expand the scope of research into the improvement of millets for the Sudanian zone (700-900 mm annual rainfall) and assist in enlarging our cooperative activities in the region.

At ISC, breeding material that has been generated will be used to produce varieties and source populations. Recurrent selection will be initiated in the ISC Composite 851 after several cycles of random mating. Efforts will be increased to both evaluate new hybrid combinations and convert inbred lines into male steriles. Multilocational evaluation and selection of breeding materials generated by the ISC program will be expanded and seed exchange with the national programs will continue.

Three varieties produced by the ICRISAT-Burkina Faso Program (IKMP 2, IKMP 3, and IKMP 5) will be evaluated in on-farm trials and the improvement of IKMP 4 and RP 1004 will continue. It is hoped that two early-maturing varieties, IKMV 8201 and IKMC 1, identified for late planting situations, will receive serious consideration for general cultivation in Burkina Faso.

In Sudan, the Bristled Population-A and Ugandi will be used in researcher-managed, on-farm trials in North Kordofan Province. Two additional testing sites in this province will be selected for multilocational yield evaluation trials.

Publications

Institute Publications

Plant Material Descriptions

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet variety ICMV 1. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet variety ICMV 2. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet variety ICMV 3. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet male-sterile line ICMA 1 and maintainer line ICMB 1. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet male-sterile line ICMA 2 and maintainer line ICMB 2. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet male-sterile line ICMA 3 and maintainer line ICMB 3. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pearl millet male-sterile line ICMA 4 and maintainer line ICMB 4. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Alagarswamy, G., and **Bidinger, F.R.** 1985. The influence of extended vegetative development and d2 dwarfing gene in increasing grain number per panicle and grain yield in pearl millet. Field Crops Research 11(2,3): 265-279.

Andrews, D.J., Gupta, S.C., and **Pheru Singh.** 1985. Registration of WC-C75 pearl millet. Crop Science 25(1): 199-200.

Andrews, D.J., King, S.B., Witcombe, J.R., Singh, S.D., Rai, K.N., Thakur, R.P., Talukdar, B.S., Chavan, S.B., and **Singh, P.** 1985. Breeding for disease resistance and yield in pearl millet. Field Crops Research 11(2,3): 241-258.

Andrews, D.J., Rai, K.N., and **Singh, S.D.** 1985. A single dominant gene for rust resistance in pearl millet. Crop Science 25(3): 565-566.

Chahal, S.S., Rao, V.P., and **Thakur, R.P.** 1985. Variation in morphology and pathogenicity in *Claviceps fusiformis*, the causal agent of pearl millet ergot. Transactions of the British Mycological Society 84(2): 325-332.

Henson, I.E., and **Mahalakshmi, V.** 1985. A rapid effect of heat girdling on stomatal conductance in pearl millet (*Pennisetum americanum* [L.] Leeke). Journal of Plant Physiology 120(4): 369-373.

Henson, I.E., and **Mahalakshmi, V.** 1985. Evidence for panicle control of stomatal behaviour in water-stressed plants of pearl millet. Field Crops Research 11(2,3): 281-290.

Krishna, K.R., Shetty, K.G., Dart, P.J., and **Andrews, D.J.** 1985. Genotype-dependent variation in mycorrhizal colonization and response to inoculation of pearl millet. Plant and Soil 86(1): 113-125.

Mahalakshmi, V., and **Bidinger, F.R.** 1985. Flowering response of pearl millet to water stress during panicle development. Annals of Applied Biology 106(3): 571-578.

Mahalakshmi, V., and **Bidinger, F.R.** 1985. Water stress and time of floral initiation in pearl millet. Journal of Agricultural Science, Cambridge, 105(2): 437-445.

Mahalakshmi, V., Subramanian, V., Bidinger, F.R., and **Jambunathan, R.** 1985. Effect of water deficit on yield and protein content in pearl millet grains. Journal of the Science of Food and Agriculture 36(12): 1237-1242.

Maiti, R.K., Raju, P.S., and **Bidinger, F.R.** 1985. Studies on germinability and some aspects of pre-harvest physiology of sorghum grain. Seed Science and Technology 13(1): 27-35.

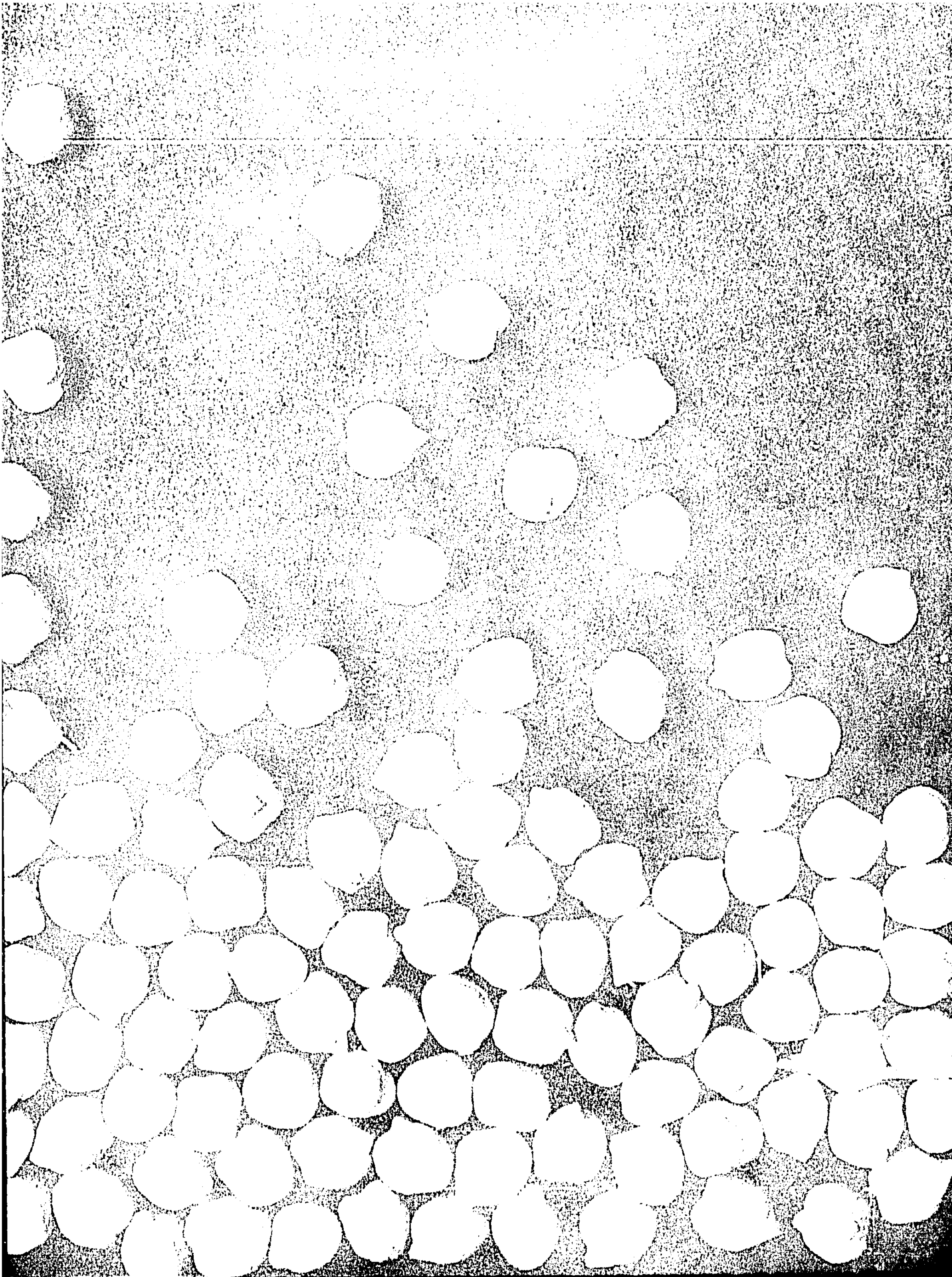
Rai, K.N., Andrews, D.J., and **Suresh Babu, V.** 1985. Inbreeding depression in pearl millet composites. Zeitschrift fur Pflanzenzuchtung 94(3): 201-207.

Singh, S.D., and **Gopinath, R.** 1985. A seedling inoculation technique for detecting downy mildew resistance in pearl millet. Plant Disease 69(7): 582-584.

Soman, P., and **Peacock, J.M.** 1985. A laboratory technique to screen seedling emergence of sorghum and pearl millet at high soil temperature. Experimental Agriculture 21(4): 335-341.

Thakur, R.P., Rao, V.P., Williams, R.J., Chahal, S.S., Mathur, S.B., Pawar, N.B., Nafade, S.D., Shetty, H.S., Singh, G. and **Bangar, S.G.** 1985. Identification of stable resistance to ergot in pearl millet. Plant Disease 69(11): 982-985.

Wani, S.P., Chandrapalaiah, S., and **Dart, P.J.** 1985. Response of pearl millet cultivars to inoculation with nitrogen-fixing bacteria. Experimental Agriculture 21(2): 175-182.



Contents

Cover photo: Seed of kabuli chickpea ICMV 4, a wilt-resistant variety that matures earlier than most kabuli cultivars.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

CHICKPEA

Although most of the world's chickpea production and consumption (>70%) is in India, this crop is of importance in many countries in Asia, Africa, Europe, and the Americas. Two main types of chickpea are commonly grown, desi and kabuli. Desi chickpeas, which are generally small-seeded with a brown seed coat, are most commonly grown in India. They are mainly used as flour, which is consumed in a variety of food preparations, or as dhal (decorticated, split seeds). In some countries, such as Mexico, desi chickpeas are also important as animal feed. The kabuli chickpeas generally have large seeds with thin, beige or light cream colored seed coats. These are more often consumed whole in a variety of preparations throughout the world, or as a paste, particularly in West-Asian countries. As the kabuli types are of particular importance in countries in the Mediterranean region, most of our research on these types is centered at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria.

Our principal objective is to develop improved cultivars and genetic stocks capable of higher and more stable yields in all types of cropping systems.

During the 1984/85 cropping season our activities continued at four main locations, ICRISAT Center (18° N, 78° E, 764 mm mean annual rainfall) on short-duration desi types; Hisar (29° N, 75° E, 450 mm annual rainfall) in cooperation with Haryana Agricultural University (HAU) on long-duration desi and kabuli types; at Islamabad, Pakistan (34° N, 73° E, 1116 mm annual rainfall) in cooperation with the National Agricultural Research Center (NARC); and at Aleppo, Syria (36° N, 37° E, 340 mm annual rainfall) in cooperation with ICARDA.

Our subsidiary testing centers include Gwalior (26° N, 78° E) in central India and, for off-season

Indian farmer threshing chickpea by the traditional method.

advancement and multiplication, Tapperwaripora (34°N, 75°E) in Kashmir, northern India, Sarghaya (36°N, 36°E) in Syria, and Terbol (34°N, 36°E) in Lebanon. Our materials are also tested at numerous other locations in many other countries by national scientists and we gratefully acknowledge the contributions of such cooperators.

Physical Stresses

We are concentrating our research efforts on physical stresses such as drought, salinity, and cold stress that limit chickpea yield. Drought is a major constraint to chickpea yield in central and southern India, and soil salinity is an increasing problem in irrigated areas where fields are inadequately drained. Low temperatures inhibit pod set in northern Indian winters. This year we report some of our work on drought and salinity tolerance.

Sowing Depth

Farmers tend to adjust sowing depth so that seeds are placed in moist soil to ensure germination. The generally observed deeper-sowing techniques and lower nodulation in farmers' fields in comparison to those on research stations have led us to postulate that deep sowing adversely affects nodulation. To test this, we conducted field trials in the 1981 postrainy season and again in 1984 for confirmation. Changes in the nodulation patterns due to sowing depth were similar in both years, although the extent of nodulation differed greatly between years and seemed to be related to the soil-moisture content at sowing. We report here the results obtained in the 1981 postrainy season.

Two chickpea cultivars, K 850 and Annigeri, were sown at 5-cm and 10-cm depth in a Vertisol, 2 days after it was irrigated. Deeper-sown seeds took 2 days longer to emerge and had lower total nodule numbers, mass, and acetylene-reduction activity (ARA) when sampled 37 days after sowing (DAS) (Table 1). These parameters were usually greater for the superior-nodulating cultivar K 850 than for Annigeri on all the three sampling dates. The interaction between sowing depth and cultivar was significant at $P<0.05$ for nodule number and mass but not for ARA.

Plants sown 10-cm deep formed epicotyl roots and nodules but those sown 5-cm deep did not (Fig. 1). The epicotyl region of deeper-sown plants contained a substantial proportion (33-45%) of the total nodule number and mass. Formation of epicotyl nodules seems to depend largely on moisture availability in this zone during the early stages of plant growth and this formation may not occur if moisture is below a critical level. This is being investigated in subsequent studies.

Table 1. Effect of sowing depth on nodulation and N_2 fixation by chickpea at 37 days after sowing (DAS), ICRISAT Center, postrainy season 1981.

Cultivar	Nodule number plant^{-1}			Nodule mass (mg plant^{-1})			ARA[1] (μm C_2H_4 plant^{-1} h^{-1})		
	5 cm	10 cm	Mean	5 cm	10 cm	Mean	5 cm	10 cm	Mean
Annigeri	10	7	8	30	13	22	1.26	0.38	0.82
K 850	20	11	15	55	20	37	1.59	0.54	1.06
SE	±0.7		±0.5	±7.9		±5.6	±0.468		±0.331
Mean	15	9		43	16		1.42	0.46	
SE	±0.5			±5.6			±0.331		

1. ARA = Acetylene-reduction activity.

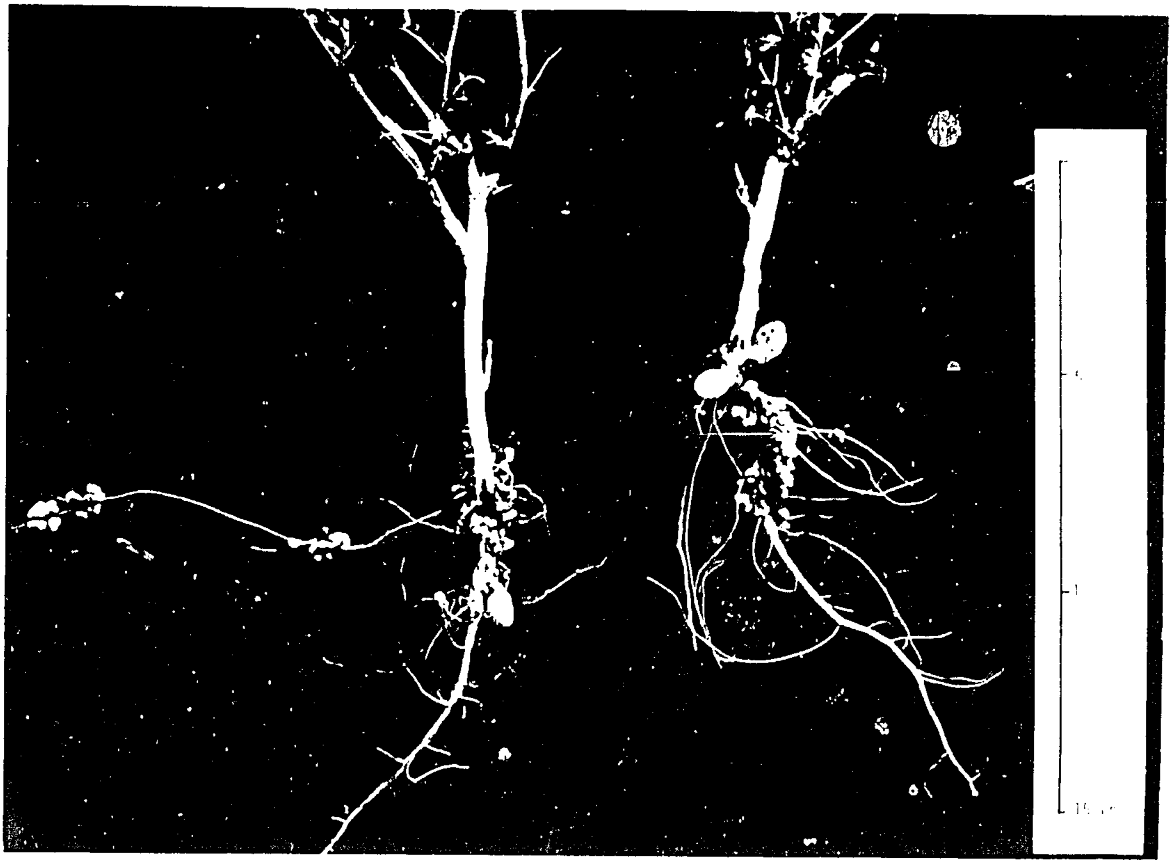


Figure 1. Effect of sowing depth on epicotyl roots and nodulation of chickpea genotype K 850; the deeper-sown plant (left) has nodulated epicotyl roots that are absent from the shallow-sown plant (right), ICRISAT Center, 1985.

Farmers obviously sow deep to ensure a good plant stand when a chickpea crop is grown on residual soil moisture. However, if the moisture near the surface is sufficient to ensure a good plant stand, shallow sowing is preferable to maximize nodulation and nitrogen fixation. The effects of sowing depth on nodulation as described here may be typical of Vertisols where about 90% of the total nodules are formed in the top 15 cm of the soil profile. In lighter soils, such as Entisols, substantial nodule development has been observed to a depth of at least 30 cm.

Screening for Drought Tolerance

In 1984/85, genotypes previously found to be either tolerant or susceptible to drought in experiments on Alfisols were grown on Vertisols differing in soil depth and therefore in water-holding capacity. In general, those genotypes previously shown to be relatively tolerant, such as ICC 4958, also performed best under limiting soil-moisture conditions on Vertisols.

Screening for Salinity Tolerance

Chickpea is particularly sensitive to saline conditions and we have therefore been trying to identify salt-tolerant genotypes. We have developed both pot and field techniques to screen for salinity tolerance. In the pot technique, plants are grown in the greenhouse under a range of soil-salinity levels, created by adding graded levels of a salt mixture representative of the salt composition of naturally saline soils (Fig. 2). In the field technique, rows of genotypes are grown across natural salinity gradients in the field and dry matter or seed yield obtained in 2-m sectors is regressed against electrical conductivity (EC) in the 0-30 cm soil horizon in each sector.

In both pot and field tests, dry matter declined linearly with increasing salinity level. The decline was steeper when soil moisture was optimum for plant growth. However, the level of soil salinity at which a 50% reduction in dry matter (3.3 m mhos cm^{-1}) or yield (2.5 m mhos cm^{-1}) occurred was the same whether soil moisture was optimum or deficient. Seed set was prevented at a higher-salinity level (4.5 m mhos cm^{-1}) than that causing a 50% reduction in shoot mass, again irrespective of the soil-moisture status. However, the large variances associated with the field technique make it impracticable for large-scale, genotypic comparisons. The pot technique is preferable for these, and we have shown that similar results are obtained in pots and in the field.

Biotic Stresses

Diseases

Disease Situation in Chickpea

Ascochyta blight (*Ascochyta rabiei*) that has caused substantial crop losses in northern India, Pakistan, and West Asia in the past few years did not widely occur in 1985. In Syria, the dry conditions even made it difficult to artificially create a sufficient level of disease in the ascochyta blight screening nursery. Stunt caused by pea leaf-roll virus was more serious in northern India than in previous years; limited surveys around Hisar

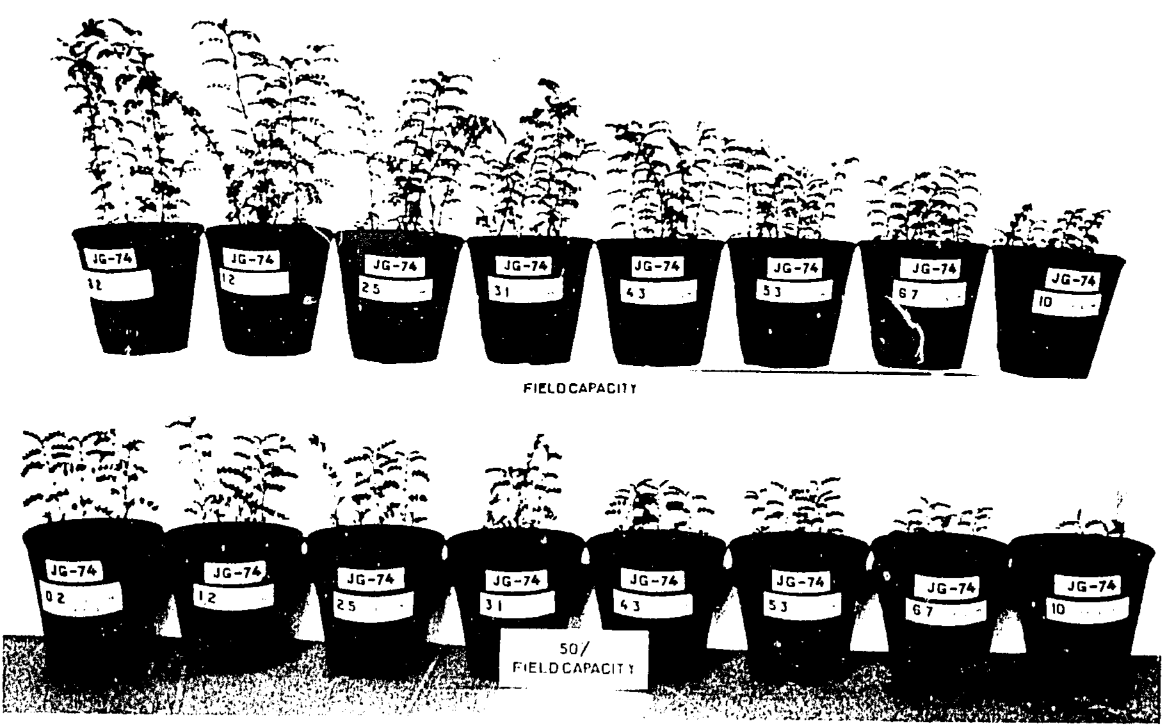


Figure 2. Effect of interaction between soil moisture and salinity on the growth of chickpea cultivar JG 74 in pots in a greenhouse, ICRISAT Center, 1984/85.

revealed about 10% incidence in farmers' fields. In the lowland regions of Nepal, botrytis gray mold (*Botrytis cinerea*) was observed more frequently than other diseases. The incidence of wilt (*Fusarium oxysporum* f.sp *ciceri*) and dry root rot (*Rhizoctonia bataticola*) was similar to that in previous years.

Fusarium Wilt (*Fusarium oxysporum* f.sp *ciceri*)

Screening for resistance. We continued to screen large numbers of germplasm accessions and breeding lines for wilt (*F. oxysporum* f.sp *ciceri*, race 1) resistance in a wilt sick plot, where the susceptible control (JG 62) sown after every two test rows showed 100% wilting. Of the 512 new germplasm accessions screened, 60 had less than 20% wilt incidence. These will be retested.

We retested the 16 lines that were found promising in the field screening in 1984 in the wilt sick plot. Only three lines, ICC 1569, 12263, and 12408, were found resistant. These will now be screened in pots, to finally confirm their resistance.

In ICRISAT Annual Report 1984, p. 135, we reported that our germplasm collection had a total of 128 wilt-resistant lines. This year we confirmed resistance of 14 more lines; ICC 859, 933, 1234, 1246, 1987, 3457, 3536, 4348, 4436, 4490, 4579, 5186, 5535, and 6027, thus bringing the total to 142 lines with confirmed wilt resistance.

A large amount of breeding material, including 42 F_2 populations, 776 F_3 and 522 F_4 progenies, and entries included in international nurseries and trials, was screened in a wilt sick plot. A total of 726 single plants and two bulks were selected for further use in the breeding program.

ICCC 32, a kabuli cultivar developed at ICRISAT Center earlier observed to be resistant to race 1 of *F. oxysporum* f. sp *ciceri*, was also found to be resistant to race 4.

Breeding for resistance. We made 34 crosses between wilt-resistant and short- and long-duration, desi and kabuli cultivars. We also made 10 backcrosses to transfer wilt resistance to ILC 482, ILC 484, K 850, L 550, and other released Indian cultivars of short, medium, and long duration.

At ICRISAT Center, we screened 32 F_2 populations and 460 F_3 progenies in a wilt sick plot and selected 512 single plants. We evaluated 1882 F_4 and more advanced-generation lines/bulks for their agronomic characteristics in normal plots; 761 single plants were selected for further progeny tests and 23 lines of short- and 42 of medium-duration were bulked for replicated yield tests in the next postrainy season. We also compared 207 wilt-resistant desi and kabuli lines in replicated tests and contributed 19 lines with higher seed yields than the controls to the International Chickpea Screening Nurseries (ICSN).

At Hisar, we screened 31 F_2 populations and 37 F_3 progenies in wilt sick plots and selected 368 single plants. We evaluated 1318 F_4 and more-advanced-generation progenies in normal fields and selected 577 single plants and 58 lines for further tests. Out of 140 lines tested in replicated yield trials, 20 were contributed to the ICSN (long duration) and two to International Chickpea Cooperative Trials (ICCT, long duration). Seed yields of the most-promising lines in preliminary and advanced yield trials are presented in Table 2.

Inheritance studies. The allelic composition of the late-wilting cultivars Radhey and GW5/7 was found to be different from that of the late-wilting K 850, C 104 and H 208. The proportion of resistant plants in the F_2 of the cross JG 62 × P 165 was higher than that of earlier crosses between susceptible and resistant parents. This suggests that different genes confer resistance in different genotypes. These studies have a bearing on the selection of suitable resistant parents for breeding programs.

Effects of soil solarization. Soil solarization is a technique that involves covering the soil with transparent polythene sheets during summer, to increase soil temperature. It has been primarily used for the control of soilborne pathogens but has other beneficial effects on subsequent crop growth as well. We evaluated this technique for

Table 2. Seed yields (kg ha^{-1}) of the highest-yielding, wilt-resistant desi chickpea lines in trials, Hisar, 1984/85.

Line/cultivar	Seed yield (kg ha^{-1})
Preliminary trials	
Trial 1	
ICCX 790340-BH-BH-2H-BH	3690
ICCX 74167-1H-1H-BH-1H-BH	3660
ICCX 790462-7H-1H-BH	3120
Control	
H 208	2130
SE	±328
Trial mean (25 entries)	2660
CV(%)	21
Trial 2	
ICCX 750736-15H-BP-1P-1H-BH	3400
ICCX 750736-19H-13P-1H-1H-BH	3340
ICCX 751239-5H-BP-2H-1H-BH	3310
Control	
H 208	2860
SE	±303
Trial mean (25 entries)	2770
CV(%)	19
Trial 3	
ICCX 750798-12H-BP-1P-1H-1H-BH	3800
ICCX 760718-2P-1P-BP-BH	3650
ICCX 760718-3P-1P-BP-BH	3500
Control	
H 208	2770
SE	±290
Trial mean (25 entries)	2970
CV(%)	17
Advanced Trial	
ICCX 750736-4H-1P-BP-1H-1H-BH	3020
ICCX 771147-BP-3H-BH	2550
ICCS 740132-B-4H-1H-1P-BP-BH	2520
Control	
H 208	1730
SE	±308
Trial mean (36 entries)	2070
CV(%)	26

its effects on chickpea, particularly in relation to control of fusarium wilt in a multidisciplinary experiment during 1984/85.

The experiment was laid out in a wilt sick Vertisol plot in a split-plot design. Irrigation and no-irrigation treatments prior to solarization were the main plots and factorial combinations of with and without solarization and wilt-resistant (JG 74) and susceptible (ICCC 4) chickpea genotypes were the subplots. The subplot size was 6 m × 6 m and there were six replications. The soil solarization treatment was applied from 17 April to 4 June 1984 and the crop was sown on 2 November 1984. Solarization increased the temperature in the 0-5 cm soil profile by more than 10°C during the day.

Solarization treatment permitted yields of a wilt-susceptible cultivar similar to those of a resistant cultivar in soil where susceptible cultivars are normally severely damaged by wilt (Fig. 3). Solarization reduced *Fusarium* propagules

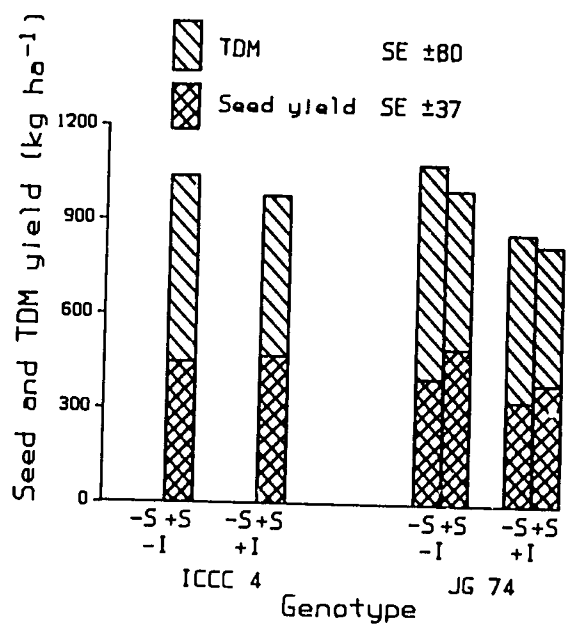


Figure 3. Effect of solarization (+S = solarized, -S = nonsolarized) and irrigation (+I = irrigated, -I = nonirrigated) at the time of solarization on seed yield and total dry matter (TDM) of wilt-susceptible (ICCC 4) and wilt-resistant (JG 74) chickpea genotypes on a Vertisol, ICRISAT Center, postrainy season 1984/85.

by approximately 90%. There was more than 90% mortality of ICCC 4 due to wilt in nonsolarized plots at maturity, but the wilt incidence in solarized plots with irrigation was only 10%. Although solarization treatment did not significantly affect the above-ground biomass of the resistant cultivar, it marginally, but significantly, increased seed yield. We found that solarization suppressed weed growth and nematode populations and enhanced mineralization of soil nitrogen; however, we are yet to establish the causal factor enhancing the yield of the resistant cultivar in solarized plots. We also found that solarization resulted in a 10-fold reduction in native chickpea *Rhizobium* populations and that nodule number and mass were less in solarized plots at 47 DAS. However, plants in solarized plots obviously recovered from this early inhibition of symbiotic nitrogen fixation (Fig. 3).

Other Soilborne Diseases

Wilt-resistant germplasm selections, breeding lines, and lines received from our cooperators in India were screened at ICRISAT Center in a multiple soilborne disease infested plot containing the following pathogens, in order of prevalence: *F. oxysporum* f.sp *ciceri, Rhizoctonia bataticola, Sclerotium rolfsii, Fusarium solani,* and *Rhizoctonia solani.*

Eight wilt-resistant lines showed less than 10% mortality due to wilt and root rots for 3 consecutive years. Their resistance to wilt was confirmed through pot screening in a greenhouse.

Three wilt- and root rot-resistant lines, ICC 1403, G 130 (Sel-6), and ICCX 7320-11-1-1-BH-EB showed some resistance to *Heliothis armigera.*

Dry Root Rot (*Rhizoctonia bataticola*)

Screening for resistance. A blotting paper technique (Chickpea Diseases: Resistance Screening Techniques, ICRISAT Information Bulletin no. 10) is being used to identify resistance to dry root rot (*R. bataticola*). This year 287 advanced lines were screened. Only one line, ICCL 79063, showed a 3 rating (highly resistant) on a 1-9 scale. Thirteen lines showed a 5 rating (tolerant). They were ICCL 81297, 82001, 83002, 83005, 83007, 83312, 83313, 83316, and 83320, ICCC 3, 21, and 24, and ICC 11314.

Inheritance studies. We have started to investigate the genetics of inheritance of resistance to dry root rot (*R. bataticola*). F_1, F_2, and F_3 progenies of the cross between resistant C 104 and susceptible P 165 were screened by using the blotting-paper technique. Our preliminary observations suggest that resistance to dry root rot is due to a single dominant gene and hence, it should be relatively easy to breed for resistance.

Botrytis Gray Mold (*Botrytis cinerea*)

Breeding for resistance. We screened 43 F_4 and 37 F_5 populations of crosses between botrytis-resistant lines and adapted cultivars, and selected 337 single plants whose agronomic characteristics will be evaluated in progeny rows in this 1985 postrainy season.

Ascochyta Blight (*Ascochyta rabiei*)

Breeding for resistance. We made 27 crosses between ascochyta-resistant parents and long-duration high-yielding cultivars. Twenty-four F_2 populations from earlier crosses were screened in the joint HAU/ICRISAT ascochyta blight screening nursery at Hisar and 126 single plants were selected. We evaluated 830 F_4 and more advanced-generation progenies/bulks and selected 225 single plants and 11 lines for further tests.

Stunt (Pea Leaf-Roll Virus)

Screening for resistance. In the stunt nursery at Hisar, the incidence of stunt disease in the susceptible control (WR 315) averaged 71% (range 50-98%). Only two (ICC 2546 and 3735) of the 23 germplasm selections tested showed less than 30% incidence. One ascochyta- and botrytis-tolerant selection (ICC 8383) showed less than 20% stunt. Of the 10 selections from the International Chickpea Root Rots/Wilt Nursery (ICRRWN) that had previously shown reduced susceptibility to stunt, only one, ICC 10466, showed less than 20% stunt this year. Of the 157 accessions/lines with tolerance to botrytis gray mold only one (ICC 3375) showed less than 10% stunt and 4 (ICC 3612, 3668, 3798, and 4203) showed less than 20% stunt. Of the 61 entries of the 1984/85 ICSN (desi, medium-duration) that were tested, one line, ICCL 84306 showed less than 20% stunt.

Breeding for resistance. We made five crosses between stunt-resistant genotypes and adapted cultivars, and screened 167 F_4 and more-advanced-generation progenies in the stunt nursery at Hisar. Twenty-three promising lines were bulked for a replicated trial and 143 single plants were selected for progeny testing. We also compared 46 lines in replicated yield tests and contributed the six most-promising lines to the ICSN (long-duration).

Phyllody

At present phyllody, characterized by bushy growth and green, leaf-like flowers, is not a serious disease. However, it is more prevalent in some areas than in others in certain years. Since mycoplasma-like organisms are associated with the phyllody diseases of several plants, we processed phylloid and healthy chickpea tissue for ultrathin sectioning. With the aid of an electron microscope, we were able to observe spherical, polymorphic bodies, typical of mycoplasma-like organisms in the phloem of phylloid tissue (Fig. 4); no such bodies were seen in the sections from healthy tissue.

Nematode Diseases

We were able to confirm the presence of several parasitic nematode species in Vertisol fields under chickpea at ICRISAT Center. These were: cyst nematodes (*Heterodera cajani* and *Heterodera* sp), the lance nematode (*Hoplolaimus seinhorsti*), the lesion nematode (*Pratylenchus* sp), the reniform nematode (*Rotylenchulus reniformis*), spiral nematodes (*Helicotylenchus indicus* and *H. retusus*), and the stunt nematode (*Tylenchorhynchus* sp).

A cyst-nematode (*Heterodera* sp) population was encountered in the chickpea multiple soil-borne disease nursery located on a Vertisol. This species differed from other cyst nematodes reported on chickpea. Nematode larvae emerged from cysts when placed in the root exudates of 10 to 15-day-old chickpea (Annigeri) seedlings. Unlike the pigeonpea cyst nematode (*H. cajani*), there was no larval emergence in distilled water.

Figure 4. Ultrathin section of leaf from chickpea plant with phyllody symptoms, showing mycoplasma-like bodies in the phloem (electron micrograph, bar length represents 0.2 μm), ICRISAT Center, 1985.

Multilocational Testing for Disease Resistance

Germplasm accessions and breeding lines found resistant to wilt, root rots, and stunt at ICRISAT Center were tested at other disease-endemic locations to identify lines with broadbased resistance, and also to share the seed of resistant materials with the national programs. We tested for wilt and root rot resistance in two cooperative disease nurseries. The nursery operated in India, the ICAR / ICRISAT Uniform Chickpea Wilt and Root Rots Nursery (IIUCWRRN), was jointly organized by ICRISAT and ICAR. The nursery operated outside India was the International Chickpea Root Rots/Wilt Nursery (ICRRWN).

ICAR/ICRISAT Uniform Chickpea Wilt and Root Rots Nursery (IIUCWRRN) 1985. This nursery was initiated during the 1981-82 postrainy season, to test chickpea lines identified as resistant to wilt and root rots by ICRISAT and the Indian national program. During 1985, 55 resistant lines and a susceptible control, JG 62, were tested at 21 locations. Good screening for wilt- and root rot-resistance was only achieved at nine locations—Berhampore, Dahod, Dholi, Gurdaspur, Hisar, ICRISAT Center, Ludhiana, Pantnagar, and Sehore. No line was resistant at all locations, but some were resistant (< 10% mortality) at each of these nine locations, except Pantnagar. Nine lines, ICC 2664, 6815, 9127, 10384, 10630, 10809, 11224, 11314, and 11324 were resistant at six locations.

ICAR/ICRISAT Uniform Chickpea Wilt and Root Rots Nursery (IIUCWRRN) 1982-84. We recently analyzed the results of the nurseries that were grown during 1982-84. We evaluated 226 entries at 14 locations in India. Lines resistant to wilt were identified at all the locations except Varanasi. Through this nursery, 18 lines resistant to wilt and root rots at 8 to 10 locations in India were also identified. These were ICC 554, 2354, 2450, 2858, 2862, 4847, 4850, 6474, 6570, 6816, 9023, 9032, 10823, 11088, 11550, and 11551, and ICCL 80001 and 80002. Lines with such broad-based resistance could serve as sources of durable resistance.

International Chickpea Root Rots/Wilt Nursery (ICRRWN) 1977-82. We analyzed results of the nurseries that were grown over a period of 6 years (1977-82). A total of 330 entries were tested at 28 locations in 12 countries. Except at one of the two locations in Mexico, wilt-resistant lines were identified at all locations. Lines such as ICC 2862, 9023, 9032, 10803, 11550, and 11551 were found resistant in at least 11 locations. Some lines were found resistant to wilt and root rots over a period of at least 3 consecutive years at some locations. Examples are: ICC 267 at Berhampore and Jabalpur; ICC 858 at Hisar, Ludhiana, and ICRISAT Center; ICC 2883 at ICRISAT Center; ICC 3103 at ICRISAT Center and Jabalpur; ICC 2083 and 3439 at Jabalpur; ICC 102, 434, 1910, 6366, 6455, and 6926, ICCC 10, and ICCX 80004 in Ethiopia; ICC 8933 in Mexico; and ICC 267, 519, 858, 2566, 2660, and 3439 in California, USA.

Breeding for Multiple Disease Resistance

Wilt and root rots. We evaluated 215 F_4 progenies from plants selected in the multiple soil-borne disease screening nursery at ICRISAT Center in the previous season, and selected 89 single plants for further tests.

Wilt and ascochyta blight. We made 25 three-way crosses between wilt- and ascochyta blight resistant parents and high-yielding cultivars. Seventy-nine F_2 populations from earlier crosses were screened in the wilt sick plot at Hisar and over 1000 single plants were selected. We screened 10 F_3 and 2 F_4 single-pod descent bulks in the joint HAU/ICRISAT ascochyta blight-screening nursery and selected nearly 200 single plants for further tests.

Wilt and stunt. We made 57 three-way crosses involving wilt- and stunt-resistant parents, and adapted long-duration cultivars. Five F_2 populations were screened in the wilt/stunt nursery at Hisar and 190 single plants were selected.

Ascochyta blight and stunt. We made two crosses and screened 10 F_2 populations and 242 F_3 progenies in the ascochyta blight screening nursery at Hisar; 355 single plants were selected for further tests.

Ascochyta blight and botrytis gray mold. At Hisar, we compared 69 F_4 bulks in two replicated yield trials and selected the 20 most-promising bulks for single-plant selection in 1985/1986. We also evaluated 546 F_5 progenies for yield and selected 106 single plants and 47 lines for further tests.

Of the 106 lines received from Ludhiana, India that were tested in a greenhouse for combined resistance to blight and gray mold, only 2 lines (GL 84125 and GL 84210) showed tolerant reactions (ratings of 6 to both diseases on a 1-9 scale).

Ascochyta blight, wilt, and stunt. We made 16 three-way crosses and grew 15 F_2 populations in the wilt/stunt nursery at Hisar; 660 single plants were selected so that their progenies could be screened against ascochyta blight.

Ascochyta blight, wilt, stunt, and botrytis gray mold. We screened 10 F_2 populations in the wilt/stunt nursery at Hisar and selected 376 single plants for screening against ascochyta blight and botrytis gray mold.

Ascochyta blight, wilt, root rots, stunt, and botrytis gray mold. We made 10 crosses to combine resistance to all five diseases.

Insect Pests

Pest incidence. As in all previous years, the pod borer (*Heliothis armigera*) was the most-damaging pest on chickpea in all areas that were visited. Although the populations of this insect were greater in 1984-85 than in the previous year, they did not reach the high levels recorded in some earlier years. Populations of *H. armigera* moths are monitored at ICRISAT Center and at several other locations in the subcontinent, by pheromone and light traps. Details of such monitoring are presented in the Pigeonpea and Resource Management sections of this report. Other lepidoptera including the cutworms (*Agrotis* spp) and the foliage and pod feeders (*Spodoptera exigua* and *Autographa nigrisigna*) were also reported as minor and localized pests in India. *Aphis craccivora*, the vector of pea leaf-roll virus that causes stunt disease in this crop, was less common than in the previous year. In West Asia and in the Mediterranean region, the leaf miner (*Liriomyza cicerina*) is the most-damaging pest in most years.

Heliothis armigera

Host-plant resistance. New germplasm accessions were not screened this year as our available resources were concentrated upon screening breeding materials, particularly the progenies of crosses involving *Heliothis*-resistant selections. Our resistant selections again proved to be outstanding in pesticide-free trials. Table 3 shows the consistent records of the relative resistance/susceptibility of some of our short-duration desi selections in trials at ICRISAT Center from 1979 to 1985. One of our medium-duration desi selections (ICCX 730008-8-1-1P-BP) performed particularly well in multilocational tests across India over the last 3 years and has been selected as a parent for the national crossing program.

Unfortunately, since most of our resistant selections have been found to be very susceptible to fusarium wilt, they cannot be used in areas where this disease is common. We are collaborating with breeders and pathologists to make crosses and select from the progenies plants that combine resistance to both *H. armigera* and fusarium wilt.

We have intensified work in screening genotypes for resistance to *H. armigera* at Hisar, as the resistant genotypes selected at ICRISAT Center are not well adapted to the climatic conditions of northern India.

Mechanisms of resistance. In field and laboratory tests, to study the mechanisms of resistance, we measured differences in oviposition, in larval

Table 3. Pod damage (%) and relative resistance ratings of short-duration, desi chickpea genotypes selected for resistance or susceptibility to *Heliothis armigera* in trials at ICRISAT Center, 1979-85.

	1979/80		1980/81		1981/82		1982/83		1983/84		1984/85	
	PD[1]	RR[2]	PD	RR	PD	RR	PD	RR	PD	RR	PD	RR
Genotype												
ICC 506	6	3	4	3	5	3	7	3	12	3	1	2
ICC 6663	4	3	10	4	4	3	12	3	4	3	9	4
ICC 10667	6	3	6	3	8	4	14	3	3	2	2	2
ICC 10817	6	3	8	3	7	3	16	4	19	4	2	2
Controls												
Annigeri	16	6	20	6	15	6	29	6	29	6	15	6
ICCX 730266 (Susceptible)	23	9	23	6	15	6	33	8	30	6	19	7

1. PD = Pods damaged by *H. armigera* (%).
2. RR = Resistance rating in relation to the control where 1 = no damage, 6 = control, and 9 = highly susceptible.

retention and in larval growth rate on resistant and susceptible genotypes. In general, larvae that were fed on resistant genotypes grew less quickly than those on susceptible genotypes, demonstrating the presence of some antibiosis. Scientists at the Max Planck Institute for Biochemistry, Munich, who are collaborating with us in the identification of the chemical differences between our resistant and susceptible genotypes, reported substantial progress in 1985.

Earlier (ICRISAT Annual Report 1983, p. 128), we reported that the differences in the percentage of pod damage between resistant and susceptible genotypes tended to diminish with increasing proximity. Thus, although the differences were substantial and obvious when plots of resistant and susceptible genotypes were compared, the differences were much less when resistant and susceptible plants were alternated in rows. This indicated a problem in selecting single plants from progenies that are segregating, as resistant plants could not be confidently distinguished from adjacent susceptible plants at the intrarow spacing (30 cm) used. It was suggested that a wider spacing might alleviate this problem. Therefore, this year we conducted a similar experiment in which a greater intrarow spacing (60 cm) was used. The results are summarized in Figure 5. Although there was some reduction in the difference between the pod-damage percentages of resistant and susceptible genotypes when they were grown as alternating plants, rather than in alternating rows or in separate plots, the differences were still substantial. At such a spacing it would appear that single-plant selection can be undertaken with a reasonable degree of confidence. We will use such spacing when we grow progenies intended

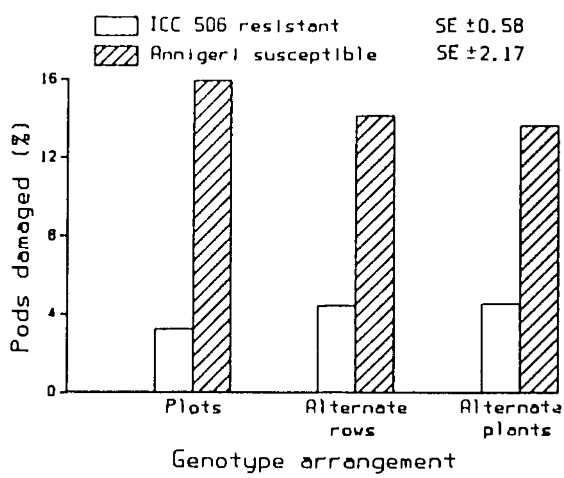


Figure 5. Pods damaged (%) by *Heliothis armigera* on resistant (ICC 506) and susceptible (Annigeri) chickpea cultivars, grown on a Vertisol at wide spacing (60 × 60 cm) without pesticide protection, in separate plots, in alternate rows, and as alternate plants, ICRISAT Center, 1984/85.

for single-plant selection for *H. armigera* resistance.

Breeding for resistance. Breeders and entomologists conducted joint trials on *Heliothis* resistance for the short- and medium-duration desi types at ICRISAT Center and for the long-duration desi and kabuli types at Hisar. This year we accomplished 73 crosses, mainly three-way, where the third parent was either a good agronomic type or wilt resistant (to combine *Heliothis* and wilt resistance) or *Heliothis* resistant (to pyramid resistant genes). In order to study the nature of inheritance of this character in the segregating populations, we conducted an F_2 trial of resistant × resistant (ICC 506 × ICC 10619), resistant × susceptible (ICC 506 × Annigeri), and susceptible × susceptible (Annigeri × ICCX 730266-3-4-1P-EB) crosses at the ICRISAT Center (Table 4). The borer damage in the resistant × susceptible cross was intermediate between the resistant × resistant and susceptible × susceptible combinations, confirming our earlier findings in F_1 diallel studies that the character is under the control of additive-gene action and thus can be handled by conventional breeding methods.

We grew 38 F_2 populations and 1380 F_3 to F_7 short- to medium-duration progenies in pesticide-free areas at ICRISAT Center and 10 F_2 and 1152 F_3 to F_7 long-duration progenies at Hisar. At ICRISAT Center, we selected 1271 single plants and, at Hisar, 973 single plants that showed low borer damage and/or high yield. Progenies with low borer damage and high productivity were individually bulked at both locations. Thus, we identified 46 progenies at ICRISAT Center and 66 at Hisar for further testing in preliminary yield trials.

We sowed, in wilt sick plots, one set each of F_3 and F_4 progenies at ICRISAT Center, and F_4 and F_5 progenies at Hisar. As expected, most of the plants died. However, we selected 91 single plants and 2 surviving lines out of 623 progenies at ICRISAT Center and 88 plants and 3 lines out of 250 progenies at Hisar for further testing.

We conducted preliminary yield trials of 37 short- to medium-duration bulked lines in the pesticide-free area at ICRISAT Center. Forty-six long-duration bulked lines were similarly tested at Hisar. Resistant and susceptible controls were included for comparison. Twelve lines gave higher yields than the resistant control ICC 506 at ICRISAT Center and five produced more than the best control (Annigeri). Some of these lines also had a lower percentage of borer damage than ICC 506. At Hisar, 7 lines outyielded the resistant control ICCX 7320-11-2-EB and 20 gave higher yields than the best control (H 208). From these trials we contributed seven entries to the International Chickpea Screening Nurseries (ICSN).

In an advanced yield trial at ICRISAT Center in insecticide treated and nontreated conditions,

Table 4. Mean pod damage (%) caused by *Heliothis armigera* in F_2 progenies from crosses of resistant and susceptible selections of short-duration desi chickpea, ICRISAT Center, 1984/85.

Cross/genotype	Character	Pod damage (%)
ICC 506 × ICC 10619	Resistant × Resistant	3.5
ICC 506 × Annigeri	Resistant × Susceptible	8.4
Annigeri × ICCX 730266	Susceptible × Susceptible	16.5
Controls		
Annigeri	Susceptible	15.2
ICC 506	Resistant	7.9
SE		±0.9
CV (%)		17

Progeny of a *Heliothis armigera*-resistant × wilt-resistant chickpea cross that survived in a wilt sick, pesticide-free plot at ICRISAT Center, 1985.

ICCL 85232, ICCL 85234, and ICCL 85235 gave good yields under both conditions and were superior to the resistant and standard controls. The borer damage recorded in these lines was similar to that of ICC 506. From these, we furnished four lines to international chickpea trials for multilocational testing in the 1986 postrainy season. It is evident that breeding lines with superior yield and borer resistance have started to emerge from this project.

Insecticide use Trials over the last 9 years at ICRISAT Center have shown that insecticide use on commonly grown cultivars of chickpea has given a mean yield increase of 216 kg ha^{-1}. However, the yield increase ranged from 99 kg ha^{-1} to 571 kg ha^{-1} while the protected crop yield ranged from 430 kg ha^{-1} to 1730 kg ha^{-1}. The low yields were due to poor crop growth. In 6 of the 9 years, insecticide use would have been very profitable. In the other 3 years, insecticides would have been a poor investment, either because crop growth was poor or because *H. armigera* attacks were not severe enough to merit insecticide use. In such circumstances, it is essential that the insecticide be used only on well grown chickpeas, and only when populations of *H. armigera* eggs and small larvae approach the economic threshold.

One approach to the determination of the economic threshold is to cage varying numbers of larvae on plants to determine the crop loss they cause. We are persevering with this method, but have found that wandering and disappearance of larvae cause great variability in our tests. An alternative approach is to study the consumption of flowers and pods by individual larvae of different ages in the laboratory. This year we conducted tests in which larvae were fed on flowers, young pods, or green maturing pods in petri dishes from 6 days after hatching to 16 days, when pupation occurs. We had earlier found that for the first 5 days larvae normally feed on leaflets causing little damage, but then feed on flowers or pods, if available. The average consumption per larva was 70 flowers, or 28 young pods, or 8 green maturing pods. We can meaningfully compare such data with field counts of larvae and damage in chickpea fields with or without pesticide protection.

Natural enemies. The incidence of natural enemies of *H. armigera* was recorded in some trials. Few predators, other than birds, were found in our chickpea fields but parasites, particularly *Campoletis chlorideae*, were common. Reports of up to 80% parasitism in the young larvae are frequently encountered, but in samples collected from pulse-entomology trials the average parasitism has rarely exceeded 30% and has often been below 10%. This year the parasitism recorded from larvae of all sizes, from a variety of plant genotypes, was just under 10%. As in previous years, the parasitism in larvae collected from genotypes resistant to this pest (6.5%) was slightly lower than in those collected from susceptible genotypes (7.5%).

Ideally, we should take natural-enemy populations into account when deciding whether or not to use insecticides. Counts of predators can be combined with pest counts, but parasitism can only be quantified after culturing samples of larvae for a few days. Visible signs of parasitism—sluggish larvae or parasite cocoons on the crop—might help an experienced pest-management specialist make a decision. However, it is unrealistic to expect most farmers to do more than base their pesticide use on simple pest counts. The economic thresholds meant for the farmer's use must include a natural-enemy factor in their determination.

Plant Nutrition

Genotypic Differences in Residual Effect

Legumes can meet most of their nitrogen (N) requirements through biological N fixation and hence leave more N in the soil for subsequent crops. Some chickpea genotypes nodulate more profusely (Fig. 6) and fix more N than others (ICRISAT 1978-79, pp. 135-136). We started a trial in the 1984 postrainy season to see if a profusely nodulating cultivar would have a greater beneficial effect than an average-nodulating cultivar on a subsequent cereal crop.

The soil N pool in a Vertisol was depleted by growing cover crops of maize in the 1983 rainy season, and sorghum in the 1984 rainy season, before the trial began. Six treatments, a profusely nodulating cultivar (K 850) with and without 20 kg N ha^{-1}, an average-nodulating cultivar (Annigeri) with and without 20 kg N ha^{-1}, safflower and fallow, were laid out in a latin square in 9.0 m × 7.2 m plots. At the time of land preparation a basal dressing of 17 kg P ha^{-1} was applied. It is intended that this experiment will continue for at least 3 years, with a cereal being grown in the subsequent rainy seasons and the above postrainy-season treatments being repeated in the same plots.

As expected, K 850 nodulated much better than Annigeri (Table 5) but both cultivars produced similar quantities of dry matter and grain (Table 6). In the subsequent rainy season, all plots were sown to a local sorghum cultivar without any fertilizer application. Sorghum grew best in the fallow-treatment plots, and next best in the plots that had K 850 with N (Table 6). Sorghum dry matter yield was about 15% greater in the K 850 + N plots than in the Annigeri + N plots and the differences in plant growth were clearly visible in three of the six replications (Fig. 7). Sorghum growth on K 850 plots was only 6% better than on Annigeri plots where N had not

Figure 6. Difference in nodulation of a profusely nodulating chickpea cultivar K 850 (right) and an average-nodulating chickpea cultivar Annigeri (left) at 60 DAS, ICRISAT Center, 1985.

been applied, perhaps because the average-nodulating cultivar was forced to fix relatively more N under N-limiting conditions. Not only did safflower itself yield poorly in the 1984 postrainy season, but also subsequent sorghum growth was poorest on the safflower plots indicating the beneficial effect of chickpea in general. The trial will continue.

Table 5. Nodulation of 43-day-old chickpea cultivars, with (+N) and without (−N) applied nitrogen[1], ICRISAT Center, postrainy season 1984.

	Nodule number plant^{-1}			Nodule mass (mg plant^{-1})		
Cultivar	−N	+N	Mean	−N	+N	Mean
Annigeri	20	19	19	45	46	45
K 850	37	39	38	126	140	133
SE	±1.2		±0.9	±7.6		±5.4
Mean	28	29		85	93	
SE	±0.9			±5.4		

1. Sample size 20 plants/replication.

Rhizobium Culture Collection

We continued to provide *Rhizobium* strains to inoculant manufacturers and researchers in India and elsewhere, and despatched 401 units of

Table 6. Dry-matter and grain yield (kg ha^{-1}) of chickpea and safflower, postrainy season 1984/85, and sorghum dry-matter yield (kg ha^{-1}), rainy season 1985, ICRISAT Center.

	Postrainy season 1984/85		Rainy season 1985
Treatment	Dry matter	Grain yield	Sorghum dry matter
Fallow	0	0	4720
K 850 + N	1750	1020	3560
Annigeri + N	1730	1030	3080
K 850	1680	950	2780
Annigeri	1760	1110	2610
Safflower	660	150	2060
SE	±110	±76	±145

Rhizobium strains as inoculants, agar slopes, or ampoules.

Grain and Food Quality

Protein Content and Quality

We analyzed 428 whole-seed samples supplied by the breeders and 1246 whole-seed samples received from the Genetic Resources Unit to monitor their protein content. The protein content of the breeding material ranged between 14.3 and 24.7% and of the germplasm accessions between 9.5 and 20%.

The amino-acid composition of three lines

Figure 7. Residual effects of a profusely nodulating chickpea cultivar K 850 (right) and an average-nodulating cultivar Annigeri (left) grown in the postrainy season 1984, on sorghum, ICRISAT Center, rainy season 1985.

developed at ICRISAT Center was determined and the results were compared with those of control cultivar G 130. Although the differences were not significant, the sulfur-containing amino acids (methionine + cystine) contents in ICCC 36, 37, and 42 were slightly lower than those in G 130. However, the lysine contents of these lines were slightly higher than in G 130.

Cooking Quality

A comparison of the cooking time of the dhal of ICCC 36, 37, and 42, all cultivars being tested in advanced All India Coordinated Pulses Improvement Project (AICPIP) trials and that of the control Annigeri are presented in Table 7. ICCC 42 required the longest cooking time (40 min) while the others required 32 min or less. The dhal protein content of the four cultivars also showed considerable differences.

Table 7. Protein content (%) and cooking time (min) of the dhal from three new desi chickpea cultivars compared to Annigeri, ICRISAT Center, 1984/85.

Cultivar	Protein (%)[1] (N × 6.25)	Cooking time[2] (min)
ICCC 36	24.6	31
ICCC 37	19.2	28
ICCC 42	24.3	40
Control		
Annigeri	21.3	32
SE	±0.22	±0.3

1. Average of five determinations.
2. Average of three determinations.

Plant Improvement

Breeding Methodology

In order to combine the characteristics of Annigeri (high-yielding and wilt-resistant), K 850 (wide adaptation and large seed), JG 62 (high-yielding and double-podded), ICC 506 (*Heliothis*-resistant), and ICCL 83151 (double-podded and wilt-resistant), we grew 4 F_2s of double crosses involving these parents in a wilt sick plot and selected 33 plants for intercrossing in the next generation. We also grew 156 F_3 progenies from plants selected from F_2s of the single crosses among these parents, obtained 24 biparental crosses among plants with desired characteristics, and selected 133 single plants for progeny testing.

We also compared, in replicated trials, 34 lines selected from our earlier study of single, three-, and four-way crosses at ICRISAT Center, and 46 F_2-derived F_6 lines and 47 lines selected from irradiated materials at Hisar. Of these, 15 lines with higher seed yields than the controls were contributed to the ICSNs. The yields of some of these are shown in Table 8.

Desi-kabuli introgression study. The desi-kabuli introgression study was initiated in 1979/80 to explore the possibility of introgressing useful genes from desi into kabuli types and vice versa and to study the variability generated by different seed types in crossing (ICRISAT Annual Report 1981, p. 108).

We selected the highest yielders in the desi, kabuli, and intermediate seed-type F_4 bulks of the desi × kabuli crosses that had been tested during 1982/83. Forty to fifty plants in each selected seed-type bulk were crossed with a desi parent (WR 315) and with a kabuli parent (No.501) to initiate the second cycle of introgression. The F_2s of the six resultant crosses were sown along with desi and kabuli control cultivars. We made observations on phenological and morphological characters to assess the extent of variability generated in the different crosses.

The mean squares for crosses were significant for all the characters studied. On partitioning these, the effects of crossing with desi and kabuli parents, and with the three seed types were also significant.

Crosses with a kabuli type as the third parent tended to increase variability for days to 50% flowering and to maturity, plant height, number of primary branches, seeds pod^{-1}, and yield.

Crosses with a desi type increased variability for number of secondary branches and seed size. The variability of the number of pods plant⁻¹ was similar in both crosses. As a group, the kabuli seed-type bulks generated more variability for days to 50% flowering and maturity, and the desi seed-type bulks produced higher variability for the number of pods plant^{-1}. Variability for number of primary branches and seed size was generated equally by both desi and kabuli seed-type bulks. The intermediate seed-type bulks produced higher variability for number of secondary branches and plant height.

Table 8. Seed yields (kg ha^{-1}) of the best chickpea lines in breeding-methodology trials, ICRISAT Center and Hisar, 1984/85.

Line/cultivar	Seed yield (kg ha^{-1})
Breeding-methodology trial, medium duration (ICRISAT Center)	
ICCX 790244-BT-BP-4P-BP	2130
ICCX 790248-BP-BT-39P-BP	2110
ICCX 790249-BT-BP-39P-BP	2110
Control	
K 850	1860
SE	±120
Trial mean (36 entries)	1900
CV(%)	11
Irradiation trial, long duration (Hisar)	
ICCX 771167-P20-6H-BH-1H-BH	2280
ICCX 771183-P5-3H-BH-4H-BH	2230
ICCX 771179-P5-2H-BH-1H-BH	2220
Control	
H 208	2010
SE	±152
Trial mean (49 entries)	1900
CV(%)	16
F_2-derived lines trial, long duration (Hisar)	
ICCX 780506-7H-BH-BH-BH	2870
ICCX 780528-4H-BH-BH-BH	2750
ICCX 780529-4H-BH-BH-BH	2710
Control	
H 208	2480
SE	±214
Trial mean (49 entries)	2370
CV(%)	18

Off-Season Nurseries

At ICRISAT Center, we grew 108 lines from the male-sterile stocks to make crosses, incorporate the open flower, and protruding-anther characters into male-sterile lines, increase the possibility of outcrossing, and use the male-sterile genes in a recurrent selection program. We backcrossed 103 selected plants using the large-seeded cultivar K 850 as the donor parent for increased seed size.

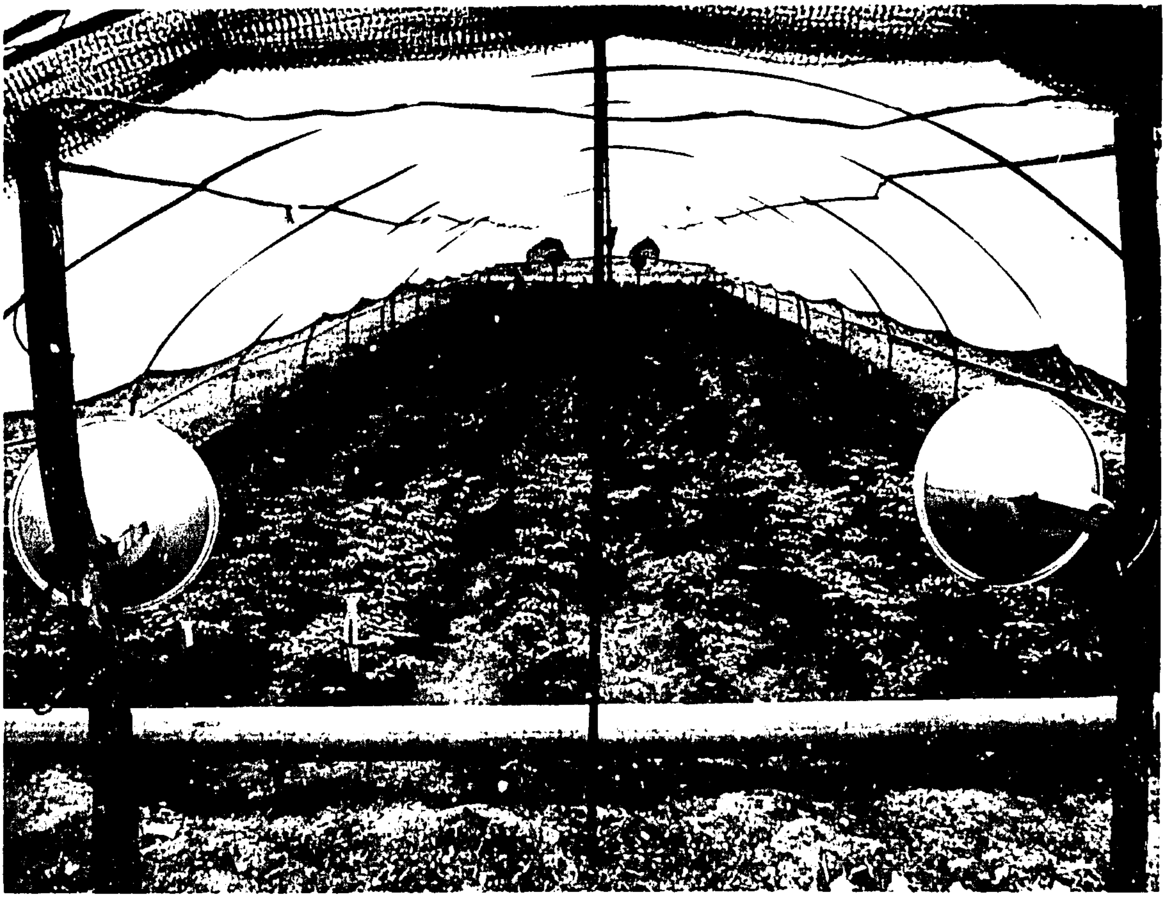
We also made a few specific crosses to combine wilt and *Heliothis* resistance and other crosses involving *Cicer reticulatum* to increase variability for selection.

We grew 219 lines received from ICARDA in the postentry quarantine isolation area at ICRISAT Center. These materials included lines from ICARDA's International Trials and Nurseries for 1985, notably the Chickpea International Screening Nursery (CISN) for winter and spring sowing; the Chickpea International Ascochyta Blight Nursery (CIABN); and the Chickpea International Yield Trials (CIYT) for large-seeded types, and for the subtropical and Mediterranean regions. We are multiplying these lines for distribution to interested cooperators within India and elsewhere.

At Tapperwaripora in Kashmir, we grew 3120 lines for generation advance. Of these, 56% were F_1s, 30% were progenies selected for ascochyta blight resistance, and the rest were other progenies and parents for making crosses. The F_1s grown were mostly three-way crosses to incorporate multiple disease resistances.

Breeding Desi Types

We made 56 single and 161 three-way crosses at ICRISAT Center and Hisar for the short-, and long-duration desi types. Single crosses were in an 8 × 7 line × tester series to combine the adapt-



Chickpea growing during the off-season under a plastic cover at ICRISAT Center, 1985. Protection from rain reduced the disease problems. The plants grew faster due to the lights used to lengthen the photoperiod.

ed and newly identified good parents in the short- and medium-duration category. Three-way crosses were made mainly to complement the characteristics already combined in the F_1, such as high yield, disease and insect resistance, double pod, multiseed, and large seed.

More than 9800 populations and progenies were evaluated at ICRISAT Center and Hisar for the short- and long-duration desi types (Table 9) whereas Gwalior served as a testing site for the medium-duration types. Two F_1 trials, a 6 × 12 line × tester and a 12 × 12, diallel, were grown at both ICRISAT Center and Hisar to collect information on the inheritance of different characteristics and also to identify high-yielding crosses. Both line × tester and diallel analyses

Table 9. Numbers of desi chickpea populations and progeny, ICRISAT Center and Hisar, 1984/85.

	ICRISAT Center		Hisar
Generation	First sowing	Second sowing	First sowing
F_1	138	-	138
F_2	161	-	129
F_3	93	-	104
F_4	74	-	128
F_5	2821	2821	2264
F_6	1117	1117	674
F_7	554	470	438
F_8	594	387	374
Total	5552	4795	4249

further confirmed that additive-gene action plays a predominant role for most of the characteristics in chickpea. The most promising 69 F_1s have been advanced for F_2 Multilocational Trials (MLTs) and the rest will be screened for fusarium wilt resistance in the wilt sick plots.

Early-generation testing was continued. We evaluated 161 F_2 and 93 F_3 short- to medium-duration bulks at ICRISAT Center and Gwalior, and 129 F_2 and 104 F_3 long-duration bulks at Hisar. All the F_2 and F_3 bulks will be advanced further for screening in wilt sick plots and the latter will also be grown for single-plant selection in normal fields.

We evaluated 5086 F_5 to F_8 progenies at ICRISAT Center, and 3841 F_4 to F_8 progenies at Hisar, in augmented design trials with appropriate controls sown at regular intervals. Depending on seed availability, a second sowing of F_5 to F_8 progenies was done in the pesticide-free area at ICRISAT Center to reject lines highly susceptible to *Heliothis* and also to select plants with low borer damage. A total of 4857 plants from different generations was selected at ICRISAT Center and 3407 plants at Hisar. Based on their actual yields, the percentage of increase over the moving average of the controls, and various visual scores such as podding ability, disease, and pest incidence, we selected 347 progenies at ICRISAT Center and 230 at Hisar. These will be tested in replicated trials and the best will then be contributed to the ICSN.

We conducted preliminary yield trials of 184 advanced-generation breeding lines at ICRISAT Center, 188 at Hisar, and 23 at Gwalior. The best-adapted local controls were included for comparison. Forty-nine lines that outyielded the controls were contributed to the ICSN. One-hundred-and-fifteen entries selected from germplasm grow-outs were also tested in replicated trials at ICRISAT Center, Hisar, and Gwalior.

Breeding Kabuli Types

We made 38 single, 11 three-way, and 13 backcrosses. The single and three-way crosses were made between high-yielding parents and sources resistant to ascochyta blight, fusarium wilt, and stunt diseases. The three-way crosses were aimed at combining more than one disease resistance. Five of the backcrosses were to incorporate wilt resistance, while the remaining eight were to increase seed size. We grew 5 F_2 populations and selected 51 single plants and grew 15 F_3 populations and selected 369 single plants from these. From 54 bulks and 1577 progeny rows in F_4 to F_9 generations, we selected 88 promising progeny rows and 1778 single plants for further evaluation in 1985/86. The best 75 progeny bulks will be further tested in 1985/86. We evaluated 111 progeny bulks in replicated, preliminary- and advanced-yield trials. Forty-nine lines were retained for further testing.

We selected ICCX 741106-3P-1H-1P-1H-1H-BH from the advanced yield trial and contributed it as ICCC 49 to the All India Kabuli Gram Coordinated Varietal Trial. In central India, ICCC 32 was tested in minikit trials after it was identified for release in 1984. It yielded 1590 kg ha^{-1} compared with 1220 kg ha^{-1} from the control, cultivar L 550. ICCC 32 has also been identified for release in the North West Plain Zone of India. Two wilt-resistant, short-duration kabuli varieties, ICCV 2 and ICCV 5, are in demonstration trials at five locations in peninsular India to popularize these among farmers.

Extending Chickpea Adaptation

Early sowing in peninsular India. Screening germplasm and breeding materials for adaptation to early sowing (mid-September) continued at ICRISAT Center. We evaluated 21 F_2 and 15 F_3 populations and 732 F_3-F_4 progenies, in addition to 684 wilt-resistant progenies earlier screened through the wilt sick plot, under early-sown conditions. In all, 1331 single plants and 25 lines were selected for further evaluation.

We also screened 175 germplasm and breeding lines, grouped according to duration, in three early-sown trials and repeated the comparison of previously identified lines under early- and normal-sowing (mid-October) to identify adapted genotypes and characters that contribute to the adaptation. In screening trials, several short-, and short-to-medium-duration lines produced higher seed yields than the control (Table 10) and 16 lines were selected for an early-sowing versus normal-sowing comparison next year.

Whenever comparisons have been possible, early-sown chickpeas have yielded better than those sown at the normal time, and several genotypes (notably P1329, P18, and P4089-1) have consistently produced higher seed yields than the control Annigeri (ICRISAT Annual Report 1981, p.111, and ICRISAT Annual Report 1983, p.136). In 1984/85 the seed yields of early-sown chickpea (1840 kg ha^{-1}) were again significantly higher than from those sown at the normal time (1090 kg ha^{-1}). The same genotypes, when sown early, prolonged their reproductive periods, resulting in increased pod and seed numbers and seed size. Several entries produced higher seed yields than the control Annigeri (Table 10).

Table 10. Seed yields (kg ha^{-1}) of some high-yielding chickpea genotypes in early-sown (September) trials, ICRISAT Center, 1984/85.

Genotype	Seed yield (kg ha^{-1})
Screening trial 1	
P 69099-2	2450
P 9650	2380
RPSP 431-1	2352
Control	
Annigeri	2207
SE	±113
Trial mean (49 entries)	2180
CV(%)	10
Screening trial 2	
T113	2770
P 4197-2	2610
1-209-15	2600
Control	
Annigeri	2400
SE	±154
Trial mean (64 entries)	2140
CV(%)	12
Early vs normal trial (early-sown)	
P 18	2360
N 31	2280
P 4089-1	2260
Control	
Annigeri	2140
SE	±101
Trial mean (49 entries)	1840
CV(%)	11

Late sowing in northern India. There is increasing interest in introducing chickpeas into new areas and cropping patterns, particularly in rotation with rice and cotton. We continued our work on this aspect at Hisar to identify and develop genotypes suited to late-sown conditions that occur when rainy-season crops vacate the fields late.

The normal time for sowing at Hisar is during the last week of October. We sowed 25 F_2 populations of the crosses of genotypes suited to late sowing a month later than usual and selected 350 single plants for testing in the F_3 generation. Over 100 desi and kabuli F_5 to F_7 progenies exceeded the moving average yields of the best control. From these 4.8 m^2 plots, the highest yield (equivalent to 4450 kg ha^{-1}) was recorded from desi-type ICCX 790515-BT-BH-BH-22H-1H and among the kabuli types the maximum (3440 kg ha^{-1}) was obtained from ICCX 800362-BH-4H-1H. We individually bulked 45 desi and 22 kabuli lines that yielded well and registered an appreciable increase over the controls. These will be tested in 1985/86.

We evaluated 57 advanced-generation desi-, and 23 kabuli lines in the preliminary yield trials for late sowing. Two desi lines gave significantly higher yields than the control H 208, the best being ICCL 85502 with 2411 kg ha^{-1}. In the kabuli trial, ICCL 85504 gave the highest seed yield of 1252 kg ha^{-1} compared with 537 kg ha^{-1} from the control (L 550).

We also conducted an advanced yield trial of 23 desi selections and one of 10 kabuli selections. The best entry in the desi trial gave 1488 kg ha^{-1}

against 1194 kg ha^{-1} for the control (H 208). In the kabuli trial, no breeding line produced a higher yield than ICCC 32, but eight outyielded the control, L 550.

Of the three lines contributed to AICPIP late-sown trials in 1983, ICCC 14 and ICCC 41 were selected for further testing.

Novel Plant Types

Tall, erect habit. We continued our efforts to breed improved medium-tall, erect, and compact genotypes. We made 35 three-way crosses involving tall types, high-yielding lines, and disease-resistant lines. We also made six backcrosses to incorporate ascochyta blight resistance into medium-tall and high-yielding lines. All the F_1s were advanced in the off-season nursery at Tapperwaripora, Kashmir.

We selected 506 plants from 30 F_2 populations at ICRISAT Center and 124 plants from 11 F_2 populations at Hisar. We evaluated 1420 F_3 to F_8 progenies at ICRISAT Center and selected 400 plants and 22 rows. At Hisar, we grew 1210 progenies and selected 725 plants, 320 progeny bulks, and 38 rows.

We conducted two replicated, preliminary yield trials at ICRISAT Center and one trial at Hisar. The best lines from these have been contributed to the ICCT and the ICSN. Data from the three highest-yielding lines from the Hisar trial are presented in Table 11.

Table 11. Plant height, 100-seed mass, and seed yield of the three highest-yielding, medium-tall and compact chickpea genotypes, preliminary yield trial, Hisar, 1984/85.

Line/cultivar	Plant height (cm)	100-seed mass (g)	Seed yield (kg ha^{-1})
ICCX 770376-BP-12H-2H-BH	100	19.7	3180
ICCX 770918-2H-1H-2H-BH	81	14.7	2870
ICCX 761281-28H-2H-3H-1H-BH	99	18.8	2620
Controls			
H 208	82	14.0	2100
ICCX 750070-48-1P-2H-BH	100	13.6	1360
SE	±2.7	±0.51	±235
Trial mean (49 entries)	95	15.1	1960
CV(%)	6	7	24

Double-podded and multiseeded types. Selection to combine double-podded and multiseeded characteristics with high yield and disease resistance continued. At ICRISAT Center, we grew 12 F_2s of crosses among wilt-resistant, double-podded, multiseeded, and high-yielding lines in the wilt sick plot, and evaluated nearly 3000 F_3 and more-advanced-generation progenies in normal fields for yield and multiseeded characters. From these, 1085 single plants were selected for progeny tests, and 133 progenies (106 short-duration and 27 medium-duration) giving higher seed yields than the moving averages of control cultivars were bulked for yield tests in the 1985/86 postrainy season. Twenty-three lines with more seeds per pod and 47 with a higher proportion of double-podded nodes were also selected for further tests.

We also evaluated 57 lines in yield tests and 3 of the best (Table 12) were contributed to the ICSNs. In another study of multiseeded and double-podded lines, in collaboration with the agronomists, two lines (MSDP 2 and MSDP 66) combining the two characteristics were identified for the first time.

At Hisar, we screened 23 F_2s and 62 F_3s in the wilt-sick plot and 10 F_2s in the ascochyta blight screening nursery, and evaluated over 1800 progenies for agronomic traits. From these, 960 plants were selected for progeny tests and 115 lines with superior performance were bulked for replicated tests. From a preliminary yield trial of 23 lines, the three most-promising lines (Table 12) were contributed to international nurseries or trials.

Cooperative Activities

International Trials and Nurseries

During 1984/85, chickpea breeders distributed 155 sets of 13 different international trials and nurseries from ICRISAT Center. These were in addition to the pathology nurseries and trials

Table 12. Seed yields (kg ha⁻¹) of the highest-yielding multiseeded and/or double-podded chickpea lines, preliminary trials, ICRISAT Center and Hisar, 1984/85.

Line/cultivar	Seed yield (kg ha^{-1})
ICRISAT Center Trial 1	
ICCX 780362-9P-BH-2P-BP	2180
ICCX 780325-35P-BP-1P-BP	2130
ICCX 780362-14P-BH-3P-BP	2070
Control	
Annigeri	1980
SE	±125
Trial mean (36 entries)	1850
CV(%)	12
ICRISAT Center Trial 2	
ICCX 780357-95P-BP-1P-BP	2240
Control	
K 850	2030
SE	±131
Trial mean (25 entries)	1890
CV(%)	12
Hisar Trial	
ICCX 800460-25H-BH	2380
ICCX 780362-25H-1H-BH	2300
ICCX 780361-12P-1H-BH	2180
Control	
H 208	1890
SE	±301
Trial mean (25 entries)	1450
CV(%)	36

described earlier. In all, a total of 198 sets were sent to 29 countries (Table 13). In the F_2 and F_3 multilocational trials, a few bulks were higher-yielding than the local control at some locations. Many cooperators are using these segregating bulks to select material adapted to their local environments.

Based on the data received, we found that some lines in the ICSNs were higher-yielding than the controls at many locations. Overall, the highest-yielding lines were ICCL 82108 in the desi short-duration nursery, ICCL 84327 in the desi medium-duration nursery, and ICCL 83448 in the desi long-duration nursery.

In the International Chickpea Cooperative Trial of Desi Short-duration (ICCT DS) lines, ICCL 83132 and ICCL 83149 gave the highest yields and these have been entered for testing in the All India Coordinated Trials. In the Interna-

Table 13. Countries to which chickpea trials and nurseries were distributed from ICRISAT Center, 1984/85.

Country	Number sent
Afghanistan	1
Argentina	1
Australia	1
Bangladesh	8
Burma	5
Canada	4
Cape Verde Islands	2
Chile	2
Colombia	1
Egypt	1
Ethiopia	6
Greece	1
India	103
Iran	1
Iraq	1
Kenya	1
Republic of Korea	4
Mexico	5
Nepal	6
Pakistan	26
Peru	1
Philippines	3
Spain	1
Sudan	1
Syria	1
Tanzania	1
Tunisia	2
USA	7
Yemen AR	1
Total	198

tional Chickpea Cooperative Trial of Desi Long-duration lines (ICCT DL) none of the entries gave high yields at all locations but some gave high yields at individual locations.

Adaptation Trials

The International Chickpea Adaptation Trials (ICAT) were conducted for three seasons from 1981/82 to 1983/84. These trials were distributed in collaboration with ICARDA to study genotypic responses in order to help refine our testing and selection strategies. We have received analyzable data from 80 out of 220 locations to which trials were sent during the 3 years. These data have been analyzed, and will be reported separately. This year, the ICATs were sent only to the Cape Verde Islands, Colombia, and Korea in response to requests from local scientists who wish to find out whether chickpea can be grown and if so, what type of material is suitable in their countries.

Distribution of Breeders' Material

We supplied 3630 seed samples of segregating populations and other breeding materials to cooperators in 23 countries. The majority of these samples went to cooperators in India (2680 samples) and Pakistan (800 samples).

Cooperation with the All India Coordinated Pulses Improvement Project (AICPIP)

We contributed two new desi lines (ICCC 47, 48) and one new kabuli line (ICCC 49) to the coordinated varietal trials of AICPIP for testing in the 1985/86 season. Out of 18 ICRISAT entries tested during the 1984/85 season, many lines gave better yields than the controls. In the Gram Coordinated Varietal Trial (GCVT), ICCC 40 ranked third in the Central Zone; and ICCC 29 ranked fourth in the Northwest Plain Zone. In the Gram Initial Evaluation Trial (GIET), ICCC 42 ranked third in the Central Zone, and ICCC 41 ranked first in the late-sown trials in the Southeast Zone. These lines along with 14 other ICRISAT contributions have been retained for further testing.

Kabuli cultivar ICCC 32, identified for release in the Central Zone in 1984, was tested in prerelease minikit trials in farmers' fields in Madhya Pradesh. It yielded 30% more than the control cultivar L 550. During this season it was also identified for release in the Northwest Plain Zone. We supplied 600 kg seed of ICCC 32 for minikit trials in Maharashtra, Madhya Pradesh, Gujarat, Rajasthan, Punjab, and Haryana States.

We supplied 430 kg breeders' seed of ICCV 1 (ICCC 4) to Gujarat to supplement seed multiplication of this variety in that State where this variety was released 3 years ago. Following a request from government agencies in Andhra Pradesh to supply seed of ICCC 37, we sent 185 kg of seed for minikit trials and 200 kg for seed multiplication by the Andhra Pradesh State Seeds Development Corporation.

In cooperation with AICPIP scientists, we initiated demonstration trials of the short-duration, wilt-resistant kabuli cultivars (ICCV 2 and 5) to popularize cultivation of kabuli chickpea in peninsular India. We also began to assess the advantage of early sowing (mid-September in comparison to the normal mid-October sowing) in peninsular India in cooperation with five national research stations.

Cooperation with ICARDA

The objective of the ICRISAT/ICARDA Kabuli Chickpea Project is to develop disease- and insect-resistant, high-yielding genotypes for different agroecological conditions to increase the productivity of kabuli chickpeas wherever they are grown. An ICRISAT chickpea breeder is stationed at ICARDA in Tel Hadya, near Aleppo in Syria, and ICRISAT scientists of other disciplines visit ICARDA for long periods to help with the research. The kabuli type of chickpea is widely grown as a spring-sown crop on conserved moisture in the Mediterranean region. In the Indian subcontinent, the Nile Valley, and

Latin America, the crop is sown in winter. Advancing the sowing date from spring to winter in the Mediterranean region and using cultivars tolerant to ascochyta blight and cold result in substantial increases in seed yield.

Three sites, i.e., Tel Hadya (low elevation, 340 mm annual rainfall), Jindiress (low elevation, 450 mm annual rainfall), and Terbol (medium elevation, 550 mm annual rainfall) have been used for testing newly developed materials for yield potential and adaptation before they are sent to the national programs. All entries included in yield trials are rescreened for resistance to ascochyta blight and cold. In addition, the genotypes are evaluated for tolerance to leaf miner (*Liriomyza cicerina*), cyst nematode (*Heterodera* sp), and a parasitic plant (*Orobanche* sp). They are also tested for reduced photoperiod sensitivity and for protein content. Lines that are more susceptible to pests or cold, and with lower protein contents than the control cultivar are rejected.

Table 14. Number of kabuli chickpea trials distributed to cooperators from Tel Hadya, Syria, 1977-86.

Season	Trial types[1]	Trials distributed	Countries
1977/78	2	34	15
1978/79	5	84	17
1979/80	6	187	31
1980/81	10	245	25
1981/82	9	300	31
1982/83	8	319	42
1983/84	9	368	48
1984/85	11	419	46
1985/86	11	447	46

1. Trial types include disease-resistance nurseries, adaptation tests, and several trials comparing new breeding materials.

International Testing Program

International trials. The kabuli-type chickpea is grown in over 30 countries; many of these are currently developing their own breeding programs. To support their efforts, we supply them with early- and advanced-generation breeding material, finished cultivars, and disease- and insect-resistant lines. The national programs have found our material useful, as is evident from a 13-fold increase in the distribution of our trials in 8 years (Table 14). In keeping with the differing agroecological conditions and consumer preferences, we have diversified the trial types from 2 in 1977/78 to 11 in 1985/86. Most of our nurseries are supplied to cooperators in the Mediterranean region and the Americas, some to the Indian subcontinent, and a few to eastern Africa. We have noticed a growing demand from many countries that do not grow chickpea, but wish to introduce it as a new crop.

On-farm trials. The on-farm trials that started in Syria during 1979/80 have been extended to other countries. During 1984/85, we furnished seed and information to Egypt, Morocco, Syria, and Turkey. Earlier, similar help was provided to Cyprus, Jordan, and Lebanon. Each year, we furnish more than a tonne of seed of different cultivars for on-farm trials. In Syria, such trials have been conducted jointly by ICARDA and the Ministry of Agriculture and Agrarian Reform.

Cultivar release. The international testing program has earlier led to the release of ILC 482 in Syria and ILC 3279 (as Yialousa) in Cyprus. Several other genotypes have now been identified for release in six countries (Table 15).

Cooperators in many other countries have found promising lines among the materials that we have supplied and are using them in their breeding programs.

Plant Improvement

Crossing program. The numbers of crosses per year have steadily increased since 1978. We have made nearly 2500 crosses, including 421 in 1985. Of this total, about 85% have been single crosses. In earlier years, the major emphasis was on the development of genotypes with tolerance to

Table 15. Kabuli chickpea lines from ICARDA that have already been released as cultivars and those under consideration for release in various countries.

Country	Released cultivars	Cultivars under consideration for release
Syria	ILC 482	ILC 3279
Cyprus	ILC 3279 (Yialousa)	
Turkey		ILC 195, ILC 482
Morocco		ILC 195, ILC 482, and ILC 484
Egypt		ILC 482
Spain		ILC 72 (Fardon), ILC 200 (Atalaya and Zegri), ILC 2548 (Almera) and ILC 2555 (Alcazaba)

ascochyta blight and cold, so crosses were invariably between parents known to possess such tolerances, and those with wide adaptation and high yields. More recently, our program has diversified and crosses are made to develop genotypes for winter and spring sowing, for tall plants and large seeds. We also make some crosses that involve desi types.

As part of our assistance to national breeding programs, we make crosses specifically for breeders in several countries. Junior scientists who come to Tel Hadya for training are shown how to make crosses and are encouraged to practice the technique.

We grew 337 F_1s in the off-season nursery under continuous light at Sarghaya. Continuous light allows us to transfer genes from long-duration genotypes, that otherwise do not flower during the summer.

Segregating populations. We grew more than 250 F_2 populations at Tel Hadya in the ascochyta blight screening nursery, but due to excessive irrigation we lost most of these and the remainder were bulk harvested.

A total of 14 225 F_3 to F_7 progenies were grown during 1984/85. Of these, 5111 F_3 progenies were grown in the off-season where the material was screened for reduced photoperiod sensitivity. The others were grown in the main season at Tel Hadya. The 1984/85 winter was unusually cold and many progenies were killed. The materials that survived were subjected to careful selection. The selected plants and bulked progenies should have a high level of cold tolerance, an important prerequisite for winter sowing. Many lines not only survived the low temperatures and waterlogged conditions, but were also productive and uniform. A total of 311 lines were bulked. These will be screened for reduced photoperiod sensitivity during the 1985 off-season and the selected lines will be tested for yield and adaptation in 1985/86.

Yield trials for winter sowing. The seed yields of about 200 newly bulked lines were recorded at Tel Hadya, Jindiress, and Terbol. Of these, 123 entries at Tel Hadya, 27 at Jindiress, and 12 at Terbol significantly exceeded the control (Table 16). A few gave greater yields than the control at all locations revealing their wide adaptation.

Yield trials for spring sowing. About 200 newly bulked lines were evaluated for yield at Tel Hadya, Jindiress, and Terbol (Table 16). Although many exceeded the control yields, only one line each at Tel Hadya and Terbol gave significant increases. Analyses of the results from past years indicate that most of the newly developed lines mature later than the control. As the growth period for the spring sowings is short, it favors short-duration lines. As a result of this observation, crosses have been initiated to generate short-duration genotypes.

Large-seeded types. There is a substantial demand from national programs for ascochyta blight resistant chickpeas with large seeds, and special emphasis is being given to the development of these types. During 1984/85, 1234 F_3 to F_5 progenies were grown, 2099 plants were selected, and 26 promising progenies were bulked. Many of the newly bulked lines have very large 100-seed mass (>50 g).

Eighteen newly developed lines that have large seeds and are resistant to ascochyta blight were evaluated for yield, the performance of the best

Table 16. Mean yield (kg ha^{-1}) performance of the newly bulked, developed chickpea lines in winter and spring trials[1], Syria and Lebanon, 1984/85.

Location and season	Trials conducted	Entries tested	Entries exceeding control[2]	Entries significantly exceeding control	Yield range of the best entries (kg ha^{-1})	SE range	CV (%) range
Tel Hadya, Syria							
Winter	15	255	208	123	630-2530	± 79-185	15-51
Spring	14	237	53	1	2090-2230	± 69-146	5-16
Jindiress, Syria							
Winter	11	193	100	27	1480-2290	±106-180	16-34
Spring	11	193	4	0	1310-1790	± 75-158	8-24
Terbol, Lebanon							
Winter	13	229	152	12	1880-2600	±149-250	11-23
Spring	13	229	78	1	2710-4030	±260-572	14-32

1. Randomized-block design, plot size 3 m^2.
2. Controls for winter = ILC 482; spring = ILC 1929.

six is shown in Table 17. A major reason for the higher yield of these entries, compared to the control, was their better cold tolerance. After another year of evaluation, the best will be provided to cooperators.

Tall chickpeas. Many farmers in the Mediterranean region prefer tall chickpeas, that can be efficiently harvested by machine. The tall chickpeas available in our germplasm collection have three major deficiencies: poor seed type, low yield, and long duration. We have now developed tall kabuli lines that are high-yielding, large-seeded, and cold-tolerant (Table 17). These

Table 17. Performance of the six large-seeded chickpea entries in the winter-sown, preliminary yield trial, Tel Hadya, Syria, 1984/85.

Entry	Time to 50% flowering (d)	Plant height (cm)	Cold tolerance[1]	100-seed mass (g)	Yield (kg ha^{-1})
FLIP 84-19C	133	38	5.0	46	1960
FLIP 84-18C	132	40	3.0	44	1790
FLIP 84-17C	138	34	5.5	45	1650
FLIP 84-1C	144	31	7.0	43	1380
FLIP 84-12C	140	30	7.0	41	1230
FLIP 84-2C	142	33	7.0	40	1030
Control					
ILC 482	136	19	8.0	26	330
SE	±1.1	±1.3		±1.5	±180
Trial mean (21 entries)	139	29		38	820
CV (%)	1	11		5	31

1. Measured on a 1-9 scale where; 1 = damage free and 9 = killed; ratings based on two replications.

A newly developed tall, erect, well-podded, kabuli type chickpea, Syria, 1985.

lines, however, are long-duration types so future emphasis will be on the development of shorter-duration types. The plant heights shown in Table 18 are less than those generally attained by these genotypes because the unusually cold season reduced plant growth and yields.

Thirty-four tall chickpea progenies were bulked during 1984/85. Some of these have a 100-seed mass exceeding 40 g. Some are as early as ILC 482, which is high-yielding and widely adapted but is susceptible to severe cold. It is hoped that one or more of the short-duration, cold-tolerant, tall chickpeas will replace this widely used cultivar.

Desi chickpea. We are also working to develop ascochyta blight resistant, desi types, especially suited to Pakistan and Northwest India. Most of the crosses were made at ICRISAT Center and F_2 seeds were sent to Tel Hadya for screening. During 1984/85, more than 50 promising F_5 progenies were bulked. They are being grown in the off-season nursery during 1985 and those with reduced photoperiod sensitivity will be sent to breeders in Pakistan and ICRISAT Center for evaluation of their yield and adaptation.

ICARDA Germplasm

During 1984/85, 400 new accessions were added to the ICARDA collection, mainly from Pakistan, Turkey, and the USSR increasing the total kabuli accessions to 5990. Publication and distribution of the Kabuli Chickpea Germplasm Catalog resulted in a large demand for seed. A total of 6265 germplasm samples were furnished to eight countries; including 2000 each to Tunisia, Turkey, and the USA and 139 to the USSR.

Screening Germplasm and Breeding Lines for Resistance to Stress Characteristics

Cold Tolerance

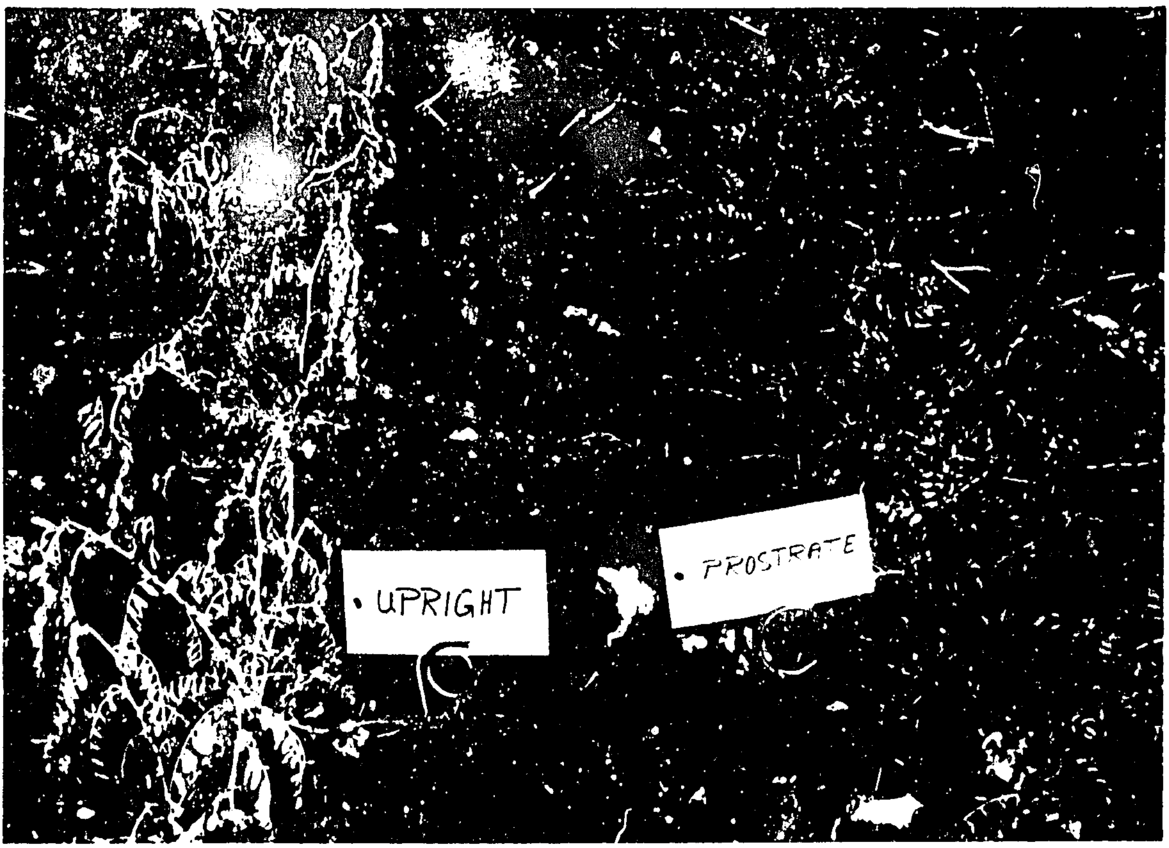
The 1984/85 winter season was one of the coldest years ever recorded in Syria. Temperatures fell below 0°C on 41 nights; -9.8°C being the lowest. There were frosts on most nights between 20 February and 15 March, when the crop had grown substantially. This killed many lines and severely damaged others. Taking full advantage of this opportunity, the germplasm accessions, breeding lines, and advanced, segregating generations were screened for cold tolerance. None of the lines remained unaffected, but 85 lines were found to be tolerant (rated 3 on a 1-9 scale, where 1 = damage free and 9 = killed) and 782 lines moderately tolerant (rated 4).

An interesting phenomenon, similar to that seen in winter-hardy wheat, was observed. In some lines, the above-ground portions were killed, but soon after the temperatures increased, plants recovered fully and some produced high yields.

Table 18. Performance of six tall chickpea lines, preliminary yield trial, Tel Hadya, Syria, 1984/85.

Entry	Time to 50% flowering (d)	Plant height (cm)	Cold tolerance[1]	100-seed mass (g)	Seed type[2]	Yield (kg ha^{-1})
FLIP 84-20C	136	37	5.5	32	K	1830
FLIP 84-43C	138	32	3.0	30	K	1630
FLIP 84-46C	137	43	4.5	34	K	1470
FLIP 84-22	140	40	6.0	34	K	1280
FLIP 84-42	142	39	6.0	32	K	1050
FLIP 82-33	139	47	5.5	37	K	980
Control						
ILC 3279	141	42	6.0	29	I	1260
SE	±1.7	±1.9		±0.9		±181
Trial mean (11 entries)	139	35		32		1050
CV (%)	2	7		4		24

1. Measured on a 1-9 scale where; 1 = damage free and 9 = killed; ratings based on two replications.
2. K = Kabuli. I = Intermediate.



The upright chickpea genotype (left) was badly damaged by cold while the prostrate chickpea genotype (right) was cold-tolerant and survived, Syria, 1985.

Cold-tolerance screening is usually done by advancing the sowing date to late September at Tel Hadya. This year's cold was so harmful that most of the genotypes sown during this period were killed. However, two lines (ILC 3426 and ILC 347) survived and fully recovered. These lines might be useful as donor parents for cold tolerance.

More than 10 000 progenies from our breeding program were screened for cold tolerance and most were found to be susceptible. However, many lines were rated 3 or 4 and some of these were very productive and uniform; the best were bulked for further evaluation.

Screening for Resistance to Cyst Nematode (*Heterodera* sp)

Greenhouse screening at Tel Hadya of 290 ascochyta blight resistant, kabuli lines in previous years revealed that 27 had relatively little damage caused by the cyst nematode. Th lines were sown in an advanced screening trial during 1984/85 and resistance to *Heterodera* sp was confirmed in four of them. Simultaneously, 183 lines developed during 1984 were screened in on augmented-design trial with 3 controls in each block, ILC 482 (susceptible), ILC 1929 (susceptible), and ILC 3279 (tolerant). Twenty-six lines were found to have some resistance, having few cysts per gram of roots. These 26 lines and the 4 lines from the previous screening were rescreened. Twelve of these were confirmed to be resistant to the cyst nematode.

We also screened 70 lines from our 1984/85 crossing program in an augmented-design trial and 7 appeared to have some resistance. These will be retested in 1985/86. Of nine lines of wild species that were screened only one, *Cicer bijugum*, appeared to have some resistance. This work on nematode diseases is carried out in cooperation with the Instituto di Nematologia Agraria, CNR, Bari, Italy.

Other Stress Conditions

Perhaps as a result of the very low temperatures in this season few *Orobanche* sp shoots developed and leaf miner populations were low. Consequently, we could not screen for resistance to these pests in 1985.

Ascochyta blight (*Ascochyta rabiei*)

Screening for resistance. The 1984/85 season was very unfavorable for the development and spread of ascochyta blight. After the extremely low temperatures during February and March, the weather became dry and unusually hot, conditions least favorable for ascochyta blight development. Despite repeated spore-suspension sprays and sprinkler irrigations, the disease did not develop in epiphytotic form. Consequently, the germplasm breeding lines could not be adequately screened and pathological experiments conducted in the field gave few useful data. The disease not only failed to develop at the experiment station, but also in farmers' fields in western Asia and northern Africa.

Effects of spore concentrations of *Ascochyta rabiei* on genotype blight reaction. The effects of inoculations using spore concentrations ranging from 50000 mL^{-1} to 7500000 mL^{-1} of *Ascochyta rabiei* (race 3) on the disease development in 10 chickpea genotypes were studied in a greenhouse at Tel Hadya (Table 19). In general, higher spore concentrations increased the disease severity, but the effects differed among the genotypes. For example, ILC 3996 resisted spore concentrations of up to 5 million mL^{-1} but at 7.5 million mL^{-1} the plants succumbed. However, ILC 182 and ILC 482 had relatively consistent resistant reactions across all concentration treatments. Some genotypes, particularly ILC 215 and ILC 1929, showed susceptibility to the lowest concentration.

Effect of 100% relative humidity (RH) on ascochyta blight severity. The effect of 100% RH for different periods on ascochyta blight development was studied in 10 chickpea genotypes that are known to differ in their reaction to race 3 of the pathogen. Longer periods of 100% RH increased disease severity and the threshold

Table 19. Effect of spore concentrations (× 1000 mL⁻¹) on reaction of chickpea genotypes to race 3 of *Ascochyta rabiei*, greenhouse trial, Tel Hadya, Syria, 1984/85.

Genotype	Blight severity[1] at different spore concentrations 50	100	500	1000	5000	7500
ILC 182	2.0	3.7	4.3	4.7	3.3	4.3
ILC 187	3.3	4.3	4.0	4.3	5.7	6.0
ILC 200	2.7	4.3	5.7	5.7	5.3	5.7
ILC 215	7.3	6.0	8.0	8.0	8.7	8.7
ILC 482	5.0	5.0	6.0	6.0	5.7	6.7
ILC 1929	8.7	8.7	9.0	7.3	9.0	9.0
ILC 3279	3.0	3.0	5.7	5.7	5.3	6.3
ILC 3346	5.7	4.7	6.0	6.0	6.0	6.3
ICC 3996	2.0	2.0	3.0	3.3	3.0	6.7
ICC 4935	4.0	3.0	5.0	6.0	5.7	6.7

SE Spore concentration at same or different level of genotype ±0.43

SE Genotypes at same level of spore concentration ±0.43

CV% 14

1. Measured on a 1-9 scale where; 1 = damage free and 9 = killed.

period differed among the genotypes (Table 20). For example, ILC 182 showed resistance in all periods, whereas ILC 3279 was resistant when exposed to high humidities for 1 day but was susceptible in longer periods. It can be concluded that if the weather conditions remain favorable for disease development for a protracted period, some of our resistant lines may suffer heavy yield losses.

Pakistan

ICRISAT has placed a plant breeder/pathologist at the National Agricultural Research Center (NARC) in Islamabad to strengthen chickpea research in Pakistan. This project, financed by the Asian Development Bank (ADB), aims to develop high-yielding chickpea genotypes that are resistant or tolerant to ascochyta blight. This disease is severe in the Punjab Province of Pakistan where 80% of the nation's chickpea crop is grown. Epidemics have devastated the crop in several years.

Germplasm Evaluation for Resistance to Blight

In 1984/85, 1688 germplasm accessions were sown in single rows in the Pathology Block of NARC. The susceptible control (C 727) was sown after every 10 test entries. Diseased plant debris was chopped and spread over the plots to help initiate blight. At 10-day intervals from February, spore suspensions of *A. rabiei* (50 000 spores mL⁻¹) were sprayed on to the trial four times followed by sprinkler irrigations. Disease reactions were recorded in April on a 1-9 scale, and are summarized in Table 21. None of the accessions was highly resistant and most were highly susceptible, but entries that were rated 5 or less will be retested next season.

Table 20. Effect of 100% relative humidity period length on reaction of chickpea genotypes to race 3 of *Ascochyta rabiei*, greenhouse trial, Tel Hadya, Syria, 1984/85.

Genotype	Blight severity[1] at 100% humidity 0 h	8 h	1 d	5 d	10 d	15 d	20 d	25 d	30 d
ILC 182	2.0	2.3	3.3	2.7	4.7	4.3	3.7	3.7	3.3
ILC 187	2.0	4.3	4.7	4.3	4.7	6.3	6.0	6.0	6.0
ILC 200	2.7	3.3	4.3	4.3	3.3	6.0	6.0	5.0	6.0
ILC 215	6.0	6.3	6.3	6.3	7.0	7.0	6.3	8.7	8.7
ILC 482	2.7	5.0	5.0	6.0	5.7	6.0	6.0	7.7	8.0
ILC 1929	7.0	9.0	8.7	9.0	8.0	8.3	9.0	9.0	9.0
ILC 3279	2.0	3.3	3.0	5.7	5.0	6.0	6.0	6.0	6.0
ILC 3346	2.3	5.0	5.7	6.0	5.7	6.0	6.0	6.7	6.7
ILC 3996	2.0	2.0	3.0	2.3	3.0	4.3	5.0	6.0	6.0
ILC 4935	2.0	5.0	2.7	5.0	4.3	5.7	4.7	6.0	6.0

SE Time periods at same or different level of genotypes ±0.42

SE Genotypes at same level of time period ±0.41

CV% 14

1. Measured on a 1-9 scale where; 1 = damage free and 9 = killed.

Table 21. Reactions of chickpea germplasm accessions to ascochyta blight in field plots, National Agricultural Research Center, Islamabad, Pakistan, postrainy season, 1984/85.

Blight severity[1]	Number of entries
1	0
2	0
3	5
4	41
5	126
6-9	1516

1. Measured on a 1-9 scale where; 1 = disease-free, and 9 = highly susceptible.

The 210 germplasm accessions that had blight ratings of 5 or less in the 1983/84 tests were also sown in the Pathology Block for confirmation, using the same method. Five were rated at 4, 27 rated at 5, and the others were rated at more than 5 and so were considered to be susceptible. Seeds of the entries with ratings of 4 and 5 were collected for future evaluation for yield and other characteristics.

Evaluation for Yield and Other Desirable Characteristics

We evaluated 205 germplasm accessions that were earlier introduced from ICRISAT and tested against blight for agronomic characteristics including yield. There were two objectives: to select accessions with desirable characteristics such as good plant type, large seed, and high grain yield that could be directly released as cultivars after proper evaluation, and to select those which, although not suitable for direct release, could be used as parents in the breeding program.

Some of the accessions flowered in just over 100 days and produced high grain yields. Such short-duration genotypes will be of particular interest for the Sind Province, where the growing season is short. Fifty accessions were selected for further testing.

Crossing Program

During the 1984/85 season, 49 crosses were made involving 16 genotypes. One parent of each cross had some resistance or tolerance to ascochyta blight. The other parent was either resistant or tolerant to blight or had qualities that would contribute to high grain yield. Most of the parents were lines bred at ICRISAT or ICARDA, except a few that were bred locally.

Segregating Populations

Eightynine F_2, 14 F_3, and 260 F_4 populations were received from ICRISAT for testing. These were sown at NARC in replicated trials or single rows. Individual plant selections were made with respect to blight tolerance, but as plant growth was restricted due to late sowing and drought, most were bulked within crosses. These will be further tested when data on reactions to blight, growth habit, yield components, and yield will be recorded.

Generation Advancement

Some F_1s and segregating populations (F_2-F_5) were sown in the Kaghan Valley (high altitude) during the off-season (July-September) for generation advancement.

Training

We were pleased to welcome many scientists for training in various aspects of chickpea research and development, in cooperation with our Training Program. The periods of training varied from as little as a few hours, for training in specific methodology, to 3 years for completion of PhDs.

The Sixth International Training Course in Pigeonpea and Chickpea Pathology was conducted, 7-22 January. Sixteen participants from nine countries (Bangladesh, Chile, Ethiopia, India, Mexico, Nepal, Pakistan, Syria, and

Thailand) attended this course. Also in pathology, a postdoctoral scientist from India completed his 2-year fellowship having worked on nematodes, and a PhD student arrived to research races of *A. rabiei.*

In agronomy, a scientist from Morocco joined us for 3 months to learn techniques used in research on chickpea *Rhizobium*, and a scientist from India also completed her training, in microbiology this year.

In entomology, a postdoctoral fellow completed his 2-year study on the use of pheromone and light traps for monitoring populations of *H. armigera.*

A scientist from Ethiopia joined us as a research scholar to study breeding methods in chickpea. He will carry out his PhD thesis research with our chickpea breeders and his course work at the local agricultural university. A scientist from India completed a 3-month training period, during which he gained experience in screening for disease resistance and various aspects of chickpea breeding. Another Indian scientist has joined us for up to 2 years and is studying the inheritance of disease resistance in chickpea, under the guidance of our pathologists and breeders.

Workshops, Conferences, and Seminars

Chickpea Scientists' Meet

This year's Annual Chickpea Scientists' Meet was jointly organized by ICRISAT and the Haryana Agricultural University (HAU) at Hisar, 3-5 April 1985. There were 59 participants from India (including scientists from ICRISAT and HAU), 2 from Pakistan, and 1 from Turkey.

ICRISAT and HAU chickpea scientists explained and showed different experiments conducted in breeding, genetic resources, agronomy, entomology, and pathology. Later, the participants selected breeding materials in the ICRISAT and HAU breeding plots. Seeds from selected plants have been sent to them for evaluation and further selection at their locations.

The main theme of the discussion was on how ICRISAT chickpea material has been utilized by recipient scientists, and how existing linkages between ICRISAT and national programs can be improved. The participants appreciated the supply of materials from ICRISAT. They reported that some of these materials have been used as sources of resistance in their crossing program and that selections from early- and advanced-generation breeding materials from ICRISAT have performed well and are being tested in regional and national trials. The participants observed that these annual meetings are helpful to exchange information. They suggested that ICRISAT should conduct more basic studies in physiology and biochemistry to help national programs.

Review and Planning Meeting for Asian Regional Research on Grain Legumes

This meeting, funded by the Australian Development Assistance Board and sponsored by ICRISAT, the Australian Centre for International Agricultural Research (ACIAR), and the International Rice Research Institute (IRRI), was held at ICRISAT Center, 16-18 December 1985. The objectives of the meeting were, to identify cooperative links between organizations concerned with legumes research in Asia, to assess the progress made since the Consultative Meeting for Asian Grain Legumes that was held at ICRISAT in 1983, and to develop plans for future cooperation in countries of South and Southeast Asia.

Ten scientists from seven countries in the region (Bangladesh, India, Indonesia, Nepal, Pakistan, Philippines, and Thailand), nine representatives from six international agencies, and ICRISAT scientists discussed research and development of chickpea as well as that of pigeonpea and groundnut in the region. Executive summaries of the technical reports, discussions, and recommendations are available from Information Services, ICRISAT.

It was announced that a Coordinator for

ICRISAT's Asian Grain Legume Program had been appointed, and that this program would be active from 1 January 1986. The meeting provided the Coordinator with strong guidance that was contained within eight specific recommendations. It was stressed that the primary objectives of the new program should include the promotion of closer contact between ICRISAT scientists and the relevant scientists in each country, and encouragement of a two-way flow of information and material. It was also emphasized that there was a need for coordination between the various international and regional organizations, both to integrate research efforts and to reduce duplication of effort. Other recommendations were to identify the problems of the three crops in the region and search for solutions, conserve germplasm, meet training requirements, determine more exactly the areas in the region where genotypes of the three legume crops are adapted and conduct socioeconomic studies to find out the potential uses of the three crops in each country of the region.

Looking Ahead

Studies directed towards understanding the response of chickpea to drought stress, and to identifying genotypic differences in this response will continue as a high priority. Work will continue on screening for salinity tolerance and identifying mineral-nutrient limitations to plant growth. The effect of mycorrhizal inoculation in chickpea is being evaluated.

Studies to monitor population changes of chickpea rhizobia in soil profiles over time are in progress. Interactions between soil-moisture status and symbiotic nitrogen fixation will be studied in more detail. In general, experiments will be conducted on how best to maximize symbiotic nitrogen fixation in chickpea. The study on residual effects of chickpea in supplying nitrogen to succeeding crops will continue. Investigations of climatic adaptation and ideal plant type in chickpea will also continue.

We will continue to screen for disease resistance, particularly for multiple disease resistance. We plan to intensify our work on the characterization of pathogenic races of *Fusarium oxysporum* f.sp *ciceri*. We will study the nuclear behavior of *Ascochyta rabiei* to develop a better understanding of its cultural and pathogenic variation.

We intend to intensify our search for genotypes that have resistance to *Heliothis armigera* and are adaptated to northern Indian conditions. We expect to make further progress with selections that combine resistance to fusarium wilt and *H. armigera*. Such genotypes will be tested in integrated pest-management trials.

Emphasis will continue to be on breeding for stability and high yield. Stability will be achieved by incorporating resistance to biotic- and abiotic-stress factors. Different ecological zones have different resistance requirements that will be met in a tailor-made fashion.

The screening for resistance characteristics in early generations under artificial stress conditions will receive increased attention, while yield and adaptation testing will shift to later generations.

The identification and breeding of genotypes adapted to early sowing at lower latitudes, late sowing at higher latitudes, and high- and low-input conditions will receive increased attention.

Studies in chickpea breeding and genetics will focus on aspects of direct practical importance such as the inheritance of resistance to wilt and root rots, and the expected yield increase from the double-podded and multiseeded-pod characteristics.

The feasibility of the use of tissue culture techniques for chickpea improvement will be explored.

The emphasis of our cooperation program at ICARDA will continue to be on developing high-yielding lines for winter and spring sowing with large kabuli-type seeds, tall stature, and blight resistance. In addition to blight resistance, the development of lines with resistance to cold, leaf miner, *Orobanche* sp, and nematodes will receive due attention. Special emphasis will be laid on developing short-duration lines for spring sowing in the Mediterranean region and for winter sowing on the Indian subcontinent.

In Pakistan, we expect that the project, to develop high-yielding genotypes with ascochyta blight resistance, will gather momentum. We also expect to increase our contributions to the development of chickpea in other countries, through our Asian Grain Legumes Program.

Publications

Institute Publications

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. International Chickpea Newsletter nos. 12 and 13. Patancheru, A.P. 502 324, India: ICRISAT.

Plant Material Description

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Chickpea cultivar ICCV 1. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Kumar, J., Haware, M.P., and **Smithson, J.B.** 1985. Registration of four short-duration fusarium wilt-resistant kabuli (*Garbanzo*) chickpea germplasms. Crop Science 25(3): 576-577.

Lateef, S.S. 1985. Gram pod borer (*Heliothis armigera*) (Hub.) resistance in chickpeas. Agriculture, Ecosystems and Environment 14(1-2): 95-102.

Saxena, N.P. 1985. Role of potassium in drought tolerance. Potash Review No. 5/85:H5. (Subject 16, Potash Fertilizer and Manuring, 102nd suite).

Singh, U. 1985. Nutritional quality of chickpea (*Cicer arietinum* L.): current status and future research needs. Qualitas Plantarum, Plant Foods for Human Nutrition 35(4): 339-351.

Conference Papers

Gowda, C.L.L., Lateef, S.S., Smithson, J.B., and **Reed, W.** 1985. Breeding for resistance to *Heliothis armigera* in chickpea. Pages 36-39 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Jagdish Kumar, Smithson, J.B., Haware, M.P., and **Harjit Singh.** 1985. Breeding chickpeas resistant to disease. Page 146 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Lateef, S.S., and **Reed, W.** 1985. A suggested system of rating pigeonpea and chickpea entries for field resistance to *Heliothis armigera*. Pages 127-131 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Sithanantham, S. 1985. Principles and methods of pest management in pulses. Pages 219-228 *in* Microbial Control and Pest Management (Jayaraj, S., ed.), Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Smithson, J.B. 1985. Breeding advances in chickpeas at ICRISAT. Pages 223-279 *in* Progress in Plant Breeding-1 (Russell, G.E., ed.). London, U.K.: Butterworth and Company, Ltd.

PIGEONPEA

Contents

Cover photo: Winnowing threshed pigeonpea in an Indian village.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

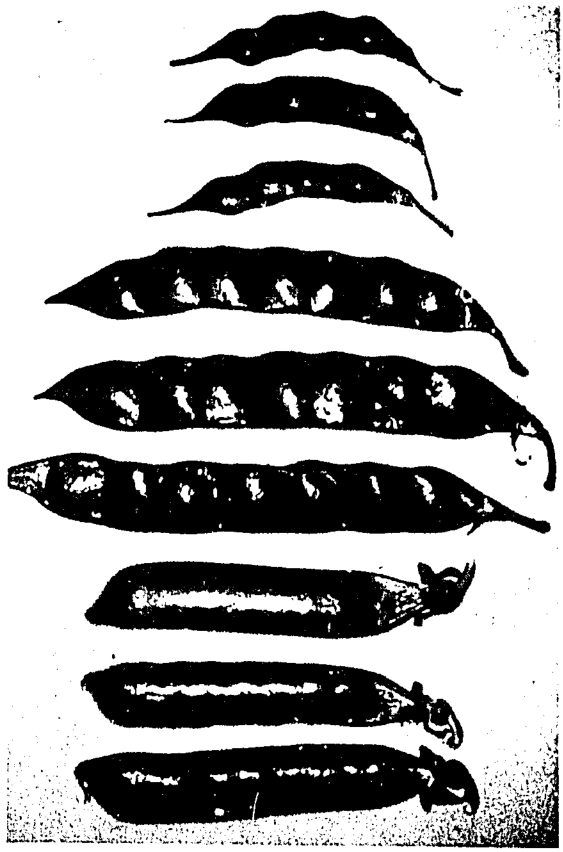
For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

PIGEONPEA

Pigeonpea is grown throughout the semi-arid tropics (SAT) but is of the greatest importance in India, where over 80% of the world's recorded production of this crop is grown and consumed. It is also an important crop in Kenya, Burma, and several of the Caribbean islands. In many other countries it is grown as a backyard crop, harvested for family use, and the statistics of such production are not available.

In India, most of the seed is consumed as dhal (decorticated split seed) in a variety of food preparations. In some parts of India, and in most other countries, green seeds are harvested, boiled, and eaten as substitutes for, or in preference to, green peas (*Pisum sativum*). The green plants are used for fodder and the dried stems are used to make baskets, as thatch, in construction, and for fuel. Pigeonpea crops are also known to improve soil structure and fertility and so give considerable benefit to subsequent crops.

A very wide range of pigeonpea types and genotypes of varying durations are grown, mostly as annual intercrops, but often as perennials. Most are unimproved landraces and there appears to be considerable potential for genetic and agronomic improvement in this very useful crop. Recent work, at ICRISAT Center and elsewhere, has shown that short-duration, close-spaced pigeonpea can be very high-yielding and profitable. Therefore research is now being increasingly devoted to such types and systems.



Vegetable-type pigeonpea (center) that can substitute for pea, *Pisum sativum* (below). The pigeonpea above is the type used for dhal.

Our research activities on this crop are concentrated at three locations in India: ICRISAT Center (18° N, 78° E, 764 mm mean annual rainfall); Hisar (29° N, 75° E, 450 mm rainfall) in cooperation with Haryana Agricultural University; and Gwalior (26° N, 78° E, 840 mm rainfall) in cooperation with Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), College of Agriculture.

At ICRISAT Center we concentrate on the development of short-duration genotypes used for sole cropping and the medium-duration genotypes used mainly in intercrops with cereals; at Hisar, we work on short-duration genotypes that can be sown in the rainy season and harvested in time to permit the timely sowing of a winter crop of wheat; and at Gwalior, we are improving the long-duration genotypes that are extensively, and very productively grown as intercrops with a range of other crops in the Indo-Gangetic Plain.

Physical Stresses

We concentrate our research efforts on physical stresses limiting pigeonpea yield. These include drought, waterlogging, salinity, low temperature, and photoperiod sensitivity. This year we report on our attempts to develop new cropping systems for pigeonpea that would best fit into environments with particular constraints. We also report on work on salinity tolerance. We are currently developing methods for screening pigeonpea for drought tolerance and will report on this in 1986.

Effect of Sowing Date on Yield of Short-duration Cultivar ICPL 87

We reported earlier that the yields of short-duration pigeonpea declined with delayed sowing (ICRISAT Annual Report 1984, p. 167). Various environmental factors could cause this decline. In 1984/85, we examined the extent to which moisture could limit yields at different sowings. The short-duration cultivar ICPL 87 was sown on four dates, 11 June, 25 June, 10 July, and 25 July 1984, with and without irrigation on an Alfisol and a Vertisol. Three harvests were made on both soils.

Yield significantly declined with sowing date on both soils (Fig. 1). On the Alfisol, irrigation did not affect the first-harvest yield, except for the latest sowing. However, a significant response to irrigation in the second-harvest yield on this soil was observed in all sowings except the first. Third-harvest yields were markedly increased by irrigation at all sowing dates.

On the Vertisol, the first-harvest yield increased with irrigation at all sowing dates except the first. The second-harvest yield declined more steeply with delayed sowing on the Vertisol than on the Alfisol. However, on the Vertisol this was not related to the lack of moisture as second-

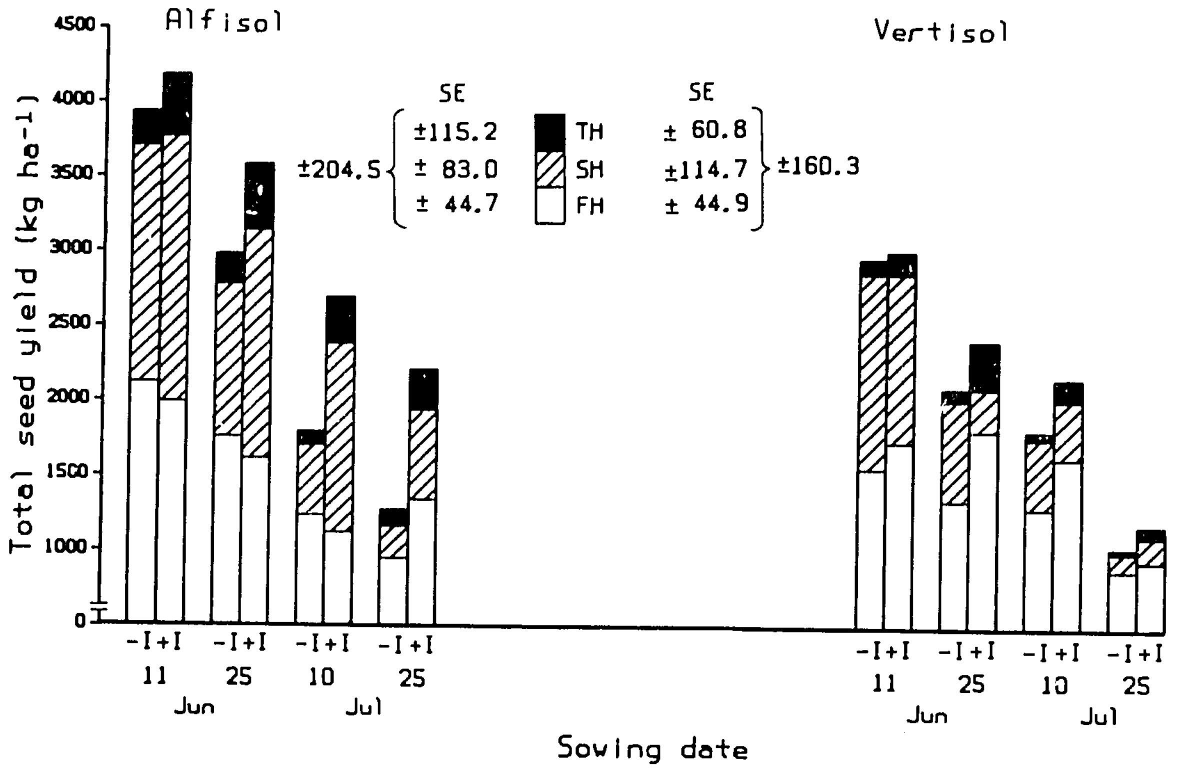


Figure 1. Effect of sowing date on the first (FH), second (SH), and third harvest (TH) and total seed yield (kg ha⁻¹) of pigeonpea ICPL 87 grown without (-I) and with (+I) irrigation on an Alfisol and a Vertisol, ICRISAT Center, 1984/85.

harvest yield was either not affected by, or was decreased by irrigation. This decrease with irrigation might be due to the development of anaerobic conditions in this soil. Except for the earliest sowing on the Vertisol, the increase in third-harvest yield from irrigation was significant for both soils. The increase in total yield due to irrigation was significant in all sowings except the earliest on the Alfisol and was not significant for any of the sowings on the Vertisol.

The results of this study confirmed earlier observations on the depressing effects of delayed sowing on the yield of ICPL 87. The decline in total yields with delayed sowing on Alfisols may be partly due to a moisture limitation. This is to be expected in view of the lower available water-holding capacity of this soil. However, in spite of this, second- and third-harvest yields on the Alfisol were generally higher than on the Vertisol, both with and without irrigation. This aspect is being investigated further. The results also suggested that, at ICRISAT Center or in similar environments, it may be desirable to sow early, not only to obtain higher first-, second-, and third-flush yields, but also to minimize the irrigation needed to obtain these flushes, particularly on Alfisols.

The major reason for the decline in yield with delayed sowing may be the progressive lowering of temperature over time resulting in reduced total dry-matter production. There were significant correlations ($P < 0.01$) between total dry-matter produced at the first harvest in various sowings in different experiments (pooled) and mean prevailing temperature ($r = 0.91$), and between dry matter and growing degree-days ($r = 0.75$).

Comparison of Short- and Medium-duration Pigeonpea Sole Crops

Our previous studies have shown short-duration pigeonpea to be lower yielding than medium-duration pigeonpea, when grown at ICRISAT Center (ICRISAT Annual Report 1977/78, p. 102). These comparisons were made using similar cultural practices, which may have disadvantaged short-duration pigeonpea. Using recently derived information on the agronomic requirements of short-duration pigeonpea, we compared the performance of a short-duration cultivar, ICPL 87, with a well-adapted medium-duration cultivar, BDN 1. The short-duration cultivar was sown at 33 plants m^{-2} and the medium-duration cultivar at 6.6 plants m^{-2} on 15 June 1984 on both an Alfisol and a Vertisol at ICRISAT Center. Both cultivars were irrigated and given optimum protection against insect pests.

Even though the growth rates of individual plants of ICPL 87 and BDN 1 were similar, crop-growth rates and rates of leaf-area development were greater with ICPL 87 due to its higher plant density. Both these characteristics are desirable for the sole cropping of pigeonpea. ICPL 87 produced two flushes of pods in a similar time to that required for BDN 1 to produce one flush. The first-harvest yield of ICPL 87 was 2380 kg ha^{-1} on an Alfisol and 1790 kg ha^{-1} on a Vertisol and the second-harvest yields were 1710 kg ha^{-1} on the Alfisol and 1360 kg ha^{-1} on the Vertisol. Thus the total yields were 4090 kg ha^{-1} on the Alfisol and 3150 kg ha^{-1} on the Vertisol. The seed yields of BDN 1 in a similar period were 2340 kg ha^{-1} on the Alfisol and 2400 kg ha^{-1} on the Vertisol, significantly lower than the total yields of ICPL 87. This result demonstrated that the overall yield potential of short-duration genotypes, when grown at an appropriate density and sown at the right time is more favorable than earlier thought.

Salt Tolerance of Pigeonpea Genotypes, Rhizobial Strains, and Symbioses

To investigate genetic variation for salt tolerance, we screened 29 pigeonpea genotypes and 14 rhizobial strains at different levels of NaCl. Considerable genotypic variation in salt tolerance was noticed among pigeonpea genotypes (Fig. 2) and a salt level of 60 mM was found to be the critical limit for survival. Pigeonpea rhizobial strains also showed significant differences in NaCl tolerance in yeast-extract, mannitol-agar

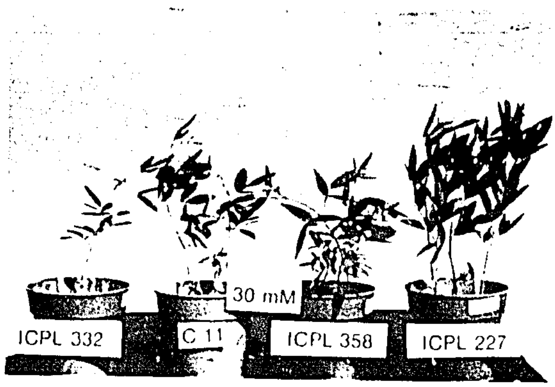


Figure 2. Effect of salt (30 mM NaCl) stress on the growth of four pigeonpea genotypes, 45 DAS, ICRISAT Center, 1985.

media, with salt levels ranging from 0.25% to 5%. Fast-growing rhizobial strains were more salt tolerant than slow growers. Strain IHP 24, a fast grower isolated from normal soil, was found to be the most tolerant, even when compared with strains isolated from saline soil.

We studied the effects of salt stress on the symbiotic ability of four pigeonpea genotypes inoculated with either of two *Rhizobium* strains, differing in their growth habit and salt tolerance, to determine the involvement of host tolerance and *Rhizobium* efficiency in symbiotic nitrogen fixation. *Rhizobium* strain IHP 195 was found to be symbiotically more efficient than IHP 100 even though the latter was more salt tolerant (Fig. 3). Among the genotypes, ICPL 227 proved to be the most tolerant to salt stress with respect to nodulation and growth. The nitrogen-fixing potential of the nodules, however, was not affected by salinity in any of the genotypes but there was an increase in the specific nitrogenase activity and the nitrogen content of shoot, root, and nodules under salt stress. It seems that plant growth is more sensitive to salinity than the *Rhizobium* strain or symbiotic function but also that plant response to salinity can be influenced by the particular *Rhizobium* strain forming the symbiosis.

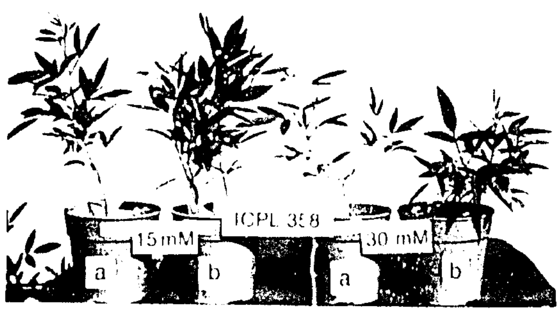


Figure 3. Effect of *Rhizobium* strains IHP 100 (a) and IHP 195 (b) on the growth of pigeonpea genotype ICPL 358, with 15 mM and 30 mM NaCl in the media, 45 DAS, ICRISAT Center, 1985.

Biotic Stresses

Diseases

Fusarium wilt (*Fusarium udum*), sterility mosaic, and phytophthora blight (*Phytophthora drechsleri* f. sp *cajani*) were observed in most states of India. Fusarium wilt incidence was, as usual, more severe in Maharashtra than in other states that we visited. Sterility mosaic was severe in the southern Indian state of Tamil Nadu. In northern India, we found phytophthora blight to be more common in experiment stations than in farmers' fields. In a limited survey in the lowland areas of Nepal, scattered incidences of fusarium wilt and sterility mosaic were observed. At Parwanipur Research Station in Nepal, we observed mosaic symptoms that could not be associated with any known virus.

Fusarium Wilt (*Fusarium udum*)

Screening for resistance. We continued to screen new germplasm accessions, progenies, and advanced lines in wilt sick plots at ICRISAT Center to identify wilt-resistant accessions and lines. Material was screened in wilt sick plots on Vertisols and Alfisols where susceptible control lines showed about 90% wilt incidence. We selected lines showing less than 20% wilt in the first screening and less than 10% in subsequent screenings. A set of 238 new germplasm accessions received from our Genetic Resources Unit was screened in the Vertisol wilt sick plot. Of these, 34 accessions showed less than 20% wilt. Of the 15 selections from germplasm accessions made in 1981/82, 11 selections from ICP 616, 1680, 4784, 6654, 6974, 11308, 11324, 11368, and 11405 showed resistance to wilt for the 4th consecutive year.

Large amounts of breeding material were screened in the Vertisol wilt sick plot, including 16 F_3, 250 F_6, and 250 F_7 single-plant progenies, 46 F_2, 9 F_7, and 4 F_8 intergeneric bulks, advanced lines in short- and medium-duration groups and entries from the Medium-duration Pigeonpea Wilt Resistant Yield Trial (MPWRY), and from the Medium-duration Pigeonpea Unselected Bulks (MPUB). We also screened inbred lines, selections from dwarf lines, and irradiated ICPL 265. In the MPWRY, four lines, ICPL 335, 8357, 8362, and 84008 were resistant to wilt, and in the advanced lines ICPL 84006, 84014, and a selection from ICPX 78153 were resistant. Materials showing less than 20% wilt were advanced for further testing.

Modification in the pot-screening technique. We published in Pigeonpea Diseases: Resistance Screening Techniques, ICRISAT Information Bulletin no.9 (1981), two methods of pot screening for wilt resistance. In one method, direct sowing was done in sick soil in pots and in the other, test seedlings were transplanted into sick soil. When we used these two techniques in inheritance studies, we found them inadequate to meet our needs because of seedling-to-seedling variation in the number of days to wilt and also because more than a month was normally required for wilting of all the seedlings of a susceptible cultivar grown in a pot. We, therefore, compared the above two methods with another one in which 7-day-old seedlings grown in sterilized sand were root-inoculated with the inoculum multiplied on potato-sucrose broth. Seedlings were then transplanted in autoclaved riverbed sand or soil in 15-cm plastic pots. This method, compared to the other two, gave more uniform wilting and in a relatively short period (Table 1).

Effects of Soil Solarization

Soil solarization is a technique that involves covering the soil with transparent polythene sheeting during summer, thus increasing soil temperatures. It has been primarily used for the control of soilborne pathogens but it also has other beneficial effects on subsequent crop growth. We evaluated this technique for its effects on pigeonpea, particularly in relation to control of wilt (*F. udum*), in a multidisciplinary experiment conducted during 1984/85.

The experiment was laid out in a Vertisol wilt sick plot in a split-plot design. Irrigation and no irrigation prior to solarization were main-plot treatments and factorial combinations of with and without solarization and wilt-resistant (ICP 8863) and susceptible (LRG 30) pigeonpea genotypes were subplot treatments. The subplot size was 6 m × 6 m and there were six replications. The soil-solarization treatment was applied from 13 April to 4 June 1984 and the crop was sown on 25 June 1984. Solarization increased temperatures in the 0-5 cm soil profile by more than 10°C during the day.

In both genotypes, solarization resulted in earlier flowering and maturity as well as greater yields of seed and total above-ground dry matter (Fig. 4). Effects were greatest for the wilt-susceptible cultivar and could, at least partly, be attributed to lower numbers of *Fusarium* propagules that resulted in less wilt incidence in the solarized plots. However, the stimulatory effects of solarization on the wilt-resistant genotype must be attributed to factors other than the control of wilt disease. Although causal factors could not be differentiated, we found that solarization suppressed weed growth and nematode populations, and enhanced mineralization of soil nitrogen. We also observed that solarization caused a fourfold reduction in the native *Rhizobium* population, and that the nodule number and mass, and acetylene-reduction activity were lower in solarized plots at 30 days after sowing

Table 1. Comparison of inoculation techniques used to pot-screen in a greenhouse for fusarium wilt (*Fusarium udum*) resistance in three pigeonpea genotypes, ICRISAT Center, 1985.

Particulars	Time from sowing or transplanting to death of 90% of the plants (d)					
	ICP 2376		ICP 8518		ICP 6997	
Sown in						
inoculated sand	66	(12.2)[1]	80	(14.7)	125	(23.0)
inoculated Vertisol	NW[2]		77	(14.3)	NW	
inoculated Alfisol	70	(12.9)	65	(12.0)	105	(19.3)
Seedlings transplanted in						
inoculated sand	56	(10.3)	38	(6.5)	58	(10.8)
inoculated Vertisol	56	(10.1)	53	(9.6)	81	(14.8)
inoculated Alfisol	39	(6.7)	31	(5.1)	37	(6.2)
Seedlings whose roots were dipped in inoculant, and transplanted in						
autoclaved sand	24	(3.7)	15	(2.2)	23	(3.5)
autoclaved Vertisol	23	(3.6)	16	(2.6)	23	(3.5)
autoclaved Alfisol	32	(5.2)	15	(1.8)	22	(3.3)
SE				(±0.92)		
CV%				(10.1)		

1. Figures in parentheses are the mean numbers of 5-day periods analyzed.
2. NW = less than 90% of the plants died in these treatments.

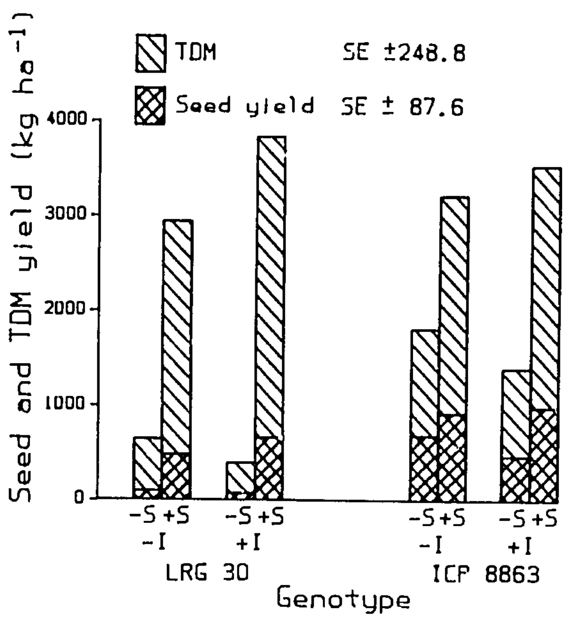


Figure 4. Effect of solarization (+S = solarized, -S = nonsolarized), and irrigation (+I = irrigated, -I = non-irrigated) at the time of solarization on seed yield and total dry matter (TDM) of wilt-susceptible (LRG 30) and wilt-resistant (ICP 8863) pigeonpea genotypes on a Vertisol, ICRISAT Center, rainy season 1984/85.

(DAS). But, plants in solarized plots obviously recovered from this early inhibition of symbiotic nitrogen fixation (Fig. 4).

Further studies are in progress to confirm, explain, and explore these dramatic effects of soil solarization on pigeonpea growth and yield.

Sterility Mosaic

Nature of the causal agent. In several purification attempts using infected leaves, we were able to consistently obtain flexuous, rod-shaped, virus-like particles (VLP) of regular thickness and different lengths (200-700 nm) (Fig. 5). We are making efforts to modify the procedure to obtain higher concentrations of VLP than those obtained so far. We were able to obtain similar particles in the vector mites *Aceria cajani* (Fig. 6) collected from infected plants, but not in the mites from healthy plants. Our attempts to transmit the causal agent through sap were unsuccessful.

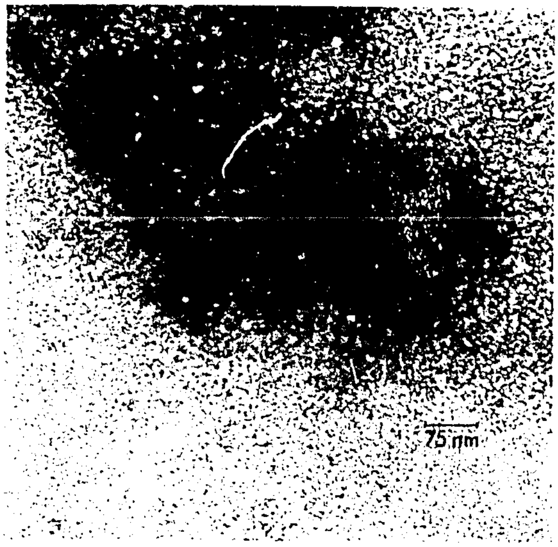


Figure 5. Flexuous rod-shaped particles that may be sterility mosaic pathogens (electron micrograph, bar length represents 75 nm), ICRISAT Center, 1985.

Healthy mite colony. We can now obtain a healthy (sterility mosaic pathogen-free) colony of the vector mites. The procedure involves inoculating 10-day-old seedlings of the sterility mosaic resistant line ICP 8136 with mites from infected plants. A 30-day interval is allowed before the mites from ICP 8136 plants are transferred to sterility mosaic susceptible BDN 1 plants. In repeated tests we found that such mites do not produce symptoms on the susceptible cultivar, clearly indicating that ICP 8136 allows multiplication of mites, but the causal agent is not transmitted to their progeny. Thus, it should be possible to obtain healthy mite colonies at any location if one uses a sterility mosaic resistant line that allows multiplication of the vector mites.

Screening for resistance. As in 1984, we screened a large amount of material including germplasm accessions, progenies, and advanced lines in the sterility mosaic nursery, using the infector-hedge technique developed at ICRISAT Center.

We confirmed resistance in 17 progenies from the 1979 resistant germplasm accessions, 52 from the 1980 selections, 100 from the 1982 selections, and 21 from the 1983 selections. Selections from 1981 were not tested. Some of these materials are already being used for multilocational testing.

Ten progenies from six *Heliothis*-resistant lines were free from the disease. Of the 92 entries included in the 1984 Arhar Coordinated Trials (ACTs) 14 were free from sterility mosaic.

Figure 6. *Aceria cajani*, mite vectors of pigeonpea sterility mosaic disease (× 30 approx.), ICRISAT Center, 1985.

Phytophthora Blight (*Phytophthora drechsleri* f.sp *cajani*)

Selective medium. After evaluating a large number of media and attempting various formulations, we succeeded in synthesizing a medium that is effective in selectively isolating *P. drechsleri* f.sp *cajani* (Fig. 7) from infected stubble as well as from field soil. The constituents of the medium, which we called SM 19, are: Benlate® (50% benomyl) 20 ppm; Hymexazol® 20 ppm; Mycostatin® 50 000 units ; pentachloronitrobenzene (PCNB) 20 ppm; Pimaricin® 5 ppm; Vancomycin® 200 ppm; and Rifamycin® 10 ppm in standard potato-dextrose agar.

Leaf-baiting technique. We adapted the well-known "leaf-baiting" technique as follows: 10 g of sieved (80 mesh) field soil is moistened in a 150 mL beaker. After 24 h, the soil is flooded with

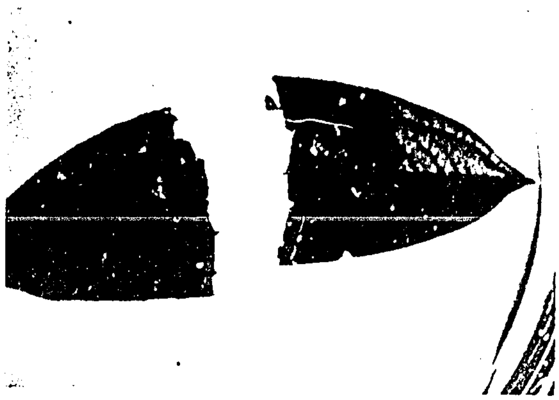


Figure 7. Sporangia (white specks) of *Phytophthora drechsleri* f.sp *cajani* from an infected leaf growing in a selective medium, ICRISAT Center, 1985.

100 mL water amended with 20 ppm Benlate®, 20 ppm Hymexazol®, and 100 ppm penicillin by pipetting along the side of the beaker so that the water remains clear. After 24 h of flooding, clean 5-mm diameter leaf discs of a phytophthora blight susceptible pigeonpea (e.g., Hy 3C) are floated on the water surface and left overnight (18 h). These leaf discs are then washed and placed in sterile distilled water. Sporangial formation can be observed on the edges of the leaf discs within 36 h, if the fungus is present in the soil. The baited leaf discs are then transferred to the selective medium, SM 19.

Survival. Using the SM 19 selective medium and the leaf-baiting technique, we established that the pathogen survives in soil and in infected plant debris for more than a year. Our earlier studies using pathogenicity tests indicated that the pathogen did not survive in infected plant debris for more than 3 months. These new findings indicating that survival is possible for at least a year, point to infected stubble as one of the sources of primary infection.

Spread. We demonstrated that the pathogen is able to spread as zoospores through rain drops accompanied by winds. Ten-day-old pigeonpea seedlings of the susceptible Hy 3C grown in pots with autoclaved soil, when placed downwind and 1.5 m away from infected plants, showed blight symptoms within 3 days after rains. We obtained repeated confirmation of this phenomenon.

Pathogenic variation. Eight isolates of *P. drechsleri* f.sp *cajani* from India P2, P3, BF, (all from ICRISAT Center), BHU (Varanasi), Dholi, His (Hisar), IARI (New Delhi), and KPR (Kanpur) were tested and found to vary in colony morphology, rate of growth, and number of sporangia and zoospores produced. All isolates, except P3 and Dholi, differed in pathogenicity on a preliminary set of differential cultivars. All the cultivars were found susceptible to the P3 and Dholi isolates.

Screening for resistance. To identify sources of resistance to the P3 isolate of *P. drechsleri* f.sp *cajani*, we continued screening a number of pigeonpea lines in pots in the greenhouse by the "soil drench" inoculation method (ICRISAT Information Bulletin no. 9). The material tested included entries from the Arhar Coordinated Trials (ACT), the Medium-duration Pigeonpea Sterility Mosaic Wilt Resistant Yield Trial (MPSMWRY), the ICAR/ICRISAT Uniform Trial for Pigeonpea Phytophthora Blight Resistance (IUTPPBR) 1983/84, sterility mosaic and wilt-tolerant lines, elite pigeonpea lines, germplasm lines previously recorded as tolerant to the P3 isolate, and selections from single plants that previously survived field inoculation with the P3 isolate. None of the 335 lines tested showed promise. We will continue to collect selfed seed from the plants surviving after inoculation for use in further testing.

Interaction between mycorrhizae and phytophthora blight. We were able to confirm the results reported in the 1984 Annual Report (p. 171) that vesicular arbuscular mycorrhizae (VAM) reduced blight incidence in greenhouse experiments.

Breeding for Disease Resistance

In short duration pigeonpea, we screened 40 advanced lines in the wilt sick nursery, to purify them before multiplication. In the sterility mosaic nursery we screened 465 advanced lines and another 50 for purification in 1984 and screened 33 lines in the multiple-disease nursery for purification before multiplication.

In medium-duration pigeonpea, we screened 11 bulk populations, 589 single-plant progenies, and 90 advanced lines in the wilt sick nursery; 83 bulk populations, 60 single-plant progenies, and 64 advanced lines in the sterility mosaic nursery; and 21 bulks and 48 single-plant progenies in the multiple-disease nursery. Selected materials are being tested for yield or screened further in 1985.

In long-duration pigeonpea, we screened 194 advanced lines in the wilt sick nursery and in the sterility mosaic nursery to purify them for multiplication. In the multiple-disease nursery, we screened 45 advanced lines for multiplication and took single pods from resistant plants in 36 F_4 bulks and 7 F_2 bulks.

Disease-resistant pigeonpea genotypes will generally yield more than normally high-yielding but susceptible cultivars when both are grown under disease pressure. However, disease-resistant genotypes will not be accepted by farmers unless their yield compares favorably with the control cultivars under normal low-disease conditions or disease-free conditions. Unfortunately, resistant genotypes often do not yield so well as susceptible ones when there is no disease incidence and therefore resistant genotypes may not be identified for release in the normal All India Coordinated Yield Trials, which are grown under disease-free conditions. For this reason the All India Coordinated Pulses Improvement Project (AICPIP) has set up a series of multilocational trials for the different duration groups designed to identify the higher-yielding, disease-resistant pigeonpea lines for direct release as cultivars. Lines from ICRISAT Center with resistance to wilt and/or sterility mosaic are being tested in these trials.

In the 1984 AICPIP Medium-maturity Pigeonpea Wilt Resistant Yield Trial (MPWRY), 18 of the 22 entries were from ICRISAT Center. Four of these lines yielded well at ICRISAT Center in 1984 (Table 2) and showed resistance to sterility mosaic. In the 1984 AICPIP Medium-maturity Pigeonpea Sterility Mosaic Resistant Yield Trial (MPSRY), 12 of the 16 lines were from ICRI-

Table 2. Performance of wilt-and sterility mosaic resistant lines in the Medium-maturity Pigeonpea Wilt-Resistant Yield Trial (MPWRY) grown in a disease-free field, ICRISAT Center, rainy season 1984.

Line	Time to 50% flowering (d)	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha^{-1})	Sterility mosaic(%)[1]	Wilt (%)[1]
ICPL 227	112	173	190	10.1	2740 (6)[2]	0	3.3
ICPL 8362	117	176	194	8.2	2730 (8)	0	0.0
ICPL 8363	120	179	197	8.1	2500 (15)	0	9.1
ICPL 335	122	181	191	8.9	2490 (17)	0	0.0
Control							
C 11	114	175	184	10.1	2980 (2)	-[3]	80.0
SE	±0.3	±0.4	±2.8	±0.20	±162		
Trial mean (22 entries)	111	170	181	10.0	2592		
CV (%)	0.5	0.5	3	4	13		

1. Disease results are from the appropriate disease nursery.
2. Figures in parentheses represent overall rank in trial.
3. - = Not grown in sterility mosaic nursery with other lines.

SAT Center. Six of these lines which showed no disease symptoms in the sterility mosaic screening nursery, were in the top seven positions for yield at ICRISAT Center (Table 3).

Three long-duration pigeonpea lines have shown some resistance to sterility mosaic, with similar yield to the control cultivar Gwalior 3 at two locations in central India over 3 years (Table 4). One of these lines, ICPL 83143, and the multiple-disease resistant line ICPL 84072, were tested in the 1984 AICPIP Late-maturity Pigeonpea Sterility Mosaic and Wilt Resistant Yield Trial (LPSMWRY). Under severe sterility mosaic disease pressure in 1985, ICPL 8398 and 83143 have shown about 40% infection, which was much less than the control. Selfed, resistant plants are being selected under this severe disease pressure to upgrade and purify the sterility mosaic resistance of these two lines.

ICP 8863, an ICRISAT selection from cultivar 15-3-3 from Badnapur in Maharashtra, was released (as Maruti) in Karnataka in 1985 because of its very high level of wilt resistance, good yield, and seed size. It has shown virtually complete wilt resistance over several years in country-wide trials. This variety was released in Karnataka because yield losses from wilt, which were assessed as 1000 tonnes of grain in 1976, have been increasing, particularly in areas of the State where cultivation of this crop has intensified. Without a variety like Maruti, pigeonpea production was becoming impossible in some areas of Karnataka.

Multiple-disease Resistance

We screened a total of 445 entries in our multiple-disease nursery on an Alfisol to identify lines with combined resistance to three major pigeonpea diseases: wilt, sterility mosaic, and phytophthora blight. The entries included breeding material (advanced progenies, F_4 single-plant selections, bulks, and progenies), elite lines, selec-

Table 3. Performance of sterility mosaic resistant lines in the Medium-maturity Pigeonpea Sterility Mosaic Resistant Yield Trial (MPSRY), ICRISAT Center, rainy season 1984.

Line	Time to 50% flowering (d)	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha⁻¹)	Sterility mosaic (%)[1]
ICPL 343	102	160	189	9.7	2430 (2)[2]	0
ICPL 84071	115	175	188	12.2	2270 (3)	0
ICPL 8349	114	172	187	8.0	2140 (4)	0
ICPL 8343	103	160	177	10.7	2140 (5)	0
ICP 2376	113	171	171	8.8	2120 (6)	0
ICPL 342	115	173	184	7.8	2110 (7)	0
Controls						
C 11	116	174	183	9.4	2740 (1)	6.7
BDN 1	98	161	161	9.6	2010 (12)	12.1
SE	±0.7	±0.8	±3.0	±0.45	±128	
Trial mean (16 entries)	110	169	182	9.9	2090	
CV (%)	1.2	0.9	3	9	12	

1. Disease results are from the sterility mosaic nursery.
2. Figures in parentheses represent overall rank in trial.

Table 4. Yield performance of three sterility mosaic resistant, long-duration pigeonpea lines, Gwalior and Morena, 1982, 1983, and 1984.

Line	Grain yield (kg ha⁻¹) 1982 Gwalior	1982 Morena	1983 Gwalior	1983 Morena	1984 Gwalior	1984 Morena	Mean[1]	Disease incidence in sterility mosaic nursery, ICRISAT Center (%) 1984	1985
ICPL 8398	2880	3710	2300	2940	2760	2570	2690	0	40
ICPL 83132	3010	3300	2040	2400	3030	3030	2700	5	NA[2]
ICPL 83143	2430	NA[2]	2040	3160	2400	3070	2620	5	40
Control									
Gwalior 3	2810	2890	2130	2370	3150	2460	2580	44	88
SE	±247	±191	±277	±245	±211	±206			
Trial mean	2530	2470	2150	2600	2570	2600			
Number of entries	22	22	20	20	16	16			
CV(%)	20	15	20	16	17	16			

1. Excluding the data from the 1982 trial at Morena.
2. NA = not available.

tions with reduced susceptibility to phytophthora blight, sterility mosaic and wilt-resistant selections of Kenyan origin, F_4 bulks from Gwalior, short-duration lines from Hisar, selections from the Indian States of Andhra Pradesh, Gujarat, and Maharashtra, and ACT entries. Of these, 37 entries showed 0-10% incidence of the three diseases. These were selections from ICP 5097 and 8094, ICPX 74360, 80057, 80060, 80061, 80063, 80204, 80264, 80267, 80273, 80275, 80284, 80287, and 80289, and BSMR 528.

Nematode Diseases

We confirmed our results of 1984, which found that eight parasitic-nematode species (*Heterodera cajani, Helicotylenchus indicus, Helicotylenchus retusus, Hoplolaimus seinhorsti, Meloidogyne* sp, *Pratylenchus* sp, *Rotylenchulus reniformis*, and *Tylenchorhynchus* sp) attack pigeonpeas. *Heterodera cajani* was found to be substantially more prevalent in Vertisols than in Alfisols, while the reverse was true with *H. seinhorsti.*

We studied the relationship between population densities of *H. cajani, R. reniformis*, and *H. seinhorsti* and the growth of pigeonpeas. *Heterodera cajani* affected shoot and root mass more than shoot length. Initial populations of 50 nematodes and more per 500 cc of soil were found to affect pigeonpea growth. In the case of *R. reniformis*, even an initial population of 5 nematodes per 500 cc was found to affect shoot mass, and all growth parameters were adversely affected at initial populations of 1000 nematodes per 500 cc of soil. In the case of *H. seinhorsti*, we found that initial populations of 50 nematodes per 500 cc soil affect growth.

Studies on the interaction between nematodes and *F. udum* indicated that the reaction of wilt-resistant line ICP 8863 was not affected by *H. cajani* and *R. reniformis*, but wilt incidence in the susceptible line ICP 2376 was earlier in the presence of nematodes. We observed that the root-knot nematode (*Meloidogyne* sp) may break the wilt resistance of ICP 8863. *Fusarium udum* had an antagonistic effect on the multiplication of these nematodes.

Figure 8. Cysts of the nematode *Heterodera cajani* on a pigeonpea root (×620), ICRISAT Center, 1985.

We made some modifications to the standard procedures adopted for obtaining the cyst nematode *H. cajani* (Fig. 8) from soils. For example, we found that the use of an 80-mesh sieve instead of the standard 60 mesh, was more efficient for collection of *H. cajani* cysts, as it retained 11-28% more cysts. Also, we discovered that eggs of *H. cajani* could be easily collected from roots by placing them in 0.2% sodium hypochlorite solution for 2-3 minutes.

Insect Pests

Pest Incidence

In the 1984/85 season, the pod borer (*Heliothis armigera*) caused heavy losses to nonprotected pigeonpea at ICRISAT Center and in farmers' fields in many areas of central and southern India. Damage was particularly severe in very-early-flowering genotypes and in medium-duration genotypes. In northern India there were reports that web-forming lepidoptera, (*Maruca testulalis* and *Cydia critica*), were unusually common and damaging, particularly on early-flowering, determinate genotypes. These larvae feed on the leaves, flowers, and pods that are tied together in their silken webs. As in most years, the flower-feeding blister beetles (*Mylabris pustulata*), were very common from September to November.

At ICRISAT Center, the hymenopteran pest (*Tanaostigmodes cajaninae*) was very damaging, particularly to the pods of the ratoon flush of the early genotypes, and long-duration genotypes. However, this pest is at present only a research-station nuisance for it is relatively rare in farmers' fields. The podfly (*Melanagromyza obtusa*) caused substantial losses in long-duration genotypes both on research stations and in farmers' fields. The pod-sucking bugs (*Clavigralla gibbosa*, *Dolicoris indicus*, and *Nezara viridula*) were more common than usual. Feeding by these insects results in shrivelled seeds with reduced market value (Fig. 9).

Many other insects were reported as pests of pigeonpea at various locations. We now have a list of about 200 insects that have been reported as pests of pigeonpea, but most are minor, sporadic, or of localized importance.

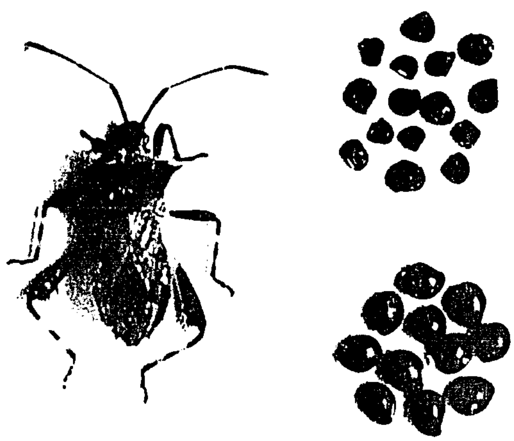


Figure 9. *Clavigralla gibbosa*, a sucking pest of pigeonpea (left) and the seeds damaged by this pest (top right) compared with undamaged seeds (below right), ICRISAT Center, 1985.

Heliothis armigera

Population monitoring. We received data of nightly catches of male moths from 110 pheromone traps at 54 locations across Bangladesh, India, Pakistan, and Sri Lanka. This network uses ICRISAT Standard Traps that were developed in collaboration with scientists of the Tropical Development and Research Institute (TDRI), London. The bait in each trap is a rubber septum impregnated with a synthetic mimic of the scent (pheromone) produced by the female moth to attract the male. The impregnated septa are supplied by TDRI and the traps are constructed at ICRISAT Center from locally available materials.

A 2-year study of the data from these pheromone traps by a postdoctoral scientist was completed in 1985. A comprehensive report on this study is now available on request from the Legumes Program. Among the many findings, the following are of particular interest:

Nocturnal observations of the traps, using night-vision goggles, revealed that many moths approached to within 30 cm of the trap where they hovered, but then flew over or around the trap and evaded capture. Less than 20% of the moths that approached the standard traps were caught. The incorporation of a slotted baffle around the septum led to a marked change in behavior, for the moths hovered at the rim of this trap. The difference in behavior may be caused by the greater diffusion of the pheromone plume caused by the baffle, and could explain the greater catches in the baffle-modified traps. Such traps have not yet been used in the network for it is considered that the advantages of retaining the standard trap design outweigh the benefit of increased catches.

The most obvious environmental factor affecting pheromone-trap catches was wind speed, with higher catches occurring when wind speeds ranged from 1.6 to 3.0 m s^{-1}. In contrast, the greatest catches in light traps occurred when there was little or no wind. Lower wind speeds led to reduced pheromone-trap catches, probably because of limited formation and spread of the pheromone plume. Wind speeds in excess of 3.0 m s^{-1} could lead to broken plumes and at higher speeds the moths would not be able to make progress when flying against the wind.

An array of 28 pheromone traps, with an intertrap spacing of 300 m, was operated on a Vertisol at ICRISAT Center from July 1984 to February 1985. Nightly catches were recorded from each trap and these data allowed us to examine variances across areas and time. The catches were influenced by the proximity of pigeonpea and sorghum crops to the traps as shown by the following regression equation.

$$y = 116.5 - 0.157(\pm 0.0297)x1 - 0.072(\pm 0.0268)x2;$$
$$r^2 = 0.50$$

Where
y = peak catch,
x1 = distance to pigeonpea (m),
x2 = distance to sorghum (m).

The distance from traps to the nearest chickpea fields had no apparent influence on the size of the peak catch.

Topography was found to have a significant effect on trap catches, traps on higher ground having greater catches, particularly in the postrainy season. This effect may have been caused by greater wind speeds at the higher locations, for wind speeds during the postrainy season were generally suboptimal for maximum trap catches.

The variances of trap catches were very large, indicating that considerable replication of traps would be required to give acceptable levels of errors for most purposes. It was therefore concluded that such traps are of little use in quantitatively monitoring populations and so are unlikely to be of use in indicating economic thresholds for pesticide use in crops.

The data from the international pheromone-trap network have shown that catches at locations in the east of the subcontinent were generally lower than those in the west. Such differences may be associated with cropping patterns, for the eastern locations generally have a dearth of *H. armigera*-preferred hosts. The greatest catches in each year have been at Hisar, where cotton, pigeonpea, chickpea, and several other *H. armigera* host crops are extensively grown.

An interesting fact emerging from the data is that trap catches across India generally show similar trends across years. For example, catches in 1981/82 were much greater than those in subsequent years at most locations. This is surprising, since *H. armigera* populations vary greatly across areas and we did not expect to find nationwide trends from year to year. However, this finding is supported by the strong correlation (r = 0.84) found between data of percentages of bored pods recorded in our surveys of farmers' pigeonpea across India, and in trials of medium-duration pigeonpea at ICRISAT Center in each year, from 1975 to 1981. We now have to determine the factors that are responsible for these widespread changes in populations.

Host-plant resistance. In 1985, we gave priority to the large-scale screening and testing of genotypes developed by our breeders from crosses incorporating previously identified *H. armigera*- and disease-resistant parents. Such work consumed most of our time. Consequently, we postponed the screening of new germplasm accessions and long-duration selections.

Table 5. Pod damage (%) caused by insect pests, and grain yields (kg ha⁻¹) from short-duration pigeonpea genotypes in a pesticide-free trial, Hisar, rainy season 1984.

Genotype	Pod damage (%)	Yield (kg ha^{-1})
ICPL 1	23.6	2570
ICPL 288	28.0	2630
ICPL 2	29.0	2603
82 H09-12	30.2	2340
ICPL 187-1	35.9	2260
ICPL 269	36.1	2060
83 HP614	36.5	2570
83 H16-16	36.5	1830
ICPL 6	36.6	1890
TAT 10	37.2	1880
ICPL 314	37.3	2410
PUSA 35	37.4	2150
H77-216	44.1	1800
PUSA 33	44.3	2350
Control		
Pant A1	46.7	1610
UPAS 120	49.0	1960
SE	±5.46	±209
CV (%)	26	17

In earlier reports we referred to the moderate levels of resistance and tolerance to *H. armigera* that we discovered among medium-duration genotypes. We are also anxious to develop resistance in short-duration genotypes, for although these have the greatest potential for expanded use as monocrops, the commonly available cultivars are very susceptible to damage by *H. armigera*. For example, in a trial of 18 short-duration genotypes on the pesticide-free Vertisol at ICRISAT Center in 1984/85 more than 70% of the pods were damaged by pod borers and the average yields were only 270 kg ha^{-1} (range 100 to 650 ± 95). We appear to be having some success in selecting for resistance in these genotypes, as shown in the data from a trial of our selections at Hisar (Table 5). In this trial, which included 14 genotypes that had previously been selected for apparent reduced susceptibility, all the selections had less pod damage than both controls, which are commonly used cultivars, and 10 gave greater yields.

Mechanisms of resistance. Studies on the mechanisms of resistance may lead to improved methods of screening, particularly of single-plant selections from segregating progenies.

In a series of trials over the last 3 years, we removed all eggs and larvae from single rows in replicated plots of resistant and susceptible genotypes at weekly intervals. The numbers of eggs and larvae were counted, just before each removal exercise, on these rows and on adjacent rows where the eggs and larvae were left undisturbed. Summarized data from two resistant and two susceptible genotypes are shown in Table 6. There were no detectable differences between the number of larvae found on undisturbed rows and on those from which eggs and larvae had been removed a week earlier. This clearly indicated substantial dispersal of larvae between the rows. This finding identifies a problem in single-

Table 6. Counts of *Heliothis armigera* larvae on resistant and susceptible pigeonpea genotypes, 1 week after all eggs and larvae had been removed, and on plants in adjacent rows on which the eggs and larvae were not disturbed, ICRISAT Center, 1982-84.

Genotype	Populations[1] of larvae on five plants	
	On undisturbed rows	On rows where eggs and larvae were removed weekly
PPE 45-2 (Resistant)	2.68	2.54
ICP 7203 (Susceptible)	3.41	3.38
ICP 1903 (Resistant)	2.17	2.11
ICP 1691 (Susceptible)	3.31	3.22
SE	±0.215	±0.203

1. Populations are the $\sqrt{x+3/8}$ transformed values where x = number of larvae counted on samples each of five plants; there were 55 such counts for each genotype treatment.

plant selection for resistance from segregating progenies. The beneficial effects of oviposition nonpreference will be negated in a resistant plant where larvae can disperse from a neighboring susceptible plant. Also, the continuing invasion of larvae from susceptible neighbors will tend to diminish the efficiency of screening, particularly where dense populations of the pest are present.

In collaboration with ICRISAT, work continued on the identification of the chemical basis of resistance at the Max Planck Institute for Biochemistry, Munich, Federal Republic of Germany. Increasing emphasis has been given to the study of volatile chemicals in the resistant and susceptible genotypes and "aromagrams" are being prepared with the aid of gas chromatographs.

Insecticide use. Short-duration genotypes can produce very high yields when sown in dense monocrops, but only if well protected from pest attacks by insecticides. There is an obvious need to use insecticides as economically as possible, and intensive research on the development of economic thresholds for insecticide use on such crops is in progress at ICRISAT Center. This year we studied the consumption of pigeonpea flowers and pods by individuals and groups of *H. armigera* larvae in both laboratory and field trials. Such data will be used in the determination of economic thresholds.

In insecticide trials at ICRISAT Center and at Hisar, we compared applications of up to five sprays of monocrotophos (Nuvacron®) on determinate and indeterminate short-duration genotypes. Summarized data from these trials are shown in Table 7. In both trials, we obtained substantial yield increases when three or more sprays were applied. At ICRISAT Center, even five sprays did not reduce pod damage by insects to an acceptable level, and therefore the yields were only moderate. At both locations, determinate genotypes gave greater yields than the indeterminate genotypes, but only when two or more sprays were applied. In general, the determinate genotypes are more prone to *H. armigera*-caused losses than the indeterminate types and consequently give poor yields unless adequately protected.

Virus use. Previously, we tested the nuclear polyhedrosis virus (NPV) of *H. armigera* on chickpea and obtained encouraging results in controlling the larvae. This year we tested NPV on pigeonpea genotype ICP 1-6. The virus was multiplied on *H. armigera* larvae at ICRISAT Center from a culture originally obtained from Tamil Nadu Agricultural University (TNAU), Coimbatore. Five sprays were applied at weekly intervals, just before dusk so that inactivation by ultraviolet light was minimized for the first few hours after application. A treatment in which the virus was combined with a half dosage of endosulfan gave at least as good control as the full insecticide treatment.

Podfly (*Melanagromyza obtusa*)

Distribution and importance. The pigeonpea podfly is thought to be restricted to the Indian subcontinent, Southeast Asia, and Australasia. In Africa, a different species, *Melanagromyza chalcosoma*, is commonly found in pigeonpea pods. Work at ICRISAT Center has established

Table 7. Insect-caused pod damage (%) and yields (kg ha⁻¹) in trials comparing the effects of differing numbers of insecticide applications on indeterminate and determinate short-duration pigeonpeas, ICRISAT Center and Hisar, 1984/85.

Plant type	Spray applications[1]	ICRISAT Center Pod damage[2] (%)	ICRISAT Center Yield (kg ha^{-1})	Hisar Pod damage (%)	Hisar Yield (kg ha^{-1})
Indeterminate[3]	5	34	1570	7	3080
	4	37	1520	9	2680
	3	44	1310	13	2160
	2	87	840	17	2090
	1	82	780	22	2010
	0	87	870	27	1860
Determinate[4]	5	56	1750	6	3610
	4	64	1770	8	2890
	3	77	1400	10	2580
	2	99	330	12	2330
	1	100	50[5]	15	1900
	0	98	210	23	1900
SE 1[6]			±88		±245
SE 2			±89		±157
CV(%)			17		13

1. Sprays of monocrotophos at 0.6 kg ai ha^{-1} started at flowering then at 10-day intervals.
2. Pod-damage data analyzed with arc sine transformation showed treatment differences to be significant; means retransformed.
3. The genotype at ICRISAT Center was ICPL 81 and at Hisar, ICPL 1.
4. The genotype at ICRISAT Center was ICPL 87 and at Hisar, ICPL 151.
5. Omitted from SE computation.
6. SE 1 for comparing plant types at same or different levels of spray applications.
SE 2 for comparing different levels of spray application within same plant types.

that *M. obtusa* has a restricted host range, having been found only in pods of pigeonpea and related wild legumes (*Atylosia* spp, *Rhynchosia* spp, *Flemingia* spp, and *Dunbaria* spp). It probably survives the lengthy periods when no pigeonpea pods are available by feeding on weed hosts, for no resting or diapause stages have been found.

Earlier ICRISAT surveys indicated that the podfly is particularly damaging in central and northern India where 21% of the pods sampled from farmers' fields were found to be damaged by the larvae of this insect. Podfly damage throughout India may result in the loss of 250000 tonnes of pigeonpea grain worth more than US $60 million per year. In 1985, 44% of the pods sampled from farmers' fields near Gwalior in central India were damaged by this pest.

Host-plant resistance. We have selected genotypes that show considerable differences in susceptibility to podfly. However, we do not yet have genotypes with sufficient resistance, combined with other desirable traits, that would merit release to farmers. Unfortunately most of our podfly-resistant selections have relatively small seeds. Most farmers and consumers demand large seeds, so we need to combine this characteristic with resistance to podfly.

In 1985, we attempted to determine the mechanisms of resistance by counts of the eggs, larvae, and pupae in the pods of resistant and susceptible genotypes, and by chemical and physical analyses of the pods. The resistant genotypes had much less oviposition than the susceptible genotypes, but there was no obvious antibiosis in the larval or pupal stages.

Nodule-damaging Fly (*Rivellia angulata*)

The nodule-damaging fly causes substantial damage to pigeonpea root nodules particularly in Vertisols where more than 90% of the nodules may be destroyed. We are studying this insect in collaboration with our microbiologists. The discovery that moistened, fermenting fish meal is very attractive to this insect has allowed us to monitor adult populations, using fish meal-baited, sticky traps. Figure 10 shows the numbers of flies caught in traps from July to October 1984.

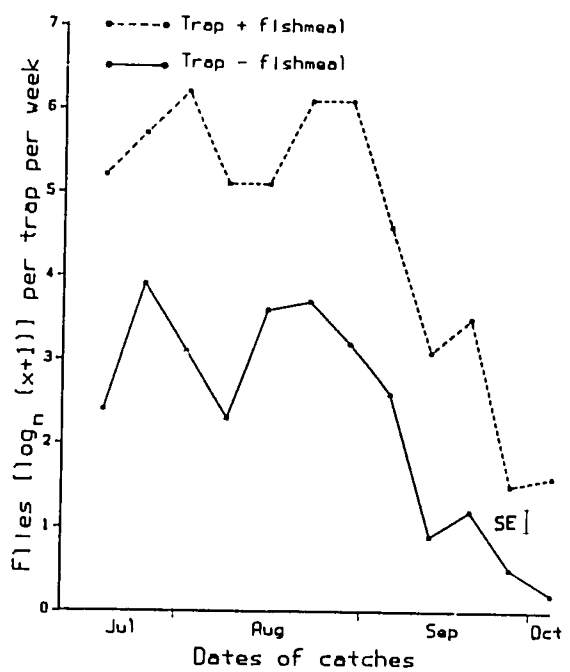


Figure 10. Mean catches of the pigeonpea nodule-damaging fly (*Rivellia angulata*) in sticky traps with and without fishmeal, ICRISAT Center, July-October 1985.

The field assessment of nodule damage by *R. angulata* is difficult and tedious, and we have not been able to assess the effect of nodule damage on plant growth. However, in 1985 we found that differing levels of nodule damage could be induced in plants growing in pots, by caging differing numbers of flies on the pots for the short oviposition period. This technique may be useful in determining the economic loss, if any, caused by such damage.

Breeding for Insect Resistance

We continued to emphasize stabilizing resistance to *Heliothis* and podfly in medium- and long-duration pigeonpea but increased our emphasis on short-duration lines. The pattern of *Heliothis* incidence in 1984 generally allowed us to identify, with some confidence, lines with resistance. However, high wilt incidence in fields used for the yield tests interfered with our attempts to measure the yield potential of the insect-resistant lines as most of these lines appeared to have little or no resistance to wilt.

From 1334 progeny rows and bulks we selected more than 600 single plants or rows with low insect damage for further testing. Of these, 34 were for testing in replicated yield trials in 1985 and over 70 were short-duration plants. The remainder were medium-duration plants that are being grown as single-plant progeny rows for further selection. Of the 24 crosses made for insect resistance, 17 involved short-duration parents.

Several trials in 1985 indicated that, under certain conditions, our insect-resistant lines have a distinct yield advantage. The Medium-duration Pigeonpea Adaptation Yield Trial (MPAY) at ICRISAT Center contained 20 entries. Although yields in this trial averaged only 145 kg ha^{-1} and the coefficient of variation was very high, the six insect-resistant lines occupied all but one of the top seven yield positions under nonsprayed conditions, even though some of them had over 20% wilt incidence. In the sprayed field, these lines gave disappointing yields because they all had over 75% wilt incidence. In another yield trial at

Table 8. Performance of six insect-resistant pigeonpea lines sown after wetland rice under zero-tillage conditions, IRRI, Los Banõs, Philippines, 1984/85.

Genotype	Time to 50% flowering (d)	Plant height (cm)	100-seed mass (g)	Yield: Grain (kg ha⁻¹)	Yield: Fodder (t ha⁻¹)	Yield: TDM[2] (kg ha⁻¹)
ICPL 84060	70	130	9.4	3250 (1)[1]	18.1 (4)	7270 (4)
ICP 909-E3-5EB	71	132	10.0	2770 (2)	16.6 (5)	5940 (5)
ICP 3009-E3-5EB	70	145	8.6	2690 (3)	23.8 (1)	9350 (1)
ICP 2223-1-E8-6EB	74	132	7.2	2540 (5)	21.3 (2)	8010 (2)
PPE 45-2-6B	78	141	10.0	1880 (16)	13.7 (7)	3840 (9)
ICPL 1-3EB	73	87	9.5	1140 (23)	6.5 (16)	4150 (7)
Control						
ICPL 295 (C 11 line)	75	129	10.1	2520 (6)	16.3 (6)	5930 (6)
SE	±7.9	±8.4	±0.78	±520	±1.64	±950
Trial mean (24 entries)	69	93	10.3	2040	10.4	3770
CV(%)	16	13	10	36	22	35

1. Figures in parentheses represent overall rank trial. 2. TDM = Total dry matter.

the International Rice Research Institute (IRRI) in the Philippines, where the mean yield was over 2000 kg ha⁻¹, out of 24 entries there were 6 insect-resistant, medium-duration pigeonpea lines from ICRISAT (Table 8). Of these, four were among the five top-yielding lines with one line, ICPL 84060, yielding 3250 kg ha⁻¹.

ICPL 332 is the first insect-resistant line to be entered into the AICPIP, multilocational-yield trial for medium-duration lines (ACT 2). Over the 18 locations where the coefficient of variation was less than 30%, ICPL 332 was above the trial mean and gave a yield similar to that of the two national control cultivars (Table 9). In 17

Table 9. Summary of the performance of the insect-resistant pigeonpea line ICPL 332 in AICPIP ACT 2 trials, rainy season 1984.

Line	Grain yield (kg ha⁻¹): Eastern Zone (1)[1]	Central Zone (8)	Southern Zone (9)	Mean all locations (18)	Time to maturity, mean 17 locations (d)
ICPL 332	870	1370	1170	1240	171
Controls					
C 11	290	1360	1200	1275	171
BDN 1	430	1390	1200	1245	160
Trial means	1070	1390	1010	1180	

1. Figures in parentheses denote number of locations with CVs < 30% for yield.

trials, ICPL 332 matured in the same number of days as C 11. The performance of this line might have been better than the controls if these trials had not been sprayed with insecticides.

A selection from the cross ICPX 77303 (Prabhat × ICP 3193-12), a cross that has produced many lines showing resistance, had very low pest damage in a replicated trial in 1984. Under nonsprayed conditions it showed 9% pod-borer damage, 10% podfly damage, and 31% total insect damage. The mean pod-borer damage in the trial was 57%, with the next-best line to ICPX 77303 having 32%. The mean total insect damage to pods was 73%, with the next-best line having 64% damage. This line has small seed (100-seed mass 5.6 g) and a rather low yield potential, although its yield was fourth greatest of the 25 under nonsprayed conditions. It is being extensively used as a parent in our breeding program. Other lines from this same cross with larger seed (100-seed mass 8 g) have been selected. These are being yield tested in 1985/86.

Table 10. Effect of sulfur and phosphorus fertilizer application on seed yield (g plant^{-1}) of pigeonpea ICPL 6, in Alfisol and Vertisol pot experiments, ICRISAT Center, 1984/85.

Element level (mg kg^{-1})	Alfisol	Vertisol	Mean
Sulfur			
0	3.32	3.26	3.29
65	2.67	3.01	2.84
130	2.61	3.16	2.88
Phosphorus			
0	0.37	0.83	0.60
40	2.93	3.84	3.38
80	5.30	4.77	5.03
SE	±0.281		±0.164
Mean	2.87	3.14	
SE	±0.208		

SE for comparing both S and P levels within a soil is ±0.232.

Plant Nutrition

Relative Response to Phosphorus and Sulfur

We used a pot experiment to determine the relative extent to which phosphorus (P) and sulfur (S) limit growth of a short-duration pigeonpea (ICPL 6), on Alfisols and Vertisols at ICRISAT Center. Previously, responses of pigeonpea to superphosphate had been obtained in pot experiments, but the proportionate responses to P and S were not identified. This information is necessary to determine the appropriate fertilizer type for pigeonpea on ICRISAT soils.

Three levels of sulfur, 0, 65, and 130 mg S kg^{-1}, as $CaSO_4.2H_2O$, and three of phosphorus, 0, 40, and 80 mg P kg^{-1}, as $Ca_3(PO_4)_2$, were applied in factorial combinations. These salts were mixed through the soil. A Vertisol and an Alfisol were studied and both had an initial level of about 1.0 mg available P kg^{-1}. The main effect of S on pigeonpea seed yield and its interactions with soil type and P treatment were not significant (Table 10). There was a large response to P on both soils and the magnitude of response was greater on the Alfisol. It was also noted that flowering was delayed by P deficiency.

Response to Mycorrhizal Inoculation

Vesicular arbuscular mycorrhizae (VAM) are zygomycetous fungi that form symbiotic associations with plant roots and help improve plant growth, mainly by increasing uptake of relatively immobile soil nutrients such as P. In an attempt to study the potential for improving pigeonpea nodulation and growth by VAM inoculation, we evaluated 15 VAM fungi in pots containing a sterilized Alfisol that was low in available P (Olsen available P $<$1 mg kg^{-1}) but amended with single superphosphate to provide 0 and 17 kg P ha^{-1}. Mycorrhizal inoculation and P fertilizer significantly increased the nodule number and mass, acetylene-reduction activity (ARA), shoot, root, and total dry matter (Fig.

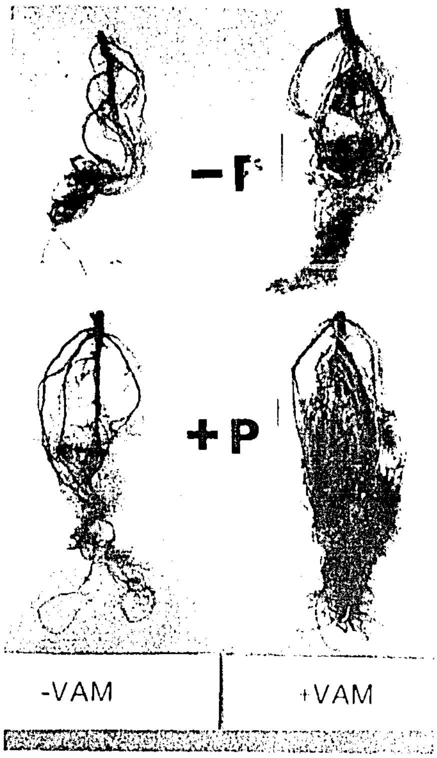
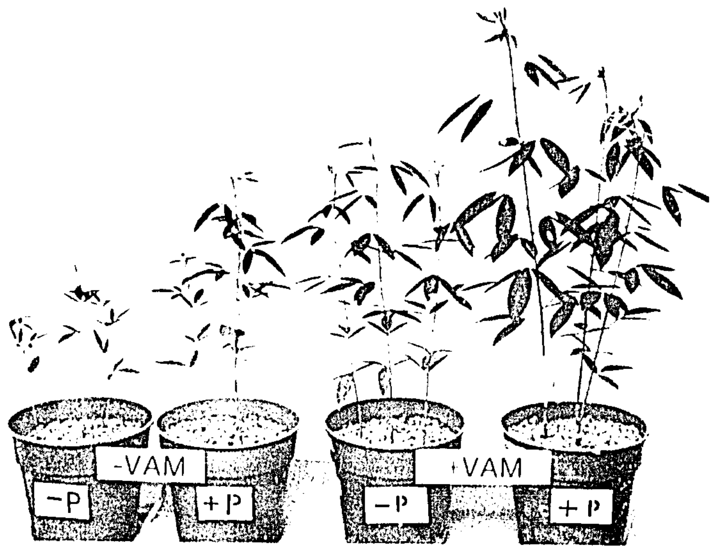


Figure 11. Response of shoots (below) and roots (left) of pigeonpea genotype ICPL 87 grown in sterilized Alfisol to mycorrhizal inoculation with and without 17 kg P ha^{-1} at 72 DAS, ICRISAT Center, 1984.



11), and total N and P uptake of pigeonpea cultivar ICPL 87. There were significant differences among mycorrhizal fungi in their beneficial effects on pigeonpea nodulation and plant growth. The interaction between fungi and P fertilizer was significant and two fungi, *Glomus fasciculatum* (E3 type) and *G. monospora*, appeared most promising. Further studies on the performance of selected fungi with pigeonpea grown in nonsterilized soil are in progress.

Response to *Rhizobium* Inoculation and Fertilizer Nitrogen

The responses of three promising pigeonpea genotypes, ICPL 87 (short-duration), ICPL 270, and ICPL 304 (both medium-duration), to *Rhizobium* inoculation and fertilizer N, applied at 200 kg N ha^{-1} at sowing, were studied in Vertisol and Alfisol fields. Twelve *Rhizobium* cultures, including four effective isolates collected from Maharashtra and Gujarat (see ICRISAT Annual Report 1984, p.182), were used. The native *Rhizobium* populations were 10^5 per gram of dry soil on Vertisols and 10^4 on Alfisols. None of the *Rhizobium* cultures significantly increased either seed or dry matter yields of pigeonpea grown on either soil type. However, fertilizer N significantly increased the total dry matter of genotypes ICPL 87 and ICPL 304 only on the Vertisol (Table 11). This suggests that N fixation by nodules was not sufficient to meet the N requirements of these genotypes on the Vertisol. Further, it was observed that nodule damage by insects was unusually high in the Vertisol field (damage range 12-100%; mean 86%) compared to the Alfisol field (range 0-94%; mean 20%). Experiments are now in progress to estimate the magnitude of loss in N fixation of pigeonpea grown in Vertisols due to the insects that feed on nodules.

Table 11. Effect of *Rhizobium* inoculation and N fertilizer application (200 kg N ha^{-1}) on total dry matter (kg ha^{-1}) at maturity of three pigeonpea genotypes grown on a Vertisol during 1984/85.

Rhizobium strain	Pigeonpea genotypes			
	ICPL 304	ICPL 87	ICPL 270	Mean
BDN A2	7000	5430	7810	6750
IHP 195	7490	4370	7070	6310
IHP 69	8670	4010	7260	6650
F 4	8280	4600	7650	6840
IHP 100	7720	3190	7990	6300
IHP 503	8320	3940	8000	6750
CC 1	7620	4520	7370	6500
KA 1	8000	5050	8090	7050
IHP 484	8480	4640	7450	6850
IHP 497	8380	4250	7420	6680
IHP 506	7420	4610	8020	6680
IHP 35	7110	4890	8560	6860
N fertilizer	10070	7050	7700	8270
Noninoculated	7870	4560	8080	6840
SE		±819[1] ±698[2]		±405
Mean	8030	4650	7750	
SE		±462		

1. SE for comparing cultivars at a given level of *Rhizobium* and N fertilizer.
2. SE for comparing *Rhizobium* strains and N fertilizer within a cultivar.

A profus... podding pigeonpea with several desiraole genetic traits, evolved through natural selection, growing in a farmer's field in a hilly tract in Malawi, 1985.

Pigeonpea Nodulation Survey in Malawi

We surveyed the major pigeonpea-growing areas of Malawi from 27 December 1984 to 8 January 1985, in collaboration with the Ministry of Agriculture and Natural Resources of the Government of Malawi, and collected nodule samples from various soil types on which the crop is grown. The pH of the soils ranged from slightly less than 4 to slightly more than 7. Pigeonpea nodulation ranged from poor to good. We observed nodule damage by insects in some of the surveyed fields.

We completed isolation and authentication of isolates from these nodules and are evaluating the isolates for nitrogen-fixing ability.

Rhizobium Culture Collection

We freeze-dried about 150 *Rhizobium* cultures during the year. We supplied peat inoculants and pure cultures of pigeonpea rhizobia on request to AICPIP and other scientists in India and other countries.

Grain and Food Quality

Protein Quality

We continued to monitor the protein content of breeding material and during 1985 we analyzed 2948 dhal samples and 396 whole-seed samples. The protein content in dhal samples ranged from 16.2 to 35.5%, and in whole-seed samples from 15.5 to 22.5%. Whole-seed samples of 783 germplasm accessions were also analyzed for protein content, which ranged between 14.7% and 23.7%.

An experiment was conducted to study the protein accumulation in a high-protein line (HPL 26) in comparison with a control cultivar (BDN 1). We analyzed samples collected at different stages of seed development (Table 12). There was little difference between the percentage of protein (N × 6.25) in the developing seeds of the two genotypes up to 30 days after flowering, but from then until seed maturity the percentage of protein in BDN 1 seeds declined. The grain mass of the high-protein line was lower than that of BDN 1 during the later stages of maturation. We analyzed the nitrogen content of leaf samples collected 45, 70, and 105 DAS. The nitrogen contents of HPL 26 leaf samples were lower than those in BDN 1 at 45 and 70 DAS.

Cooking Quality

We determined the cooking quality of 78 advanced-breeding lines. Seed samples were soaked for 8 hours, dried at 55°C overnight, and then dehulled using a barley pearler. We then determined cooking time, water absorption, solids dispersed into the cooking water, and texture in the dhal samples. Cooking time ranged between 20 and 40 min, with a mean of 29 min, and water absorption ranged between 1.5 and 2.5 g per gram of dhal material (Table 13).

Table 13. Seed mass, protein content, and cooking quality evaluation of 78 pigeonpea advanced breeding lines, ICRISAT Center, 1985.

Constituent	Range	Mean	SE±
100-seed mass (g)	6.6-12.7	9.2	1.37
Protein content (%)			
Whole seed	15.2-20.1	18.1	1.06
Dhal	18.6-23.2	21.4	1.02
Cooking time (min)	20.0-40.0	29.0	4.45
Water absorption ($g\ g^{-1}$)	1.5-2.5	1.9	0.21
Solids dispersed (%)	25.5-67.3	42.1	11.25
Texture (force, kg)	60.0-243.0	123.8	45.40

1. Protein = (N × 6.25)

Table 12. Protein content and 100-seed mass at different stages of grain development of a high-protein pigeonpea line HPL 26 and control, ICRISAT Center, rainy season 1984/85.

		Days after flowering				
Genotype	Constituent[1]	10	20	30	40	50
HPL 26	Protein (%)	33.6 ±0.31	27.1 ±1.89	23.6 ±0.82	23.5 ±0.91	25.4 ±0.36
	100-seed mass (g)	0.3 ±0.04	1.7 ±0.67	6.4 ±0.06	6.5 ±0.21	7.6 ±0.23
Control BDN 1	Protein (%)	36.3 ±0.80	25.5 ±0.35	22.7 ±0.73	19.0 ±0.42	17.5 ±0.35
	100-seed mass (g)	0.2 ±0.06	2.2 ±0.33	6.0 ±0.47	8.9 ±0.66	9.5 ±0.57

1. Values are averages of three determinations.

Milling Quality

We tried to compare the milling quality of ICP 7041 and ICPL 276 with control C 11 using a commercial dhal mill in Hyderabad. Since a commercial mill can only deal with relatively large samples our breeding program provided about 100 kg of each of the three genotypes. These were processed according to the standard procedure in the mill. The dhal yield was 79.2% for C 11, 77.9% for ICPL 276, and 75.9% for ICP 7041. The lower dhal yield in ICP 7041 might have been due to its smaller seed size that resulted in an increase in the powder fraction. Total recovery values varied from 96.3 to 99.4%. We intend to compare these results with values obtained from these genotypes milled in a Prairie Regional Laboratory mill, a barley pearler, and a manually operated stone mill.

Plant Improvement

Short-duration Pigeonpea

There was increasing interest in short-duration pigeonpea because its early maturity provides a crop in areas where pigeonpea is not traditionally grown. The crop's ability to produce more than one harvest from a single sowing continues to generate interest and it is starting to replace the traditional medium- and long-duration types in some areas. For these reasons, we continued to emphasize breeding short-duration genotypes.

We have been identifying high-performance lines for northwestern India that can be sown any time from March to July and still mature before mid-November, allowing wheat to be sown in time to give a good crop. A line that has consistently outperformed the control cultivars when sown in April, June, or July is ICPL 151 (Table 14). This line was identified as a candidate for release as a cultivar for the Northwest Plain, Northwest Hill, and Central Zones of India. ICPL 151 is a determinate line with large, round, cream-colored seed (100-seed mass > 10 g vs 100-seed mass < 7 g for UPAS 120) in pods borne in large clusters at the top of the branches. This line, selected from the cross ICP 6997 × Prabhat, is about 20% shorter than UPAS 120 and has field-tolerance to sterility mosaic.

Diseases have not generally been a problem in the many new areas where short-duration pigeonpea is grown, but where this crop extends into

Table 14. Comparison of grain yield (kg ha^{-1}) of pigeonpea line ICPL 151 with controls UPAS 120 and Prabhat, sown in April (early), June (normal), and July (late), Hisar, 1979-84.

	April-sown		June-sown						July-sown	
Line	1982	1983	1979	1980	1981	1982	1983	1984	1982	1983
ICPL 151	2290	1590	2070	2660	2800	3080	2610	2920	3050	2100
Controls										
UPAS 120	2140	-[1]	-	2270	-	2840	-	2430	2870[2]	-
Prabhat	-	1200[3]	1290	-	2090	-	1460	-	2060[3]	1620[3]
SE	±91	±237	±164	±154	±154	±52	±200	±247	±92	±115
Trial mean	2290	1970	1610	2320	2700	2920	1720	2450	2570	1440
No.of entries	15	14	31	30	18	12	14	14	12	13
CV(%)	9	17	20	13	11	4	23	14	6	14

1. - = Not tested.
2. ICPL 1, a line derived from UPAS 120.
3. ICPL 4, a line derived from Prabhat.

An ICPL 151 plant showing typical pod development, Hisar, 1985.

the more traditional pigeonpea-growing areas it is affected by some diseases. We are therefore trying to identify high performance, short-duration lines with resistance to wilt, sterility mosaic, and phytophthora blight. Some lines, e.g., ICPL 288, 8324, and 8377 have been identified with combined resistance to two diseases at ICRISAT Center.

We have intensified our efforts to identify short-duration lines with some resistance to attack by insects such as *H. armigera, M. testulalis*, and podfly, and at Hisar have selected plants with the least insect damage from breeding lines.

Five short-duration lines were entered into three AICPIP Coordinated Multilocational Trials, EXACT, EACT, and ACT 1.

ICRISAT also supplied multilocational yield trials containing advanced-breeding lines to scientists in national programs. Results from nine locations (Table 15) indicated that the short-duration line ICPL 8306 outyielded the control ICPL 4 (a Prabhat line) as it did at Hisar in 1983 (ICRISAT Annual Report 1984, p.186-7). In a 500 m² plot in a farmer's field, ICPL 8306 had yielded about 3200 kg ha⁻¹ by the end of October 1985.

We identified several new lines that yielded over 3000 kg ha⁻¹ before mid-November at Hisar

Table 15. Performance of ICPL 8306, a promising short-duration pigeonpea line at Hisar, and its yield, at nine Indian locations, rainy season, 1984.

	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha⁻¹) Hisar	Mean (nine locations)	Range (nine locations)
ICPL 8306	137	153	7.3	2830	2420	820-3440
Control						
ICPL 4[1]	135	167	5.6	2480	1880	690-2810
SE	±2.4	±3.8	±0.2	±141		
Trial mean (14 entries)	142	139	7.5	2010		
CV(%)	3	5	4	12		

1. ICPL 4 is a line derived from Prabhat.

(Table 16). Harvesting in early November would allow ample time to remove the crop and prepare the land for wheat. Most of these lines are short statured and have a 100-seed mass exceeding 9 g. These lines are all in multilocational yield trials and are also being monitored in disease nurseries.

Medium-duration Pigeonpea

The major objective of our medium-duration pigeonpea breeding program is to stabilize yield by breeding lines with resistance to diseases and insect pests. Details of this work are reported in

Table 16. Performance of some promising short-duration pigeonpea lines at Hisar (20 entries in each trial), June, 1984.

Line	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha^{-1})	Line	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (kg ha^{-1})
Determinate					Indeterminate				
Trial 1					Trial 1				
ICPL 85005	145	153	9.1	3750	ICPL 85035	127	202	9.1	3270
					ICPL 85040	136	210	9.4	3050
Controls					Control				
ICPL 4	127	170	6.3	2270	H 77-216	136	205	7.2	2780
ICPL 87	155	155	10.7	2920					
SE	±0.8	±6.9	±0.36	±364	SE	±1.8	±5.0	±0.2	±175
Trial mean	151	178	10.1	2391	Trial mean	131	203	8.2	2715
CV(%)	0.7	5	5	21	CV(%)	2	4	5	11
Trial 2					Trial 2				
ICPL 85012	136	157	10.8	3320	ICPL 85045	141	207	9.1	3150
ICPL 85015	124	161	9.6	3170					
Control					Control				
ICPL 4	122	173	6.0	2520	H 77-216	135	217	7.1	2500
SE	±2.9	±5.1	±0.2	±145	SE	±2.3	±5.9	±0.2	±180
Trial mean	127	152	9.1	2517	Trial mean	139	208	8.1	2421
CV(%)	4	6	4	10	CV(%)	3	5	5	13
Trial 3					Trial 3				
ICPL 85016	130	183	8.2	3540	ICPL 85050	139	155	11.5	3160
ICPL 85017	134	148	10.1	3250	ICPL 85051	143	175	10.6	310
ICPL 85018	129	183	9.8	3220					
Control					Control				
ICPL 4	119	168	5.8	2830	H 77-216	139	180	7.3	2920
SE	±2.2	±4.6	±0.3	±221	SE	±3.0	±11.9	±0.3	±295
Trial mean	130	165	9.8	3025	Trial mean	141	166	9.0	2804
CV(%)	3	5	5	13	CV(%)	3	10	4	15

the diseases and insect pests sections of this report. However, in 1985 we also continued to breed for yield in medium-duration pigeonpea. We made 72 crosses and grew out 6 F_1s, about 490 single-plant progenies, and 33 bulk populations, and yield-tested almost 500 advanced lines.

Long-duration Pigeonpea

As for medium-duration pigeonpea, our main objective is to stabilize yield in long-duration pigeonpea by breeding for disease and insect resistance. This work is reported in the diseases and insect pest sections of this report.

Vegetable-type Pigeonpea

In many areas, such as East Africa, the Caribbean region, and Gujarat State in India, green pigeonpea seed is commonly used as a vegetable in the same way that green peas (*Pisum sativum*) are used. For this purpose, pigeonpea varieties with large pods and large, sweet seeds are preferred. In our breeding program to develop vegetable-type varieties, we identified some indeterminate, large-seeded, medium-duration lines that yielded well in 1984 (Table 17). Short-duration, vegetable-type lines are also being bred.

During 1985, line ICP 7035 was released in Fiji as a vegetable-type cultivar named Kamica

Vegetable pigeonpea on sale in Gujarat, India.

Table 17. Performance of promising medium-duration, indeterminate, vegetable-type pigeonpea lines, ICRISAT Center, rainy season 1984.

Entry	Parentage	Time to 50% flowering (d)	Time to maturity (d)	Seeds pod^{-1}	100-seed mass (g)	Grain yield (kg ha^{-1})
5111	C 11 × JA 275	119	174	4.0	12.0	2830
5110	AS 71-37 × JA 275	118	168	4.0	12.3	2650
5108	(ICP 8504 × BDN 1) × C 11	117	172	4.6	12.3	2370
5102	ICP 7979 × ICP 8503	119	175	4.7	12.3	2140
5106	(ICP 8503 × ICP 7979) × C 11	116	173	4.7	15.1	1870
Controls						
C 11		118	172	3.6	9.9	2530
BDN 1		110	162	3.7	10.5	1820
T 15-15 (Vegetable)		114	172	4.3	11.2	1340
SE		±0.9	±2.4	±0.30	±0.37	±179
Trial mean (16 entries)		115	170	4.37	11.9	2020
CV (%)		1.3	2.4	12	5	15

(sweet) because of its sweet seed. This cultivar is a medium-duration, indeterminate type with large red seeds (100-seed mass 18 g). It is resistant to wilt, sterility mosaic, and alternaria blight diseases.

Hybrids

ICPH 8

In 1984, ICPH 8, the short-duration hybrid we reported as outstanding in 1983 (ICRISAT Annual Report 1984, pp.187 and 189), continued to perform well at Hisar. Over 1981, 1983, and 1984 the yield of this hybrid averaged almost 50% more than the control UPAS 120 at Hisar (Fig. 12). To see how widely it is adapted, ICPH 8 was grown at 22 locations throughout India using 3 m × 4 m row plots in replicated trials with five control cultivars. In the 15 trials that had a coefficient of variation (CV) less than 24%, the yield of ICPH 8 ranged from 480 to 4310 kg ha^{-1} (Table 18). The standard heterosis of ICPH 8 over the national control cultivar (UPAS 120) ranged from -5% to 124% with an average of 25.6%. ICPH 8 ranked first or second out of 6 entries in 11 of the 15 trials. If this hybrid continues to perform well in multilocational trials in 1985 it will be entered in the All India Coordinated Yield Trials in 1986.

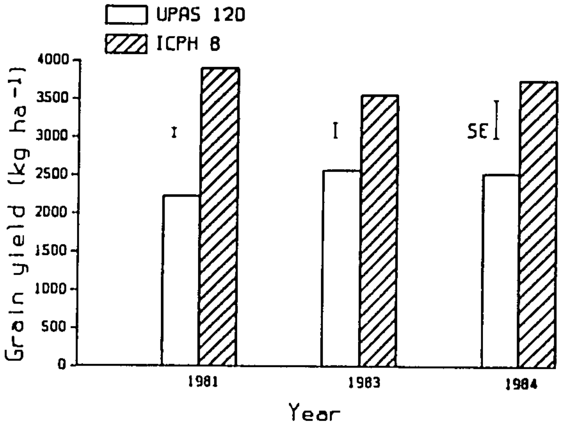


Figure 12. Grain yields (kg ha^{-1}) of pigeonpea hybrid ICPH 8 and control cultivar UPAS 120, Hisar, 1981, 1983, and 1984.

High-yielding hybrid ICPH 8 growing at ICRISAT Center, 1985.

Broadening the Genetic Base of Male-sterile Plants

To stabilize the performance of hybrids across environments and production systems, we have developed male-sterile plants with high combining ability from diverse genetic backgrounds in all three major duration classes at ICRISAT Center (Table 19). These include lines where the male sterility is controlled by the ms_1 or ms_2 gene. Resistance to the two important diseases of pigeonpea, wilt and sterility mosaic, behaves as if controlled by recessive genes, so both parents must be resistant in order to produce resistant

Table 18. Performance of the short-duration pigeonpea hybrid ICPH 8 compared to the national control cultivar UPAS 120 at 15 locations in four Zones of India, rainy season 1984.

Zone and location	Yield (kg ha⁻¹) ICPH 8 Hybrid	Yield (kg ha⁻¹) UPAS 120 Control	SE	Trial mean (6 entries)	CV (%)	Standard heterosis (%)
Northeast Plain						
Varanasi	2700 (2)[1]	2640 (3)	±216	2670	11	3
Northwest Plain						
Hisar (ICRISAT)	3720 (1)	3070 (4)	±190	3080	9	21
Hisar (HAU)	2380 (1)	1550 (4)	±45	1880	3	53
Kaul	1890 (1)	1670 (3)	±99	1390	10	13
Pantnagar	2520 (6)	2670 (5)	±332	2910	16	-5
Central						
Jalna	2110 (3)	1790 (5)	±334	2070	22	18
SK Nagar	2880 (2)	2450 (4)	±294	2660	16	17
Rahuri	2230 (1)[2]	1000 (5)	±172	1290	19	124
Bharuch	2930 (2)	2050 (4)	±360	2340	22	43
Badnapur	480 (2)[2]	340 (6)	±19	440	6	42
Sehore	4310 (1)[2]	2950 (4)	±88	3510	4	46
Junagadh	2110 (1)	1860 (3)	±212	1810	17	13
Phaltan	1480 (3)	1400 (4)	±47	1390	5	6
Southern						
Secunderabad	1530 (1)[2]	980 (5)	±97	1080	13	57
ICRISAT Center	1810 (2)	1520 (3)	±241	1400	24	19
Mean	2340	1860				25.6

1. Figures in parentheses represent rank in trial.
2. Significantly superior to the control at $P < 0.05$.

Table 19. Characteristics of male-sterile pigeonpea lines maintained at ICRISAT Center, backcrossed at least five times to the recurring parent.

Line name	Time to 50% flowering (d)	Plant height (cm)	Plant spread[1]	Seeds pod^{-1}	100-seed mass (g)	Seed color[2]	Remarks
Determinate growth habit							
QMS 9[3]	52	90	C	4.0	10.0	W	
QMS 7[3]	56	125	C	6.0	11.0	W	
IMS 1	60	85	C	3.5	7.0	B	Photo insensitive
MS-Prabhat (DT)	69	87	C	3.6	6.6	B	Good combiner
QMS 2[3]	70	150	C	5.0	11.0	B	
QMS 1[3]	80	140	C	6.0	9.1	W	
QPL 5	82	-	SS	4.0	11.0	B	
Indeterminate growth habit							
MS-Prabhat (NDT)	80	145	C	3.8	6.9	B	
MS-T 21	83	152	SS	3.9	7.5	B	Good combiner
MS-BDN 1	101	143	SS	3.5	9.0	B	Wilt resistant
MS-ICP 7120	109	128	SS	3.9	10.5	B	
MS-ICP 102	110	138	S	3.5	10.8	B	
MS 3A	110	230	SS	3.5	9.5	W	
MS 4A	110	230	SS	3.5	9.5	B	
MS-ICP 1	115	154	SS	4.0	10.4	B	
MS-C 11	124	207	SS	3.6	10.0	B	Wilt resistant
MS-ICP 3783	132	235	SS	4.8	18.1	W	Wilt and sterility mosaic resistant
MS-ICP 7035	136	176	SS	4.8	19.1	P	Wilt and sterility mosaic resistant
MS-ICP 6978	136	275	SS	3.6	8.6	Bl	
MS-NP(WR) 15	146	230	C	3.5	8.7	W	Wilt resistant
MS-ICP 7086	147	170	C	4.5	16.1	W	
MS-ICP 7105	158	179	SS	4.0	9.2	B	

1. Plant spread, C = Compact, SS = Semispreading, S = Spreading.
2. Seed color, W = White, B = Brown, P = Purple, Bl = Black.
3. These lines have the ms_2 gene; the remaining lines contain the ms_1 gene.

hybrids. We have therefore developed wilt and sterility mosaic resistant, male-sterile lines through backcrosses, using resistant lines as the recurrent parent and screening the progenies in the appropriate disease nursery. We now have male-sterile lines with good seed size that are resistant to both diseases (Table 19).

Plant Regeneration from Immature Pigeonpea Embryos

We have sucessfully made intergeneric crosses between *Cajanus cajan* and several *Atylosia* spp (ICRISAT Annual Report 1981, p.146). However, several attempted crosses have not been successful. Many of these failures may happen because in certain combinations after fertilization, the endosperm fails to develop. To overcome this failure, we attempted to standardize culture conditions for plantlet regeneration from immature embryos so that we could rescue embryos from crosses where the endosperm did not develop. We only used four genotypes of *Cajanus*, as most crosses between *Cajanus* and *Atylosia* are only successful with *Cajanus* as the female parent. We used two culture media (MS, and B5 supplemented with 2,4-D).

We found that embryos that were less than 11 days old did not form plantlets, even when the medium was supplemented with several hormone combinations. Eleven- to 14-day-old embryos developed callus, with about 12% forming plantlets. About 80% of 15- to 19-day-old embryos produced plantlets, accompanied by small amounts of callus at their bases. The germplasm line ICP 7035, which had the largest seeds, gave the most plantlets, and the B5 culture medium was consistently better than the MS.

Earlier work at ICRISAT Center has shown that postpollination hormone treatments in intergeneric crosses involving pigeonpea can allow the pods to develop for 8 days compared to 3 days for nontreated crosses. Hence, we still need to close the 3-day gap through better postpollination hormone treatment, or a better embryo-culture technique that will allow the rescue of embryos before they are 11 days old.

Cooperative Activities

International Trials

Pigeonpea Observation Nursery. For several years we have offered the Pigeonpea Observation Nursery (PON) for scientists who are unfamiliar with the range of pigeonpea material available. This nursery contains about 24 lines from the shortest to longest durations, with a range of plant types, plant heights, seed types, and resistance to such factors as disease, insect pests, salinity, and flooding. Growing this nursery allows scientists to identify the type of material most suited to their conditions and requirements as well as any potential problems they may have with the crop. This also permits them to specify the type of material from ICRISAT they wish to test in greater detail.

This year we received results of PONs from several locations, some of which exhibited a high yield potential. The PON at the Plant Industry Central Experimental Farm at Manila in the Philippines averaged around 2000 kg ha^{-1} with ICP 8863 yielding about 3500 kg ha^{-1} and two other medium-duration lines yielding about 3000 kg ha^{-1}. The results suggested that the medium-duration types were most adapted to conditions at that location. Another PON trial in Yavello in southern Ethiopia clearly showed that long-duration lines were best adapted under the conditions of the trial. In this trial, the 8 short-duration lines averaged grain yields of 670 kg ha^{-1}, the 11 medium-duration entries 1280 kg ha^{-1}, and the 5 long-duration lines 2630 kg ha^{-1}. In contrast, out of four PONs sent to Argentina, two failed because the growing season was too short and in the other two, only the short-duration lines produced seed. These results were backed up when the Early Maturity Pigeonpea International Trial (EPIT) grown at Salto I in Argentina averaged 3340 kg ha^{-1} with the highest yield being 4840 kg ha^{-1}, while a medium-duration trial grown at the same location did not yield.

International Pigeonpea Wilt Nursery (IPWN)
During 1985, 33 wilt-resistant lines and a susceptible control (ICP 2376) were tested at a location in Malawi and at ICRISAT Center. Lines such as ICP 7855, 8863, 8864, 9134, 9174, 10958, 10960, 11297, 11299, 12730, 12733, 12738, 12741, 12744, and 12748, showed less than 20% wilt while the susceptible control showed more than 90% wilt at both locations.

All India Coordinated Trials

Cooperation with AICPIP

We continued to cooperate with the AICPIP. In the 1984/85 Arhar Coordinated Trials (ACT), ICRISAT submitted five entries to the Extra-Extra-Early Maturing Trial (EXACT), eight to the Extra-Early Maturing Trial (EACT), three to the Early-maturing Trial (ACT 1), five to the Medium-maturing Trial (ACT 2), and five to the

Late-maturing Trial (ACT 3). For the Medium-maturing Pigeonpea Sterility Mosaic Resistant Yield Trial (MPSRY) we contributed 12 entries, 2 to the Late-maturing Pigeonpea Sterility Mosaic Resistant Yield Trial (LPSRY), and 17 to the Medium-maturing Pigeonpea Wilt Resistant Yield Trial (MPWRY).

The performance of ICPL 332 in the ACT 2 has already been reported in the section on breeding for insect resistance. The line ICPL 151 from the EACT was identified by the 1985 AICPIP Kharif Pulses Workshop as promising for release. Details of this line are given in the section on short-duration pigeonpeas in this report.

ICAR/ICRISAT disease nurseries. Pigeonpea germplasm and breeding lines identified by ICRISAT as resistant to wilt, sterility mosaic, and phytophthora blight were tested multilocationally through four different cooperative, disease nurseries. The objectives of these disease nurseries were to identify pigeonpea lines with broadbased resistance to the major diseases and to share the seed of resistant materials with the Indian national programs. The results from these nurseries are summarized below. Detailed reports are available from the Program Director, Legumes Program.

ICAR/ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR) 1985. This nursery has been in operation since the 1980-81 season. In 1985, 33 resistant lines along with a susceptible control (ICP 2376) were tested at 13 locations in India. Proper evaluation for wilt resistance was done at 11 locations and varying numbers of lines were recorded to be resistant at each of these locations. A few lines such as ICP 9174, ICP 12745, ICPL 84007, AWR-74/15, and Banda Palera, were resistant at 9 or 10 locations.

Results of IIUTPWR for 1981-83. Our recent analyses indicated that during a period of 3 years (1980/81 to 1982/83), 70 lines were tested in these trials at 12 locations in India and, excepting at Baroda (Gujarat) and Palem (Andhra Pradesh), several lines were found resistant to wilt. Lines such as ICP 4769, 7118, 7182, 8863, 9168, 10957, 10958, 11299, and Bori-1-sel were found resistant in 8 or 9 out of the 12 locations tested. ICP 8863 and 10958 were found resistant for 3 consecutive years at Annigeri and ICRISAT Center (southern India), Badnapur and Jabalpur (central India), Delhi and Kanpur (northern India), and Dholi and Berhampore (eastern India). ICP 8863 and ICP 10960 were found resistant for 3 years at Gulbarga (southern India).

ICAR/ICRISAT Uniform Trial for Pigeonpea Sterility Mosaic Resistance (IIUTPSMR). Thirty-three lines and a susceptible control (BDN 1) were tested at 13 different locations in India but effective screening was obtained at only nine locations. At each of these nine locations several lines were found resistant and two entries (ICP 7867 and ICP 10976) were resistant at all locations. ICP 7867 was also found resistant to wilt at some locations.

ICAR/ICRISAT Uniform Trial for Pigeonpea Phytophthora Blight Resistance (IIUTPPBR). Sixteen promising lines and a susceptible control (Hy 3C) were tested at nine locations and effective screening was obtained at six of these. The reactions of the lines varied from location to location. No line was found resistant at all six locations, but KPBR 80-2, was found resistant at all three locations where it was tested.

Training

We were pleased to welcome many scientists for training in various aspects of pigeonpea research and development, in cooperation with our Training Program. The periods of training varied from as little as a few hours, for training in specific methodology, up to 3 years for completion of PhDs.

Sixteen participants from nine countries (Bangladesh, Chile, Ethiopia, India, Mexico, Nepal, Pakistan, Syria, and Thailand) attended the Sixth International Training Course in Pigeonpea and Chickpea Pathology from 7-22 January

1985. Two postdoctoral scientists from India completed their 2-year fellowships in pigeonpea pathology. One worked on nematodes, including studies of interactions between these pests and fusarium wilt, the other studied the epidemiology of phytophthora blight.

In entomology, a postdoctoral scientist from UK completed 2 years work on the analyses of catches of *H. armigera* in light and pheromone traps, and a young scientist from Senegal spent a few months studying pigeonpea pest management.

Our agronomists provided short periods of training in *Rhizobium*-production techniques to four scientists from India and a scientist from China was trained in pigeonpea agronomy.

In pigeonpea breeding, a student from India successfully completed his PhD at a local university, having worked with us on intergeneric hybrids. A postdoctoral fellow from Australia is now working with us for 2 years on embryo-culture techniques in such hybrids. An Indian PhD student was with us for 4 months studying the genetics of protein content in pigeonpea seed and a Kenyan PhD student from the University of Nairobi came to learn methods that will benefit his studies in the inheritance of fusarium wilt resistance in this crop. Two months training in breeding methodology was given to a scientist from the Philippines.

Workshops, Conferences, and Seminars

Pigeonpea Scientists' Meet

The first meet exclusively for long-duration pigeonpea organized by ICRISAT was held at the JNKVV College of Agriculture, Gwalior, 18-20 March 1985. Thirty-eight scientists including breeders, entomologists, pathologists, microbiologists, and agronomists participated. Two were from Kenya, one each from Tanzania and the Philippines, and the rest were from ICRISAT and India. Participants, invited to present short papers on the uses and impact of ICRISAT material on national, pigeonpea-improvement programs, unanimously agreed that material from ICRISAT was important in their programs. They particularly appreciated many germplasm and breeding lines with disease and insect resistance, synchronous flowering, and male sterility, new plant types and lines from intergeneric crosses. It was noted that, because resistance to wilt and sterility mosaic was often location-specific, the disease resistance of material should be reconfirmed in each location before it is extensively used in the breeding program for that area.

Papers from outside India indicated that there is little breeding work on long-duration pigeonpea in other countries. Participants urged ICRISAT to increase its involvement in the improvement of material for their countries, as the available long-duration material from ICRISAT is not suitable for their requirements. All scientists examined the material in the field and selected over 500 lines and plants that appeared to most nearly meet their requirements. Participants said that this meeting provided a chance for pigeonpea workers from many disciplines to walk, talk, and work together in order to share their ideas, and improve understanding and the coordination of effort.

Review and Planning Meeting for Asian Regional Research on Grain Legumes

This meeting, funded by the Australian Development Assistance Bureau and sponsored by ICRISAT, the Australian Centre for International Agricultural Research (ACIAR), and the International Rice Research Institute (IRRI), was held at ICRISAT Center, 16-18 December 1985. The objectives of the meeting were, to identify cooperative links between organizations concerned with legumes research in Asia, to assess the progress made since the Consultative Meeting for Asian Grain Legumes that was held at ICRISAT in 1983 and to develop plans for future cooperation in countries of South and Southeast Asia.

Ten scientists from seven countries in the region (Bangladesh, India, Indonesia, Nepal, Pakistan, Philippines, and Thailand), nine representatives from six international agencies, and ICRISAT scientists discussed research and development of pigeonpea as well as that of chickpea and groundnut in the region. Executive summaries of the technical reports, discussions, and recommendations are available from Information Services, ICRISAT.

It was announced that a Coordinator for ICRISAT's Asian Grain Legume Program had been appointed, and that this program will be active from 1 January 1986. The meeting provided the Coordinator with strong guidance that was contained within eight specific recommendations. It was stressed that the primary objectives of the new program should include the promotion of closer contact between ICRISAT scientists and the relevant scientists in each country, and encouragement of a two-way flow of information and material. It was also emphasized that there was a need for coordination between the various international and regional organizations, both to integrate research efforts and to reduce duplication of effort. Other recommendations were to identify the problems of the three crops in the region and search for solutions, conserve germplasm, meet training requirements, determine more exactly the areas in the region where genotypes of the three legume crops are adapted, and conduct socioeconomic studies to find out the potential uses of the three crops in each country of the region.

Looking Ahead

Studies on genotypic differences in response to drought of short- and medium-duration pigeonpea will intensify. Screening for tolerance to waterlogging and salinity will continue. Studies to define mineral nutrient limitations to pigeonpea growth on various soils, and their interaction with soil-water status, will also continue. Studies are in progress to determine the timing and extent of nitrogen limitation to pigeonpea growth and yield under field conditions. These and other studies will allow us to assess the extent to which we can improve symbiotic nitrogen fixation in pigeonpea, and suggest how this may best be done. Assessment of the potential for mycorrhizal inoculation will continue. Newly developed, short-duration pigeonpea genotypes will be tested to determine optimum agronomic practices for their cultivation. Studies on optimum plant types for both monocrops and intercrops will be intensified.

We plan to continue screening all the short-duration breeding material for resistance to sterility mosaic and phytophthora blight, while ensuring that it is not susceptible to fusarium wilt. The medium- and long-duration materials will be screened for combined resistance to fusarium wilt and sterility mosaic, while ensuring that these are not susceptible to phytophthora blight. We hope to make good progress towards purification of not only the sterility mosaic pathogen, but also of the yellow mosaic virus. We will focus our attention towards identifying pathogenic races of *Fusarium udum* and *Phytophthora dreschsleri* f.sp *cajani.*

Our cooperative efforts to strengthen pigeonpea resistance to *Heliothis armigera* and podfly, and to combine such resistance with other required traits, including disease resistance and desirable seed quality, will be intensified. We expect to make further progress in understanding the population dynamics of *H. armigera.* We plan to determine the economic thresholds for the major pests and to embark upon integrated pest-management trials. We also intend to further extend our entomological activities to other countries.

In breeding, we intend to continue our efforts to develop short-duration pigeonpea with high and stable yields. Such types are needed for double cropping with wheat in northern India and for many other cropping systems and areas. Work on short-duration hybrids and vegetable types will be strengthened. The incorporation of resistances to biotic and abiotic stresses in all duration types will continue to be of high priority. International testing and collaboration through national programs and regional networks will be further developed, not only for varietal testing, but also for adaptation trials in various cropping systems, and for utilization and processing studies. We hope to increase our impact in southern Asia, the Caribbean region, and in Africa. The medium-duration, high-protein lines will be tested for adaptability in India, and in other countries in Asia, for possible use as better-quality food for humans and as feed for animals.

Publications

Institute Publications

Bibliography

Nene, Y.L., Kaiser, W.J., Grewal, J.S., Kannaiyan, J., and **Beniwal, S.P.S.** 1985. An annotated bibliography of pigeonpea diseases, 1906-81. Patancheru, A.P. 502 324, India: ICRISAT.

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. International Pigeonpea Newsletter no. 4. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Brader, L., Buyckx, E.J., Davies, J.C., and **Reed, W.** 1985. Field and plantation crop pest control. Pages 217-248 *in* Pesticide Application: Principles and Practice, (Haskell, P.T., ed.). Oxford: Clarendon Press.

Kannaiyan, J., Nene, Y.L., and **Raju, T.N.** 1985. Host specificity of pigeonpea wilt pathogen, *Fusarium udum*. Indian Phytopathology 38: 553-554.

Lateef, S.S., Reed, W., and **LaSalle, J.** 1985. *Tanaostigmodes cajaninae* LaSalle sp. n. (Hymenoptera: Tanaostigmatidae), a potential pest of pigeonpea in India. Bulletin of Entomological Research 75(2): 305-313.

Reed, W., Davies, J.C., and **S. Green.** 1985. Field experimentation. Pages 153-174 *in* Pesticide Application: Principles and Practice, (Haskell, P.T., ed.). Oxford: Clarendon Press.

Sateesh Kumar, P., Subrahmanyam, N.C., and **Faris, D.G.** 1985. Intergeneric hybridization in pigeonpea. I. Effect of hormone treatments. Field Crops Research 10(4): 315-322.

Venkataratnam, N., and **Sheldrake, A.R.** 1985. Second harvest yields of medium duration pigeonpeas (*Cajanus cajan*) in peninsular India. Field Crops Research 10(4): 323-332.

Conference Papers

Lateef, S.S., and **Reed, W.** 1985. A suggested system of rating pigeonpea and chickpea entries for field resistance to *Heliothis armigera*. Pages 127-131 *in* National Seminar on Breeding Crop Plants for Resistance to Pests and Diseases, 25-27 May 1983, Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Sithanantham, S. 1985. Principles and methods of pest management in pulses. Pages 219-228 *in* Microbial Control and Pest Management (Jayaraj, S., ed.), Coimbatore, India. Coimbatore, Tamil Nadu, India: Tamil Nadu Agricultural University.

Contents

Cover photo: Groundnut pods and kernels infested with larvae of *Caryedon serratus*, a pest that causes serious losses to stored groundnuts.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502324, India.

GROUNDNUT

Seventy percent of the world's groundnuts are produced in the semi-arid tropics (SAT). Containing approximately 25% protein and 50% edible oil, groundnuts are important to SAT farmers as both food and cash crops. The haulms, remaining after the pods are removed, are a valuable and nutritious animal feed. The average yield of groundnut in the SAT remains extremely low (around 800 kg dried pods ha^{-1}) and fluctuates widely due to unreliable rainfall. Disease and insect pest attacks also severely reduce yields.

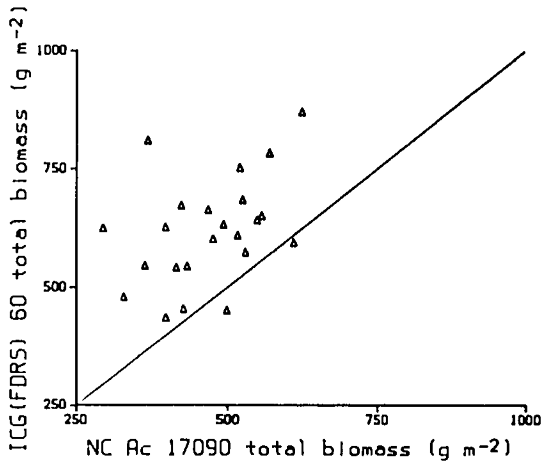
During the 1984/85 postrainy and 1985 rainy seasons, we continued research into disease and insect pest problems, as well as drought and nutrient stresses. We also studied interactions between the various stress factors. Our continuing improvement strategy is to use the genetic diversity in groundnut and its wild relatives to breed for stable resistance or tolerance to the major yield reducers.

Physical Stresses

Drought

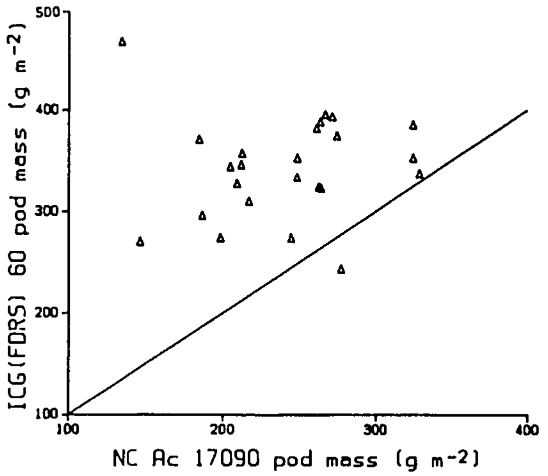
Screening Genotypes

During the 1984/85 postrainy season, we drought-screened a limited number of genotypes to confirm responses observed in previous years. Using the line-source sprinkler technique, we screened 128 genotypes belonging to var *fastigiata*, out of which 71 were germplasm lines and 57 were breeding lines. Among the breeding lines there were 37 lines selected for foliar diseases resistance having drought and foliar diseases resistant landraces as parents. Some of the foliar diseases resistant selections maintained the drought tolerance of the parental types but produced higher yields. This effect is demonstrated by the performance in the terminal-stress treatment of ICG(FDRS) 60 relative to that of drought tolerant NC Ac 17090 (ICG 1697), (ICRISAT Annual Report 1984, p. 197) (Figs. 1 and 2).



Probability (ICG (FDRS) 60 < NC Ac 17090 = 0.94.)

Figure 1. Biomass performance of groundnut genotype ICG (FDRS) 60 relative to the drought-resistant line NC Ac 17090 in a terminal drought situation, ICRISAT Center, postrainy season 1984/85.



Probability (ICG (FDRS) 60 < NC Ac 17090 = 0.96.)

Figure 2. Pod-yield performance of groundnut genotype ICG (FDRS) 60 relative to the drought-resistant line NC Ac 17090 in a terminal drought situation, ICRISAT Center, postrainy season 1984/85.

Table 1. Total biomass (g m⁻², energy adjusted) produced by the top 10 groundnut cultivars, Dryland Research Station, Anantapur, rainy season 1985.

First sowing		Second sowing	
Genotype	Total biomass ($g\ m^{-2}$)	Genotype	Total biomass ($g\ m^{-2}$)
KU No. 206	621	NC Ac 17090	416
GB (FDS) 127	617	GB (FDS) 218	411
J 11 × Robut 33-1	617	GB (FDS) 127	402
GB (FDS) 218	598	EC 76446	360
NC Ac 17090	580	EC 21139	359
GB (FDS) 34	572	GB (FDS) 149	353
NC Ac 17142	569	ICGS 21	352
Variety 27	564	GB (FDS) 18	350
Voleta	562	NC Ac 17142	349
GB (FDS) 18	562	NC Ac 569	344
SE	±22.4	SE	±15.5
Control		Control	
TMV 2	513	TMV 2	290
SE	±8.5	SE	±5.8
CV(%)	10	CV(%)	12

Table 2. Pod yield of top 10 groundnut cultivars, Dryland Research Station, Anantapur, rainy season 1985.

First sowing		Second sowing	
Genotype	Pod yield ($g\ m^{-2}$)	Genotype	Pod yield ($g\ m^{-2}$)
ICC (FDS) 127	178	EC 21139	114
GB (FDS) 34	174	Gangapuri	111
ICGS 11	169	GB (FDS) 127	110
Voleta	166	NC Ac 17090	109
X41-X-X-113 × Goldin I	166	GB (FDS) 218	109
GB (FDS) 218	165	EC 21040	104
EC 21024	164	ICGS 21	103
NC Ac 17142	164	NC Ac 569	102
Gangapuri	164	Voleta	101
Ah 2105 × Chico	163	TMV 2 × NC Ac 17142	101
SE	±6.9	SE	±5.2
Control		Control	
TMV 2	156	TMV 2	90
SE	±2.6	SE	±2.0
CV(%)	11	CV(%)	15

The breeding selections tested also included those *fastigiata* lines selected for seed dormancy, some of which were also found to tolerate terminal drought.

During the 1985 rainy season, at Anantapur, a site in southern India characterized by low and erratic rainfall, we tested 42 genotypes in a replicated trial with TMV 2 as a systematic control cultivar. The genotypes were sown on two dates so that they experienced drought during different growth phases. The first sowing, that received 315 mm of rainfall, experienced drought for 4 weeks during the early phase and for 2 weeks during the pod-filling phase. The second sowing, which received 200 mm of rainfall, experienced a short, early drought, and severe drought from the start of pod-filling until harvest. Pod yields ranged from 1200 to 1800 kg ha^{-1} from the first sowing, and 400 to 1100 kg ha^{-1} from the second sowing. In both experiments, genotypes showed large differences in pod yield for a given accumulation of total dry matter (TDM). In the second sowing, the pod yields varied from 40 to 120 g m^{-2} ($P<0.05$) for those genotypes that accumulated 300 g m^{-2} total biomass. A similar trend was also observed in the first sowing. The total biomass and pod yields of the top 10 genotypes for the two sowings are presented in Tables 1 and 2. It was encouraging to note that in both the trials several foliar diseases resistant lines that had shown drought tolerance at ICRISAT Center significantly outyielded TMV 2 under drought conditions at Anantapur.

The parent line NC Ac 17090 ranked high for total biomass in both trials, although only reaching the top 10 for pod yield in the second trial. In this trial where it had the highest biomass it also had twice as much vesicular arbuscular mycorrhizal (VAM) colonization as TMV 2.

We also examined 64 selected genotypes for recovery responses from midseason drought, from 32 to 84 days after sowing (DAS). There was considerable genotypic variation in crop growth following relief from drought (Fig. 3).

We completed analysis of an experiment conducted in collaboration with the Overseas Development Administration (ODA) Unit, School of Agriculture, Nottingham University, UK, during the 1982/83 postrainy season. In this experiment, four genotypes were subjected to drought or regularly irrigated. In the dry treatment, the crop was irrigated regularly only up to 17 DAS, after which the plots received irrigation 72 and 107 DAS. This allowed us to examine the genotypes' responses in two drying cycles and two recovery cycles. In addition to the variations in recovery response reported last year, (ICRISAT Annual Report 1984, p.200). there were significant genotypic differences in the water-use efficiency (WUE), although the total amount of water transpired was not different (Table 3). There were also genotypic differences in the pattern of water extraction from the soil profile. NC Ac 17090 was more efficient than other geno-

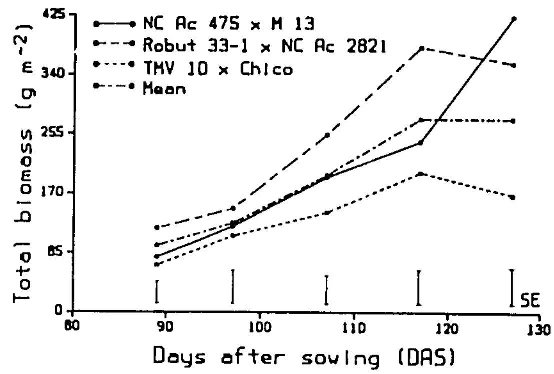


Figure 3. Genotypic variability for recovery responses from midseason drought, ICRISAT Center, postrainy season 1984/85.

Table 3. Water use efficiences (WUEs) of four groundnut genotypes in the dry treatment, ICRISAT Center, postrainy season 1982/83.

Genotype	Water transpired (mm)	Total intercepted radiation (MJ m^{-2})	WUE (g kg^{-1})
TMV 2	220	1060	1.9
Robut 33-1	226	1070	2.2
NC Ac 17090	225	1030	2.1
EC 76446(292)	223	1080	1.7
SE	±24	±87	±0.03

types in extracting water from the top 40 cm of soil, but this efficiency was not associated with more roots in this zone at 35 DAS. The substantial mycorrhizal association observed for this genotype at Anantapur may have been responsible for this attribute.

Biotic Stresses

Diseases

Foliar Fungal Diseases

Leaf spot and rust diseases were less severe than usual in the 1985 rainy season because of the low rainfall. Losses in pod yield of susceptible cultivars were estimated at around 35%. However, disease levels were sufficiently high to permit effective evaluation of germplasm accessions for resistance to late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*).

Resistance screening. In 1985, we screened 2125 germplasm accessions for resistance to rust and late leaf spot. We selected 190 accessions that rated between 2 and 5 on a 9-point disease scale (where 1 = no disease, and 9 = 50-100% foliage destroyed) for advanced screening in 1986.

Fifty-six germplasm lines, rated resistant to rust and/or late leaf spot in preliminary screening in 1984 were further screened in the 1985 rainy season in replicated field trials at ICRISAT Center, where both rust and late leaf spot attack were substantial, and at Bhavanisagar, where late leaf spot was severe and rust attack was negligible. Forty-three accessions were resistant or moderately resistant to rust, and nine were also resistant or moderately resistant to late leaf spot. This material provides a wide range of pod type and seed color for use in resistance breeding.

Resistance breeding. Multilocational yield trials. In the 1985 rainy season, we evaluated 150 advanced breeding lines with resistance to rust

Table 4. Pod yields (kg ha^{-1}) of some rust- and/or late leaf spot-resistant groundnut selections, multilocational trials, rainy season 1985.

	Irrigated pod yields (kg ha^{-1})		Rainfed pod yields (kg ha^{-1})		
Genotype	ICRISAT	Bhavanisagar	ICRISAT	Anantapur	Dharwad
ICG (FDRS) 48	1400	4400	1180	1390	3180
ICG (FDRS) 17	2360	3790	1310	1030	3580
ICG (FDRS) 40	1750	4150	530	1360	3500
ICG (FDRS) 22	1740	3750	680	1500	4030
ICG (FDRS) 42	1580	4260	860	1150	2990
ICG (FDRS) 43	1440	2940	1340	1610	3440
ICG (FDRS) 10	1190	2820	1540	1630	3070
ICG (FDRS) 36	2150	3350	1010	1390	3350
Controls					
Robut 33-1[1]	1690	2780	580	1360	3260
JL 24[1]	930	2920	1100	1310	2380
NC Ac 17090[2]	650	3740	670	1500	2880
SE	±122	±377	±109	±108	±253
Trial mean (36 entries)	1390	3270	990	1330	2750
CV(%)	15	20	19	14	15

1. Rust- and late leaf spot-susceptible. 2. Rust- and late leaf spot-resistant.

and/or late leaf spot for yield at five locations in India. At two of the locations, ICRISAT Center and Bhavanisagar, we had irrigation facilities and crops were given supplementary irrigation whenever necessary to maintain good growth. Disease scores for the test entries at ICRISAT Center on the irrigated crops were 2-3 for rust and 4-9 for late leaf spot (measured on a 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed). The resistant control NC Ac 17090 was scored at 3 for rust and 5 for late leaf spot. The susceptible control cultivars Robut 33-1 and JL 24 were scored at 9 for both diseases. The yield data for selected entries from one trial with advanced breeding lines are shown in Table 4, and it is evident that they have excellent yield ability under natural disease pressures in southern India.

Table 5. Pod yields (kg ha^{-1}) of some rust- and/or late leaf spot-resistant advanced-generation groundnut selections, multilocational trials, rainy season 1985.

Genotype	Irrigated pod yields (kg ha^{-1}) ICRISAT Center[1]	Bhavanisagar[1]	Rainfed pod yields (kg ha^{-1}) ICRISAT Center	Anantapur	Dharwad
Trial 1 (F_{10})					
RMP 91 × DHT 200	2490	3610	880	1250	4080
OG-69-6-1 × NC Ac 17090	1710	5080	400	1470	2750
GAUG 1 × EC 76446(292)	2470	3860	960	1570	2640
OG-71-3 × EC 76446(292)	1600	4110	1440	1260	3060
NC Ac 17090 × Robut 33-1	1490	4310	1000	1130	3010
Controls					
Robut 33-1[2]	1360	1940	510	1580	1860
JL 24[2]	1280	3790	816	1600	2010
NC Ac 17090[3]	960	4010	650	1440	3470
SE	±138	±370	±174	±128	±235
Trial mean (40 entries)	1480	3550	820	1200	2550
CV (%)	16	18	37	18	16
Trial 2 (F_{10}-F_{13})					
2-5 × NC Ac 17090	2490	4850	920	1560	3380
GAUG 1 × NC Ac 17090	2250	4360	1210	1380	4990
HG 1 × EC 76446(292)	2220	4710	790	1630	3010
NC Ac 1107 × NC Ac 17090	2070	4380	1210	1530	3650
Florigiant × Krap. St.No.16	1780	5130	1040	1320	2280
Controls					
Robut 33-1[2]	1760	3150	510	1310	2260
JL 24[2]	1180	3990	790	1400	2140
NC Ac 17090[3]	690	4540	560	1420	4160
SE	±158	±294	±92	±104	±274
Trial mean (49 entries)	1580	4110	910	1260	2650
CV (%)	17	12	18	14	18

1. Supplementary irrigation provided to ensure ample supply of water.
2. Foliar diseases-susceptible.
3. Rust- and late leaf spot-resistant.

Results of two advanced-generation selection trials (F_{10}-F_{13}) are given in Table 5. In Trial 1, the selection from OG 69-6-1 × NC Ac 17090 gave the highest yield of 5080 kg dried pods ha^{-1} at Bhavanisagar, significantly outyielding the control cultivars. Several other lines also performed well.

Resistance breeding. Yield trials at ICRISAT Center. We tested a further 350 breeding lines under high-input (60 kg P_2O_5 ha^{-1}, irrigation, and insecticides when required) and low-input (20 kg P_2O_5 ha^{-1}, rainfed, without insecticides) conditions. The controls, JL 24 and Robut 33-1, were released, disease-susceptible cultivars. Thirty-four selections under high-input, and 18 under low-input conditions significantly outyielded the controls.

We continued to select for good plant type from interspecific hybrid derivatives with resistance to rust and late leaf spot. Yield data for nine lines with virginia bunch growth habit, very high resistance to rust, and moderate resistance to late leaf spot indicate (Table 6) that these lines have excellent promise, several outyielding the control cultivars. These lines also have good pod and seed characteristics.

Table 6. Performance of some rust- and late leaf spot-resistant virginia bunch type interspecific hybrid-derivative groundnut selections, ICRISAT Center, rainy season 1985.

		Disease scores[1]	
Pedigree	Pod yield ($kg\ ha^{-1}$)	Rust	Late leaf spot
CS-13/1-B_1-B_1-B_1	2830	2	5
CS-16-B_2-B_2-B_1	2690	2	4
904/1-B_1-B_2-B_1	2670	2	5
CS-13-B_1-B_1-B_1	2460	2	5
2024-B_1-B_1-B_1	2390	2	5
CS-29/1-B_2-B_1-B_1	2380	2	5
CS-9-B_1-B_1-B_1	2260	2	5
CS-30/1-B_2-B_2-B_1	2250	2	4
904-B_1-B_2-B_1	2220	2	5
Controls			
Robut 33-1[2]	1690	9	9
JL 24[2]	1250	9	9
NC Ac 17090[3]	710	2	5
SE	±149	±0.1	±0.5
Trial mean (18 entries)	2090	-	-
CV (%)	12	7	16

1. Field disease scored on a 1-9 scale, where 1 = no diseases and 9 = 50-100% foliage destroyed.
2. Foliar diseases-susceptible.
3. Foliar diseases-resistant.

Stability of resistance. The international groundnut foliar diseases nursery was grown at ICRISAT Center in the 1985 rainy season for the 7th consecutive year. Rust and late leaf spot disease scores for the 5 susceptible control cultivars and for most of the 43 test entries agreed closely with those obtained in previous years. However, ICG 3580 scored 4.5 for rust compared with 6.1 (average) in earlier years; ICG 7886 scored 4.8 for late leaf spot compared with 6.5 in earlier years, and ICG 7887 scored 3.4 for late leaf spot compared with 6.0 in earlier years. The trial will be repeated in the 1986 rainy season.

Economics of resistance. We grew rust- and late leaf spot-resistant and susceptible cultivars in the 1985 rainy season, with and without fungicidal protection, in replicated trials at ICRISAT Center and in farmers' fields in Dokur village, Andhra Pradesh. The trials in farmers' fields suffered severely from drought and yields were negligible. Yields in the ICRISAT Center trial with supplementary irrigation were also low, but treatment effects were evident (Table 7). The resistant cultivars in plots without fungicidal protection had significantly higher pod yields than the susceptible control cultivars. One of the resistant cultivars, ICG(FDRS) 18, had significantly higher haulm yields than all other entries in both protected (fungicide sprayed) and non-protected treatments.

Fungicide evaluation. We compared bitertanol and an experimental fungicide, with chlorothalonil, a fungicide that has provided excellent control of rust and leaf spot diseases over several

Table 7. Performance of two foliar diseases-resistant, and three susceptible groundnut cultivars, with and without fungicide application, field trial, ICRISAT Center, rainy season 1985.

	Mean yields of dried produce (kg ha^{-1})			
	Pods		Haulms	
Genotype	Water spray	Daconil® applied[1]	Water spray	Daconil® applied
Susceptible				
J 11[2]	288	690	1180	1650
JL 24[2]	383	985	938	1440
Local[3]	310	780	1240	1770
Resistant				
ICG (FDRS) 10[4]	1010	1020	1060	1570
ICG (FDRS) 18[4]	901	888	2660	2910
SE	±144		±229	
CV (%)	20		14	

1. Daconil® (chlorothalonil) applied at 10-day intervals.
2. Released Indian cultivars.
3. Farmer's own seed.
4. Rust-and late leaf spot-resistant breeding lines.

seasons at ICRISAT Center, for control of foliar diseases. The cultivar ICGS 11 was used, and a water spray control was included. The diseases were less severe than usual. All three fungicides increased pod yields. Chlorothalonil gave the best control of the diseases but bitertanol application gave the highest increase in haulm yield (Table 8).

Soilborne Fungal Diseases

The Aflatoxin Problem

Effects of drought stress. In two field trials at ICRISAT Center in the 1984/85 postrainy season, we examined the effects of drought stress on preharvest seed invasion of groundnut by *Aspergillus flavus*, and on contamination of the seed with aflatoxin. Eight groundnut genotypes were used, four with resistance to in-vitro colonization of rehydrated, stored, mature seeds by *A. flavus* in laboratory inoculation tests, and four susceptible ones. Drought stress was induced by withholding irrigations. Data from one of the trials are shown in Table 9, and it can be seen that genotypes with seed resistance to *A. flavus* in laboratory tests had lower levels of invasion by this fungus, and lower levels of contamination with aflatoxin B_1 at lifting (i.e., preharvest) than the susceptible genotypes. Drought stress increased both *A. flavus* invasion and aflatoxin contamination in seed of all genotypes.

Resistance screening in the field. Germplasm accessions evaluated in the 1984 rainy season at four locations and found to have preharvest resistance of seed to invasion by *A. flavus* and other fungi were again tested at the same locations in the 1985 rainy season. Two breeding lines and three susceptible controls were included. Significant genotypic differences were found in seed invasion by *A. flavus* and other fungi (Table 10). Rankings were similar across locations and similar to those determined in 1984. There were interactions between genotypes and locations for fungal invasion.

Thirty germplasm accessions that showed seed resistance to *A. flavus* in preliminary tests in

Table 8. Evaluation of fungicides for control of groundnut foliar diseases, field trial using cultivar ICGS 11, ICRISAT Center, rainy season 1985.

Plants sprayed with[1]	Leaf area damaged (%) by		Defoliation (%)	RGL[2] (%)	Mean yields of dried produce (kg ha^{-1})		Shelling %
	Rust	Leaf spots			Pods	Haulms	
Bitertanol	2.9	0.9	20.1	76.9	1620	1620	70.6
Experimental fungicide	5.0	0.5	16.4	78.9	1480	1440	71.0
Chlorothalonil	1.3	0.1[3]	0.2[3]	98.4	1530	1750	72.1
SE	±0.76[4]	±0.29[4]					
Control							
Water	19.2	5.0	30.4	52.9	1050	1460	72.7
SE	±6.66[5]	±0.63[5]	±5.29	±4.79	±143	±158	±0.77
CV (%)				6.2	10	10	1

1. All fungicides and water control applied at 10-day intervals.
2. RGL = remaining green leaf.
3. Excluded from computation of standard error.
4. Standard error of fungicide spray treatments.
5. Standard error of water spray treatment.

Table 9. Preharvest seed infection by *Aspergillus flavus* and aflatoxin contamination in eight groundnut genotypes grown under full irrigation and with drought stress, ICRISAT Center, postrainy season 1984/85.

Genotype	Seeds infected by *A. flavus*		Aflatoxin B1 content of seeds (μg kg^{-1})	
	Full irrigation	No irrigation from 95-125 DAS	Full irrigation	No irrigation from 95-125 DAS
IVSCAF-resistant[1]				
Ah 7223	0.4 (2.5)[2]	1.4 (6.8)[2]	3 (0.9)[3]	4 (1.3)[3]
J 11	0.7 (3.1)	2.0 (8.0)	3 (0.8)	9 (1.8)
UF 71513	0.7 (3.4)	2.3 (8.4)	1 (0.3)	5 (1.5)
PI 337394F	1.2 (6.3)	3.4 (10.6)	3 (0.7)	22 (2.8)
SE	(±0.85)	(±0.59)	(±0.31)	(±0.28)
IVSCAF-susceptible[1]				
TMV 2	2.9 (9.5)[2]	6.6 (14.6)[2]	10 (2.0)[3]	28 (3.2)[3]
NC Ac 17090	2.4 (8.6)	14.2 (21.9)	10 (1.5)	96 (4.3)
Gangapuri	4.6 (12.3)	12.8 (20.8)	5 (1.4)	161 (4.7)
EC 76446(292)	5.8 (13.5)	13.7 (20.8)	22 (2.4)	692 (5.8)
SE	(±0.75)	(±1.32)	(±0.45)	(±0.27)

1. IVSCAF = in vitro seed colonization by *A. flavus*.
2. Values in parentheses are arc sine transformations.
3. Values in parentheses are log transformations.

Table 10. Natural seed infection of 13 groundnut genotypes with *Aspergillus flavus* (AF) and other fungi (OF) at four Indian locations, rainy season 1985.

	Seeds infected (%)							
	Tirupati		Anantapur		Bapatla		ICRISAT Center	
Genotype	AF	OF	AF	OF	AF	OF	AF	OF
Ah 7223	0.5 (3.9)[1]	1.2 (6.3)	0.7 (4.9)	1.2 (6.3)	0.3 (2.9)	2.6 (9.3)	0.5 (3.9)	0.9 (5.5)
J 11	0.8 (5.2)	0.9 (5.5)	0.9 (5.3)	1.4 (6.8)	0.1 (2.0)	1.2 (6.3)	0.3 (3.0)	0.5 (4.2)
U4-47-7	0.7 (4.8)	0.9 (5.5)	0.7 (4.9)	1.0 (5.8)	0.0 (0.0)[2]	2.1 (8.4)	0.5 (4.0)	0.6 (4.5)
UF 71513	1.8 (7.8)	5.5 (13.5)	1.1 (6.1)	2.7 (9.5)	0.5 (3.9)	7.8 (16.2)	0.6 (4.5)	2.8 (9.7)
PI 337394F	2.1 (8.4)	7.3 (15.7)	1.6 (7.3)	6.7 (15.0)	0.7 (4.9)	9.1 (17.6)	0.7 (4.9)	4.2 (11.8)
Var. 27	3.6 (10.9)	4.3 (11.9)	4.6 (12.4)	7.9 (16.3)	1.9 (8.0)	7.4 (15.8)	2.5 (9.0)	4.9 (12.8)
ICGS (AF) 58	6.5 (14.8)	13.8 (21.8)	6.2 (14.4)	9.5 (17.9)	3.8 (11.3)	12.5 (20.7)	3.7 (11.1)	6.1 (14.3)
ICGS (AF) 78	5.0 (12.9)	12.7 (20.9)	5.5 (13.5)	7.2 (15.5)	3.0 (9.9)	17.6 (24.8)	5.1 (13.0)	8.4 (16.8)
TMV 2	6.5 (14.7)	12.4 (20.6)	4.0 (11.6)	7.8 (16.2)	2.7 (9.4)	10.6 (19.0)	4.2 (11.8)	7.6 (16.0)
F_1-5 ×								
NC Ac 17090	8.4 (16.8)	13.6 (21.6)	4.5 (12.2)	5.6 (13.7)	4.4 (12.1)	8.8 (17.3)	4.2 (11.8)	6.0 (14.2)
Gangapuri	15.8 (23.4)	29.5 (32.9)	12.2 (20.4)	8.6 (17.0)	5.2 (13.2)	16.0 (23.6)	8.0 (16.4)	10.0 (18.4)
NC Ac 17090	20.0 (26.5)	39.8 (39.1)	20.9 (27.2)	14.0 (22.0)	4.9 (12.7)	17.6 (24.8)	16.0 (23.6)	11.0 (19.3)
EC 76446(292)	21.3 (27.5)	44.8 (42.0)	40.8 (39.7)	15.9 (23.5)	6.2 (14.4)	29.4 (32.8)	25.3 (30.2)	19.8 (26.4)
SE	(±1.29)	(±2.26)	(±1.18)	(±1.94)	(±1.27)	(±1.67)	(±1.36)	(±1.40)
CV (%)	(19.0)	(22.9)	(17.1)	(27.1)	(31.4)	(18.3)	(23.9)	(21.0)

1. Values in parentheses are are sine transformations.
2. Excluded from the computation of SE's.

1984 were again screened in a field trial at ICRISAT Center in the 1985 rainy season. Invasion ranged from 0.5 to 30%. The best material will be screened again in 1986.

Breeding for resistance. We made several new crosses involving genotypes with seed resistance to *A. flavus* invasion, genotypes with low capacity to support aflatoxin production, and high-yielding adapted lines.

During the 1984/85 postrainy and 1985 rainy seasons, we grew and advanced 2882 bulk selections derived from crosses between *A. flavus*-resistant lines and high-yielding adapted lines from F_3 to F_{11} generations. We made 2371 selections from this material and these are being screened in the laboratory for seed resistance to colonization by *A. flavus*.

Seed from 126 breeding lines, derived from crosses involving genotypes with seed resistance to *A. flavus* invasion and adapted lines, were tested for in-vitro resistance to invasion of rehydrated seeds by *A. flavus*. The material was from trials grown at ICRISAT Center (under high- and low-input conditions), Bhavanisagar, and Hisar. Data from one set of trials are given in Table 11. In all, nine lines showed resistance and gave high yields, and these will be further evaluated in 1986.

Stem and Pod Rots

Groundnuts grown on Vertisols under irrigation in the postrainy season at ICRISAT Center are subject to pod and stem rots caused by *Sclerotium rolfsii* in association with *Fusarium* spp.

In the 1984/85 postrainy season we screened 64 breeding lines for resistance to *S. rolfsii* in a replicated field trial, and 3 showed lower than

Table 11. *Aspergillus flavus* seed colonization (% SC) and pod yield (kg ha^{-1}) of selected groundnut breeding lines resistant to *A. flavus*, grown at four Indian locations in the 1984 rainy season, tested in 1985.

		ICRISAT Center HI[1]		ICRISAT Center LI[2]		Bhavanisagar		Hisar		Mean	
Identity	Pedigree	% SC	Pod yield	% SC	Pod yield	% SC	Pod yield	% SC	Pod yield	% SC	Pod yield
ICGS (AF) 5	J 11 × PI 337394F	13.2	2960	14.6	490	8.5	3030	12.9	3200	12.3	2420
ICGS (AF) 6	PI 337409 × UF 71513-1	10.3	2710	13.2	780	8.5	2190	10.6	3510	10.6	2290
ICGS (AF) 7	Ah 32 × PI 337409	16.9	2990	12.7	760	13.2	2100	16.5	3510	14.8	2340
ICGS (AF) 11	Faizpur 1-5 × PI 337409	10.9	2810	17.8	680	7.5	1690	13.7	3550	12.4	2180
ICGS (AF) 12	UF 71513-1 × PI 337394F	14.8	2370	11.8	870	9.7	2540	13.3	3270	12.4	2260
ICGS (AF) 13	NC 17 × PI 337394F	10.9	2330	17.3	820	13.1	2490	20.2	3260	15.3	2220
ICGS (AF) 21	MH 2 × PI 337394F	12.3	2540	18.6	560	12.1	2210	16.7	3120	14.9	2110
Controls											
J 11[3]		10.7	2300	11.6	860	9.3	2000	13.9	3150	11.3	2080
UF 71513-1[3]		7.4	2260	13.9	860	6.9	2310	9.8	3170	9.5	2150
JL 24[4]		33.9	2520	32.4	420	41.0	2030	49.5	3040	39.2	2000
Robut 33-1[4]		20.7	2800	32.1	980	37.8	1580	33.9	2960	31.1	2080
SE		±5.54	±295	±4.25	±133	±4.61	±345	±6.01	±47		
Trial mean (36 entries)		20.32	2570	21.79	710	20.12	2050	24.70	3270		
CV (%)		47	14	34	23	40	21	42	17		

1. HI = High input (60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays).
2. LI = Low input (20 kg P_2O_5 ha^{-1}, rainfed without insecticide sprays).
3. Resistant to seed colonization by *A. flavus*.
4. Susceptible to seed colonization by *A. flavus*.

average incidence of pod rot (< 8%).

In the 1985 rainy season there was an unusually severe attack by *S. rolfsii* on groundnuts grown in some Alfisol fields. We screened 134 interspecific hybrid derivatives with resistance to rust and late leaf spot and found that almost all were susceptible to pod rot. The few lines that showed slight resistance will be rescreened in 1986.

Virus Diseases

Bud Necrosis Disease (BND)

During the 1985 rainy season we screened over 2700 germplasm accessions, breeding lines, and interspecific hybrids (involving *Arachis chacoense*) for field resistance to BND. Several field-resistant germplasm lines have been identified (Table 12), and crossed with germplasm lines resistant to the thrips vector, *Frankliniella schultzei*. Several advanced-generation, field-resistant breeding lines with desirable pod and seed characteristics and with lower field incidence of BND than the field-resistant cultivar Robut 33-1 have been identified in preliminary trials, and will be evaluated for yield potential in 1986.

Peanut Clump Virus (PCV)

Causal agent. Isolates from five geographically separated locations have been shown to have similar chemical properties and particle morphology (ICRISAT Annual Report 1984, p.212). We studied serological cross reactions among the five isolates and found that the Bapatla (Andhra Pradesh), Chinnaganjam (Andhra Pradesh), and Talod (Gujarat) isolates were

Table 12. Groundnut germplasm and breeding lines with low incidence of bud necrosis disease (BND), ICRISAT Center, rainy season 1985.

Genotype	BND incidence (%)
C 145-12 P	9
Ah 7729	10
NC Ac 18002	11
MK 383	15
CS 14	16
No. 943	19
NC Ac 343	21
EC 36892	22
CS 39	28
Controls	
Robut 33-1[1]	30
TMV[2]	50
SE	±3.8
CV (%)	23

1. Cultivar with low field incidence of BND.
2. Susceptible cultivar.

serologically related and distinct from the Ludhiana (Punjab) and Hyderabad (Andhra Pradesh) isolates. The results of decoration tests (a form of immunosorbent electron microscopy) are shown in Figure 4. The five isolates were distinguished by host range on selected leguminous and solanaceous plants.

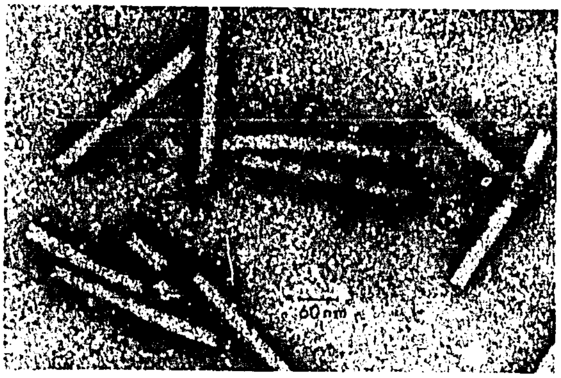


Figure 4. Indian peanut clump virus (Talod isolate) particles reacted with its own antibodies. Note decoration of virus particles with antibodies. (Bar length represents 60 nm).

Transmission. We found levels of seed transmission of PCV as high as 15% and detected the virus in embryo, cotyledons, and testa. The fungus, *Polymyxa graminis*, found in all PCV-infested soils examined (ICRISAT Annual Report 1982, p. 189) has now been detected in soils from two new PCV locations. Wheat, wild sorghums (*Sorghum bicolor* and *S. arundinaceum*), *Setaria italica*, and *Eleucine coracana* were found to be hosts for both PCV and *P. graminis*. Air-dried, PCV-infested wheat roots containing *P. graminis* cystosori, stored for $2\frac{1}{2}$ years in a refrigerator, when powdered and incorporated into sterilized soil induced the disease in wheat and *S. italica*. Furthermore, soakates from the PCV-infested wheat roots containing *P. graminis* cystosori produced PCV infection in graminaceous hosts. Addition of kinetin to root soakates resulted in nearly 90% infection. These results confirm our earlier observations (ICRISAT Annual Report 1984, p. 212) that PCV can be transmitted by *P. graminis*.

Resistance screening. In the 1985 rainy season, we screened 874 germplasm accessions at Bapatla and 1500 in Ludhiana in PCV-infested soils. In both locations, several accessions showed tolerance to PCV. The *Arachis* species 30036, which did not become infected in 1984 rainy-season tests (ICRISAT Annual Report 1984, p. 212), and several entries that showed tolerance, will be retested in Ludhiana and Bapatla in 1986.

Peanut Mottle Virus (PMV)

Resistance screening. In the 1984/85 postrainy and 1985 rainy seasons, we screened 264 breeding and germplasm lines for resistance to PMV. Four breeding lines and one germplasm accession showed less than 5% yield loss in both the seasons, and are being tested in a replicated trial in 1986.

We conducted additional tests on genotypes EC 76446 (292) and NC Ac 17133 (RF) for seed transmission of PMV. So far, over 17000 seeds of each of the genotypes were shown not to transmit PMV through seed, thus confirming our earlier results (ICRISAT Annual Reports 1982, p. 189; 1984, p. 212). Further testing of over 5000 seeds of a cross involving FSB7-2 and EC 76446(292) confirmed that it did not transmit PMV through seed (ICRISAT Annual Report 1984, p. 212). We also tested several high-yielding breeding lines, that are also resistant to rust and leaf spot, and one selection from a cross involving Comet and NC Ac 17090. None of the 5000 seeds so far tested transmitted PMV.

Peanut Yellow Spot Virus (PYSV)

This widely distributed virus was shown to be transmitted by *Scirtothrips dorsalis*. It resembles tomato spotted wilt virus (TSWV) in particle morphology. The virus was partially purified from groundnut leaflets showing early PYSV symptoms, and an antiserum was produced. We tested serological relationships of PYSV using antisera for TSWV from several sources. In these tests no serological relationships were detected between TSWV and PYSV. We also found that PYSV differed from TSWV in host range and symptoms.

Virus Disease Surveys

A simple enzyme-linked immunosorbent assay (ELISA) test procedure has been standardized for use in detecting groundnut viruses in disease surveys. Collaborating with scientists in Thailand and the Philippines, we identified PYSV in Thailand and PMV and peanut stripe viruses (PStV) in both the countries.

In disease surveys in India, veinal-chlorosis symptoms on young leaflets followed by severe stunting was observed on postrainy-season groundnuts at several locations. Disease incidence reached as high as 45%. We observed a similar disease at low incidence in our surveys in 1977, 1979, and 1980 in many parts of Andhra Pradesh, Karnataka, and Maharashtra States.

Nematode Disease

In cooperation with scientists of Andhra Pradesh Agricultural University (APAU), we screened 560 germplasm accessions for resistance to the nematode *Tylenchorhynchus brevilineatus* in a replicated trial in a farmer's field in the 1985 rainy season. Disease was severe and uniform. Several entries that showed lower-than-average disease severity are being further tested in the 1985/86 postrainy season.

Insect Pests

Incidence at ICRISAT Center

Thrips (*Frankliniella schultzei* and *Scirtothrips dorsalis*) caused considerable leaf damage early in the postrainy season in crops not protected with insecticides. Populations of the groundnut leaf miner (*Aproaerema modicella*) were high during the pod-filling stage of this crop and insecticides were applied for their control. Jassids (*Empoasca kerri*) and the tobacco caterpillar (*Spodoptera litura*) did not cause problems during 1985.

Rainy-season crops were relatively pest free. Initially, the groundnut aphid (*Aphis craccivora*) caused isolated plants to wilt but disappeared without causing extensive damage. The same was true of thrips (*S. dorsalis*) and white flies (*Bemisia* sp). *F. schultzei* infestations were sufficiently high to ensure high levels (up to 60%) of BND in some fields. *Heliothis armigera* destroyed a few flowers in the crossing block. An earwig (*Anisolabis annulepes* = *Euborellia stali*) bored holes in almost 40% of the pods of susceptible genotypes in a Vertisol field. The groundnut leaf miner was not a problem in the rainy season, possibly because it was heavily (90%) parasitized in its first two generations.

Host-plant Resistance

Groundnut Leaf Miner (*Aproaerema modicella*). We screened 480 genotypes in the postrainy season (274 in replicated trials) and demonstrated, for the first time, clear evidence of resistance to this pest in a wide range of genotypes, including germplasm accessions, early-maturing breeding lines resistant to foliar diseases, and interspecific derivatives (see below).

Jassids (*Empoasca kerri*). We selected 16 of 510 genotypes screened in the rainy season for jassid resistance for further testing. The germplasm lines, EC 36892 and Ah 7729, and the *Arachis chacoense* derivatives No.943, CS 14, and CS 39, had low levels of jassid damage and gave about twice the yields of the control cultivars TMV 2 and Robut 33-1.

The influence of 10 resistant genotypes on the bionomics of jassids was studied by releasing 10 adults on three plants of each line. Adults of the subsequent third generation were weighed and then placed on a preferred host (cowpea *Vigna unguiculata* cv C 152) to test for any carry-over effect of host genotype on their fecundity. Adult longevity was significantly reduced on all the test genotypes (Table 13). There was a corresponding reduction in fecundity on all except NC Ac 2142, while on Nc Ac 343 the fecundity was significantly lower than on the control, but was higher than the means of the other genotypes. Jassids reared on NC Ac 343, 2214, and 2230 did not survive through a second generation. The fecundity of individual jassids reared on four of the resistant genotypes was still low after two generations on cowpea plants.

Thrips (*Frankliniella schultzei* and *Scirtothrips dorsalis*). Of the 25 elite lines screened for thrips resistance GBPRS 312 and GBPRS 138 were resistant to both species; GBPRS 145 was resistant to *S. dorsalis* but only moderately resistant to *F. schultzei*; GBPRS 302 was resistant to *F. schultzei* but susceptible to *S. dorsalis*.

Low bud necrosis disease incidence in 34 lines that had previously been screened was shown to be caused by resistance to *F. schultzei*. We iden-

Table 13. Biology of jassid *Empoasca kerri* on resistant and susceptible groundnut genotypes.

Genotype	Mean adult longevity (d)[1]	Mean fecundity $female^{-1}$	Mean body mass of third generation adults (μg)	Mean fecundity on cowpea after two generations
M 13	9.1	4.3	4.5	42.3
NC Ac 2142	8.8	23.7	4.6	24.4
NC Ac 2240B	8.0	3.7	2.6	1.1
NC Ac 2144	7.3	2.3	4.6	20.0
NC Ac 2242	7.1	5.7	2.6	4.7
NC Ac 2240T	6.9	1.3	4.8	0.0
NC Ac 2243	6.6	2.2	6.5	0.0
NC Ac 343	6.4	9.7	NS[2]	
NC Ac 2214	6.0	1.3	NS	
NC Ac 2230	6.0	2.3	NS	
Control				
Robut 33-1	12.8	24.0	5.7	29.0
SE	±0.54	±0.16	±0.44	
Mean	8.2	7.0	4.6	
CV (%)	11	40	16	

1. Mean of three replications, 10 jassids $plant^{-1}$.
2. NS = Jassids did not survive through three generations.

tified additional sources of resistance to this insect.

Integrated Control

Determination of groundnut leaf miner damage threshold. A series of experiments was initiated in the 1984/85 postrainy season to determine the population density (damage threshold) at which the groundnut leaf miner causes yield loss. Groundnut leaf miner densities in 20 m × 20 m plots of Robut 33-1 were regulated by means of the insecticide schedule in Table 14.

The maximum density occurred after three generations of the pest and coincided with the pod-filling stage. There were few larvae in the plots that received the higher rate of dimethoate (Table 14). The lower rate of dimethoate reduced the groundnut leaf miner population to about 10% of that in the nonsprayed plots. Diflubenzuron (a moulting inhibitor) had no significant effect on larval density.

The mean haulm yield from the high dimethoate treatment was significantly higher than that from the control plots. The other treatments gave intermediate effects. The mean pod yield in the control plots was 35% lower than in those that received the high rate of dimethoate, but only slightly lower than in plots that received the low rate of dimethoate. The pod yields in the other two treatments were also significantly higher than in the control plots, but significantly lower than in both dimethoate treatments.

Plotting the pod yields of each population density showed that yield loss did not occur unless there were in the order of 60 mines $plant^{-1}$. This is a good indication of the damage threshold of groundnut leaf miner on Robut 33-1.

Estimating the required degree of pest resistance. In collaboration with the Resource Management Program, the data collected in the 1984/85 postrainy-season experiment is being used in the development of a dynamic programing procedure designed to determine the amount of host resistance to groundnut leaf miner that is needed to avoid insecticide application without losing yield.

Table 14. Effect of four insecticide regimes on the maximum number of groundnut leaf miner (*Aproaerema modicella*) larvae and some yield parameters in a field trial, ICRISAT Center, postrainy season, 1984/85.

Treatment[1]	Mean maximum larvae $plant^{-1}$	Mean maximum damaged leaflets $plant^{-1}$	Final plant population ('000 ha^{-1})	Mean haulm yield (kg ha^{-1})	Mean pods $plant^{-1}$	Pod yield (kg ha^{-1})
Dimethoate high rate[2]	1.9	20	81.9	1880	20.9	1780
Dimethoate low rate[3]	31.4	176	81.1	1640	18.0	1700
Diflubenzuron[4]	74.9	381	81.9	1420	16.5	1430
Dichlorvos[5]	67.9	299	83.4	1510	16.5	1580
Control						
No spray	85.0	366	82.1	1270	15.7	1150
SE	±5.40	±22.6	±2.8	±0.14	±1.70	±0.11
CV (%)	23	20	3	9	21	7

1. Insecticides applied at a water rate of 350 l. ha^{-1}.
2. 400 g ai ha^{-1}; 8 sprays.
3. 200 g ai ha^{-1}; 3 sprays.
4. 250 g ai ha^{-1}; 3 sprays.
5. 300 g ai ha^{-1}; 3 sprays.

Genotypic response to groundnut leaf miner attack. Sixteen genotypes were sown in a split-plot arrangement in RBD (3 replicates, 8 rows $plot^{-1}$). Four adjacent rows in each plot received three applications of dimethoate (200 g ai ha^{-1}, in 300 L water ha^{-1}) during the season to reduce groundnut leaf miner numbers. ZMB 2087, SM 231, NC Ac 12, and M 13 had about half the level of leaf damage of the other genotypes and suffered comparatively little loss in yield (Table 15). NC Ac 17090 was susceptible to groundnut leaf miner attack but this had little influence on yield, whereas No. 75-22 with the lowest leaf damage ranked 12th in terms of yield loss.

Tobacco Caterpillar (*Spodoptera litura*)

Spodoptera litura defoliates groundnut crops throughout Asia. It has therefore been selected as the subject of an intensive study that will produce computer models that can be used to evaluate pest-management procedures. Such models are usually 'driven' by climatic events, temper-

Table 15. Yield loss caused by the groundnut leaf miner (*Aproaerema modicella*) to groundnut genotypes, a comparison of insecticide-treated and nontreated subplots, ICRISAT Center, postrainy season 1984/85.

Genotype	Growth habit	Damaged foliage in nontreated plots (%)[2]	Yield of SMK[1] ($kg\ ha^{-1}$)		Yield loss (%)
			Sprayed[3]	Nontreated	
Porto Alugue	Valencia	93 (81)[4]	937	632	33
NC Ac 17090	Valencia	57 (49)	1380	1230	11
NC Ac 17133	Valencia	87 (72)	1090	560	49
V 20	Spanish bunch	83 (70)	1020	747	27
TMV 2	Spanish bunch	77 (61)	1020	581	43
RS 69	Spanish bunch	87 (73)	868	411	53
ZMB 2087	Spanish bunch	33 (35)	434	477	0
SM 231	Spanish bunch	33 (35)	607	488	20
NC Ac 12	Spanish bunch	30 (33)	709	509	28
No. 75-22	Spanish bunch	25 (30)	552	347	37
Robut 33-1	Spanish bunch	70 (57)	1310	672	49
Ah 3	Runner	37 (37)	1170	865	26
M 13	Runner	35 (36)	708	653	8
S 1	Runner	53 (47)	1120	724	36
VRR 222	Runner	28 (32)	833	600	28
VRR 159	Runner	30 (33)	748	554	26
SE 1[5]		(±5.7)	±70		
SE 2[5]			±61		
Cultivar × spray		(67.2)			
CV (%)		(20)	14		

1. SMK = Sound mature kernels.
2. The level of infestation in protected plots was negligible.
3. Three sprays of dimethoate 225 g ai ha^{-1} were given at 10-day intervals starting from 60 DAE.
4. Figures in parentheses are are sine transformed values.
5. SE 1 for comparing cultivars under same or different spray treatment.
   SE 2 for comparing spray treatment under same cultivar.

ature being the most important. Therefore, the first step has been to determine the effect of temperature on the development rates of this pest—the lower developmental threshold temperatures and the thermal requirements (degree days) of the egg, larval, pupal, and preoviposition stages of this pest under constant temperatures are shown in Table 16. These results are being compared with field-development rates in order to adjust them for the effect of diurnal and seasonal temperature fluctuations.

Storage Pests

Assessment of storage losses in India. We made a detailed study of postharvest insect infestation and the associated weight loss to unshelled groundnuts in a large commercial warehouse at Kurnool, Andhra Pradesh. Fifty sacks (total mass 1.5 t) were placed in a store in July 1985 and sampled once a month. We estimated the population density of each pest species present and the percentage weight loss it caused. The most damaging pest was the groundnut bruchid *Caryedon serratus*, which caused nearly 20% seed loss (dry mass) over the 5-month study period.

This represents the first accurate report of this pest causing serious damage to groundnuts in India. Populations of the other pest species present (*Tribolium castaneum*, *Oryzaephilus mercator*, *Corcyra cephalonica*, and *Tenebroides mauritanicus*) remained low and caused little damage.

Storage pest resistance. We are developing methods that will enable groundnut genotypes to be screened quickly and reliably for resistance to some of the major postharvest pests. In one of these studies the seed of 15 genotypes (each replicated six times) were examined for resistance to *C. cephalonica*. The larval survival on the least-susceptible genotype (Robut 33-1) was approximately one-third of that on TMV 2, the most-susceptible genotype (Table 17). Other possible parameters of resistance, such as percentage dry-mass loss of seed and total mass of larvae produced, were closely correlated with the number of larvae surviving each treatment.

Breeding for Pest Resistance

Multilocational Pest Resistance Varietal Trial. During the 1985 rainy season, we evaluated 53 high-yielding selections resistant to jassids and

Table 16. Developmental thresholds (°C) and thermal requirements (degree days) for *Spodoptera litura*, ICRISAT Center, 1985.

Stage	Lower developmental threshold temperatures[1]	Rate of development[2] (d)	Degree days	% of total thermal developmental period
Egg	8.2 (4.1-12.2)[3]	-12.83 + 1.57x r = 0.95	64 (49-78)	12
Larval	10.0 (6.6-13.4)	-3.29 + 0.33x r = 0.96	301 (241-365)	55
Pupal	10.2 (9.6-10.8)	-6.59 + 0.65x r = 1.00	155 (149-160)	28
Pre-oviposition	10.2 (7.5-14.1)	-37.1 + 3.45x r = 0.95	29 (22-36)	5

1. As calculated by rearing larvae only on groundnut leaves at constant temperatures of 15, 20, 25, 30, and 35°C.
2. d = a+bx where; d = rate of development day⁻¹ (%), a = intercept, b = slope, and x = temperature (°C).
3. Figures in parentheses are 95% confidence intervals.

Table 17. Groundnut genotypes showing a range of susceptibility to *Corcyra cephalonica*, laboratory tests, ICRISAT Center, 1985.

Genotype	Mean number surviving larvae[1]
TMV 2[2]	43.7
TMV 2[3]	42.5
ICGS 11	40.0
ICGS 5	34.0
ICGS 6	31.5
ICGS 44	31.3
ICGS 30	31.2
M 13	28.7
ICGS 26	22.0
CS 2	19.8
888	18.5
Robut 33-1[4]	16.7
JL 24	14.2
J 11	13.0
Robut 33-1[3]	12.3
SE	±2.96
Mean	27.2
CV (%)	27

1. 120 eggs per replicate, replicates = 6.
2. Rainy-season crop 1984.
3. Postrainy-season crop 1984/85.
4. Postrainy-season crop 1983/84.

thrips, and three control cultivars, Robut 33-1, JL 24, and NC Ac 343, in field trials at Anantapur, Dharwad, Hisar, and Bhavanisagar. The trials at Anantapur and Dharwad were rainfed; irrigation was applied when required at Hisar and Bhavanisagar.

The selections varied considerably in yield performance across locations (Table 18). At Dharwad, six selections significantly outyielded Robut 33-1 and NC Ac 343. At Anantapur, no selection significantly outyielded the control cultivars. At Hisar, no selection significantly outyielded Robut 33-1 and NC Ac 343, but 17 selections gave significantly higher yields than JL 24. Selection (Golden-1 × Faizpur 1-5) × NC Ac 2232 gave the highest yield of 5760 kg ha^{-1}. At Bhavanisagar, four selections significantly outyielded the three controls, ICGS 13 × NC Ac 2232 giving the highest pod yield of 4420 kg ha^{-1}.

Selections Robut 33-1 × NC Ac 2232 and Gujarat Dwarf Mutant × NC Ac 2232 recorded the highest mean pod yields across locations of 3260 kg ha^{-1}. All the other selections showed adaptation to specific locations whereas the performance of these two selections was satisfactory under both rainfed and irrigated conditions.

Yield trials of multiple pest-resistant lines. We tested for yield 270 advanced-generation, pest-resistant selections under natural pest infestation and high-input (60 kg P_2O_5 ha^{-1} with irrigation) and low-input (20 kg P_2O_5 ha^{-1} without irrigation), pesticide-free conditions at ICRISAT Center in the 1985 rainy season. Some of the results from one trial showed that selection Ah 6279 × NC Ac 2232 recorded the highest pod yield of 2500 kg ha^{-1} and significantly outyielded the three control cultivars under high-input conditions. This selection has a virginia erect bunch habit with excellent pod and seed characteristics. Eight other selections outyielded Robut 33-1 and JL 24, and possess moderate levels of resistance to thrips and jassids.

Under low-input conditions (Golden 1 × Faizpur 1-5) × NC Ac 2232 produced the highest pod yield of 902 kg ha^{-1} and outyielded the best control cultivar (NC Ac 343). It is a spanish bunch type and, therefore, matures earlier than the virginia bunch selections. The poor yields under the low-input conditions were probably due to the late sowing date and prolonged periods of drought during the crop season. Despite the harsh environment, this and several other selections outyielded at least one of the control cultivars. They will be tested for drought resistance.

We also identified 94 other selections that possess high levels of resistance to jassids, but did not have high yield potentials under either high- or low-input conditions. In future, we shall intercross selections with high levels of resistance with high-yielding, moderately-resistant lines to improve their level of resistance to jassids and thrips.

Table 18. Yield (kg ha^{-1}) of some high-yielding jassid- and thrips-resistant groundnut selections, multilocational trial, rainy season 1985.

Pedigree	Yield (kg ha^{-1}) Rainfed Anantapur	Dharwad	Mean	Irrigated[1] Hisar	Bhavanisagar	Mean	Mean of four locations
Robut 33-1 × NC Ac 2232	1740	2610	2170	5470	3210	4340	3260
[(Mani Pintar × Robut 33-1) × NC Ac 2214]	1830	2370	2100	4190	3710	3950	3030
ICGS 2 × NC Ac 2214	1330	2720	2020	4130	3790	3960	2990
ICGS 20 × NC Ac 2214	1210	2820	2020	5360	3460	4410	3210
Makulu Red × NC Ac 2232	1940	2000	1970	4780	3220	4000	2990
ICGS 1 × NC Ac 2232	1290	1990	1640	5100	4390	4750	3190
ICGS 12 × NC Ac 2232	1250	1910	1580	5660	3740	4700	3140
Chalimbana × NC Ac 2214	1160	2370	1770	5320	3960	4640	3200
(Gujarat Dwarf Mutant × NC Ac 2232)	1690	2070	1880	5270	3990	4630	3260
ICGS 12 × NC Ac 2214	1040	1970	1510	5120	4140	4630	3070
Controls							
Robut 33-1	1180	1910	1550	5600	3480	4540	3040
JL 24	1120	2270	1700	3940	3220	3580	2640
NC Ac 343	1010	1990	1500	5120	3280	4200	2850
SE	±275	±206	±172	±403	±245	±23	±146
Trial mean (56 entries)	1200	2170	1690	4890	3680	4290	2990
CV (%)	39	16	-	14	11	-	-

1. Irrigation applied as required to ensure ample supply of water.

Generation advance and selection for resistance and other desirable traits. Recently identified germplasm lines with resistance to the groundnut leaf miner were crossed with high-yielding selections with resistance to thrips and jassids in order to to develop multiple pest-resistant lines. We have also crossed groundnut leaf miner resistant genotypes with three drought-resistant/tolerant lines because we have observed more severe leaf miner attack in years of drought. The F_1s generated from such crosses will be extensively used as pollinators for crossing with other high-yielding breeding lines having resistance to other stress factors. We also crossed a number of high-yielding, pest-resistant selections with three high-yielding lines with resistance to foliar diseases. These and about 900 other (F_2 – F_9) selections with pest resistance, are being evaluated.

Plant Nutrition

Nitrogen Nutrition

Nitrogen Use Efficiency

Responses of groundnut genotypes to fertilizer nitrogen have been erratic, and to investigate the reasons for this we compared the responses of sorghum and groundnut crops to fertilizer nitrogen application. Since reduction of nitrate to nitrite by the enzyme nitrate reductase (NR; EC 1.6.6.1, NADH: nitrate oxidoreductase) is believed to be the rate-limiting process for the utilization of NO_3, we compared nitrate reductase activity (NRA) and nitrate content in the leaves of sorghum and groundnut during the 1984/85 postrainy season. We tested two sorghum genotypes (CSH 8R and M 35-1), one non-nodulating, and one nodulating groundnut genotype (see ICRISAT Annual Report 1981, pp. 187-189). At different growth stages, we sampled three plants and counted the total leaves on each branch, divided them equally into leaves representing top, middle, and lower canopy positions, and estimated leaf NRA and leaf nitrate content for each layer. Total NRA $plant^{-1}$ and nitrate $plant^{-1}$ were estimated by adding these values.

Sorghum accumulated very little nitrate in the leaves (maximum 350 μg $plant^{-1}$, Fig. 5a), whereas groundnut accumulated considerable nitrate in the leaves (up to 6000 μg $plant^{-1}$ for the nodulating genotype and 200 μg $plant^{-1}$ in the non-nodulating genotype). Sorghum leaves had higher leaf NRA than groundnut (Fig. 5b).

The high NRA activity at low nitrate content in sorghum leaves and low NRA at high nitrate content in the groundnut leaves implies that groundnut is a poor user of mineral nitrogen. This was observed at all stages of growth and shows that the lack of response to fertilizer nitrogen by this crop has a physiological basis. This phenomenon could be due to either, higher nitrate concentration being required to induce nitrate reductase (NR) in groundnut than in sorghum, or nitrate reductase in groundnut having a lower affinity for the substrate (higher km, the Michaelis-Menten constant) compared to that of sorghum.

Siderophore Production by *Rhizobium* Strain NC 92

Earlier we reported that a *Rhizobium* strain NC 43.3 fixed more nitrogen than strain NC 92 in pot culture, and formed more or less the same percentage of nodules as that formed by the latter in a field containing adequate levels of native rhizobia. However, only inoculation with strain NC 92 increased the pod yield of Robut 33-1 (see ICRISAT Annual Report 1984, pp. 220-221). One possible explanation is that the effect of strain NC 92, on groundnut yield may not be entirely due to its symbiotic nitrogen-fixing ability. While looking for other differences between strains NC 43.3 and NC 92, we found that strain NC 92 secretes a siderophore, an iron-chelating compound, into the culture medium, whereas no siderophore was detected in the culture medium of NC 43.3. Under natural aerobic soil conditions most of the iron exists in insoluble ferric forms. The siderophore could help in chelating iron, thereby improving its availability to the plant. We are now investigating whether this siderophore has any effect on the iron nutrition of the plant.

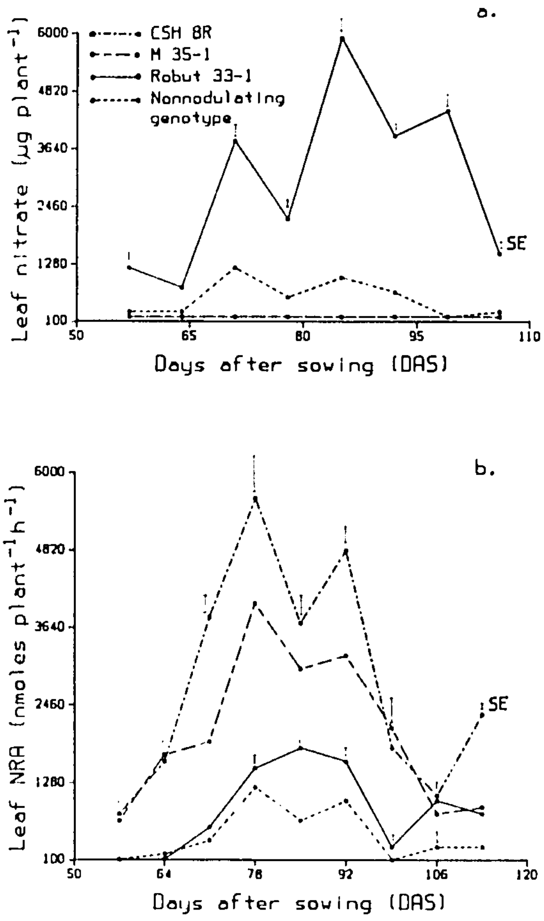


Figure 5. Changes in (a) nitrate content (μg $plant^{-1}$), (b) nitrate reductase activity (nmoles nitrite $plant^{-1}$ h^{-1}) in sorghum and groundnut genotypes following application of fertilizer containing 200 kg N ha^{-1}, ICRISAT Center, postrainy season 1984/85.

Table 19. Effect of manganese on plant growth and nitrogen fixation in groundnut genotypes at pH 4.0, in pot culture, 60 DAS, greenhouse trial, ICRISAT Center, 1985.

	Shoot mass (g)		N_2-ase activity (μmoles C_2H_4 plant^{-1} h^{-1})	
Genotype	Control[1]	Manganese[2] (15 μg mL^{-1})	Control[1]	Manganese[2] (15 μg mL^{-1})
JL 24	6.2	6.3	6.1	7.2
J 11	6.4	6.6	14.3	14.9
NC Ac 2821	8.6	8.1	15.0	13.8
Argentine	7.8	6.1	7.6	7.9
Robut 33-1	7.8	7.0	16.3	10.6
Kadiri 71-1	7.5	6.9	20.0	15.5
PI 259747	6.9	6.8	23.5	19.8
TMV 2	7.4	6.8	10.0	11.1
MH 2	5.3	5.7	13.0	6.4
Gangapuri	8.9	6.9	9.7	10.3
SE	±0.48		±2.27	
Mean	7.3	6.7	13.5	11.7
SE	±0.15		±0.72	

1. Control plants were grown with nutrient solution.
2. Mn (15 μg mL^{-1}) was supplied as manganese sulfate in the nutrient solution.

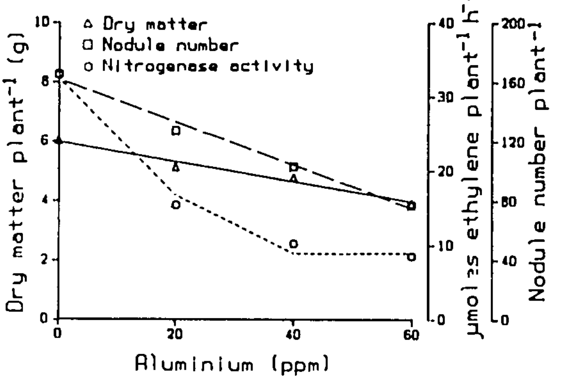
Table 20. Effect of aluminium on plant growth and nitrogen fixation in groundnut genotypes at pH 4.0, in pot culture, 60 DAS, greenhouse trial, ICRISAT Center, 1985.

	Shoot mass (g)		N_2-ase activity (μmoles C_2H_4 plant^{-1} h^{-1})	
Genotype	Control[1]	Aluminium[2] (60 μg mL^{-1})	Control[1]	Aluminium[2] (60 μg mL^{-1})
JL 24	4.7	1.7	5.3	2.1
J 11	3.3	2.1	4.5	2.9
NC Ac 2821	3.0	2.3	5.9	3.3
Argentine	4.0	2.0	4.6	2.5
Robut 33-1	2.8	2.2	5.3	2.5
Kadiri 71-1	4.8	2.5	15.2	3.0
PI 259747	3.5	2.3	8.2	2.1
TMV 2	4.1	2.0	9.0	2.2
MH 2	4.5	2.1	11.9	3.0
Gangapuri	4.7	3.3	7.5	3.3
SE	±0.35		±1.29	
Mean	4.0	2.3	8.0	2.7
SE	±0.10		±0.37	

1. Control plants grown with nutrient solution.
2. Al (60 μg mL^{-1}) supplied as potassium aluminium sulfate in the nutrient solution.

Toxic Effect of Aluminium and Manganese on Nitrogen Fixation and Plant Growth

In mineral soils with low pH, acidity is often associated with low concentrations of calcium and high concentrations of aluminium (Al) and manganese (Mn). In pot experiments we investigated the effects of acidity and these toxic elements on plant growth per se and on symbiotic nitrogen fixation by root nodules in a range of genotypes. Mn (as manganese sulfate) and Al (as potassium aluminium sulfate) were added to the nutrient solution (pH 4.0), which was changed daily during the experiments. Acidity alone did not significantly influence plant growth. Some genotypes developed toxic symptoms, such as cupping of younger leaves and marginal leaf spots, at 15 μg Mn mL^{-1} nutrient solution. A higher concentration of Al (20 μg mL^{-1}) was required to produce observable plant responses, which were limited to stunted plant growth. These data indicate that *Rhizobium* strains and groundnut genotypes that overcome Mn and Al toxicity merit investigation. Mn and Al toxic effects were greater on nitrogen fixation than on plant growth (Fig. 6,and Tables 19,and 20). We observed genotypic variation for toxic symptoms of these elements.



Dry matter
$y = 5.96 - 0.034x$, rse = 0.17
$r = 0.96$, $P < 0.05$.

Nodule number
$y = 161.2 - 1.4x$, rse = 4.94
$r = 0.98$, $P < 0.05$.

Nitrogenase activity
$y = 32.4 - 0.99x + 0.01x2$, rse = 5.79
$r = 0.98$, $P < 0.05$.

Figure 6. Effect of aluminium on nitrogenase activity, nodulation, and plant growth of groundnut genotype ICG 5494 in pot culture, ICRISAT Center, 1985.

Mycorrhizae

Groundnut forms symbiotic associations with certain zygomycetous fungi, known as vesicular arbuscular mycorrhizae (VAM). The VAM fungi are known to augment plant phosphorus (P) uptake ability from soils deficient in this element. Groundnut roots usually show extensive VAM colonization.

Root showing dark vesicles formed by the VAM fungus (×100).

VAM, P Nutrition, and Growth

We conducted a pot trial using an Alfisol with and without VAM at different levels of available P. Mycorrhizal-inoculated plants had higher shoot dry matter and total P at available P levels between 2.45 and 12.25 ppm (Fig.7). Generally,

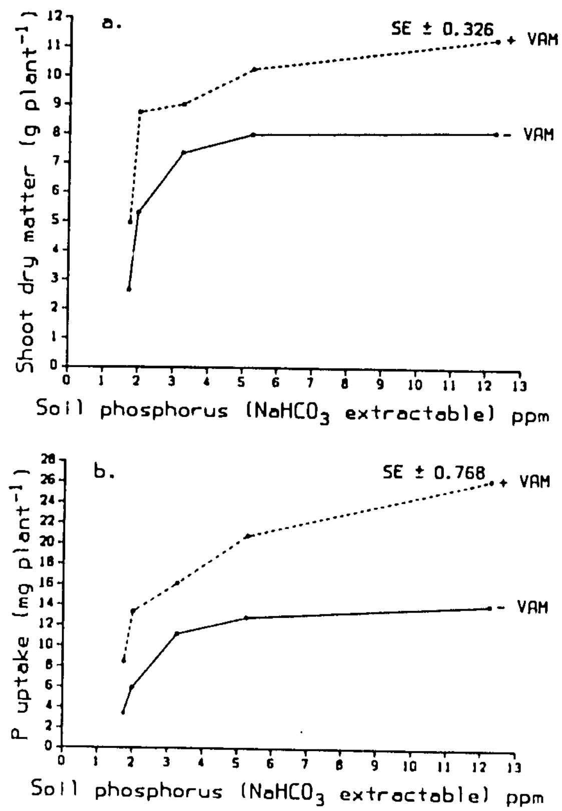


Figure 7. Shoot dry matter (a) and phosphorus uptake (b) of groundnuts grown in an Alfisol at different levels of available phosphorus, with and without VAM inoculation, ICRISAT Center, summer 1985.

for both VAM-inoculated and noninoculated plants, there was a rapid increase in growth and P uptake in response to increased P availability in soil from 2.45 to 4 ppm. Between 4 and 12.25 ppm, the noninoculated plants did not respond to P application, while inoculated plants responded with increased growth and P uptake. Clearly, groundnut derives appreciable benefits in terms of P uptake from VAM inoculation.

Effects of VAM Strains on P uptake and Plant Growth

VAM fungi are also known to augment P uptake from rock phosphates containing sparingly soluble phosphorus. We compared the efficiencies of P uptake and host-plant growth response from 10 different VAM cultures from Kodjari rock phosphate. The VAM cultures differed significantly in their abilities to enhance P absorption from Kodjari rock phosphate, and to stimulate growth (Fig.8). Inoculation with *Gigaspora calospora* resulted in the highest growth stimulation, while *Glomus mosseae* resulted in the highest P uptake.

Genotype-dependent Differences in VAM Colonization

We sowed 10 genotypes each of spanish, valencia, virginia bunch, and virginia runner types, at ICRISAT Center and Anantapur to see if VAM colonization differed with genotype. The mean percentage VAM colonization for the genotypes ranged from 20 to 45% for spanish types, 17-31% for valencias, 22-50% for virginia bunch types, and 21-36% for runners (Table 21). Of the 40 genotypes screened, ICG 2671 showed the highest mean VAM colonization, 50%, and ICG 10509 the lowest, 17%. Such differences in VAM colonization are attributable to the interaction of differences in root anatomy and physiology with VAM fungi.

Groundnut genotypes differed significantly in P uptake ($P<0.05$). The highest mean P uptake, of 31 mg plant^{-1} was recorded for ICG 5139 and the lowest, 8 mg P plant^{-1} for ICG 1908 (Table 22). Within each of the four types the P uptake differed significantly ($P<0.05$).

It is therefore probable that VAM colonization and P nutrition are components in genotype and site interactions, and selection of host genotypes with horizontal susceptibility to VAM could improve the adaptation of genotypes to varying nutritional environments.

Plant Improvement

Breeding for High Yield and Quality

Generation Advance and Selection

A large number of germplasm accessions with large pods and seeds were selected in 1985 for use

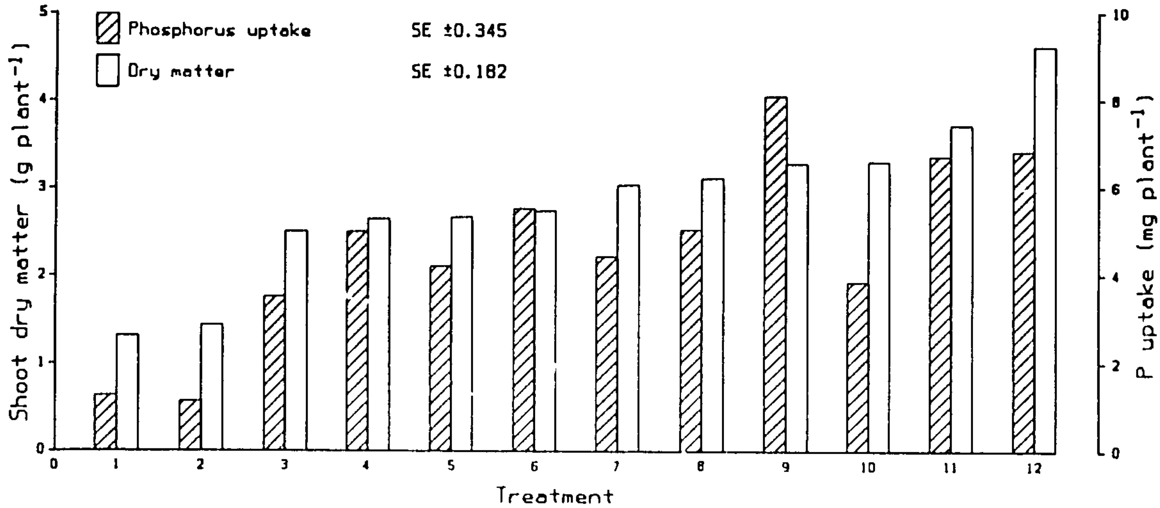


Figure 8. Response of groundnut cultivar TMV 2 to ...culations with various mycorrhizal fungi in an Alfisol amended with Kodjari rock phosphate (at the rate of 6 kg P ha^{-1} basal). ICRISAT Center, summer 1985. Treatments;

1 = Control	4 = *Gigaspora margarita*	7 = *Glomum clarum*	10 = *Acaulospora*
2 = Rock phosphate (RP)	5 = *Glomus caledonium*	8 = *Glomus monosporum-2*	11 = *Glomus epigaum*
3 = *Glomus mosseae*	6 = *Glomus monosporum-1*	9 = *Glomus fasciculatum*	12 = *Gigaspora calospora*

in breeding for high yield and quality. We crossed ICG(CG)S 49, a high-yielding confectionery selection, with thin-shelled breeding lines to improve the shelling percentage.

To study the genetics of quality characteristics we completed a full diallel cross involving eight diverse cultivars with various quality attributes.

Some high-yielding confectionery groundnut selections were crossed with high-yielding, genotypes with resistance to rust and late leaf spot to combine these desirable characteristics.

We grew 442 segregating generations (F_2-F_8) under irrigation and made several selections.

Multilocational Yield Trial

In the 1985 rainy season, we evaluated 320 advanced-generation breeding lines for yield and quality. One-hundred-and-twenty lines were tested in multilocational trials at five sites and selected data from one of these trials are shown in Table 23. The lines Dh 3-20 × Robut 33-1 and GAUG 1 × Robut 33-1 performed well under rainfed conditions but were outyielded by other lines in the irrigated trials. Lines Robut 33-1 × NC Ac 316 and TG 16 × J 11 gave good yields in the irrigated trials, but did not perform well under rainfed conditions.

In general, selections that did well under rainfed conditions did not always give comparable performance when grown under irrigation and vice versa. However, several selections behaved like Robut 33-1 × 865 (Table 23) and gave good yields under both rainfed and irrigated conditions.

Yield Trials at ICRISAT Center

In the 1985 rainy season at ICRISAT Center, we evaluated for yield 200 new selections and some earlier identified selections. Yield data for 16 selections from one trial are shown in Table 24.

Table 21. Colonization (%) of roots of groundnut genotypes by vesicular arbuscular mycorrhizae (VAM) ICRISAT Center, rainy season 1985.

	Mean VAM (%)				Mean VAM (%)		
Genotype	ICRISAT	Anantapur	Mean	Genotype	ICRISAT	Anantapur	Mean
Spanish				Valencia			
ICG 10505	60	30	45	ICG 10974	32	29	31
ICG 7827	60	29	44	ICG 7885	25	31	28
ICG 1101	46	41	44	ICG 2738	16	36	26
ICG 1164	39	45	42	ICG 4790	15	34	24
ICG 10525	51	27	39	ICG 1629	21	25	23
ICG 1521	41	29	35	ICG 1908	34	11	23
ICG 1773	42	17	29	ICG 1707	28	16	22
ICG 5305	39	17	28	ICG 1697	23	17	20
ICG 221	36	16	26	ICG 10470	16	21	18
ICG 1506	23	17	20	ICG 10509	19	15	17
SE	±4.9	±4.6	±4.8	SE	±4.9	±4.6	±4.8
Mean	44	27		Mean	23	24	
SE	±1.5	±1.4		SE	±1.5	±1.4	
Virginia				Runner			
ICG 2671	46	53	50	ICG 4344	17	54	36
ICG 3047	40	57	48	ICG 5139	35	38	36
ICG 3833	34	38	36	ICG 5363	29	41	35
ICG 3030	28	34	31	ICG 3948	30	39	35
ICG 4507	29	32	30	ICG 5302	27	41	34
Robut 33-1	29	32	30	ICG 4159	39	26	33
ICG 3064	34	19	26	ICG 156	37	30	33
ICG 4445	19	33	26	ICG 2607	17	36	27
ICG 4224	16	32	24	ICG 5622	19	23	21
ICG 2490	12	32	22	ICG 4149	20	21	21
SE	±4.9	±4.6	±4.8	SE	±4.9	±4.6	±4.8
Mean	29	36		Mean	27	35	
SE	±1.5	±1.4		SE	±1.5	±1.4	

All 16 selections significantly outyielded the control cultivars Robut 33-1 and JL 24 under high-input (60 kg P_2O_5 ha^{-1}, irrigated, and with insecticide sprays) conditions. Some of the selections are derivatives from interspecific (*Arachis hypogaea* × wild *Arachis* species) crosses that have been selected for their good yield and desirable pod and seed characteristics.

Breeding for the Confectionery Market

At ICRISAT Center in the 1985 rainy season, we evaluated, under high-input and low-input (20 kg P_2O_5 ha^{-1}, rainfed and without insecticide sprays) conditions, advanced generation, large-seeded, breeding lines. Data from one trial on 14 selected lines are shown in Table 25. All 14 lines significantly outyielded the bold-seeded control cultivar M 13, and seven lines outyielded the control cultivar Robut 33-1, under high-input conditions. Under low-input conditions only three lines significantly outyielded both control cultivars. Selection HYQ(CG)S 57, an interspecific hybrid derivative, performed well under both conditions.

Nutritional and Food Quality

In addition to seed size and testa color, there are other quality factors such as high oil content and oleic:linoleic ratio, high protein content, and sugar content, that influence acceptability of confectionery groundnuts. We have already identified breeding lines with high oil and/or protein

Table 22. Mean phosphorus (P) uptake (mg $plant^{-1}$) of groundnut genotypes, ICRISAT Center, rainy season 1985.

	Mean P uptake				Mean P uptake		
Genotype	ICRISAT	Anantapur	Mean	Genotype	ICRISAT	Anantapur	Mean
Spanish				Valencia			
ICG 10505	28	15	22	ICG 4770	33	18	25
ICG 5305	25	16	21	ICG 7885	27	18	22
ICG 1521	26	12	19	ICG 10509	29	13	21
ICG 1101	19	17	18	ICG 1707	23	18	20
ICG 221	22	14	18	ICG 10974	25	15	20
ICG 1506	22	11	16	ICG 1697	23	15	19
ICG 1773	21	9	15	ICG 10470	23	13	18
ICG 7827	14	14	14	ICG 1629	21	13	17
ICG 10525	16	12	14	ICG 2738	13	12	12
ICG 1164	15	11	13	ICG 1908	10	5	8
SE	±2.9	±1.4	±2.4	SE	±2.9	±1.4	±2.4
Mean	21	13		Mean	23	14	
SE	±0.9	±0.44		SE	±0.9	±0.44	
Virginia				Runner			
ICG 4224	43	15	29	ICG 5139	34	29	31
ICG 2671	43	15	29	ICG 4159	42	17	30
ICG 3047	37	17	27	ICG 156	35	20	27
ICG 3833	36	17	27	ICG 4149	34	14	24
ICG 4445	37	16	27	ICG 4344	32	16	24
Robut 33-1	37	14	26	ICG 5363	30	16	23
ICG 2490	27	21	24	ICG 3948	27	18	23
ICG 3030	28	18	23	ICG 2607	24	21	22
ICG 4507	32	13	23	ICG 5622	27	15	21
ICG 3064	30	15	22	ICG 5302	20	16	18
SE	±2.9	±1.4	±2.4	SE	±2.9	±1.4	±2.4
Mean	35	16		Mean	30	18	
SE	±0.9	±0.44		SE	±0.92	±0.44	

Table 23. Pod yield (kg ha⁻¹) of some high-yielding groundnut selections, multilocational trial, rainy season 1985.

		Rainfed pod yields (kg ha^{-1})				Irrigated pod yields (kg ha^{-1})[1]				Mean across six
Pedigree	Growth habit[2]	ICRISAT Center	Dharwad	Anantapur	Mean	ICRISAT Center	Bhavanisagar	Hisar	Mean	locations
Dh 3-20 × Robut 33-1	SB	780	2790	1440	1670	2670	3720	3750	3380	2520
GAUG 1 × Robut 33-1	VB	790	2690	1460	1650	3840	3620	3030	3500	2570
[(USA 20 × TMV 10) × Robut 33-1-10-12)]	SB/VB	1000	2540	1400	1640	3440	3810	3930	3730	2690
Robut 33-1 × 865	VB	1080	2280	1550	1640	3480	3590	4780	3950	2790
[Robut 33-1-21-11 × (Manfredi × M 13)]	VB	990	2460	1400	1620	3440	4040	3450	3640	2630
Robut 33-1 × NC Ac 316	VB	510	1930	1460	1300	3320	3740	5540	4200	2750
TG 16 × J 11	SB	670	1460	1170	1100	3370	3890	4860	4040	2570
MGS 9 × Robut 33-1	VB	680	2160	1540	1460	3370	3870	4650	3960	2710
ICGS 22 × ICGS 16	SB	480	2360	1570	1470	3240	4210	4300	3910	2690
Controls										
Robut 33-1	VB	400	1500	1240	1050	2090	2720	3050	2620	1830
JL 24	SB	590	1530	1390	1170	2290	2410	3160	2620	1890
SE		±72	±205	±105	±80	±225	±279	±401	±179	
Trial mean (81 entries)		640	2180	1290	1370	2960	3420	3670	3350	
CV (%)		19	16	14		13	14	19		

1. Supplementary irrigation provided to ensure ample supply of water.
2. SB = Spanish bunch, VB = Virginia bunch.

contents and are using them in our quality breeding program.

From the 1984 rainy-season trials at ICRISAT Center, we selected 300 high-yielding lines and compared the oil and protein contents of their seed with those of the two popular Indian cultivars JL 24 and Robut 33-1. JL 24 had an oil content of 40% and a protein content of 29%, and Robut 33-1 had 42% oil content and 25.8% protein content. Oil contents of the test lines ranged from 38 to 50% (mean 45.7%), while protein contents ranged from 16.2 to 23.7% (mean 25.2%).

We also evaluated high-yielding confectionery breeding lines from the 1984 rainy-season ICRISAT Center trials under high-input conditions for oil and protein seed contents. Oil contents ranged from 39 to 45.5%, and protein contents from 21.4 to 28.3%. Several lines were selected for further testing in 1985.

Breeding for Earliness

In the 1985 rainy season, we used the 'staggered-harvesting' approach (ICRISAT Annual Report 1984, pp. 226-229), to screen 129 breeding and germplasm lines for pod and sound mature kernel (SMK) yields, and other maturity-related characteristics in five trials. We made 14 and 18 extra-early and early line selections based on SMK yield levels in 75- and 90-day harvests respectively. Eight lines were common, we also screened 44 advanced generation breeding lines, selected for earliness and high yields in 1984, at seven sites in India in the 1985 rainy season. Data on pod yields of selected entries from six locations are shown in Table 26. There were strong genotype × environment interactions. The 10 breeding lines shown, and 11 other lines that performed well at one or more locations will be retested in the 1986 rainy season.

Table 24. Pod yields (kg ha^{-1}) of some high-yielding groundnut selections under high input conditions[1], ICRISAT Center, rainy season 1985.

Pedigree	Pod yields (kg ha^{-1})
Goldin 1 × G 201	3560
Manfredi × F334A-B-14	3290
ICGS 31 × ICGS 44	3230
[(Florigiant × Chico)$F_{12}B_1$ × ICGS 11]	3050
A. hypogaea × *A. chacoense*	3040
A. hypogaea × *A. chacoense*	3030
A. hypogaea × *A. cardenasii*	2970
[Robut 33-1-21-11 × (Manfredi × M 13)]	2970
TMV 10 × Robut 33-1	2940
Ah 2105 × Chico	2860
ICGS 5 × C 166	2860
F334A-B-14 × ICGS 20	2820
Robut 33-1 × Ah 7299	2790
Makulu Red × J 11	2790
(M 13 × Robut 33-1) × ICGS 11	2710
ICGS 44 × L.No.95 A	2620
Controls	
Robut 33-1[2]	2100
JL 24[3]	1910
SE	±170
Trial mean (64 entries)	2320
CV (%)	12

1. High input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays.
2. Virginia bunch cultivar.
3. Spanish bunch cultivar.

Flowering Patterns in Relation to Earliness

We studied flowering patterns and other maturity-related characteristics in 16 groundnut genotypes representing a range of crop durations. We identified three distinct patterns of flowering, one mainly associated with early-maturing groundnut cultivars. In this pattern, represented by Chico, ICGS(E) 56, and Gangapuri (Fig. 9a, b, and c), flower production increased rapidly up to 44 to 47 DAS, then decreased with very few flowers being produced from 65 to 70 DAS. Late-maturing cultivars like NC Ac 343 had a flowering pattern (Fig. 9d) with flowers being produced continuously throughout the season. Some lines were also found with a flowering pattern intermediate between the two extreme patterns.

Using Wild *Arachis* Species

Using New Accessions

We crossed four new diploid accessions, *Arachis* sp 30080, *A.* sp 30081, *A.* sp 30085, and *A.* sp 35001 with resistance to rust and/or late leaf spot with cultivars belonging to two subspecies of *A. hypogaea* (Table 27). We established a large number of triploid hybrids and we will record their disease reaction against rust and late leaf spot; any progeny from these hybrids will be screened for disease resistance and analyzed cytologically.

The new accessions have also been crossed with *A. batizocoi*, *A. cardenasii*, *A. chacoense*, and *Arachis* sp HLK 410, which are resistant to rust and leaf spot, as well as among themselves as the first step in the production of amphidiploids. All the crosses produced some seed, and 33 seeds have been harvested. Seedlings of these species were also treated with colchicine to produce autotetraploids.

Production of Cytologically Stable Interspecific Derivatives

Backcrossing to *A. hypogaea* or advancement by selfing of derivatives from 29 different combinations resulted in the production of an additional 79 stable *A. hypogaea*-like tetraploid derivatives (Table 28). Twenty-five of them were bred from 12 different combinations of three wild species with different cultivars of *A. hypogaea* following the hexaploid route, while 54 were bred from 17 different combinations of seven wild species by the amphidiploid route. Several of them were screened in the 1985 rainy season against rust

Table 25. Performance of some high-yielding confectionery groundnut selections under high- and low-input conditions, ICRISAT Center, rainy season 1985.

Identity	Pedigree	Growth habit[1]	Pod yield (kg ha^{-1})	
			HI[2]	LI[3]
HYQ (CG) S 55	Robut 33-1 × NC Ac 2821	SB	3430	620
HYQ (CG) S 57	*A. hypogaea* × (*A. villosa* × *Arachis* sp HLK 410)	SB	3320	940
HYQ (CG) S 50	Robut 33-1 × NC Ac 2821	SB	2990	760
HYQ (CG) S 38	Shulamith × Chico	SB	2950	660
HYQ (CG) S 49	Ah 114 × NC Ac 1107	VB	2940	920
HYQ (CG) S 13	(Robut 33-1 × NC Ac 2821) × NC 3033	SB	2840	760
HYQ (CG) S 6	Robut 33-1-21 × (Manfredi × M 13)	SB	2790	750
HYQ (CG) S 23	TG 17 × NC Ac 2785	SB	2730	760
HYQ (CG) S 15	Manfredi × M 13	SB	2650	760
HYQ (CG) S 59	T 64 × NC Ac 1107	SB	2580	670
HYQ (CG) S 39	NC Ac 311 × Ah 8254	SB	2520	780
HYQ (CG) S 10	Robut 33-1-21-11 × (Manfredi × M 13)	VB	2420	770
HYQ (CG) S 47	Kadiri 71-1 × Chico	VB	2390	910
HYQ (CG) S 16	Robut 33-1 × F334A-B-14	SB	2390	710
Controls				
Robut 33-1		VB	2150	640
M 13		VR	1700	660
SE			±198	±79
Trial mean (64 entries)			2340	750
CV (%)			14	18

1. SB = Spanish bunch, VB = Virginia bunch, VR = Virginia runner.
2. HI = High input (60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays).
3. LI = Low input (20 kg P_2O_5 ha^{-1}, rainfed without insecticide sprays).

and late leaf spot and advanced to subsequent generations for further screening.

Selection for Resistance to Rust and Late Leaf Spot among Segregating and Uniform Interspecific Populations

From segregating populations of interspecific derivatives, we selected another 105 lines or single plants resistant to late leaf spot, 50 resistant to rust, and 100 with low field incidence of BND.

Seventy-eight near uniform lines, derived from six species of Section *Arach*· through different cytogenetic manipulations, w .e sown at ICRISAT Center in a 9 × 9 triple lattice. Sixty-two of these were also sown in a 8 × 8 triple lattice at Bhavanisagar. Botanical and agronomic characteristics were recorded at ICRISAT Center, and 28 different lines were selected, after rejecting duplicates and lines with undesirable attributes. At Bhavanisagar, we made a further 23 late leaf spot-resistant selections. These selections represent the wide genetic variability in botanical and agronomic features that has arisen from our wild species crosses.

Agronomic Characterization of Advanced Lines

The three species *A. cardenasii*, *A. batizocoi*, and *Arachis* sp GKP 10038, have produced 59

Table 26. Pod yields (kg ha^{-1}) of selected early-maturing groundnut breeding lines at six Indian locations, rainy season, 1985.

Identity	Pedigree	Pod yields (kg ha^{-1}) ICRISAT Center HI[1] (90)[3]	LI[2] (131)	LI[2] (115)	Anantapur (113)	Bhavanisagar (90)	Dharwad (95)	Mean
ICGS (E) 52	Shantungku No. 203 × R 33-1	2920	950	1170	1240	1940	2520	1790
ICGS (E) 119	(2-5 × NC Ac 741) × PI 337409	2940	690	810	1150	2020	2810	1740
ICGS (E) 129	MH 2 × Shantungku No. 203	3850	850	1060	950	1400	2050	1690
ICGS (E) 188	Selection from ICG 3754	3270	760	1060	1140	1770	2150	1690
ICGS (E) 123	(2-5 × NC Ac 741) × PI 337409	3040	620	850	1020	1620	2890	1670
ICGS (E) 22	Ah 65 × Chico	2710	700	940	1220	1970	2480	1670
ICGS (E) 170	Selection from ICG 1369	2450	610	1000	1210	1820	2920	1670
ICGS (E) 80	Dh 3-20 × Chico	2700	830	1160	1190	1990	2070	1660
ICGS (E) 56	ICGS 44 × TG 2E	3460	870	1040	1050	1710	1770	1650
ICGS (E) 147	Selection from ICG 147	3010	600	1050	1100	2090	2060	1650
Controls								
Robut 33-1		2690	880	1130	1170	2060	2000	1660
JL 24		2820	730	980	1180	1770	2300	1630
Chico		2030	360	220	760	1220	470	840
SE		±223	±55	±62	±107	±173	±243	
Trial mean (49 entries)		2740	700	900	1150	1670	2040	
CV (%)		14	14	12	16	18	21	

1. HI = High input (60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays).
2. LI = Low input (20 kg P_2O_5 ha^{-1}, rainfed without insecticide sprays).
3. Figures in parentheses are number of days from sowing to harvest.

Table 27. Crossability of new diploid accessions with cultivars of two subspecies of *A. hypogaea*, ICRISAT Center, postrainy season 1984 to rainy season 1985.

♀ Parent \ ♂ Parent	*A.* sp 30080 a	b	c	*A.* sp 30081 a	b	c	*A.* sp 30085 a	b	c	*A.* sp 35001 a	b	c[1]
A. hypogaea ssp *hypogaea*												
Robut 33-1				45	17	38	42	23	55	54	23	43
Shulamith	68	16	24				77	6	8	97	20	21
A. hypogaea ssp *fastigiata*												
J 11	41	4	10	29	6	21	19	1	5	58	15	26
ICGS 11	61	4	7	11	3	27	50	4	8	74	1	1
ICGS 26				28	4	14	47	2	4			
JL 24							8	3	38	13	6	46

1. a = Number of pollinations.
   b = Number of pods.
   c = Percentage pods per pollination.

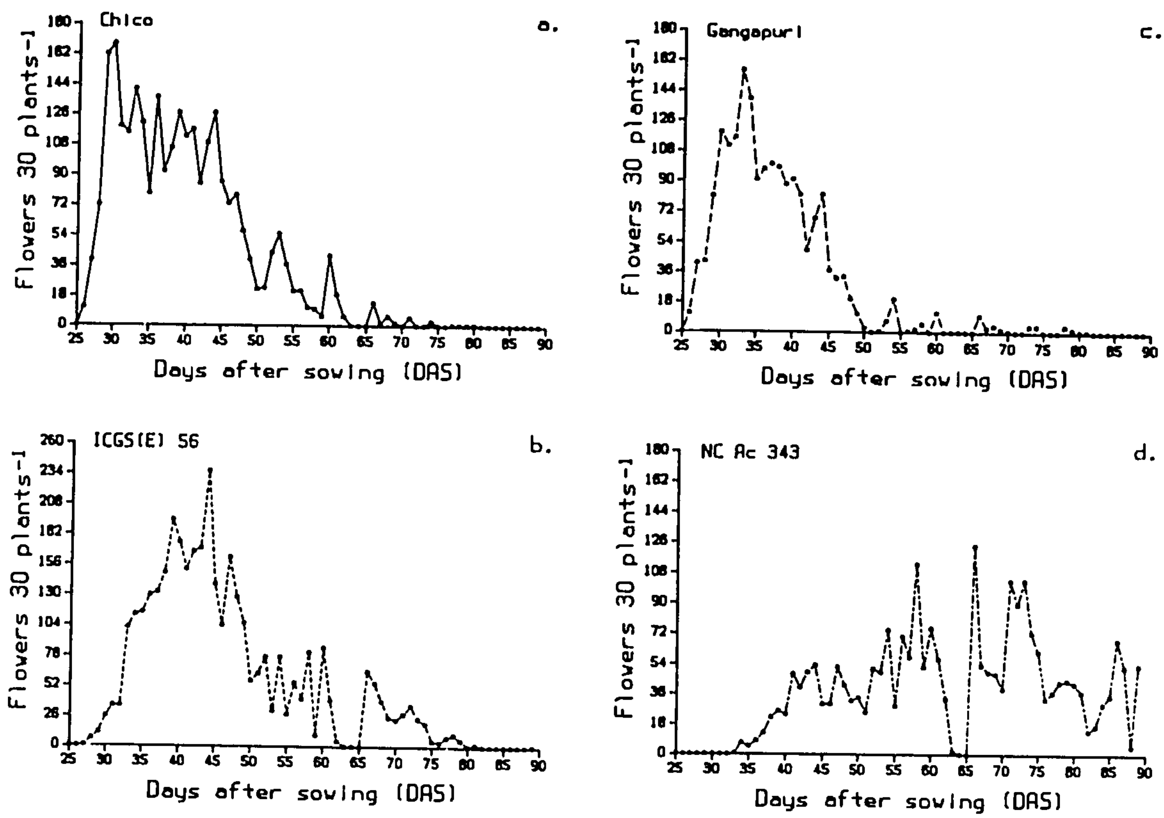


Figure 9. Flowering patterns in four groundnut cultivars, ICRISAT Center, rainy season 1985.

advanced, uniform lines. These were classified into three groups, based on the 1984 rainy-season trials.

The first group of 33 lines, selected for high yield and resistance to rust and/or late leaf spot, were sown with three controls in a 6×6 triple lattice. From these we selected 10 lines that differ from each other in agronomic and botanical characteristics (Table 29). Nine of these involved *A. cardenasii*, a species resistant to both rust and late leaf spot, and one involved *A. batizocoi* and *Arachis* sp GKP 10038, both resistant to rust.

The second group, consisting of 11 advanced lines with high pod yield and moderate levels of rust resistance was sown with national and local controls and a high-yielding breeding selection in a randomized-block design (RBD). Two agronomically different selections were made (Table 29), with moderate rust disease resistance and yields significantly higher than all the controls.

The third group consisted of 15 populations that were still segregating. From these, three lines with high pod yield, good rust resistance, and moderate levels of late leaf spot resistance were selected (Table 29).

Most of these lines also produced good haulm yields, that can be made into valuable hay for feeding livestock. Haulm yields from the 1984 rainy season are shown in Table 29.

Detailed information on characterization of all these derivatives is now available to cooperators.

Introduction of Interspecific Derivatives in AICORPO Trials and their Distribution among Cooperators

Four advanced lines from *A. cardenasii* interspecific derivatives were entered in an AICORPO multilocational yield trial. ICG(C) 5 and ICG(C)

Table 28. Number of progenies producing cytologically stable tetraploid plants and number of plants produced from various combinations of *Arachis hypogaea* × wild species crosses by two routes, ICRISAT Center, 1984-85.

	Route		
		Amphidiploid	
Species	Hexaploid	f[1]	m[2]
A. villosa		3 (5)	1 (1)
A. correntina		9 (27)	
A. chacoense	4 (7)[3]		2 (10)
A. cardenasii	1 (1)		
A. sp HLK 410	7 (17)	1 (5)	4 (17)
A. duranensis			3 (5)
A. sp GKP 10038		4 (17)	
A. batizocoi			7 (21)
Total	12 (25)	17 (54)	

1. Wild species used as female in production of amphidiploid.
2. Wild species used as male in production of amphidiploid.
3. Figures in parentheses are numbers of stable plants.

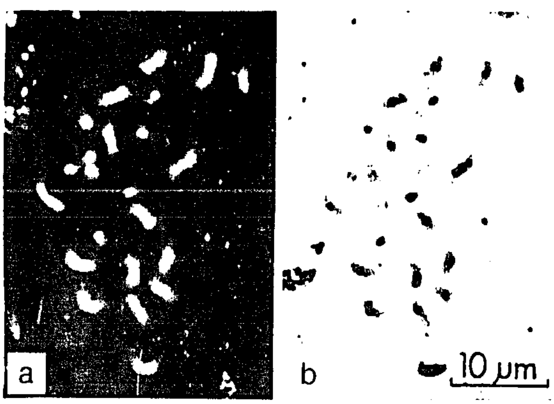
6, that incorporate both rust and late leaf spot resistance, were entered in the Foliar Disease Resistant Varietal Trials (FDRVT), whereas another two, ICG(C) 8 and ICG(C) 12, with moderate levels of resistance to the two foliar diseases and high yield capacities were entered in the Initial Evaluation Trial (IET) for virginia group genotypes.

Seed samples of wild species, segregating populations, and advanced lines have been supplied on request to six different centers in India, and to 15 centers in eight different countries outside India.

Cytogenetic Analysis

Analysis of the genomic constitution of new accessions provides information of value in planning routes for incorporation of desirable genes from wild species. Karyomorphological studies of the somatic complements of wild species accessions continued; slides were prepared and photographed from the root tips of several new accessions. Meiosis was studied in F_1 hybrids from crosses between *A. hypogaea* and new diploid accessions, and from crosses between new diploid accessions and A and B genome species (Table 30). The crosses with *A. hypogaea* confirmed that these new accessions have one genome, either A or B, in common with *A. hypogaea*, and the chromosome associations and pollen fertility in the diploid hybrids suggest that *A.* sp 30081 is probably another representative of the B genome, whereas the other accessions probably contain the A genome.

The chromosome-banding technique for constitutive hecterochromatin (C) and quinacrine flourescent (QF) bands has been standardized for *Arachis* chromosomes (Fig.10). Currently it is being used to characterize A and B genomes observed among the old diploid accessions of Section *Arachis*. Most of the bands are confined to the area around the centromere, and coalesce into one band at the perfect metaphase stage, when the chromosomes are at their maximum contraction. This technique may therefore only be useful to identify and characterize genomes, and would be of very little use in the development of cytological markers for individual chromosomes.



Mitotic chromosomes of the same cell of *Arachis duranensis* (a) stained with quinacrine for QF bands and (b) subsequently with Giemsa for C bands. (Bar length represents 10 μm).

Table 29. Agronomic and botanical features of advanced interspecific derivatives resistant to rust and late leaf spot in three different field trials, ICRISAT Center, rainy season 1985.

	Yield (kg ha^{-1})		Disease scores[1]		Pod characteristics[2]				Seed characteristics		
Identity	Pod	Haulm	Rust	Leaf spot	Size	Constriction	Beak	Reticulation	Color	100-seed mass (g)	Shelling %
Resistant lines											
CS 14	3600	7200	2	7	M	Sl	Sl	Sl	Red	28	64
CS 9	3510	8230	3	4	M-B	Sl	Mo	Mo	Red	32	62
856	3240	5460	2	5	M-B	Sl	Mo	Sl	Red	33	64
CS 2[4]	3230	5590	2	8	M	Sl	Sl	Sl	Tan	33	76
CS 39[5]	3200	6760	6	3	M	Sl-Mo	Sl	Sl	Red	27	64
838	3180	7110	2	4	M-B	Sl	Mo	Mo	Red	40	60
CS 26	3110	8600	2	4	M	Sl	P	Mo	Red	35	66
2245	3080	7410	2	4	M-B	Sl	M	Mo	Red	33	65
799	2340	7190	2	3	S-M	Sl	P	Mo	Red	29	65
CS 19[6]	2290	4840	2	8	S	Sl-D	Mo	Mo	Red	30	72
Control											
Robut 33-1	1700		9	9	M	N	A	Sm	Tan	36	70
SE	±186		±0.02	±0.4						±0.8	
CV (%)	12		14	13							
High-yielding lines											
CS 52	3260	6320	3	5	M-B	Sl	Mo	Mo	Tan	40	60
CS 16	2920	7220	4	4	M-B	Sl	Mo	Sl	Red	44	68
Control											
Robut 33-1	2170		9	9	S-M	Sl	A	Sm	Tan	36	70
SE	±336.8	±1156.7	±0.7	±0.9						±1.1	
CV (%)	12	21	15	15							
Segregating lines											
2256	3270		2	6	M-B	Sl	Sl	Sl	Red	47	61
CS 22	3150	8680[3]	2	4	M-B	Sl	Mo	Mo	Red	43	65
840636	3070		2	5	S-M	Sl-Mo	Mo	Sl	Red	42	61
Control											
Robut 33-1	1900		9	9	S-M	Sl	A	Sm	Tan	36	70
SE	±333.7		±0.4	±0.7						±1.1	
CV (%)	11		13	14							

1. Field disease scored on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage destroyed.
2. M = medium, M-B = medium to bold, N = normal, S-M = small to medium, S = small, Sl = slight, Sl-Mo = slight to moderate, Sl-D = slight to deep, Mo = moderate, P = prominent, A = absent, Sm = smooth.
3. Haulm yield from 1984 field trials (ICRISAT Annual Report 1984, p. 233).
4. Line with low incidence of pod rot.
5. Line resistant to BND and jassids.
6. *A. batizocoi* × *A.* sp GKP 10038 derivative.

Table 30. Chromosome association and pollen fertility in F_1 hybrids from crosses between section *Arachis* species, ICRISAT Center, 1985.

Cross	Cells analyzed	Chromosome association[1] Average number cell^{-1} I	II	III	IV	Chiasmata cell^{-1}	Chiasmata terminalized	Pollen fertility (%)
Arachis sp (2x) × *Arachis* sp (2x)								
A. sp 30081 × *A. cardenasii*	11	5.6 ±0.68	7.1 ±0.39	0.1 ±0.09		12.6 ±0.73	12.5 ±0.74	2
A. sp 35001 × *A. cardenasii*	7	0.3 ±0.29	9.9 ±0.14			20.3 ±0.57	19.4 ±0.30	74
A. sp 35001 × *A. batizocoi*	19	6.2 ±0.57	6.8 ±0.32	0.1 ±0.05		12.7 ±0.55	12.6 ±0.55	1
A. hypogaea ssp *hypogaea*								
Shulamith × *A.* sp 35001	25	10.1 ±0.41	9.2 ±0.27	0.4 ±0.12	0.1 ±0.04	20.0 ±0.44	18.6 ±0.52	15
A. hypogaea ssp *fastigiata*								
J 11 × *A.* sp 35001	10	7.8 ±0.53	9.3 ±0.52	1.2 ±0.29		21.3 ±0.58	21.2 ±0.59	18
ICGS 11 × *A.* sp 30085	16	7.7 ±0.49	9.4 ±0.29	1.2 ±0.19		21.2 ±0.44	19.4 ±0.70	6

1. I = univalent, II = bivalent, III = trivalent, IV = quadrivalent.

Barriers to Hybridization

Gibberellic acid (87.5 mg L^{-1}) was earlier found to produce pegs in a range of interspecific crosses (ICRISAT Annual Report 1982, p.222; 1983, p.215) but we did not obtain pods in all the crosses we attempted. We applied higher concentrations of gibberellic acid to MK 374 flowers pollinated with *A. pusilla* to examine its effect on peg and pod production. We obtained more pegs (Table 31) than with application of gibberellic acid at 87.5 mg L^{-1}, but, only two pods were formed from pollinated flowers. Previous controls when 87.5 mg L^{-1} gibberellic acid was applied to nonpollinated flowers had not produced any pegs. However, higher levels of gibberellic acid stimulated peg production from emasculated, nonpollinated flowers of MK 374 (Table 31). Pegs obtained from the latter elongated normally and some entered the soil but eventually all the pegs died and no pods were formed.

Salt-soluble proteins from 26 different calli originating from cultures of hybrid proembryos from the cross *A. hypogaea* × *Arachis* sp PI 276233 were subjected to disc electrophoresis on 7% polyacrylamide gels. The gels were incubated

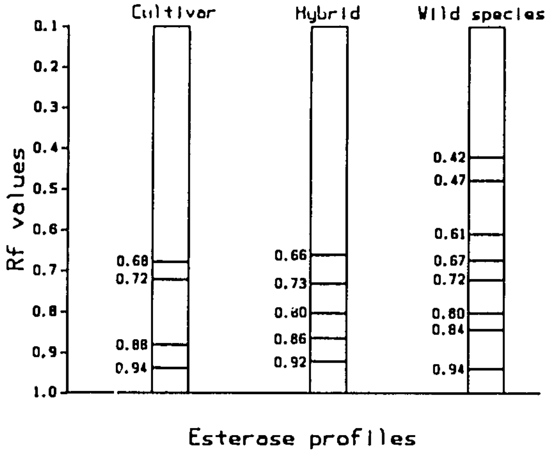


Figure 10. Esterase profiles of calli from *A. hypogaea* cultivar MK 374 (left), a wild rhizomatous species PI 276233 (right), and their hybrid (culture number 8587, center).

Table 31. Effect of gibberellic acid (GA) on peg and pod production in groundnut cultivar MK 374 pollinated with *Arachis pusilla*, and on emasculated flowers of MK 374, ICRISAT Center, 1985.

	Pollinated			Nonpollinated			
GA concentration (mg L^{-1})	Pollinations	Pegs	Pods	Emasculated flowers	Pegs	Pegs in soil	Pods
87.5	122	68 (56)[1]	0				
117	80	58 (73)	1	22	18 (82)[2]	9	0
175	95	74 (78)	0	16	15 (94)	10	0
224	84	75 (89)	0	16	14 (88)	14	0
350	56	46 (82)	1				

1. Figures in parentheses are numbers of pegs per 100 pollinations.
2. Figures in parentheses are numbers of pegs per 100 emasculated flowers.

in a mixture containing 20 mg alpha-naphthyl acetate in 50 mL of 0.2 M phosphate buffer with 38 mg Fast Blue RR Salt to reveal esterase bands. The resulting esterase profiles were compared to those from calli of *A. hypogaea*. Profiles from six cultures were similar to *A. hypogaea*; these cultures may have arisen from accidental selfing, the embryos may have developed parthenogenetically, there may have been elimination of wild species chromosomes in culture, or the calli may have developed from maternal tissue in the cultured ovule. That 20 cultures showed an esterase profile different from that of *A. hypogaea* is important since this method can be used to identify the hybridity of the cultured material as soon as callus becomes available.

Regional Program for Southern Africa

The ICRISAT Regional Groundnut Improvement Program for Southern Africa is based at the Chitedze Agricultural Research Station, Lilongwe, Malawi. The program aims to develop high-yielding breeding lines and populations with resistance to factors limiting production by small-scale farmers in southern Africa. Breeding for resistance to the two major diseases of the region—early leaf spot and groundnut rosette virus—receives top priority.

Growing conditions. We sampled groundnut field soils in July 1984, their pH was 5.1-5.5 and available phosphorus was low. We applied P_2O_5 at 40 kg ha^{-1} and gypsum at 400 kg ha^{-1}. Preemergence application of alachlor at 4 L ha^{-1} resulted in satisfactory weed control for about 30 days. The hybridization block and F_1 plants were treated with fungicides and insecticides to control leaf spots and aphids. All trials were sown on 60-cm ridges with either 10 or 15 cm spacing according to the genotypes' branching habit.

Germplasm Accessions

We received 21 wild *Arachis* species from ICRISAT Center and 15 rosette-resistant cultivars from Burkina Faso and Senegal to enrich our germplasm base for the disease resistance breeding program. We also obtained seven drought-tolerant lines from ICRISAT Center.

Evaluation. We evaluated and described 45 germplasm lines from Mozambique under Chitedze conditions. In the alternate-branching group, the control, ICRISAT selection ICGMS 42 significantly outyielded all germplasm lines in the trial. Germplasm line Ah 117 had a lower mean early leaf spot score compared to other lines 90 days after emergence (DAE). We retained 16 lines for further evaluation.

Yield trials. We evaluated 101 germplasm lines in three replicated yield trials using local cultivars as controls. Twenty-one ICGM lines yielded significantly more than the highest-yielding controls (Table 32). We retained 51 ICGM lines for final evaluation in the 1985/86 season. Outstanding lines from these trials will be included in the cooperative regional yield trials for Southern Africa.

Hybridization. In the field hybridization program, we made 62 crosses among indigenous cultivars (Chalimbana, Chitembana, Egret, and Mani Pintar), ICRISAT selections (ICGMS 2, 9, 33, and 45), and germplasm lines (ICGM 93, 281, 284, 285, 286, 336, 484, 526, 617, 623, 627, and 652). A further 87 crosses were made for various inheritance studies. Our average success rate improved to 15% and the maximum success in the field hybridization was 36% in some crosses. We repeated 75 crosses for genetic studies in the greenhouse, where our average success rate improved to 45% with a maximum of 73% in some crosses.

Fungal Diseases

Early Leaf Spot (*Cercospora arachidicola*)

Early leaf spot assumes epidemic proportions every season at Chitedze. We measured leaf retention as a possible component of tolerance by counting leaflets lost, and leaflets retained. We examined the data in relation to yield for this year's replicated field trials.

In all trials with sequentially branched lines, the highest-yielding line retained more leaflets than did the control cultivars, but so did a small number of poorer-yielding lines (Table 33). Analysis of data from one trial indicated highly significant differences in leaf retention between cultivars but there was no correlation between leaf retention and yield (Table 33). Highest-yielding lines not only retained more leaves but

Table 32. Performance of some ICGM lines in an elite germplasm trial, Chitedze, Malawi, rainy season 1984/85.

Identity	Group	Origin	Time to maturity (d)	Pod yield (kg ha^{-1})	Shelling %	100-seed mass (g)	Seed color	Mean early leaf spot score[1]
ICGM 286	Valencia	Brazil	123	3330 (3)[2]	75	37.3	Red	7.0
ICGM 285	Valencia	Brazil	124	3200 (1)	69	35.3	Red	7.0
ICGM 284	Valencia	Brazil	119	3190 (5)	75	35.3	Red	7.5
ICGM 197	Valencia	Bolivia	124	3030 (7)	74	35.5	Red	7.0
ICGM 281	Valencia	Bolivia	123	2970 (4)	73	38.2	Red	7.0
ICGM 189	Valencia	Brazil	119	2770 (8)	75	40.7	Red	7.0
ICGM 292	Valencia	Brazil	124	2650 (9)	75	29.5	Red	7.0
ICGM 177	Valencia	Brazil	124	2620 (6)	73	38.8	Red	7.5
ICGM 282	Valencia	Bolivia	123	2520 (11)	74	33.0	Red	7.5
ICGM 48	Valencia	Brazil	120	2480 (19)	74	38.2	Red	9.0
Local controls								
Spancross	Spanish	Ex. USA	108	1550	71	23.9	Tan	9.0
Malimba	Spanish	Malawi	108	1500	73	25.4	Tan	9.0
SE				±141				
Trial mean (36 entries)				2310				
CV (%)				12				

1. Field disease scored on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage destroyed.
2. Figures in parentheses indicate yield performance ranking in the 1983/84 yield trial.

Table 33. Leaf retention (%) at 70 and 88 DAE in relation to pod yield (kg ha^{-1}) in certain sequential-branching groundnut selections and varieties, Chitedze, Malawi, 1984/85.

Trial	Entry	Leaf retention (%)			Pod yield	
		70 DAE	88 DAE	Rank 88 DAE	kg ha^{-1}	Rank
Regional Yield Trial (36 entries)	ICGMS 30	54	43**	1	2350	1
	ICGMS 29	62	40**	2	1730	14
	Controls					
	Spancross	43	29	9	1960	7
	Malimba	46	26	12	1660	19
	SE		±2.3			
	CV (%)		14.6			
Elite Germplasm Trial (36 entries)	ICGM 285	63	45**	1	3300	2
	ICGM 281	59	45**	1	3050	5
	ICGM 189	57	43**	2	2780	6
	ICGM 286	56	42**	3	3370	1
	Controls					
	Sellie	46	26	15	1600	23
	Spancross	35	28	14	1530	25
	Malimba	46	28	14	1460	26
	SE		±3.0			
	CV (%)		17.8			
Advanced Germplasm Trial (25 entries)	ICGM 550	43	37	2	2310	1
	ICGM 473	46	39	1	1430	10
	Controls					
	Spancross	45	24	11	1320	15
	JL 24	42	29	6	1270	17
	Sellie	43	27	8	1100	20
	Malimba	46	21	14	1050	20
Preliminary Germplasm Trial (25 entries)	ICGM 525	51	47	1	2610	1
	Controls					
	Sellie	45	27	10	1710	8
	Spancross	49	26	11	1540	14
	JL 24	47	28	9	1510	17
	Malimba	45	23	14	1410	22

lost proportionately fewer as the season advanced. In these preliminary studies, we have thus identified, under severe disease pressure at Chitedze, a number of sequentially branched lines whose high yield seems to be associated with a comparatively higher degree of leaf retention. These are ICGMS 30, and 39, ICGM 189, 197, 281, 284, 285, 286, 292, 300, 473, 500, and 525, and OG 69-6-1 × NC Ac 17090.

Leaf retention in alternately branched lines appeared more uniform and no marked differences were apparent between higher-yielding ICRISAT lines and controls.

Breeding for resistance. Germplasm lines and breeding populations were screened under high natural disease pressure for resistance to early leaf spot. Of the 765 germplasm lines screened in the 1984/85 crop season, none showed any appreciable level of resistance.

We received from ICRISAT Center 105 F_5-F_7 *Arachis hypogaea* populations resistant to foliar diseases and 108 interspecific derivatives involving *A. hypogaea* and *A. chacoense*, *A. cardenasii*, and *Arachis* sp HLK 410. All *A. hypogaea* populations were heavily defoliated by early leaf spot before harvest. For the interspecific derivatives, early leaf spot disease scores, measured on a 1-9 scale (where 1=no disease, and 9=50-100% of foliage destroyed), ranged from 6 to 8 at 90 DAE, but all had a score of 9 prior to harvest.

We made 10 single-plant and 45 bulk selections. Two of the interspecific selections, 337/2 and 127/2, were selected for entry in replicated trials. The selection from population 337/2 rated well for pod yield.

From the old 278 F_2-F_{11} foliar diseases resistant *A. hypogaea* populations we made 35 single-plant and 156 bulk selections. All the F_2 populations performed poorly. They were advanced to the next generation through single pod per plant bulks.

Yield trials. We evaluated 59 populations with local controls in two replicated yield trials. Early leaf spot scores for these lines ranged from 6 to 9 on the 9-point scale. We have retained 17 populations for further evaluation.

Phoma-resistant selections. We grew 21 selections from populations resistant to *Phoma arachidicola* under heavy natural early leaf spot pressure. Leaf spot disease developed more slowly on this material but eventually all selections scored 8 or 9 for early leaf spot just before harvest. We made 2 single plant and 19 bulk selections. Seven of these have been included in the 1985/86 yield trials.

Virus Diseases

Groundnut Rosette Virus (GRV) Disease

Analysis of seasonal occurrence. Incidence and patterns of spread of GRV in 1984/85 were remarkably similar to those in 1983/84, but the disease appeared a month earlier, reflecting the earlier onset of the 1984/85 rains. The experimental crop emerged between 28 and 31 December in 1983 and between 26 and 29 November in 1984; GRV was recorded on 18 January 1984 and on 20 December in 1985: a similar period of about 21 days elapsed between these two events in each year. The number of primary infections was the same (12) and overall incidence in the ICRISAT fields was again very low (<1%).

We thus confirmed our tentative conclusions, drawn from 1984 data, that primary infections tend to occur soon after emergence, and that these alone give rise, by radial spread, to patches of GRV in which incidence is high and in which disease gradients from the source point are steep.

Vector ecology. We continued trapping *Aphis craccivora* with Moericke water traps and trap plants. There were two periods of intense aphid-flight activity, during the growing season in January and February and, after a population crash in March and April, again in May and June. Although populations were greatly reduced by July, *A. craccivora* was caught in low numbers throughout the dry season. In early August, we established eight bait plots of groundnut in the Central Region and eight in southern Malawi and studied immigration into these during the dry season months of September, October, and November. *A. craccivora* was recorded in four out of seven plots in the south and all eight plots in the Central Region. GRV was not recorded in the south, but in the Lilongwe Plain four plants were infected at one site.

Dry-season aphid activity was assessed in terms of number of sites infested, and number of plants infested per site. Population increase within a site, was greater in the Lilongwe Plain than in the south, where infestation was apparently confined to low-lying areas near rivers or lakes. Clearly, *A. craccivora* is able to maintain itself locally throughout the dry season in both central and southern areas of Malawi. The detection of viruliferous aphids towards the end of the dry season shows that a local source of GRV exists, but does not indicate its extent or significance.

Resistance screening and breeding. Using an infector-row system together with release of viruliferous aphids, we screened 28 populations consisting of 5912 F_2 plants for resistance to GRV in the field. Only 678 plants remained symptomless. Seed from 406 of these was sown in the greenhouse and the resulting plants were inoculated with GRV. Seed from the 161 F_3 plants that survived this test will be included in the 1986 disease nursery. Two of the plants are spanish types, 6 are virginia runners, and 153 are virginia bunch types. We also grew 25 F_1 crosses involving sources of GRV resistance (RG 1, RMP 93, and RRI/6) and promising exotic germplasm and breeding lines.

Preliminary inheritance studies. Our results from the preliminary inheritance studies with crosses resistant and susceptible to rosette confirmed the double recessive nature of resistance. Furthermore, these limited studies have also indicated an absence of reciprocal differences in virginia × virginia, or virginia × spanish crosses. We have planned a detailed investigation for the 1985/86 crop season involving F_1 and F_2 reciprocals and their backcross generations.

Pests

Resistance Screening

We screened 64 ICG(PS) lines and 13 F_6–F_9 insect-resistant populations in observation plots. We made 5 single-plant and 15 bulk selections that had average or above-average ratings for pod yield. Single-plant selection from ICG(PS) 62 had good pod yields and moderate thrips injury. One bulk selection was chosen for replicated yield trials. Jassid damage was too slight for meaningful scoring.

We evaluated 23 other ICG(PS) lines in a replicated trial with ICGMS 2 and 42 as controls. Four lines were retained for further evaluation next season.

Plant Improvement

Breeding for Increased Yield, Improved Seed Quality, and Earliness

Breeding material. Twenty-eight ICGS(E) lines from ICRISAT Center were sown in observation plots. The period from emergence to 75% flowering in these lines ranged from 25 to 31 days, ICGMS(E) 7 being the earliest. However, these differences in time to flowering were not reflected in the maturity period due to early and severe defoliation by early leaf spot. We retained 18 lines from which 4 single-plant and 14 bulk selections were made.

We grew 73 F_1 crosses between indigenous cultivars and exotic germplasm and breeding lines. Ten crosses yielded well.

We sowed 611 F_2–F_{12} breeding populations including single-plant progenies in nonreplicated plots. From 358 populations, we made 50 single-plant and 412 bulk selections. Seventy-eight of these bulk selections will be included in replicated yield trials next season.

Although F_2 populations in general were vigorous, their performance was below expectation. Two F_9 selections (Mani Pintar × Dh 3-20)-B_1 and (Makulu Red × Dh 3-20)-B_1 retained more foliage at the time of harvest and had fewer early leaf spot stem lesions. Some of the good and very good selections for pod yield came from the following crosses: (F334A-B-14 × Makulu Red), (Jacana × L.No. 95A), (J 11 × HG 1), (ICGS 22 × 75-24 × Chico), (Robut 33-1 × 994), (NC Ac 171352 × Makulu Red), (ICGS 49 × Makulu Red), (SM 5 × EC 76446(292) × Robut 33-1), (ICGS 7 × ICGS 17), (ICGS 15 × TMV 10 × Chico), (J 11 × Ah 114), (NC Ac 171352 × Ah 114), (Chalimbana × Mani Pintar), (FSB 7-2 × Ah 114), (USA 20 × TMV 10 × Robut 33-1), (MH

2 × 28-206), (JH 171 × Robut 33-1), (ICGS 27 × 75-24 × Chico), and (Manfredi × Ah 114).

Yield trials. We evaluated 21 sequential and 11 alternate-branching breeding lines in two replicated yield trials together with controls. We retained 19 of these lines for further evaluation. The performance of some of the sequential-branching lines is presented in Table 34.

ICRISAT Southern African Cooperative Regional Yield Trials. Yield data for the sequential-branching cooperative regional yield trial were received from seven locations in five countries. Results from Sebele, Botswana, were incomplete, and Tanzania could not sow the trial. Coefficients of variation (CVs) were high at Lupembe and Boane (Table 35). Based on data from two seasons we have tentatively identified 15 of the 34 lines in the trial for further regional testing.

Data for the alternate-branching trial were received from four locations in three countries (Table 36). No results were obtained from Tanzania, Mozambique, and one location in Malawi. We have tentatively selected 9 of the 14 lines tested in the trial for further evaluation in the region.

Seed Supply

We supplied 442 groundnut seed samples to our cooperators in the region. This included 144 samples to Angola, 34 to Botswana, 197 to Malawi, 33 to Mozambique, and 34 to Tanzania.

Cooperation with National Programs

Cooperation with AICORPO

Coordinated Yield Trials

ICRISAT Center trials. During the 1985 rainy season, we conducted nine AICORPO-sponsored

Table 34. Performance of some sequential-branching groundnut lines retained for further evaluation in the increased yield, better seed quality, and earliness program, Chitedze, Malawi, rainy season 1984/85.

Identity	Time to maturity (d)	Pod yield (kg ha^{-1})	Shelling %	100-seed mass (%)	Mean early leaf spot score[1] at 90 DAE
ICGS 51	123	2610	67	39.2	8.0
H 3/5	123	1960	70	37.5	8.0
(MGS 8 × NC 2)F_{12}	113	1980	73	26.6	8.5
ICGS 30	119	1830	67	31.3	8.0
(X 14-4-B-19-B × MH 2)F_{12}	108	1780	74	28.0	8.5
(JH 171 × Robut 33-1)F_{12}	108	1710	72	31.7	9.0
(Tifspan × NC Ac 2944)F_{12}	118	1670	73	27.0	8.0
Local controls					
Malimba	108	1550	73	24.8	9.0
Spancross	111	1370	69	21.8	8.5
SE		±68			
Trial mean		1570			
CV (%)		9			

1. Field disease scored on a 1-9 scale, where 1=no disease and 9=50-100% foliage destroyed.

Table 35. Pod yields (kg ha[-1]) of groundnut selections in the ICRISAT Southern African Cooperative Regional Yield Trial-Sequential Branching, rainy season 1984/85.

	Botswana	Malawi		Mozambique	Zambia		Zimbabwe
Identity	Sebele	Chitedze	Lupembe	Boane	Msekera	Magoye	Gwebi
ICGM 1	1180	2040	710	670	2040	1180	600
ICGM 2	1040	2220	710	550	2810	1390	1070
ICGM 5	-[1]	2040	240	1050	2880	1430	1430
ICGM 9	1170	1970	770	670	2330	1140	940
ICGM 11	-	2010	450	1160	2980	1770	1530
ICGM 12	1080	1620	350	880	2650	1630	1080
ICGM 14	-	1290	700	1200	2000	1260	1060
ICGM 18	-	1540	530	630	2620	1370	830
ICGM 21	1140	1620	760	600	2070	1520	880
ICGM 22	1110	1560	710	640	2380	1500	780
ICGM 23	-	1760	760	920	2320	1320	1180
ICGM 28	-	1640	470	930	2100	1310	1030
ICGM 30	-	2340	100	470	2640	1120	1310
ICGM 31	-	1900	250	630	2240	1630	1490
ICGM 33	-	1450	250	600	1860	1070	1020
Control							
A	650	1690	590	780	2250	1330	1310
B		1950	350	790	2350	1370	2570
SE		±105	±97	±145	±108	±147	±86
Trial mean (36 entries)		1730	430	690	2290	1330	1080
CV (%)		12	39	42	9	22	16

1. - = Not recorded.

trials on Alfisols at ICRISAT Center. These included many ICRISAT entries.

In the Initial Evaluation Trial (IET) with spanish bunch cultivars, the entries DORG 1810 and ICGS 67 significantly outyielded the national control cultivar JL 24. In the IET for virginia bunch cultivars, ICG(C) 8 and ICG(C) 12 significantly outyielded both the minikit control, C 198, and the national control, Robut 33-1.

No entry significantly outyielded JL 24 in the Coordinated Varietal Trial (CVT) for spanish bunch cultivars. Two ICRISAT entries, ICG(C) 13 and ICGS 62, significantly outyielded the minikit control culivar C 198 in the virginia bunch CVT, while ICG(C) 13 outyielded the national control Robut 33-1.

The entries CGC 4018, ICGS 30, and ICG (FDRS) 4, significantly outyielded the national control JL 24 in the National Elite Trial (NET) for spanish bunch cultivars. In the NET for virginia bunch cultivars, entry ICGS 6 significantly outyielded the minikit control C 198, but not the national control Robut 33-1.

In the Foliar Diseases Resistant Varietal Trial (FDRVT), four ICRISAT entries, ICG(C) 5 and 6, ICG(FDRS) 33 and 43, significantly outyielded the control cultivars JL 24 and Robut 33-1. ICG(C) 5 had the highest pod yield of 2129 kg ha[-1]. All four entries have resistance to rust, and ICG(C) 5 and 6—selections from interspecific crosses—also have resistance to late leaf spot.

A Hand-Picked Selection Varietal Trial began in 1985. The ICRISAT selection ICG(CG)S 49 gave the highest yield, 1782 kg dried pods ha^{-1} and, together with entries RSHY 10 and ICG (CG)S 19, significantly outyielded the control cultivar Chandra, but not M 13, the other control cultivar.

Multilocational trials. The current status of ICRISAT materials in multilocational testing in the AICORPO system is shown in Table 37 for the rainy season trials and in Table 38 for postrainy season trials.

Release of ICGS 11. Following successful testing in adaptive trials over several postrainy seasons, the cultivar ICGS 11 was recommended by the AICORPO rabi/summer groundnut workshop for release in Zones 3 and 5 of India for postrainy-season cultivation.

International Trials

Early-maturing Varietal Trial

Three international trials for evaluation of early-maturing cultivars were organized in 1985 and sent to 52 locations in Asia (25), Africa (24), and elsewhere (3). Data from trials in Botswana, Mali, Pakistan, the Philippines, and Thailand indicate that the trial entries have compared well with local control cultivars in terms of yield and some have shown advantages in quality and earliness.

Confectionery Groundnut Varietal Trial

An international trial with 24 test entries was sent to 15 locations in Australia, Burkina Faso, the People's Republic of China, Cyprus, Egypt,

Table 36. Pod (P) and seed (S) yields (kg ha^{-1}) for selected groundnut entries in the ICRISAT Southern African Cooperative Regional Yield Trial–Alternate Branching, rainy season 1984/85.

	Malawi		Zambia				Zimbabwe		Overall mean	
	Chitedze		Msekera		Golden Valley		Gwebi			
Identity	P	S	P	S	P	S	P	S	P	S
ICGM 35	2400	1680	2030	1220	2150	1400	1790	1290	2090	1400
ICGM 36	2130	1580	2530	1830	2490	1860	980	650	2030	1480
ICGM 38	1930	1390	2100	1300	2290	1530	1380	1000	1930	1310
ICGM 39	2360	1700	2240	1280	2400	1360	1780	1260	2200	1400
ICGM 42	3200	2400	2430	1750	2630	1680	2630	1900	2720	1930
ICGM 43	2100	1530	2030	1380	2220	1390	1920	1410	2070	1430
ICGM 45	2070	1390	2600	1560	2010	1350	2020	1430	2180	1430
ICGM 47	1600	1100	1920	1400	2250	1470	1480	1110	1810	1270
ICGM 48	1710	1210	1740	1140	2610	1660	1390	930	1860	1240
Control										
A	2490	1710	1770	1150	1700	1050	2520	1740	2120	1410
B	2930	2170	2890	2070	2680	1660	2690	1880	2800	1950
SE	±109	-[1]	±112	±74	±135	±131	±104	± 80		
Trial mean (16 entries)	2070	-	1980	1310	2130	1370	1620	1150		
CV (%)	11	-	11	11	12	19	13	14		

1. - = Not analyzed.

Table 37. Current status of ICRISAT entries in AICORPO rainy-season trials, 1985.

Trial	Entry	Zone[1]
Initial Evaluation Trial (Virginia bunch)	ICGS 50, [ICG (C) 13] 54, 56, 67	4
	ICGS 63,64	1,4
	ICGS 65	1,2,4
	ICGS 76,79	1,2,3,4,5,6
	ICG(PRS) 92,214	1,2,3,4,5,6
	ICG (C) 8,12	1,2,3,4,5,6
Coordinated Varietal Trial (Virginia bunch)	ICGS 47,18	1
	ICGS 49,18	4
	ICGS 50, [ICG (C) 13],66	5
	ICGS 46,48	6
	ICGS 62	1,2,5,6
National Elite Trial (Virginia bunch)	ICGS 4,6	4,5
Adaptive Trial (Virginia bunch)	ICGS 5	1
Initial Evaluation Trial (Spanish bunch)	ICGS 35-1,57	4
	ICGS 44-1	3,4
	ICGS 67	4,5
	ICG (PRS) 1	1,2,3,4,5
	ICG (PRS) 2	1,2,3,4
	ICGS 75,77,81,82	1,2,3,4,5,6
Coordinated Varietal Trial (Spanish bunch)	ICGS 11,21,30	2
	ICGS 26	4
	ICGS 35-1,44-1	1,2,5
	ICGS 51	2,3,4
	ICGS 67	1
	ICG (FDRS) 10,23	1,2,3,4,5,6
	ICG (FDRS) 1,4	2,3,4,5
National Elite Trial (Spanish bunch)	ICGS 11,26	1
	ICGS 30, ICG (FDRS) 4	5
Adaptive Trial (Spanish bunch)	ICGS 1	1
Hand Picked Selection Varietal Trial	ICG (CG) S 10,11,12,13 17,18,19,20,21,49	1,2,3,5,6,14,15,16,
Foliar Disease Resistant Varietal Trial	ICG (FDRS) 20,22,25,33,34 38,41,42,43	In selected locations
	ICG (C) 5,6	In selected locations

1. Zone 1 - Northern zone (Uttar Pradesh, parts of Haryana, Punjab, Rajasthan, and Bihar)
Zone 2 - Western zone (Gujarat)
Zone 3 - Central zone (parts of Maharashtra and Madhya Pradesh)
Zone 4 - South-eastern zone (Orissa and West Bengal)
Zone 5 - Peninsular zone (Andhra Pradesh, Karnataka, and parts of Maharashtra)
Zone 6 - Southern zone (Tamil Nadu).

Table 38. Current status of ICRISAT entries in AICORPO postrainy (rabi/summer) season trials, 1985/86.

Trial[1]	Entry	Zone[2]
Initial Evaluation Trial	ICGS 84,91,103,105,106	1,2,3,4,5,6
Initial Evaluation Trial (early lines)	ICGS (E) 21,52,56,121,122	In selected locations
Coordinated Varietal Trial	ICGS 2, ICG (FDRS) 31	2
	ICGS 21	3,4
	ICGS 44	3,4,5
	ICG (FDRS) 33	5,6
National Elite Trial	ICGS 6,19,37	3,4
	ICGS 21	5
Adaptive Trials	ICGS 44	2

1. All postrainy season entries are SB (spanish bunch types).
2. Zone 1 - Northern zone (Uttar Pradesh, parts of Haryana, Punjab, Rajasthan, and Bihar)
   Zone 2 - Western zone (Gujarat)
   Zone 3 - Central zone (parts of Maharashtra and Madhya Pradesh)
   Zone 4 - South-eastern zone (Orissa and West Bengal)
   Zone 5 - Peninsular zone (Andhra Pradesh, Karnataka, and parts of Maharashtra)
   Zone 6 - Southern zone (Tamil Nadu).

Gabon, Pakistan, the Philippines, Senegal, Sudan, Taiwan, Thailand, the USA, and Zambia, in 1985. From trial data received so far it is clear that several of the large-seeded, confectionery type cultivars have outyielded local cultivars and shown excellent quality characteristics. The highest yield so far recorded was for entry HYQ(CG)S 48 that gave 9000 kg dried pods ha^{-1} in a trial in Cyprus.

Pest-resistant Varietal Trial

A set of nine genotypes has been sent to 13 countries for evaluation in an international pest-resistant varietal trial. In addition, 40 lines were sent to Thailand and the Philippines to be screened for resistance to jassids, thrips, leaf miner, and termites. Thirteen of the lines were sent to Australia, and 15 to West Africa for similar screening.

Training

In 1985, two postdoctoral fellows, one from India and one from the UK, completed 2 years in groundnut microbiology and physiology. In physiology and breeding, two research scholars successfully completed their MSc courses with Andhra Pradesh Agricultural University (APAU); thesis research being done at ICRISAT Center.

Specialized training was given on the following subjects: Breeding methods, drought-resistance screening methods, methods of screening for resistance to pests and diseases, cytogenetic techniques and tissue culture, methods for serological typing of rhizobia, serological methods for identifying groundnut viruses, physico-chemical virus characterization techniques, methods of testing for aflatoxins, identification of insect pests and pest damage. The training periods ranged from a few days to several months depending upon the number of subjects and depth of knowledge required. There were 17 trainees from eight countries: People's Republic of China (3), India (2), Iran (1), Mozambique (1), the Netherlands (1), the Philippines (5), Sri Lanka (2), and Thailand (2).

Workshops, Conferences, and Seminars

Consultative Group Meeting to Discuss Collaborative Research on Groundnut Rosette Virus

This meeting was held in Cambridge, UK, 13-14 April. Fifteen participants represented ICRISAT (ICRISAT Center and the Regional Groundnut Program for Southern Africa), research institutions working on groundnut rosette virus disease in Nigeria, the Federal Republic of Germany, and the UK, and institutions in the USA and Australia. The research findings and future plans of each group were presented and discussed. Arrangements were made to avoid duplication of work and to improve collaboration. ICRISAT and Peanut CRSP agreed to coordinate research. Proceedings are available from Information Services, ICRISAT.

Review and Planning Meeting for Asian Regional Research on Grain Legumes

This meeting, funded by the Australian Development Assistance Bureau and sponsored by ICRISAT, the Australian Centre for International Agricultural Research (ACIAR), and the International Rice Research Institute (IRRI), was held at ICRISAT Center, 16-18 December 1985. The objectives of the meeting were, to identify cooperative links between organizations concerned with legumes research in Asia, to assess the progress made since the Consultative Meeting for Asian Grain Legumes that was held at ICRISAT in 1983, and to develop plans for future cooperation in countries of South and Southeast Asia.

Ten scientists from seven countries in the region (Bangladesh, India, Indonesia, Nepal, Pakistan, the Philippines, and Thailand), nine representatives from six international agencies, and ICRISAT scientists discussed the research and development of groundnut as well as that of chickpea and pigeonpea in the region. Executive summaries of the technical reports, discussions, and recommendations are available from Information Services, ICRISAT.

It was announced that a Coordinator for ICRISAT's Asian Grain Legume Program had been appointed, and that this program will be active from 1 January 1986. The meeting provided the Coordinator with strong guidance that was contained within eight specific recommendations. It was stressed that the primary objectives of the new program should include the promotion of closer contact between ICRISAT scientists and the relevant scientists in each country, and encouragement of a two-way flow of information and material. It was also emphasized that there was a need for coordination between the various international and regional organizations, both to integrate research efforts and to reduce duplication of effort. Other recommendations were to identify the problems of the three crops in the region and search for solutions, conserve germplasm, meet training requirements, determine more exactly the areas in the region where genotypes of the three legume crops are adapted, and conduct socioeconomic studies to find out the potential uses of the three crops in each country of the region.

Regional Groundnut Breeders Tour in Southern Africa

The ICRISAT Regional Groundnut Program for Southern Africa organized a breeders' tour to visit national groundnut breeding programs in Zimbabwe, Zambia, and Malawi from 25 February-1 March. Breeders from Botswana, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe participated. They were able to examine breeding and other material in the field, and to deliberate and comment on strategies, including that of the ICRISAT breeder.

Groundnut Field Day

Thirty-five cooperators from the AICORPO, visiting scientists, in-service fellows and trainees concerned with groundnut, and staff of the Program participated in the 1985 Field Day held 23-24 September at ICRISAT Center. Activities included a seminar and discussion on drought research, visits to laboratories to see research on nitrogen fixation, utilization of wild *Arachis* species, storage pests, aflatoxin, laboratory screening for foliar diseases resistance, identification of viruses, and visits to field trials. There was a general discussion on the research that had been highlighted in the laboratory and field visits and on other topics. Much useful information was exchanged.

Looking Ahead

Diseases. Research on the foliar fungal diseases will continue to receive high priority, with emphasis being placed on early leaf spot. Field screening for resistance to this disease will be expanded at the ICRISAT Regional Program for Southern Africa, using locally produced lines, breeders' lines from ICRISAT Center including interspecific hybrid derivatives, and wild *Arachis* species. Evaluation of cultivars with resistance to rust and late leaf spot will be carried out in cooperation with national and regional programs, and the economics of foliar diseases management will be studied in cooperation with ICRISAT economists.

We will continue to give high priority to research on the aflatoxin problem. Cultivars and breeding lines with resistance to pod and seed invasion by the aflatoxigenic fungus *Aspergillus flavus* will be evaluated in multilocational trials and under farmers' conditions.

Research on groundnut rosette virus disease will continue to be coordinated from ICRISAT Center, and studies on the epidemiology of the disease and breeding for resistance will continue to have high priority in our Southern Africa Program. Work on the disease will be extended to West Africa when the Groundnut Program begins at the ICRISAT Sahelian Center, Niger in 1986. We shall carry out more virus disease surveys in Asia and Africa in cooperation with national and regional programs.

Insect pests. We shall give priority to incorporating resistance to the thrips vector of bud necrosis disease into high-yielding, commercially acceptable cultivars. A similar approach will be made to breeding for jassid resistance.

We shall screen more wild *Arachis* species and interspecific hybrid derivatives for resistance to the tobacco caterpillar *Spodoptera litura* and the groundnut aphid, *Aphis craccivora*, the vector of groundnut rosette virus disease and of several other important virus diseases.

Research on storage pests will continue, and work on management of termites will expand if proposed cooperative research with the Tropical Development Research Institute (TDRI) and AICORPO is implemented.

Drought stress, plant nutrition, and photoperiod. Cooperative studies on interactions of soil temperature and drought with pod and seed invasion by soil fungi will be continued. We shall also continue to study the mechanisms behind the genotypic variation in drought recovery and tolerance. An international trial to evaluate drought-resistant cultivars will be established.

Work on symbiotic nitrogen fixation will continue, but we shall give greater emphasis to the study of the role of mycorrhizae in groundnut nutrition. There will be further investigations of the calcium requirements of pods, and we hope to carry out some research on iron chlorosis.

Investigations will continue into response of groundnuts to photoperiod in cooperation with the University of Bonn.

Plant improvement. Breeding for resistance to stress factors, and adaptive breeding for particular traits will continue. Cooperative research with ICRISAT biochemists on seed-quality factors for confectionery groundnuts and maintaining the quality of oil in groundnut cultivars destined for the vegetable oil trade will be expanded.

The recently introduced International Evaluation Trials for confectionery cultivars and for short-duration cultivars will be extended to more countries.

Wild species. We will continue to screen new accessions of wild species for useful traits and incorporate them into desirable agronomic backgrounds by conventional and unconventional techniques. Gamma radiation will be used to induce translocation between introgressed chromosomes from the wild species and *A. hypogaea*.

Publications

Institute Publications

Information Bulletin

McDonald, D., Subrahmanyam, P., Gibbons, R.W., and Smith, D.H. 1985. Early and late leaf spots of groundnut. Information Bulletin no. 21. Patancheru, A.P. 502 324, India: ICRISAT.

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Proceedings of the Regional Groundnut Workshop for Southern Africa, 26-29 March 1984, Lilongwe, Malawi. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Collaborative research on groundnut rosette virus. Summary proceedings of the consultative group meeting, 13-14 April 1985, Cambridge, UK. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Amin, P.W. 1985. Apparent resistance of groundnut cultivar Robut 33-1 to bud necrosis disease. Plant Disease 69(8): 718-719.

Amin, P.W., and Palmer, J. 1985. Identification of groundnut Thysanoptera. Tropical Pest Management 31(4): 286-291.

Amin, P.W., Ghanekar, A.M., Rajeshwari, R., and Reddy, D.V.R. 1985. Tomato spotted wilt virus as the causal pathogen of leaf curl of mung bean, *Vigna radiata* (L.) Wilczek, and urd bean, *Vigna mungo* (L.) Hepper in Andhra Pradesh, India. Indian Journal of Plant Protection 13: 9-13.

Amin, P.W., Singh, K.N., Dwivedi, S.L., and Rao, V.R. 1985. Sources of resistance to jassids (*Empoasca kerri* Pruthi), thrips (*Frankliniella schultzei* Trybom) and termites (*Odontotermes* sp.). Peanut Science 12: 58-60.

Jambunathan, R., Madhusudana Raju, S., and Barde, S.P. 1985. Analysis of oil content of groundnuts by nuclear magnetic resonance spectrometry. Journal of the Science of Food and Agriculture 36(3): 162-166.

Mayo, M.A., and Reddy, D.V.R. 1985. Translation products of RNA from Indian Peanut Clump Virus. Journal of General Virology, 66: 1347-1351.

Mehan, V.K., Bhavanishankar, T.N., and Bedi, J.S. 1985. Comparison of different methods for extraction and estimation of aflatoxin B1 in groundnut. Journal of Food Science and Technology 22(2): 123-125.

Nageshwara Rao, R.C., Sardar Singh, Sivakumar, M.V.K., Srivastava, K.L., and Williams, J.H. 1985. Effect of water deficit at different growth phases of peanut. I. Yield responses. Agronomy Journal 77(5): 782-786.

Nambiar, P.T.C. 1985. Increasing groundnut yields with *Rhizobium* inoculum. NifTAL Newsletter 2: 1 and 8.

Nambiar, P.T.C. 1985. Response of groundnut (*Arachis hypogaea* L.) to *Rhizobium* inoculation in the field: problems and prospects. MIRCEN Journal of Applied Microbiology and Biotechnology 1: 293-309.

Nambiar, P.T.C., and Anjaiah, V. 1985. Enumeration of rhizobia by enzyme-linked immunosorbent assay (ELISA). Journal of Applied Bacteriology 58(2): 187-193.

Nigam, S.N., Dwivedi, S.L., Nambiar, P.T.C., Gibbons, R.W., and Dart, P.J. 1985. Combining ability analysis of N_2 fixation and related traits in peanut. Peanut Science 12(2): 55-57.

Nolt, B.L., and Reddy, D.V.R. 1985. First report of *Polymyxa graminis* in India. Plant Disease 69: 542.

Reddy, D.V.R., Murant, A.F., Duncan, G.H., Ansa, O.A., Demski, J.W., and Kuhn, C.W. 1985. Viruses associated with chlorotic rosette and green rosette diseases of groundnut in Nigeria. Annals of Applied Biology 107: 57-64.

Reddy, D.V.R., Murant, A.F., Raschke, J.H., Mayo, M.A., and Ansa, O.A. 1985. Properties and partial purification of infective material from plants containing groundnut rosette virus. Annals of Applied Biology 107(1): 65-78.

Reddy, D.V.R., Robinson, D.J., Roberts, I.M., and Harrison, B.D. 1985. Genome properties and relationships of Indian peanut clump virus. Journal of General Virology 66: 2011-2016.

Reddy, D.V.R., Wongkaew, S., and Santos, R. 1985. Peanut mottle and peanut stripe virus diseases in Thailand and the Philippines. Plant Disease 69: 1101.

Subrahmanyam, P., Moss, J.P., McDonald, D., Subba Rao, P.V., and Rao, V.R. 1985. Resistance to leaf spot caused by *Cercosporidium personatum* in wild *Arachis* species. Plant Disease 69(11): 951-954.

Subrahmanyam, P., Reddy, L.J., Gibbons, R.W., and McDonald, D. 1985. Peanut rust: a major threat to peanut production in the semiarid tropics. Plant Disease 69(9): 813-819.

Witzenberger, A., Williams, J.H., and Lenz, F. 1985. Yield, components of yield and quality responses of groundnut cultivars (*Arachis hypogaea* L.) as influenced by photoperiod and a growth regulator. Field Crops Research 12(4): 347-361.

Conference Papers

Amin, P.W. 1985. Resistance of wild species of groundnut to insect and mite pests. Pages 57-61 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Amin, P.W. and McDonald, D. 1985. Methodology of surveys and field experiments to assess crop losses due to insect pests of groundnut. Pages 169-179 *in* Proceedings of the Regional Groundnut Workshop for Southern Africa, 26-29 March 1984, Lilongwe, Malawi, Patancheru, A.P. 502 324, India: ICRISAT.

McDonald, D. 1985. The ICRISAT groundnut program. Pages 17-31 *in* Proceedings of the Regional Groundnut Workshop for Southern Africa, 26-29 March 1984, Lilongwe, Malawi, Patancheru, A.P. 502 324, India: ICRISAT.

Mehan, V.K., Bhavanishankar, T.N., and McDonald, D. 1985. Zearalenone production in groundnut. Pages 73-78 *in* Trichothecenes and other mycotoxins: proceedings of the International Mycotoxin Symposium, Aug 1984, Sydney, Australia, (Lacey, J., ed.). Chichester, UK: John Wiley.

Moss, J.P. 1985. Breeding strategies for utilization of wild species of *Arachis* in groundnut improvement. Pages 93-99 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Moss, J.P. 1985. Introduction to the ICRISAT groundnut improvement program. Pages 5-9 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Moss, J.P. 1985. Wild species in Crop Improvement. Pages 199-208 *in* Biotechnology in International Agricultural Research: Proceedings of the Inter-Center Seminar on International Agricultural Research Centers (IARCs) and Biotechnology, 23-27 April 1984, Manila, Philippines. Manila, P.O. Box 933, Philippines: International Rice Research Institute.

Nalini Mallikarjuna and **Sastri, D.C.** 1985. In vitro culture of ovules and embryos from some incompatible interspecific crosses in the genus *Arachis* L. Pages 153-158 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Nalini Mallikarjuna and **Sastri, D.C.** 1985. Utilization of incompatible species in *Arachis*: sequential hormone applications. Pages 147-151 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Nigam, S.N. and **Bock, K.R.** 1985. A regional approach to groundnut improvement. Pages 33-43 *in* Proceedings of the Regional Groundnut Workshop for Southern Africa, 26-29 March 1984, Lilongwe, Malawi, Patancheru, A.P. 502 324, India: ICRISAT.

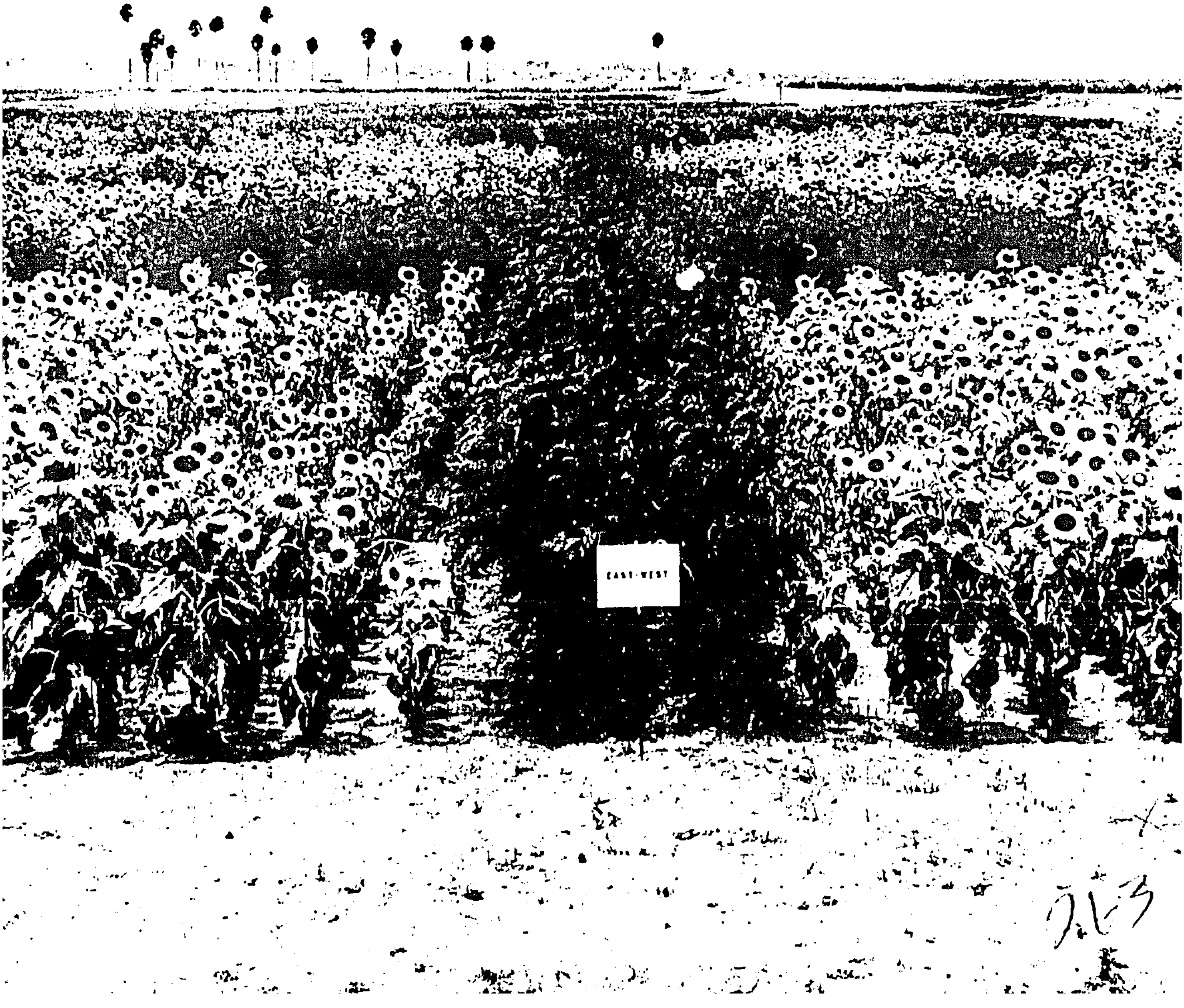
Sastri, D.C. and **Nalini Mallikarjuna.** 1985. Techniques for overcoming incompatibility in wide crosses. Pages 209-217 *in* Biotechnology in International Agricultural Research: Proceedings of the Inter-Center Seminar on International Agricultural Research Centers (IARCs) and Biotechnology, 23-27 April 1984, Manila, Philippines. Manila, P.O. Box 933, Philippines: International Rice Research Institute.

Singh, A.K. 1985. Genetic introgression from compatible wild species into cultivated groundnut. Pages 107-117 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Subrahmanyam, P., Ghanekar, A.M., Nolt, B.L., Reddy, D.V.R., and **McDonald, D.** 1985. Resistance to groundnut diseases in wild *Arachis* species. Pages 49-55 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Williams, J.H. 1985. Some physiological reasons for genotype × drought interactions in groundnuts. Pages 237-244 *in* La sécheresse en zone intertropicale: Pour une lutte intégrée. Actes du colloque "Résistance à la sécheresse en milieu intertropical: quelles recherches pour le moyen terme?" 24-27 septembre 1984, Dakar, Sénégal: CIRAD-GERDAT, ISRA.

RESOURCE MANAGEMENT



Contents

Cover photo: Agroforestry experiment designed to study the interaction between leucaena and sunflower, and the effects of row orientation, ICRISAT Center, rainy season 1985.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

264

RESOURCE MANAGEMENT

Introduction

The Resource Management Program (RMP) was formally created towards the end of 1985 by merging two research programs—Farming Systems and Economics—into one administrative unit. This merger was the outcome of extensive discussions on the need perceived by scientists for more intensive interdisciplinary interaction and for an organizational structure that would be more conducive to such interaction at the research-station level as well as in farmers' fields.

The disciplinary separation of the earlier programs and subprograms had served a useful purpose during the initial stages when ICRISAT's scientists began their agricultural research on the vast territory of semi-arid tropical agriculture. Disciplinary research was an effective means to establish a basic understanding of the principles and constraints involved. As this knowledge increased, so did our understanding of the complexity of many problems and of the interdependency of possible solutions. It was soon apparent that to resolve complex problems, increased interdisciplinary research efforts were required, and this decision was confirmed by the External Program Review of 1984.

Consequently the new program is being organized in a way that will promote increasingly interdisciplinary research approaches to be applied in the future. The basic objectives contained in the mandate of the RMP are:

- characterization of resources,
- research on components and systems for improved use of resources, and
- evaluation of resource management systems.

These three objectives are pursued by three interdisciplinary research groups with differing emphasis as indicated by the number of crosses in the following table:

	Research Group		
Activities	Agronomy	Engineering	Economics
Characterization	×××	××	××
Use	××	×××	×
Evaluation	×	×	×××

The three groups provide a broad framework of disciplinary organization for research teams to address commonly perceived constraints. This framework is also sufficiently flexible to accommodate changes in emphasis across disciplines or to permit the temporary addition of a discipline with particular expertise in studying special aspects of a problem.

Priorities for research are being identified on the basis of a regional assessment of the area and human population in various agroclimatic zones. Within each region, the prevailing constraints determine the direction and intensity of our research efforts. Other determinants for setting research priorities include trends in constraining factors, the probability of success, and our advantage compared to national programs. Priority regions identified in India are:

- Vertic soils under low to high rainfall (500-1500 mm),
- shallow Alfisols under low to medium rainfall (500-700 mm), and
- deep Vertisols under low rainfall;

and in Africa:

- sandy soils under low and medium rainfall, and
- Vertisols under low rainfall.

In this report, we have made a first attempt to group our research reports in terms of priority regions and main activities. The presentation may not always appear to be consistent because the research projects reported for 1985 were initially conceived prior to the present organizational framework and therefore many address a range of problems with different foci. For instance, the reader will not find a section on Vertic soils in this report, even though this is a high priority region in India; this is because our work in the past on Vertic soils was done in projects that also covered other soil types and such results are reported in the section where we compare results across different environments.

Sandy Soils of the Sahel

Coarse-textured soils containing more than 65% sand are the most prevalent types found in the Sahel region of West Africa. These soils occur extensively, mostly on flat to undulating topography, developed in aeolian and alluvial sands. Their low fertility, low water-holding capacity, and poor physical condition are important constraints to their use. Those in Niger, for example, are very sandy with the sand fraction exceeding 80% in most cases. Among the climatic factors, the low and highly variable rainfall, and the high demand for water imposed by the constant high radiation throughout the year are important.

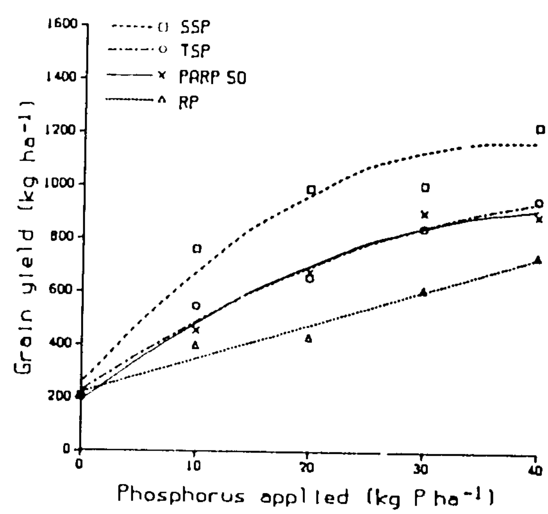
The average farm size in this region is small and the farm incomes are meager. Characterization of the farmers' socioeconomic environment and its constraints are important considerations influencing both technology design and transfer.

While the native fertility in most West African soils is low, there is little or negligible fertilizer use. For example, while the fertilizer use in Africa as a whole is 20 kg nutrients ha^{-1}, in West Africa fertilizer consumption was less than 1 kg ha^{-1} in 1982/83.

Component Research

Phosphorus

At ISC we compared Parc-W rock phosphate (RP) with commercially available sources such as triple superphosphate (TSP), single superphosphate (SSP), and partially acidulated rock phosphate (PARP) prepared at International Fertilizer Development Center (IFDC) Laboratories, Muscle Shoals, Alabama, USA. Partial acidulation is a process that only uses a percentage of the sulfuric acid normally required to convert relatively insoluble rock phosphate to water-soluble phosphorus. Rock phosphate was acidulated at three levels with sulfuric acid: 25% (PARP 25), 40% (PARP 40), and 50% (PARP 50). The RP was applied annually. In a field trial initiated in 1982, we applied P annually as RP, PARP 50, SSP, and TSP. The 50% PARP performed as well as TSP (Fig. 1), indicating that PARP 50 made from Niger rock deposits can meet the P needs of pearl millet as well as commercially available fertilizer. The fact that SSP (which contains sulfur) performed better than TSP (which contains little or no sulfur) shows that the traditional practice of cropping millet continuously would be improved by the use of fertilizer containing sulfur. RP performed poorly, indicating the need for acidulation.



SSP = single super phosphate
TSP = triple super phosphate
PARP 50 = partially acidulated rock phosphate
RP = rock phosphate.

Figure 1. Effect of phosphorus sources and rates of application on pearl millet grain yield (kg ha^{-1}) ISC, Niger, rainy season 1985.

Long-term Soil Management

The objectives of this experiment are to study various soil management factors: the effects of presowing cultivation, mulching, and fertilizer addition on crop growth, water use, and changes in the soil's physical and chemical properties. The experiment is locateJ on land with 3-4% slope that was under bush fallow until 1983. The cultivation treatments consisted of plowing, ridging, and zero tillage. Measurement of runoff was carried out on three "Wischmeier" type plots. In the mulch treatment we used pearl millet residue left from the 1984 season. The fertilizer treatment was 17 kg P ha^{-1} added before cultivation, and 40 kg N ha^{-1} in a split dose applied 2 and 5 weeks after sowing. In 1985, we sowed improved pearl millet (CIVT) and local pearl millet (Sadoré Local) at 13300 hills ha^{-1}.

From establishment onwards, which was excellent at 97% of the hills sown, growth was positively influenced by cultivation treatments, fertilizer, and mulching. Plowing and ridging increased plant height, as did mulching and fertilizer applications. Adequate, well-distributed rainfall kept the first meter of the soil profile virtually at field capacity from 3 weeks after sowing until harvest favoring good vegetative growth. A 98.2 mm storm was the only one to produce a 1% runoff from the zero-tilled plot.

Grain yields depended on the tillage method used, mulching, fertilizer, and pearl millet cultivar sown (Fig. 2). There is a strong interaction between mulching and fertilizer; mulching did not produce the same effect with fertilizers compared to the large response to mulching in plots without fertilizers (Fig. 3). The small drop in grain yield following ridging was unexpected; elsewhere at ISC, crops grown on ridges performed well. Soil analyses showed a slightly lower pH of 4.91 for ridging, compared to 5.11 for plowing, and 5.18 for control plots. Mulching increased the organic matter content from 0.26 to 0.29%.

The method of cultivation had a profound effect on early weed growth. Weed growth was more on zero-tilled plots and on plots where the mulch was completely buried. We determined weed dry matter after harvest from 3-m^2 plots. Fertilizer application reduced weed levels from 256 to 176 kg weed dry matter ha^{-1}. Sadoré Local millet supressed weeds better, 153 kg ha^{-1}, than the improved pearl millet CIVT, 276 kg ha^{-1}. There was some *Striga* infestation, 1.14 *Striga* plants m^{-2} affecting Sadoré Local pearl millet compared to 0.27 *Striga* plants m^{-2} affecting CIVT.

Crop water use during growth depended on the method of cultivation, mulching, and fertilizer application. However, total water use at the

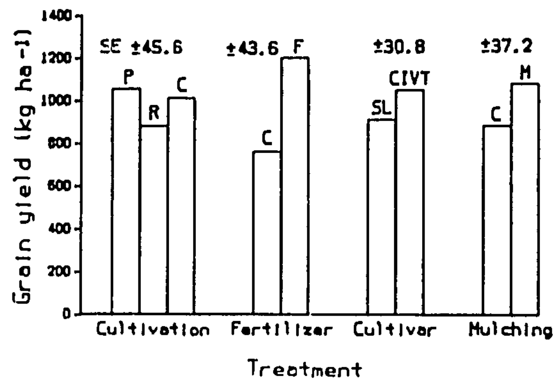


Figure 2. Effect of presowing cultivation (P = plowing, R = ridging, C = control), fertilizer application (F), cultivar (SL = Sadoré Local, CIVT = improved), and mulching (M) on pearl millet grain yields (kg ha^{-1}) ISC, Niger, rainy season 1985.

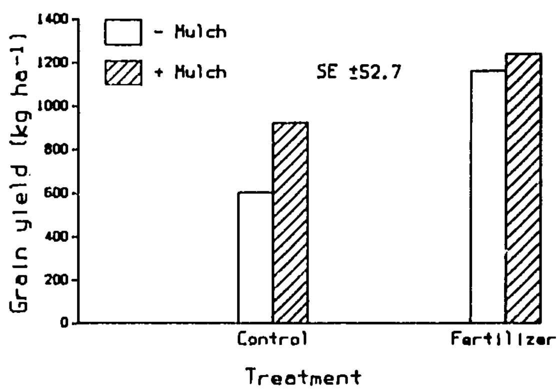


Figure 3. Effect of mulching × fertilizer interaction on pearl millet grain yield (kg ha^{-1}) ISC, Niger, rainy season 1985.

end of the season did not differ significantly, ranging between 287 mm and 320 mm in different treatments. Water-use efficiencies (kg ha^{-1} mm^{-1}) ranged from 1.83 for ridged plots without fertilizer to 4.87 for mulched and plowed plots with fertilizer.

Soil Variability and Plant Establishment

Variability of crop establishment, growth, and yield within short distances (1-3 m) is a common problem in soils at ISC and throughout the Semi-Arid Tropics (SAT). This variability hinders research because the irregularity of crop growth in a single plot is often greater than the differences between treatments and between replications of the same treatment. Apart from the effects on experimental results, the areas with low yields in farmers' fields obviously cause substantial production loss.

We took soil samples (0-10 cm depth) at 101 locations along the steepest gradients in crop growth; pH, exchangeable bases, exchangeable hydrogen and aluminium and Cation Exchange Capacity (CEC) were correlated with plant growth and yield. These confirmed, as we reported last year (ICRISAT Annual Report 1984, p. 308), that variability is caused by pH-related problems at ISC and in farmers' fields. The difference in acidity between the nonproductive and productive areas can be detected to a depth of about 50 cm (Fig. 4).

In another experiment, we studied the effects of presowing cultivation, fertilizer application, and residual fertility on the establishment of three pearl millet cultivars. The cultivation methods were plowing, ridging, use of sand-fighter, and a zero-tilled control. We evaluated the residual fertilizer effect from 1984 by imposing the cultivation treatments in a split-plot design with 1984 fertilizer treatments as the main plot.

Two improved cultivars, 3/4 HK and CIVT, and Sadoré Local were sown in 75-cm-spaced rows at 13000 hills ha^{-1}. The direction of the rows was perpendicular to the prevailing erosive winds during storms. Establishment and survival later in the season were superior for plowing

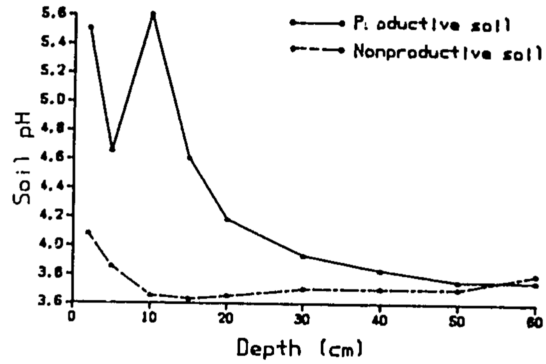


Figure 4. Profiles of soil pH in two adjacent areas of a Lubucheri soil, one that supports good plant growth and one that does not. ISC, Niger, 1985.

and ridging treatments (Fig. 5). Storms at 8 days after sowing (DAS), and 10 DAS, with average hourly wind speeds exceeding 7 m s^{-1}, did not affect the pearl millet stands.

Early growth, expressed in plant height measured on various dates, showed positive management effects. The intensive cultivation methods were better than the sand-fighter and zero-tillage treatments; plant heights measured at 40 DAS were 54.6 cm for plowing, 47.4 cm for ridging, 36.3 cm for zero-tillage, and 32.5 cm for sand-fighter treatment. Fertilizer application increased plant height from 34.4 cm on control plots to 51 cm in plots with fertilizer. The resid-

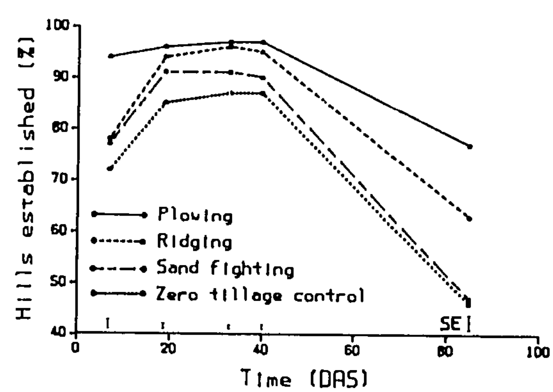


Figure 5. Effect of pre-sowing cultivation method on pearl millet stands measured as percentage survival of 13 300 hills sown ha^{-1} ISC, Niger, rainy season 1985.

ual effect was less pronounced with a plant height of 38.6 cm on control plots against 46.8 cm on plots with fertilizers.

The decline in hill survival later in the season depended on the same factors, as did grain yield (except for the residual fertilizer effect). There were significant tillage × fertilizer and tillage × cultivar interactions. Intensive tillage enhanced the effect of fertilizer and CIVT performed best when grown on ridges (Table 1).

Some cultivation treatments aimed at limiting wind erosion damage might not have expressed themselves on the 19 m × 20 m plots used, so we tested these treatments using 30 m × 30 m plots and observed the same trends and yield levels.

In another experiment, we evaluated the effects of sowing depth and seed size on establishment and early growth of the same three pearl millet cultivars. We graded the seeds to obtain three distinct size groups, and determined the 1000-seed mass and germination percentage in the laboratory. (Table 2).

We sowed lots of seeds at depths of 1, 3, 5, and 7 cm. Plant stand differed significantly for sowing depth: 84% for 1 cm, 90% for 3 cm, 91% for 5 cm, and 87% for seeds sown 7-cm deep. Sowing depth had little effect on the number of seedlings within hills, but the effect of seed size was significant. Fifty-four percent of the large seeds emerged compared with 51% for medium, and 40% for small seeds. Cultivar 3/4 HK performed best with 57% emergence followed by CIVT with 48%, and Sadoré Local with 40%. There was no significant interaction between seed size and sowing depth.

Table 1. Grain yield responses (kg ha^{-1}) of pearl millet to fertilizer application and presowing cultivation, ISC, Niger, rainy season 1985.

Treatment	No fertilizer	Fertilizer	Mean
Presowing cultivation			
Plowing	253	706	480
Ridging	173	772	473
Sandfighter use	125	393	259
Control (zero tillage)	158	419	289
SE	±48.0		±56.1
Millet cultivar			
3/4 HK	83	339	211
CIVT	204	765	485
Sadore Local	245	614	430
SE	±41.6		±19.7
Mean	178	573	
SE	±24.0		

Table 2. Thousand grain mass (g) of different seed sizes obtained by grading seed lots, and laboratory germination rates (%), for three pearl millet cultivars, ISC, Niger, rainy season 1985.

Cultivar	Seed size: Large	Medium	Small
	1000-grain mass (g)[1]		
3/4 HK	11.7±0.26	8.3±0.08	6.8±0.13
CIVT	12.3±0.26	7.8±0.13	5.7±0.22
Sadoré Local	11.3±0.32	7.1±0.05	5.2±0.46
	Germination %		
3/4 HK	93.7±1.5	92.2±1.4	89.7±2.1
CIVT	87.7±3.7	78.7±4.0	77.1±8.8
Sadore Local	79.9±6.0	68.3±4.1	60.4±5.3

1. Average of four replications.

We sampled hills at 24 DAS to determine the number of secondary roots, hypocotyl length, and shoot dry mass. Shoot dry mass measured in g (5 hills)$^{-1}$ depended on the sowing depth and was 2.85 g for 1 cm, 3.77 g for 3 cm, 3.92 g for 5 cm, and 2.92 g for 7 cm. Large seeds yielded 5.11 g, medium seeds 3.15 g, and small seeds 1.82 g. The number of secondary roots depended on the seed size; large seeds produced 3.5, medium seeds 3.1, and small seeds 2.9 roots seedling^{-1}. Among the cultivars, CIVT produced 3.4 roots seedling^{-1}, Sadoré Local 3.2 roots seedling^{-1}, and 3/4 HK 3 roots seedling^{-1}.

The results showed that the optimum sowing depth was between 3 and 5 cm, and that use of large seeds can result in more vigorous seedling development. The current method of hand sowing results in many seeds being sown over a wide range of depths. Well-controlled sowing depth could offer the advantage of economy in seeding rate, and uniformity in seedling development. The question of competition within a hill, between large and small seeds in a common seed lot, needs to be examined to assess the advantages of grading.

Cowpea-based Cropping Systems

The principal objective of the cooperative cowpea program between the International Institute of Tropical Agriculture (IITA), Nigeria, and ICRISAT at ISC is the adaptation and development of cowpea cultivars with higher and more stable yields in both sole and intercropping systems in the Sahel region. The major intercropping system under study is pearl millet/cowpea, the most prevalent cropping system in the region, particularly at the subsistence level.

We continued the evaluation and search for adapted dual-purpose cowpea cultivars that have the capacity to produce vegetative matter and increased grain yield, since favorable combinations of cowpea dry fodder and pearl millet straw may provide good food for livestock. In addition to the 13 cultivars identified in 1984 on the basis of their ability to retain green leaves at pod maturity, we identified 3 more this year from new breeding lines. The performance of selected cultivars is presented in Table 3. These cultivars will be further evaluated for their adaptability to the traditional cropping systems. Their nutritional value will also be determined.

Although vegetable cowpea is more adapted to growing in humid areas, some cultivars introduced to the dry Sahel have proved to yield reasonably well on the sandy soils at ISC. In the 1984 drought year, in a preliminary test, their fresh pod yields ranged from 2300 to 7500 kg ha^{-1}, while in the 1985 cropping season the average yield of three harvests commencing 55 DAS ranged from 3400 to 9840 kg ha^{-1} in less than 70 DAS. These cultivars can be useful early in the season before the principal cereal crop is ready and are also ideal for market gardening, thus providing a source of income for farmers. In addition to contributing to the nitrogen status in the soil, their fodder yield is also substantial.

Table 3. Performance of some dual-purpose cowpea cultivars at ISC, Niger, 1985.

Cultivar	Yield (kg ha^{-1}) Grain	Yield (kg ha^{-1}) Hay	Green leaf retention[1]
Trial 1			
IT83S-755-1	310	3460	5
ITVX 1948-01F	780	3350	3
IT83S-878	550	2690	4
IT83S-725-15	700	2420	4
IT82D-872	1280	2160	4
SE	±128	±360	
Trial mean (16 entries)	700	1880	
CV (%)	32	33	
Trial 2			
IT83S-9[illegible]	900	2230	3
IT81D-994	220	2010	5
TVX 4059-03E	1600	2080	4
Vita 3	260	1610	4
Controls			
TN3-78	520	1800	5
Local Sadoré	-	3530	5
SE	±105	±172	
Trial mean (8 entries)	820	1920	
CV (%)	25	13	

1. Assessed on a 1-5 scale, where 1 = all leaves drop, 5 = more than 95% leaves retained at pod maturity.
2. - = No grain yield.

Sowing densities and fertilizer. In the traditional pearl millet/cowpea intercropping system, both pearl millet and cowpea are sown at low plant densities, with cowpea 2-4 weeks after pearl millet. Our research findings demonstrate that this traditional system can be intensified and made more productive by increasing the plant densities of the component crops, by an appropriate choice of cultivars for both crops, and by the use of fertilizers, particularly phosphorus.

In 1985, we conducted an experiment with three fertilizer levels: no added fertilizer, half the optimum dose (22.5 kg N ha^{-1}, 10 kg P ha^{-1}, 6.3 kg K ha^{-1}) and the optimum dose (45 kg N ha^{-1}, 20 kg P ha^{-1}, 12.5 kg K ha^{-1}). Two pearl millet densities were used: the recommended density (10000 hills ha^{-1}) and the optimum (20000 hills ha^{-1}). Three intercropping intensities were compared to that of the sole pearl millet: 2500, 5000, and 10000 cowpea hills intercropped with the pearl millet.

The findings in an average rainfall year (540 mm) showed that fertilizer application significantly ($P<0.01$) increased pearl millet yield but had no effect on the cowpea hay yields (Fig. 6), although cowpea is known to respond to an increase in soil phosphorus. Better growth of the pearl millet, the dominant crop in the intercrop, at the higher fertilizer level might have suppressed the response of cowpea to applied fertilizer. Light interception data collected when the pearl millet flowered showed increased light interception with added fertilizer. Higher cowpea intercrop levels were not associated with increased light interception.

Pearl millet grain yield increased by 9% with higher pearl millet density, but the extra grain yield was overshadowed by a 38% reduction in cowpea hay yield at this density. Although cowpea hay yields increased significantly ($P<0.001$)

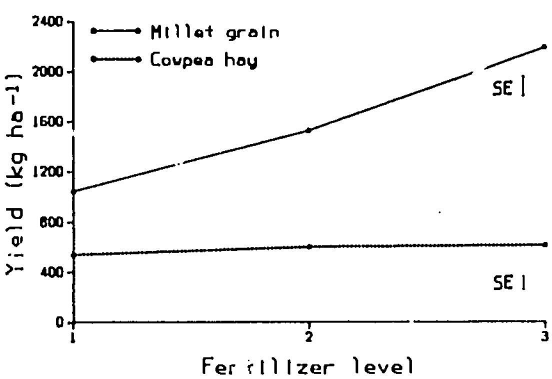


Figure 6. Yield response of a pearl millet/cowpea intercropping system to three levels of fertilizer application (level 1 = 0; level 2 = 22.5 kg N, 10 kg P, and 6.3 kg K ha^{-1}; level 3 = 45 kg N, 20 kg P, and 12.5 kg K ha^{-1}), ISC, Niger, rainy season 1985.

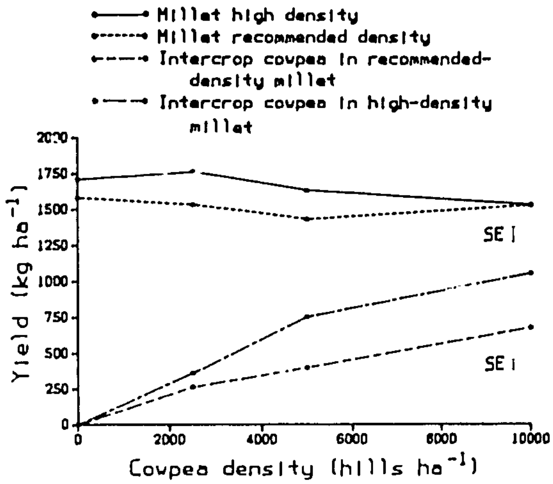


Figure 7. Pearl millet grain and cowpea hay yield response (kg ha^{-1}) in a pearl millet/cowpea intercropping system to three cowpea and two pearl millet sowing densities, ISC, Niger, rainy season 1985.

with increased amounts of cowpea in the intercrop, this trend was significantly ($P<0.05$) reduced at the higher pearl millet density (Fig. 7).

Our findings demonstrate that intercropping late, hay-type cowpeas with pearl millet results in greater overall production. Gains achieved by sowing the pearl millet at the higher plant density are offset by reduced cowpea hay yields. Therefore, an efficient productive cropping system would be to sow pearl millet at the near-optimal density level, and use cowpea to take advantage of any extra resources such as moisture in the system. The traditional practice of intercropping pearl millet with late cowpea appears to be a viable cropping system even under the more intensified pearl millet production system.

Date and pattern of sowing. In the traditional system cowpea is often sown after pearl millet. This practice, although dictated by the moisture status in the soil, leads to domination of cowpea by the pearl millet crop, leading to lower productivity. To study the impact of sowing date on competition and yield, four cowpea cultivars were sown in pearl millet (10000 hills ha^{-1}) on

Traditional cowpea varieties (left) are largely spreading, photosensitive, adapted to low plant populations, late-maturing, with a growing period considerably longer than the rainy season. Owing to their sensitivity to photoperiod, flowering often coincides with the end of the rainy season, rendering them highly vulnerable. Crop losses approach total failure in years of erratic rainfall. The improved cultivars (right) are early maturing and insensitive to photoperiod. If planted simultaneously, it is possible to harvest them 1 month before pearl millet. Research at ISC is exploring how best these improved cultivars can be fitted into pearl millet-based cropping systems to increase production, ISC, 1985.

different dates. The four cultivars comprised an extra-early-maturing erect (IT83S-844), an early-maturing erect (IT82D-716), an early-maturing semierect (TVX 3236), and a late-maturing spreading (Sadoré Local) type. The first three cultivars are among the best in the IITA/ICRISAT cowpea program and the last is the local variety. The cowpeas were sprayed twice with insecticides. Cowpea and pearl millet yields from the three sowing dates are presented in Table 4. The low

Table 4. Grain yield (kg ha^{-1}) of cowpea and pearl millet from three sowing dates of cowpea, ISC, Niger, 1985.

	IT83S-844		IT82D-716		TVX 3236		Local Sadore	
Sowing treatment	C[1]	M	C	M	C	M	C	M
Simultaneous	234	1070	377	1060	484	1040	-	342
	(1.40)[2]		(1.40)		(1.25)			
Cowpea 6 days after millet	104	1320	197	1230	240	1310	-	631
	(1.22)		(1.22)		(1.21)			
Cowpea 25 days after millet	-	1220	72	1510	80	1120	-	1310
			(1.22)		(0.43)			
Sole cowpea	376	-	603	-	932	-	-	-
Sole millet	-	1380	-	1380	-	1380	-	-

1. C = cowpea, M = pearl millet.
SE Millet yield over cowpea sowing dates ±96.
SE Cowpea yield over sowing dates ±54.
2. Figures in parentheses are LERs.

yield of IT83S-844 in both sole and intercrops was attributed to the high incidence of bacterial blight (*Xanthomonas vignicola*) to which this cultivar is susceptible. The three improved cowpea cultivars reduced pearl millet yields with a decreasing magnitude, with simultaneous sowing of Sadoré Local giving the greatest reduction. Sowing cowpea 25 days after pearl millet gave a near sole-crop yield of pearl millet, but resulted in low cowpea yields. In relative terms, however, the greatest advantage with intercropping was associated with cowpea sown at the same time as pearl millet.

We examined a number of sowing patterns to explore the potential of increasing cowpea yield without sacrificing pearl millet yield. In one experiment, three patterns including alternate rows, paired rows of both crops, and sowing in the same hill were examined. There was no significant difference in the yields of pearl millet in the three sowing patterns.

In another experiment, three contrasting cowpea cultivars were sown at four spacings among an evenly spaced pearl millet crop of 10000 hills ha^{-1}. Significant differences occurred among pearl millet yields, the best being obtained with IT82D-716 sown in the traditional system of 4 plants in widely spaced hills (Table 5). Different spacing patterns with the local cultivar produced the lowest pearl millet yields.

Table 5. Grain yield (kg ha^{-1}) of cowpea (C) and pearl millet (M) from four sowing systems, ISC, Niger, 1985.

Spacing of cowpea along pearl millet row	IT83S-844		IT82D-716		Local Sadoré	
	C	M	C	M	C	M
1 plant, 10 cm apart	205	1348	581	1092	—[1]	867
2 plants, 30 cm apart	210	1702	490	1205	—	880
3 plants, 50 cm apart	267	1661	501	1302	—	907
4 plants, 100 cm apart	114	1334	325	1825	—	850
SE millet	± 148					
CV %	24					
SE cowpea	± 34					
CV %	30					

1. — = no grain yield produced.

Animal Traction in Farming Systems

In collaboration with ICRISAT, the International Livestock Center for Africa (ILCA), Ethiopia, initiated two research projects in Niger in 1984. The first evaluated the productivity of livestock and its contribution to the farming systems economy; the second, reported here, studied the role of animal traction in farming systems.

Our objective was to evaluate the extent that animal traction can reduce labor requirements for pearl millet production. Various cultivation methods were studied to determine the best combination of the method of soil preparation, type of animal traction, and implements used. As in 1984, the traditional method of pearl millet land-cultivation was used as a control. The pearl millet CIVT was used with SSP (200 kg ha^{-1}) and calcium ammonium nitrate (100 kg ha^{-1}) fertilizer treatments. We used the sine hoe (a three-toothed cultivator) with donkeys and the Canadian cultivator with oxen to weed the crops.

Figure 8 gives the labor inputs for the different

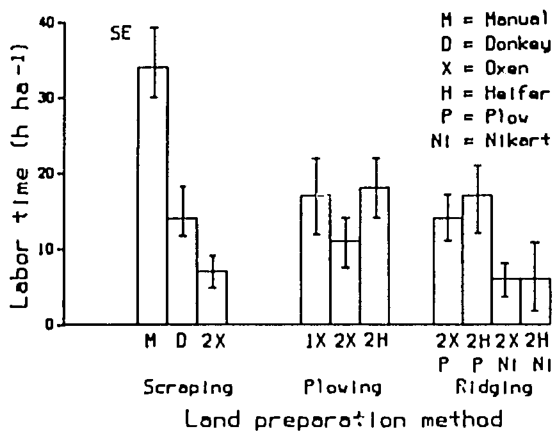


Figure 8. Labor time (h ha^{-1}) required for three different methods of land preparation (scraping, plowing, and ridging) using manual, donkey, oxen, and heifer power, and two implements (plow and Nikart), ISC, Niger, 1985.

cultivation methods tested. The labor requirement was markedly reduced by 80% of the manual scraping time when the ox-drawn Nikart tool carrier was used for ridging, and by 45-49% when a pair of heifers or oxen were used for plowing. Compared to manual methods, the reduction in labor requirement achieved with donkey traction was 14% in 1984, when the soil was cultivated for the first time and required secondary weeding, and 60% in 1985.

The tractive effort and power developed by the animals in each case (except for the ox-drawn Nikart) are given in Table 6. The relative tractive effort, i.e., the ratio between sustained tractive effort and the mass of the implement, is 15% for donkey-draft and 10-18% for ox-draft.

Good rainfall this year resulted in better yields than in 1984, 640-1160 kg grain ha^{-1} and 1220-1810 kg straw ha^{-1}. The tillage method did not significantly affect yield, thus the main advantage of the different cultivation methods was the reduction in the required labor inputs.

Alfisols in India

Alfisols cover about one-third of the geographical area in the SAT. Characteristically, Alfisols are red, reddish brown, or yellowish brown in color with a clay content that increases with depth. The surface soils are usually sandy or loamy sand. They are the most widespread soils in the SAT, and have been the subject of much research. Many of the constraints that limit production are known; but as yet appropriate practical solutions for subsistence farmers have not been found. Yields in farmers' fields are still very low.

The major constraints are low water-holding capacity, low soil fertility, and poor structural stability of the surface soil. The latter causes freshly tilled soil to slump and form surface crusts, which restrict infiltration of rainfall and promote runoff and erosion. The poor surface structure also hinders emergence of seedlings, especially those of small-seeded crops.

Component Research

Drought and Intercropping

The long period of drought during the 1985 rainy season provided a good opportunity to examine the validity of the finding from line-source sprinkler experiments during the summer (Annual

Table 6. Tractive effort (kn) and power (kw) developed by draft animals for different methods of cultivation ISC, 1985.

Cultivation method	Draft animal(s)	Animal live mass (kg)	Implement Type	Implement mass (kg)	Tractive effort Rel-ative[1]	Tractive effort Abs-olute[2]	Tractive effort SE	Speed ($km\ h^{-1}$)	Speed SE	Power[3] (kw)	Power SE	Plowing depth (cm)	Row spacing (cm)
Scraping	1 donkey	138	Sine hoe	18	17.9	46.5	±3.9	2.8	±0.67	0.35	±0.046		
Plowing	1 ox	255	Canadian cultivator	32	10.8	58.0	±0.5	3.0	±0.14	0.46	±0.017		
Scraping	2 oxen	533	Plow	17	12.0	64.3	±0.6	2.9	±0.21	0.47	±0.039	10	25
Plowing	2 oxen	533	Plow	35	10.6	56.3	±1.9	2.7	±0.13	0.41	±0.023	11	75
Ridging	2 oxen	533	Plow	35	10.3	46.5	±2.7	2.1	±0.30	0.25	±0.036	8	26
Plowing	2 heifers	450	Plow	35	10.6	47.5	±2.2	2.5	±0.26	0.31	±0.035	8	70
Ridging	2 heifers	450											

1. Relative effort = $\frac{\text{Absolute effort}}{\text{Live weight}} \times 100$
2. Absolute effort = Force recorded.
3. Power = Force exerted on the plow (kn) × speed ($m\ s^{-1}$).

Report 1981, pp. 257) that relative yield advantages of intercropping increase with severity in drought stress. Results of pearl millet/groundnut intercrop (1:3) studies from 1978 to 1983 gave yield advantages of only 8-31%, whereas this year's results are similar to the high values achieved in the line-source experiments (Table 7). We used pearl millet cultivars BK 560 and groundnut Kadiri 3 in all experiments. This year we obtained data from a multidisciplinary project initiated with pathologists in ICRISAT's crop improvement programs to relate crop microclimate to the incidence of foliar diseases. The lowest intercropping yield advantages were recorded in 1981, the highest rainfall year. However, there was no consistent trend between total rainfall and intercropping advantages.

This year the high yield advantage (57%) is mainly due to the improved harvest index of the pearl millet intercrop (Table 8) and to a small increase in the yield of the groundnut intercrop. The total advantage in the combined dry matter produced by the intercrop (32%) is 4% greater than that recorded in previous years. The exceptionally low harvest index of the sole pearl millet is probably due to the greater drought stress during grain filling. The pearl millet intercrop suffered less drought stress because of its lower population, which produced about 70% of the

Table 7. Intercropping advantages in grain yield (LER)[1] of a 1:3 pearl millet/groundnut combination on an Alfisol, ICRISAT Center, rainy seasons 1978-1985.

Year	Rainfall during growing period (mm)	LER[1]	SE
1978	932	1.26	±0.21
1979	690	1.21	±0.12
1980	591	1.28	±0.13
1981	1072	1.08	±0.09
1982	656	1.31	±0.10
1983	1022	1.28	±0.11
1984	591	—[2]	—[2]
1985	448	1.57	±0.12

1. LER = Land Equivalent Ratio.
2. — = No experiment.

Table 8. Grain yield, total dry matter, and harvest index of pearl millet, groundnut, and pearl millet/groundnut intercrop on an Alfisol, ICRISAT Center, rainy season 1985.

	Grain yield (kg ha^{-1})	Total dry matter (kg ha^{-1})	Harvest index (%)
Sole pearl millet	1230	6100	20.3
Intercrop pearl millet	850	2990	28.8
SE	±48	±182	±1.5
Sole groundnut	930	2860	32.6
Intercrop groundnut	820	2380	34.7
SE	±64	±102	±1.6

sole crop grain yield. Comparison of the leaf area index (LAI) and the dry matter accumulation during the season, of both sole crops with average results from 1978 to 1980, clearly showed that pearl millet suffered from terminal drought stress and that growth of groundnut was very slow from 50 DAS onwards (Fig. 9).

The 1985 results supported the finding from the line-source intercropping experiments and confirmed that relative yield advantages are greatest in drought years.

Tillage

Primary tillage in the SAT is mainly intended to break open the soil surface to enhance rainfall infiltration. Tillage experiments on Alfisols, conducted in the past have shown that an intensive primary tillage performed by splitting the bed with a ridger followed by two strip plowings with right- and left-hand moldboard plows (split-strip plowing) increased infiltration. But at the same time this operation inverted the soil and thus tended to aggravate the problem of crusting, which in turn enhanced runoff and soil loss.

We compared the noninverting primary tillage with conventional split-strip plowing to determine their effect on water-holding characteristics of surface soil. The experiment was

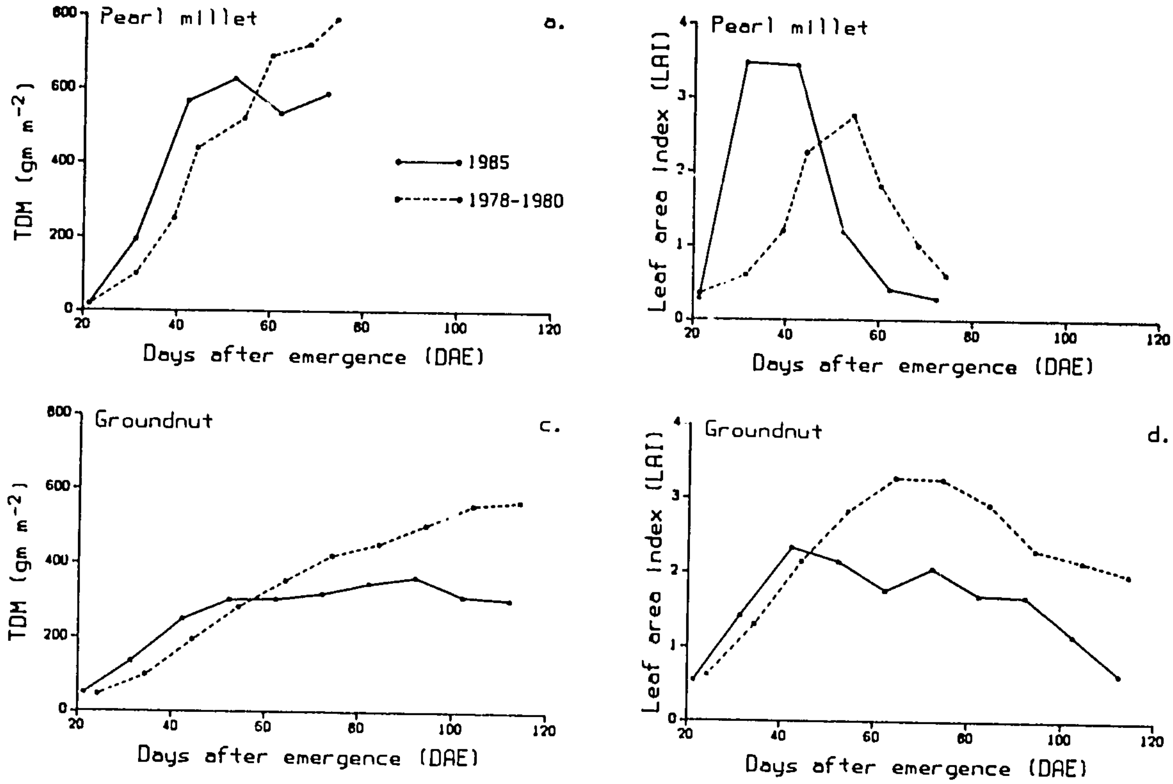


Figure 9. Dry matter production (TDM, g m^{-2}) and leaf area indices (LAI) of sole pearl millet (a and b) and sole groundnut (c and d) on Alfisols, ICRISAT Center, rainy season 1985 and on an average of three years (1978-1980).

organized in a randomized-block design and repeated thrice on a medium Alfisol during 1985. Two of the experiments were conducted during summer with nine replications and without any crop. The third experiment was conducted in the rainy season, with six replications and sorghum as the test crop. The primary tillage methods were as follows:

T_1 = tillage with shovels, T_2 = chisel plowing at crop rows followed by shallow tillage with a cultivator, T_3 = shallow tillage with a cultivator, and T_4 = splitting the bed with a ridger followed by two strip plowings with a moldboard plow.

All the tillage methods were noninverting except T_4 (split-strip plowing, 10-cm deep). The shovels (T_1) broke and pulverized the soil to a depth of 10 cm. The chisel plow (T_2) penetrated to a depth of 15 cm and resulted in minimum loosening of the soil. The depth of shallow tillage by cultivator (T_3) was about 5 cm and it simulated the soil conditions produced by traditional practice. In the first and second experiments, the fields were irrigated to saturate the surface layer of the soil. During the first experiment, there was a 26-day period without rain. In the second experiment, a total of 51 mm rain fell between 30 March and 6 April 1985. The third experiment was conducted in the rainy season and depended on monsoon rain only. About 64 mm rain fell during 2 days before observations began on 31 July. Another 23 mm rain fell between 2 and 16 August and 60 mm between 24 August and 12 November. For the remainder of the experiment no rain fell.

The water held in surface soil (0-20 cm) and its depletion with time followed a similar trend. Among all the three experiments during the entire period, water held in the surface layer was most in the shovel-tilled and least in the chisel-tilled plots. The differences in soil water content under different tilled treatments were statistically significant ($P<0.05$) at field capacity. By the time the water content had decreased to about half the field capacity, the differences were no longer significant. This implies that shovel tillage provides for a good water-holding capacity at the wet end of the moisture characteristic curve. In general, the rate of water decrease was greater in the cropped than in the noncropped experiments. The amount of water loss from all the treatments was similar. Further experiments are planned to confirm these findings.

Runoff and Erosion

Experiments aimed at developing appropriate land surface configurations for Alfisols have been conducted at ICRISAT Center since 1976. Our main objective was to develop a land and water management system for Alfisols, that increases and stabilizes agricultural production by improving the moisture environment for crop growth. A controlled runoff, causing an increased infiltration and a decreased soil loss was part of this objective. During the first 4 years (1976-79) our main attention was given to a comparison of the flat-on-grade and broadbed-and-furrow systems at 0.8% slope. The performance of these systems was evaluated in replicated field-scale plots (0.3-0.4 ha). The major problems encountered with both systems were high runoff and soil loss. It was found that the 0.8% slope is too steep for Alfisols.

Since 1980, we have tested and compared various land surface configurations at several slopes. The systems compared include flat on grade, flat on grade plus ridging during last intercultivation, narrow ridge and furrow (75 cm), broadbed and furrow, wave-type bed and furrow, and wave-type bed and furrow plus additional small furrows. The cross sections of these land surface configurations are shown in Figure 10. For Alfisols at ICRISAT Center, the most appropriate slope was found to be 0.2-0.4%. Among all the land configurations we tried with general land slope less than 1.5%, the flat-on-grade system was the most effective in reducing runoff and soil loss (Table 9).

We found several factors responsible for the poorer performance of the raised land surface configurations in controlling runoff and soil loss. Smoothing the land surface after storms was found to be much quicker in the raised land surface configuration, resulting in less surface-depression storage. The raised land surface configuration exposed the lower argillic soil horizon during the shaping process. This horizon has an extremely low initial infiltration. The broadbed-and-furrow configuration (Fig. 11a) has about 30-35% of its total area in the furrow where the initial infiltration rate is only half that of the top soil surface (Fig. 11b). This results in lower overall infiltration from the broadbed-and-furrow

Table 9. Effect of alternative land surface configurations on crop yield, runoff, and soil loss on an Alfisol, ICRISAT Center, 1981-85.

Land treatment	Crop yield (kg ha^{-1}) Intercropping system: Sorghum	Crop yield (kg ha^{-1}) Intercropping system: Pigeonpea	Crop yield (kg ha^{-1}) Sole crop: Pearl millet	Runoff (mm)	Soil loss (t ha^{-1})
Broadbed and furrow at 0.4% slope	2740	830	2510	276	3.06
Narrow ridge and furrow at 0.4% slope	2910	870	2620	233	2.41
Flat on grade at 0.4% slope	2960	880	2760	152	1.60
Flat on grade at 0.4% slope plus ridging up during last intercultivation	2880	840	2560	170	2.10
SE	±121	±65	±170	±21.2	±0.213

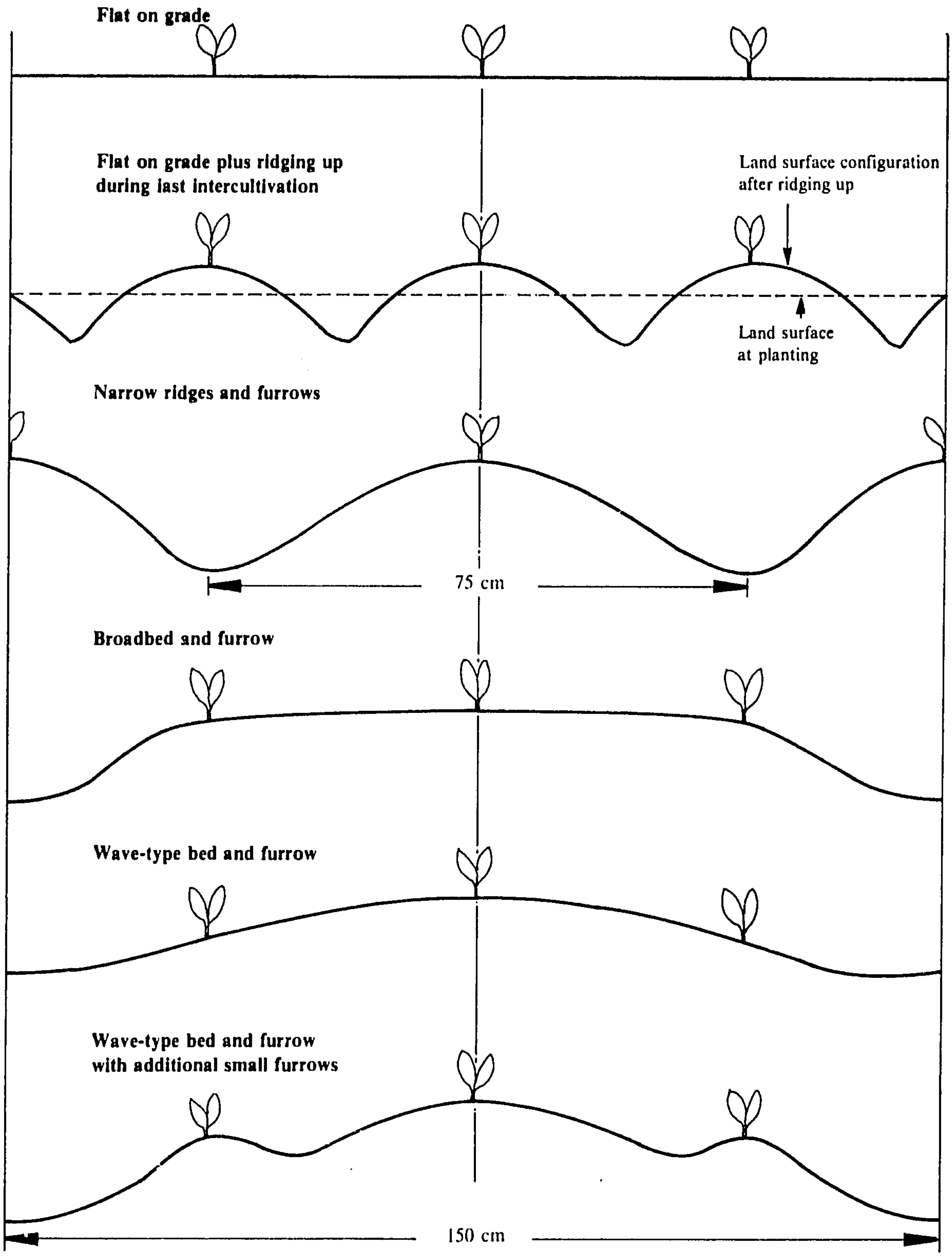


Figure 10. Schematic cross sections of different land surface configurations.

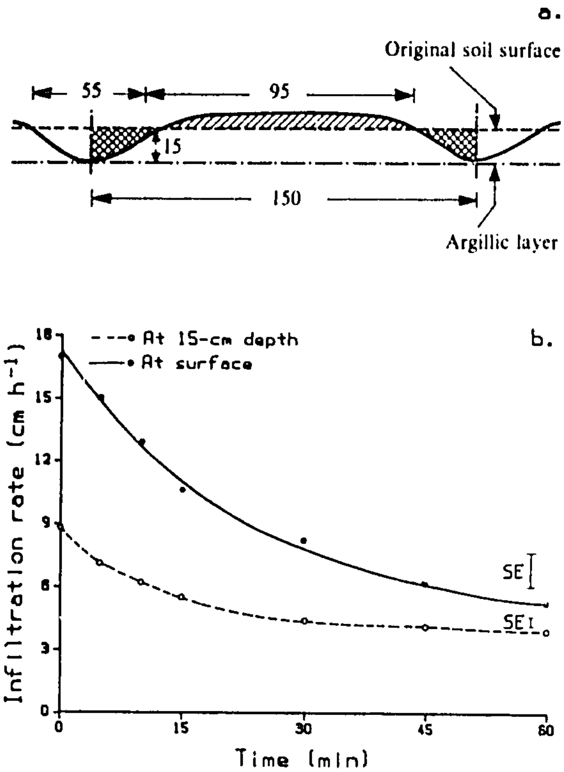


Figure 11. a. Dimension of broadbed and furrow (all measurements in cm). b. Infiltration characteristics determined by double ring infiltrometer, Alfisol watershed, ICRISAT Center, postrainy season 1980.

system than the flat-on-grade system. The other raised land configurations also have lower overall infiltration than the flat-on-grade system. In a permanent raised land surface configuration system (where the land form is maintained over several seasons) we found the compaction in furrows partially responsible for higher runoff.

The other factor which is responsible for higher runoff from the raised land surface configurations is the kind of tillage implements used to form the configurations. In raised land surface configurations, the soil from the argillic horizon (which contains a lot of clay and silt) is brought to the surface during construction. This results in problems of crusting, sealing, and higher runoff. Thus in raised land configurations, the expected benefits from high infiltration rate and reduced velocity of overland flow from land configurations are counteracted by the extremely low surface depression storage, and other problems which result both from turning the soil, and the exposure of the compact argillic horizon in the furrow zone. Therefore, for Alfisols with moderate slopes, the flat-on-grade configuration is probably most effective both in increasing crop yields, and in reducing runoff and soil loss. The second best land configuration with respect to crop yields is the narrow ridge and furrow configuration (Table 9).

Vertisols in India

Vertisols, better known as Black Cotton soils or Cracking Clays, cover extensive areas (about 73 million hectares) in India. The most important attribute of these soils is their ability to store a large amount of water, sufficient for the growth of crops such as sorghum, safflower, and chickpea sown at the end of the rainy season. Postrainy-season cropping was the traditional land use of deep Vertisols in India; during the rainy season they were left unused, under a bare fallow.

On the deep Vertisols where rainfall is assured, systems for double-cropping—which involves growing a crop in the rainy season prior to one in the postrainy season—have been developed since the inception of ICRISAT. Key elements in the improved systems have been the preparation of a good seedbed during the hot and dry summer, dry-sowing crops just before the arrival of the rainy season, improved cultivars and cropping systems, nutrient inputs, land and water management practices to promote both infiltration and drainage of excess surface water, and good agronomic practices such as sowing in rows, seed and fertilizer placement, weed control by intercultivation, etc. These elements were developed at ICRISAT Center, in detailed component research followed by operational-scale testing of promising combinations of components on small watersheds at ICRISAT Center.

Over the past 5 years, the double-cropping system has been tested in farmers' fields. We established three benchmark sites, in 1980 and

1981, to gain first-hand experience of the problems likely to be encountered with on-farm testing. Subsequently, many other sites have been established by national programs, who will be the major institutions or agencies responsible for conducting the appropriate development research to test and improve the various options of the double-cropping technology in the varied subenvironments within our target area.

This year, our on-farm testing encompassed the final phases of studies at two of the original benchmark sites, and the initial phase of collaborative on-farm research with national programs to improve the performance of some components.

Technology Transfer

On-farm Testing of Improved Systems

In 1984, we continued to test the Vertisol double-cropping technology for the 3rd year at two benchmark locations: at Farhatabad (730 mm rainfall) in Karnataka and at Begumganj (1400 mm rainfall) in Madhya Pradesh. The Departments of Agriculture in our five collaborating States—Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, and Tamil Nadu—increased the number of their on-farm testing sites to a total of 40 (Fig. 12).

Begumganj (Madhya Pradesh). In 1984, the total rainfall (1308 mm) was slightly lower than the long-term average (1400 mm), but the double-cropping technology again demonstrated its potential for higher returns than the farmers' traditional single-cropping system (Table 10). Soybean/pigeonpea intercrops again gave good returns. This double-cropping system has consistently yielded profits above Rs 2300 ha⁻¹ over the past 3 years, in contrast to an average profit of less than Rs 700 ha⁻¹ from the traditional single postrainy-season crop. Other soybean-based double-cropping systems also showed their potential to perform well, but not consistently.

Encouraged by the results, farmers increased the area in our study watershed sown to a soybean/pigeonpea intercrop from 12% of the total area in 1982/83 to 65% in 1983/84.

The traditional single crop of wheat grown after a rainy-season fallow, was less profitable than other single postrainy-season crops, such as lentils and linseed. A sole crop of soybean, grown in the rainy season, was more profitable than wheat.

Soybean and pigeonpea yields and profits varied widely between fields in both 1983/84 and 1984/85 postrainy seasons. The causes of this variation merit further study; better agronomic practices might give higher and more stable yields. Some of the reasons for poor yields and low profits have already been identified.

Dry-sowing crops just before the arrival of the southwest monsoon was not so successful at Begumganj as at ICRISAT Center. Soybean

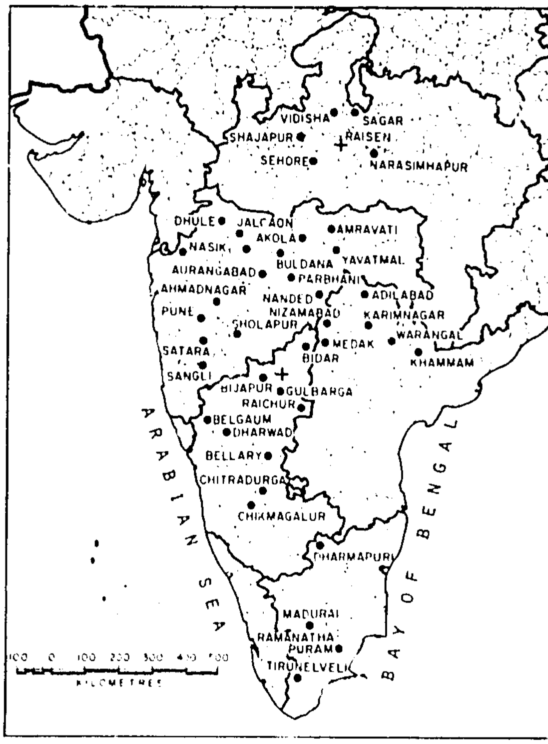


Figure 12. Locations of on-farm sites in India where ICRISAT Vertisol double-cropping technology was tested, 1984/85 (+ = ICRISAT trials; • = National Program trials).

Table 10. Value of inputs and gross profits (Rs ha^{-1}) from various improved and traditional cropping systems on a deep Vertisol at Begumganj, Madhya Pradesh in three seasons 1982/83 to 1984/85.

		Season					
		1982/83		1983/84		1984/85	
Cropping system	Land treatment[1]	Inputs	Gross profits	Inputs	Gross profits	Inputs	Gross profits
Improved Watershed							
Improved cropping systems (double-cropping)							
Sorghum/pigeonpea	BBF	1450	1876	—	—	—	—
Soybean/pigeonpea	BBF	4099	3318	2310	2726	1294	2983
Soybean/pigeonpea	FG	—	—	2172	2335	1090	2818
Soybean/pigeonpea	FF	—	—	—	—	1267	2976
Soybean-wheat	BBF-FG	677	-33	2261	3117	1733	1035
Soybean-chickpea	BBF-FG	3303	295	2532	2345	—	—
Soybean-lentil	BBF-FG	3410	3215	—	—	1519	687
Soybean-linseed	BBF-FG	2476	696	—	—	—	—
Improved single crop (in rainy season)							
Soybean-fallow	BBF	—	—	—	—	1056	808
Soybean-fallow	FG	—	—	—	—	791	802
Soybean-fallow	FF	—	—	—	—	980	1345
Traditional single crop (in postrainy season)							
Fallow-wheat	FG	—	—	—	—	490	463
Fallow-wheat+chickpea	FG	—	—	—	—	622	344
Fallow-lentil	FG	—	—	—	—	488	682
Fallow-linseed	FG	—	—	—	—	501	1294
Traditional Fields							
Improved cropping systems (double-cropping)							
Soybean/pigeonpea	TRD	—	—	1497	3087	1497	3000
Soybean-wheat	TRD	—	—	1488	2400	—	—
Soybean-chickpea	TRD	—	—	1781	2909	—	—
Improved single crop (in rainy season)							
Soybean-fallow	TRD	963	534	—	—	894	655
Traditional single cropping system (in postrainy season)[2]							
Fallow-wheat	TRD	962	370	914	401	465	306
Fallow-chickpea	TRD	920	344	937	728	—	—
Fallow-lentil	TRD	741	1680	—	—	419	755
Fallow-linseed	TRD	664	796	—	—	313	868
Pigeonpea (sole)[3]	TRD	474	1708	—	—	—	—

1. BBF = Broadbed and furrow; FG = Flat on grade (or furrow on grade); FF = Furrow on flat; TRD = Traditional.
2. Outside the improved watershed management area.
3. Single crop spanning both seasons.

germination was poor on some farms in 1982 and 1983, and we therefore discontinued dry sowing in 1984.

The postrainy-season crop is less assured after a soybean crop in the rainy season. During 1984, because of lack of moisture in the seed-bed soil, the majority of the fields sole-cropped with soybean in the rainy season could not be sown to a subsequent postrainy-season crop, or the sown crop failed. But in 1983, all the fields sole-cropped with soybean were successfully double-cropped, the second crop being either wheat or chickpea.

The broadbed-and-furrow (BBF) land management system, which provides improved drainage for waterlogging-sensitive crops such as cereals, does not appear to be necessary for rainy-season soybean. Excess surface water appears to be adequately drained from the land by a simpler land drainage treatment such as furrow-on-grade (with a distance of about 3 m between furrows) in combination with land smoothing, waterways, and drainage channels.

Farhatabad (Karnataka). Farhatabad in Karnataka has an average annual rainfall of only 730 mm, and is considered to be outside the area for reliable double-cropping. For this reason, it provides a useful benchmark site for testing the robustness of the double-cropping technology.

In 1985, total rainfall at Farhatabad was 539 mm, well below average. The southwest monsoon arrived only on 12 July, leaving little time to sow sequential double-cropping systems, and the intended sorghum/pigeonpea intercrop. The latter was replaced by some farmers with a pearl millet/pigeonpea intercrop. Mung bean (*Vigna radiata*) gave low yields (87 kg ha^{-1}) because of the late sowing. Many farmers preferred not to attempt a rainy-season crop, but instead bare-fallowed the soil in preparation for a traditional crop of postrainy-season sorghum.

Despite the marginal environment at Farhatabad for double-cropping, farmers have been keen to experiment with it. Over the last 3 years, double-cropping gave them an average increase of 45% in gross profits above the traditional systems of mung bean-sorghum and sole pigeonpea cropping, and a 31% increase above the fallow-sorghum system. The highest economic returns over a 3-year period were obtained from a sesamum (*Sesamum indica*)/pigeonpea intercrop sown in 2:2 row arrangement; that gave a gross return of Rs 6620 ± 1830 ha^{-1}. A groundnut/pigeonpea intercrop (2:2 ratio) gave a return of Rs 5178 ha^{-1}, and sole pigeonpea gave Rs 4430 ± 711 ha^{-1}. Fallow-sorghum gave only Rs 1830 ± 751 ha^{-1}. Input costs were lowest for fallow-sorghum (Rs 736 ± 76 ha^{-1}).

Planter Testing

In cooperation with the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, we evaluated the performance of a planter-and-fertilizer applicator in farmers' fields, at their Operational Research Watershed at Chevella, 85 km northwest of ICRISAT Center. We also tested the Agribar tool carrier (ICRISAT Annual Report 1984, p.276) fitted with a three-row hand-metered sowing attachment, and three machines developed by CRIDA, two versions of a three-row hand-metered seed-and-fertilizer drill (Rayal and Eenati gorrus), and a single-row hand-metered unit called the FESPO (fertilizer seed pora) plow.

We sowed a sorghum/pigeonpea intercrop in wet Vertic Inceptisols after rain on the previous day. All the five machines performed satisfactorily. In the 1985 rainy season, little rain fell during the first 3 weeks after sowing, and the weather remained generally dry during the entire cropping season.

During the sowing operations, we measured the pull requirements of the implements (Table 11) and found they did not differ significantly. The planter-and-fertilizer applicator, Agribar, Rayal gorru, and Eenati gorru had similar field capacities, ranging between 0.16 and 0.20 ±0.018 ha h^{-1} (Table 11). The FESPO plow had a field capacity of only 0.10 ha h^{-1}, primarily because it sowed only a single row compared to the three rows sown by the other machines. The amount of time spent in turning and furrow-opener cleaning was similar for all these machines.

Table 11. Field performance of different sowing machines at Chevella watershed, rainy season 1985.

Treatment	Pull requirement (N)	Actual field capacity (ha h^{-1})	Labor requirement (man-hour ha^{-1})
Planter-and-fertilizer applicator	1210	0.20	10.0
Agribar	1060	0.18	21.6
Rayal gorru	880	0.17	23.6
Eenati gorru	NR[1]	0.16	24.4
FESPO plow	1040	0.10	30.0
SE	±81	±0.018	±1.51

1. NR = Not recorded.

The sowing machines differed markedly in their labor requirements. The planter-and-fertilizer applicator could be operated by only two persons, the FESPO plow needed three persons; but the Agribar, and the Rayal and Eenati gorrus needed four persons each. The planter-and-fertilizer applicator is the only machine that has the additional advantage of a seat for its driver.

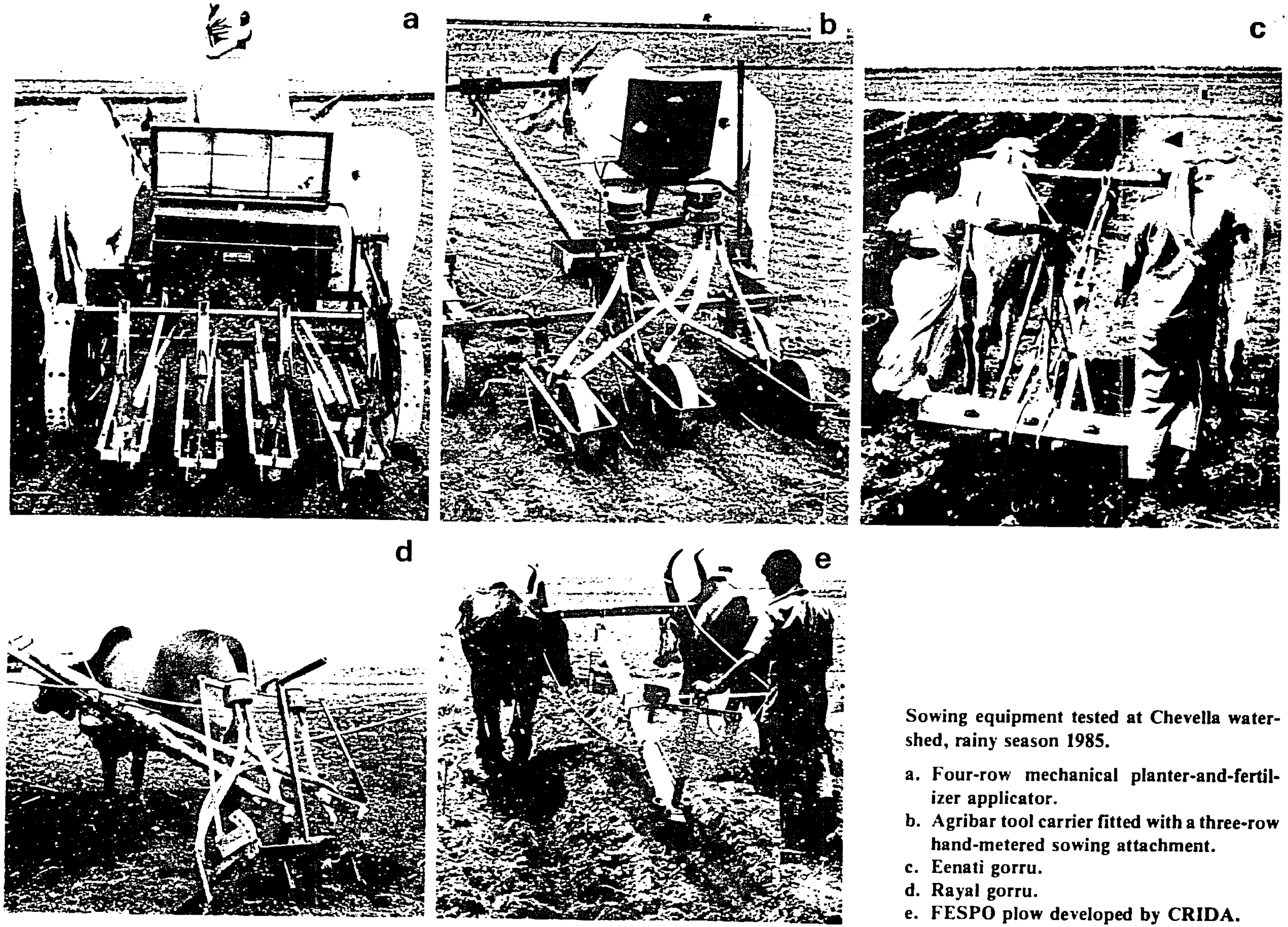
The effect of the sowing machines on plant population and distribution of sorghum and pigeonpea crops is given in Table 12. We recorded plant counts and spacings at three 7.5-m^2 locations in each plot. The uniformity of crop establishment is highest for the planter-and-fertilizer applicator. The higher variability of the remaining seeders may be due to seed distribution by hand metering.

We aimed at a plant population of 120 000 sorghum plants ha^{-1} and 60 000 pigeonpea plants ha^{-1}. A sorghum plant population close to this was obtained by the planter-and-fertilizer applicator and Eenati gorru (Table 12). For pigeonpea, the planter-and-fertilizer applicator, Agribar, and Eenati gorru gave plant populations close to the desired figure. The Rayal gorru and FESPO plow gave rather high stands for pigeonpea.

During this relatively dry cropping season in 1985/86, drought reduced the population of sorghum by 30-50% between establishment and

Table 12. Effect of sowing machines on sorghum and pigeonpea plant population and yield at Chevella watershed, rainy season 1985.

	Crop	Type of sowing machine: Planter-and-fertilizer applicator	Agribar	Rayal gorru	Eenati gorru	FESPO plow	SE
Initial plant population (10^3 ha^{-1})	Sorghum	116	99	66	119	100	
	Pigeonpea	67	60	106	68	113	
Standard deviation of number of plants per 7.5 m^2	Sorghum	11.0	20.4	15.9	18.5	27.3	
	Pigeonpea	9.5	25.2	37.3	18.3	35.4	
Final plant population (10^2 ha^{-1})	Sorghum	79	62	41	56	61	
	Pigeonpea	63	58	97	60	96	
Yield (kg ha^{-1})	Sorghum	2530	2400	2480	2510	2460	±182
	Pigeonpea	500	370	430	440	460	±62



Sowing equipment tested at Chevella watershed, rainy season 1985.

a. Four-row mechanical planter-and-fertilizer applicator.
b. Agribar tool carrier fitted with a three-row hand-metered sowing attachment.
c. Eenati gorru.
d. Rayal gorru.
e. FESPO plow developed by CRIDA.

harvest stage (Table 12) which masked possible treatment differences in grain yield. A final plant population as low as 41000 plants ha^{-1} in the Rayal gorru treatment gave almost the same yield as 79000 plants ha^{-1} from the planter-and-fertilizer applicator.

Component Research

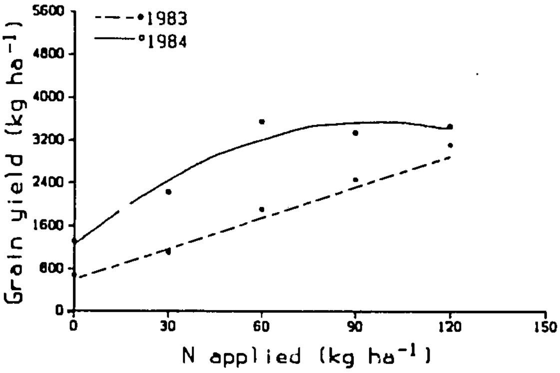
Fertilizer-N

In 1985, our joint ICRISAT/IFDC research project continued its studies on the efficiency of nitrogen fertilizer applied to rainfed sorghum on shallow soils, and we studied in detail the effect of applying fertilizer in bands on sorghum. The completion of N analyses on soil and plant samples from earlier experiments allowed assessments to be made of the recovery of fertilizer-N.

In 1983, we observed that—on a shallow black soil (Vertic Inceptisol) with above-normal June-September rainfall (910 mm)—the crop responded to applied-N almost linearly up to 120 kg N ha^{-1} (Fig. 13). In contrast the yield response to fertilizer-N in 1984 reached a maximum beyond 80 kg N ha^{-1}.

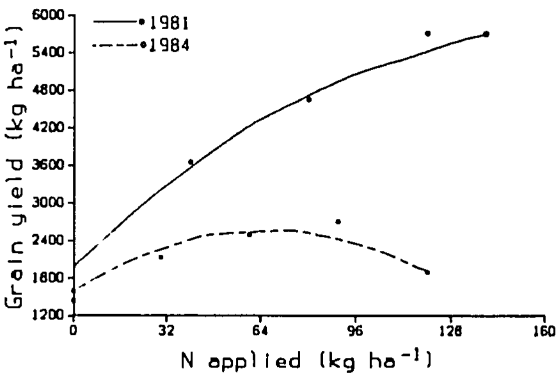
On the shallow red soil, in 1984, the response of sorghum to fertilizer-N was quite small (Fig. 14). The agronomic efficiency was low [16 kg sorghum grain (kg N)$^{-1}$] even at low rates of applied-N (up to 60 kg N ha^{-1}); on a shallow black soil, the sorghum responded much better as the same rate of fertilizer-N gave an agronomic efficiency of 35 kg grain (kg N)$^{-1}$ in 1984 (Fig. 13) A deep Alfisol, with 900 mm rainfall (in 1981) gave the high agronomic efficiency of fertilizer-N of 37 kg grain (kg N)$^{-1}$ from an application of 60 kg fertilizer-N (Fig. 14).

The recovery by the crop of fertilizer-N applied in different carriers on the shallow black soils (Vertic Inceptisol) in 1983, and on a deep Vertisol in 1982, has recently been determined with the completion of ^{15}N analyses. Rainfall between sowing and harvesting of CSH 6 sorghum differed markedly in these 2 years; it was 550 mm in 1982, and 910 mm in 1983. The results (Table 13) show that on the deep Vertisol under average rainfall, the total recovery of fertilizer-N in crop and soil was high, and that all the carriers tested were of similar effectiveness. But, on the shallow black soil, under high rainfall, fertilizer-N recovery by crop and soil was low (< 70%) indicating substantial losses of about 30-40%. Losses were greater from nitrate-carrier (40%) than from urea (29%) or nitrophosphate (30%);



1983 y = 602 + 20.8x R = 0.996, rse = 90
1984 y = 1250 + 47.0x - 0.241x^2 R = 0.90, rse = 304

Figure 13. Nitrogen response curves for grain yield of sorghum grown in the rainy season on a shallow black soil (Vertic Inceptisol), in 1983 and 1984, ICRISAT Center.



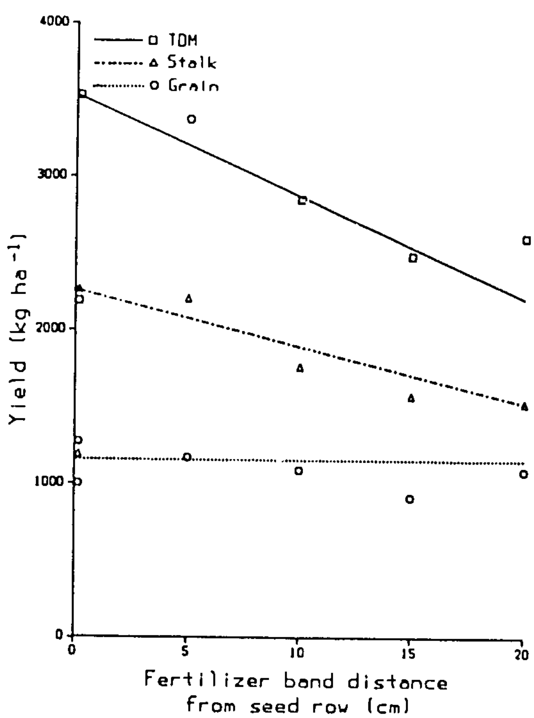
1981 y = 1980 + 45.2x - 0.137x^2 R = 0.99, rse = 106
1984 y = 1610 + 28.4x - 0.215x^2 R = 0.82, rse = 179

Figure 14. Nitrogen response curves for grain yield of sorghum CSH 6 grown in the rainy season on a deep red soil (Alfisol) in 1981 and shallow red soil in 1984, ICRISAT Center.

Table 13. Recovery (%) of fertilizer-N applied in different carriers to sorghum CSH 6 on a Vertisol in 1982 and a Vertic Inceptisol in 1983, ICRISAT Center, rainy seasons.

N carrier	Vertisol (1982)[1]			Vertic Inceptisol (1983)[1]		
	Plant	Soil	Total	Plant	Soil	Total
Urea	56.2	35.0	91.2	36.3	34.6	70.9
Potassium nitrate	66.1	25.6	91.7	34.8	23.4	58.2
Nitro-phos[2]	60.6	32.5	93.1	29.7	40.5	70.2
USG[3,4]	57.2	26.9	84.1	-	-	-
Ammonium nitrate	55.0	31.8	86.8	-	-	-
SE	±3.2	±3.1	±3.0	±1.0	±2.0	±1.4

1. Rainfall during the crop season was 550 mm in 1982, and 910 mm in 1983.
2. Ammonium-nitrate-phosphate (20-20-0)
3. Urea super granule (approximately 1g granule^{-1})
4. Recovery calculated from basal dose, others are average recovery from basal dose and top dress dose.



TDM $y = 3516 - 55x$ $r = 0.91$ rse = 190
Stalk $y = 2284 - 42.2N$ $r = 0.94$ rse = 116
Grain $y = 1232 - 12.8N$ $r = 0.67$ rse = 99

Figure 15. Effect of fertilizer band distance from seed row on dry matter yield of pearl millet (BJ 104) on a shallow red soil (Alfisol) ICRISAT Center, rainy season 1984.

we assume that the cause was leaching of nitrate-N from this shallow black soil by the heavy rainfall in 1983.

In previous years, our results indicated that fertilizer bands need not be placed 5 cm away from the seed row, but could be located within the seed row without harming the crop. Fertilizer placement within the seed row obviates the need for a "double-shoe furrow-opener", thus reducing the pull force (draft) of seeding equipment.

This year we examined the effect of the distance of the fertilizer band from the seed row of BJ 104 pearl millet in a shallow red soil. The fertilizer bands were placed 0, 5, 10, 15, and 20 cm from the seed row, and the rates of fertilizer were 40 kg N ha^{-1} (as urea) and 26 kg P ha^{-1} (as single superphosphate). All treatments were applied at sowing. In the early growth stage, the vigor of the crop was inversely proportional to distance of the fertilizer band from the seed row. That trend lasted up to harvesting, as shown by the yields in Figure 15.

Crop Rotation

To provide information on the best combination of improved legumes and nonlegumes for sustained productivity and maintenance of soil nitrogen status, we started a long-term rotation experiment on deep Vertisols at ICRISAT Center in 1983. This development followed logically from the results of earlier studies that showed double-cropping is feasible on deep Vertisols, and that many combinations of two crops yielded well. However, most of this previous work examined the yields of various cropping systems only in a single year. The sustainability of these annual cropping systems, and their various combinations required an experiment comparing various sequences of annual cropping systems over many years.

The experiment compared 10 different cropping patterns using a 2-year period for the standard length of a rotation (Table 14). Some treatments involved continuous cropping to an annual system. Others involved an alternation of annual systems; for these, we duplicated the treatment so that each annual phase of the rotation could be examined every year. This increased the number of treatments from 10 to 15 (Table 14).

The annual cropping systems were based on just 7 crops that yield well on deep Vertisols. They consisted of 3 rainy-season crops—sorghum (CSH 6), cowpea (EC 6216), and mung bean (S 8); 3 postrainy-season crops—sorghum (CSH 8R), safflower (Manjira), and chickpea (Annigeri); and one that spans both seasons—medium-duration pigeonpea (ICP 1-6).

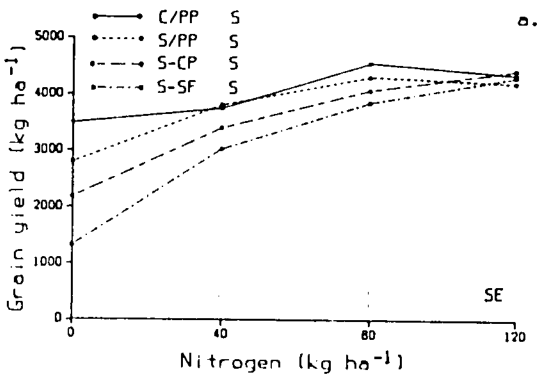
These 10 different cropping patterns provide two different general types of comparisons; traditional versus improved cropping systems, and systems with differing proportions of legumes: nonlegumes. The traditional cropping systems consist of a single crop each year, grown in the postrainy season after a rainy-season fallow. The improved cropping systems involve double-cropping by growing crops in the rainy as well as the postrainy season. The most N-depleting systems were expected to be treatments 1 (fallow-sorghum) and 4 (sorghum-safflower), and the least depleting to be treatments 8 and 9 (sorghum-chickpea alternating with a sorghum/pigeonpea intercrop), 10 and 11 (cowpea/pigeonpea alternating with sorghum-safflower), and 2 and 3 (fallow-sorghum alternating with fallow-chickpea).

The responses of rainy-season sorghum to N

Table 14. Crop combinations used in the long-term rotation experiment, started on a deep Vertisol, ICRISAT Center, 1984.

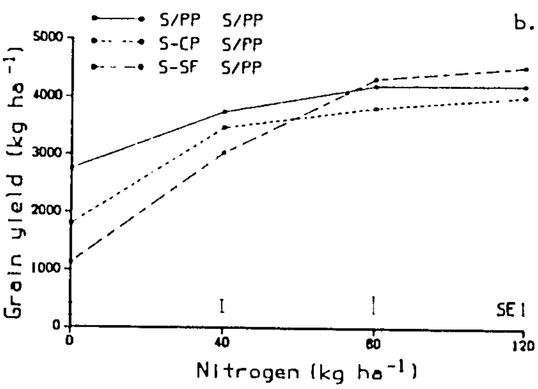
Treatment		Cropping systems	
		1st year	2nd year
T_1	Traditional	Fallow-sorghum	Continuous
T_2	"	Fallow-sorghum	Fallow-chickpea
T_3	"	Fallow-chickpea	Fallow-sorghum
T_4	Improved	Sorghum-safflower	Continuous
T_5	"	Sorghum-chickpea	Continuous
T_6	"	Sorghum/pigeonpea	Continuous
T_7	"	Mung bean-sorghum	Continuous
T_8	"	Sorghum/pigeonpea	Sorghum-chickpea
T_9	"	Sorghum-chickpea	Sorghum-pigeonpea
T_{10}	"	Sorghum-safflower	Cowpea-pigeonpea
T_{11}	"	Cowpea/pigeonpea	Sorghum-safflower
T_{12}	"	Sorghum-chickpea	Sorghum-safflower
T_{13}	"	Sorghum-safflower	Sorghum-chickpea
T_{14}	"	Sorghum-safflower	Sorghum-pigeonpea
T_{15}	"	Sorghum/pigeonpea	Sorghum-safflower

in 1984 (Fig. 16) show very clearly the markedly different residual effects of the cropping systems in the previous year; especially important was the effect of the proportion of legume in the previous year. Sorghum attained grain yields



a. Sole crop sorghum
1983/84 system

C/PP S	$y = 3420 + 17.0x - 0.072x^2$	$R = 0.48$
S/PP S	$y = 2790 + 32.8x - 0.175x^2$	$R = 0.81$
S-CP S	$y = 2200 + 34.8x - 0.136x^2$	$R = 0.97$
S-SF S	$y = 1360 + 47.7x - 0.194x^2$	$R = 0.95$



b. Sorghum intercropped with pigeonpea
1983/84 system

S/PP S/PP	$y = 2760 + 30.5x - 0.153x^2$	$R = 0.84$
S-CP S/PP	$y = 1860 + 44.9x - 0.229x^2$	$R = 0.94$
S-SF S/PP	$y = 1110 + 60.4x - 0.264x^2$	$R = 0.95$

rse = 187

Figure 16. Effect of cropping system grown in 1983/84 season on response of rainy-season sorghum grain yield (kg ha⁻¹) to fertilizer-N in 1984/85, grown as a. sole crop, and b. intercropped with pigeonpea, Vertisol, ICRISAT Center, 1985

about 4300 kg ha^{-1} in all treatments when adequate fertilizer-N was applied; in the absence of fertilizer-N, grain yields were as high as 3500 kg ha^{-1} after the double-legume intercrop (cowpea/pigeonpea) and as low as 1400 kg ha^{-1} after a double-nonlegume sequential crop (sorghum-safflower). The legume-nonlegume combinations gave intermediate yields—sorghum/pigeonpea (2800 kg ha^{-1}) and sorghum-chickpea (2200 kg ha^{-1}). The results shown in Figure 16a are for sorghum grown as a sole crop in the 1984 rainy season; similar results were obtained when sorghum was grown in a sorghum/pigeonpea intercrop (Fig. 16b).

These results indicate that the inclusion of one legume crop in the double-cropping system in 1984 gave a residual effect equivalent to 15-40 kg of fertilizer-N ha^{-1}; and that N uptake by the sorghum increased by 11-22 kg N ha^{-1}.

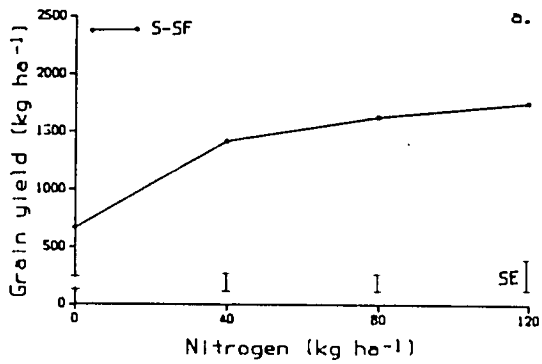
Postrainy-season crops were markedly affected by the previous crop or sequence of crops. An early indication was provided by safflower. In the initial year (1983), safflower after a rainy-season crop of sorghum gave a strong response to fertilizer-N inputs, in line with other results obtained previously at ICRISAT Center (ICRISAT Annual Report 1983 pp. 258, 1984 pp. 260). And, in 1984, a range of different cropping systems produced somewhat similar low yields (350-630 kg ha^{-1}) without added fertilizer-N, but a range of good yields (900-2450 kg ha^{-1}) with the maximum rate (120 kg N ha^{-1}) of fertilizer (Fig. 17). The responses, however, did not conform to our expectations based on legume-N inputs; the lowest response to added-N occurred in the cropping system without legumes (sorghum-safflower—sorghum-safflower).

These initial results strongly suggest that comparisons of the residual effects of the various legume versus nonlegume crops should involve not only nitrogen, but also the importance of water use by each crop in the various sequences.

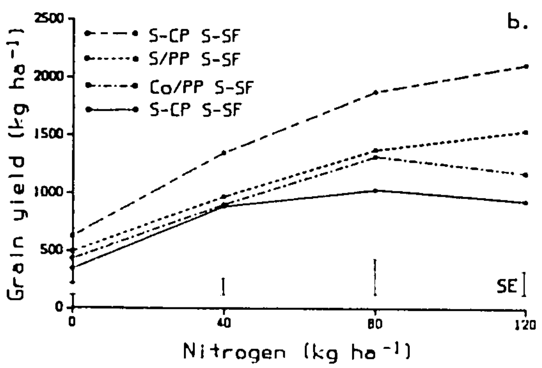
Primary Tillage

Many Vertisols have poor physical characteristics when wet; these include low infiltration rate, and poor aeration, poor trafficability, and workability. We therefore, initiated an experiment to measure the long-term effects of different tillage practices and soil amendments primarily designed to alleviate physical constraints.

Various tillage treatments, described in Table 15, were applied during the subsequent postrainy season (in early 1983). A sequential cropping system of maize (DH 103)-chickpea (Annigeri) was used, with a medium level of fertilizer application (60 kg N ha^{-1} and 13 kg P ha^{-1}).



a. Previous cropping system 1983/84
S-SF $y=690+20.5x-0.099x^2$ R=0.58



b. Previous cropping system 1984/85

S-CP S-SF	**$y=620+21.6x-0.049x^2$**	**R=0.94**
S-PP S-SF	**$y=490+14.7x-0.049x^2$**	**R=0.82**
Co/PP S-SF	**$y=410+18.2x-0.097x^2$**	**R=0.83**
S-SF S-SF	**$y=360+16.8x-0.100x^2$**	**R=0.91**

rse = 97

Figure 17. Effect of previous cropping system in a. 1983/84 and b. 1984/85 on response of safflower yield (kg ha^{-1}) to fertilizer-N, on a Vertisol at ICRISAT Center, 1985.

We intend to conduct this experiment for at least 5 years, so that we can determine the long-term effects of alternative tillage practices. However, consistent treatment effects were obtained in the first 2 years, 1983/84 and 1984/85.

Zero tillage significantly reduced grain yields of both maize and chickpea in both years. The lower yield of chickpea may be attributed at least partly to inadequate weed control by prometryne. But, atrazine controlled weeds in maize at least as well as tillage, so we attribute the lower yield of maize in the zero-tilled treatment to reduced infiltration and/or an inadequate seedbed. This aspect needs further investigation.

There was no significant ($P < 0.05$) difference between grain yields on the normally tilled (15-cm deep) and deep-tilled (30-cm deep) treatments for either of the two surface configurations (Table 16). We expect that it is not necessary to till Vertisols below seeding depth. Cross-plowing and reforming beds every year did not improve yields.

Blade-hoeing (T_6) after harvesting the rainy-season crops and before sowing the postrainy-season crops significantly increased the yield of postrainy-season chickpea in 1983/84; without blade-hoeing (T_7), yields were 200 kg ha^{-1} lower, reflecting the poorer weed control and seedbed conditions.

Incorporation of crop residue (T_9) and application of phosphogypsum (T_8) significantly increased grain yields of both maize and chickpea in 1983/84, a relatively wet year, but not in 1984/85 the drier year. We will study the effects of these treatments on soil physical and chemical properties.

We measured infiltration rates using a double-ring infiltrometer, after the chickpea harvest in 1983/84 (Fig. 18). Tilling increased infiltration, compared to zero tillage, but tillage depth had relatively little effect on infiltration rate. Incorporation of crop residues markedly increased infiltration only during the first few minutes of the infiltrometer test, but the application of phosphogypsum caused a sustained increase in infiltration rate.

Table 15. Effect of different tillage practices and amendments on runoff and soil loss from maize plots, Vertisol, ICRISAT Center, rainy season 1984.

Treatment	17 July rainfall 39 mm		1 August rainfall 91 mm	
	Runoff (mm)	Soil loss (t ha^{-1})	Runoff (mm)	Soil loss (t ha^{-1})
T_1 Zero tillage	6.8	60	14.8	103
T_4 15-cm deep tillage (normal tillage)	4.4	110	12.9	205
T_6 30-cm deep tillage	2.1	65	7.5	93
T_8 30-cm deep tillage + phosphogypsum	1.3	25	1.8	35
T_9 Crop residue + 30-cm deep tillage	2.0	70	7.4	98
SE	±0.20	±5.9	±0.53	±4.9

Because 1984 was a dry year, there were very few occasions when runoff was appreciable. Runoff and soil loss on two dates in 1984 are given in Table 15; the treatment effects were consistent and in agreement with the infiltration measurements. Runoff was highest from the zero-tilled plots and it was higher from soil tilled to normal depth (15 cm) than from deep-tilled (30 cm) soil. The phosphogypsum treatment gave least runoff, less than 20% of that from the

Table 16. Effect of different tillage practices and amendments on grain yields (kg ha^{-1}) of maize and chickpea, Vertisol, ICRISAT Center, 1983/84 and 1984/85.

Treatment		Yield (kg ha^{-1})			
		1983/84		1984/85	
		Maize RS[1]	Chickpea PRS[1]	Maize RS	Chickpea PRS
Flat Configuration					
T_1	Zero tillage (including chemical weed control)	3500	330	2320	340
T_2	15-cm deep primary tillage (normal tillage)	4030	990	2970	970
T_3	30-cm deep primary tillage	4390	1160	3140	1060
BBF Configuration					
T_4	15-cm deep primary tillage (normal tillage)	4380	1150	3320	1090
T_5	15-cm deep primary tillage, cross plowing and reformation of beds every year	4290	1160	3110	1030
T_6	30-cm deep primary tillage	4240	1050	3300	1170
T_7	30-cm deep primary tillage (without blade hoeing before sowing second crop)	4210	830	3280	1060
T_8	30-cm deep primary tillage + application of phosphogypsum at 10 t ha^{-1}	4710	1280	3270	1060
T_9	Crop residue[2] incorporation at 5 t ha^{-1} with 30-cm deep primary tillage	5010	1240	3240	1250
SE		±133	±49	±105	±56

1. RS = rainy season; PRS = postrainy season.
2. Chopped dry rice straw incorporated in 1983/84, chopped dry maize stalks incorporated in 1984/85.

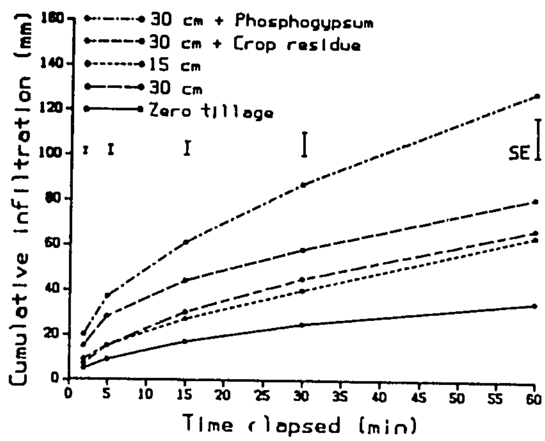


Figure 18. Effect of tillage and soil amendments on cumulative infiltration during the first hour of an infiltration test, ICRISAT Center, 1985.

zero-tilled treatment. The treatments ranked differently for soil losses in runoff than for the runoff itself. Normal tillage (15-cm depth) caused the greatest soil loss, and phosphogypsum caused the least, losses were similar in the other three treatments.

Experiments Across Different Environments

Mali

The objective of the agronomy program in Mali continues to be the development of improved cropping systems based on sorghum and pearl millet. As part of this objective, we assist the crop improvement program to identify more productive and agronomically responsive sorghum and millet cultivars, especially those suitable as components of cropping systems. Because groundnut is a useful cash crop, with good residual effect due to its biological N fixation, this year we initiated studies on cereal/groundnut intercropping systems. We began to examine the production potential of using sorghum and pearl millet as the component cereal in groundnut-based intercropping systems. We also began to study the agronomic requirements of these cropping systems. We examined such factors as cereal density, groundnut density, and the time of sowing the cereal intercrop using factorial experiments at different locations in southern Mali.

Our studies on groundnut-based intercropping were aimed at two agroecological areas in Mali: the southern Sudanian zone in southwestern Mali, with relatively assured rainfall, for sorghum/groundnut intercropping; and the northern Sudanian zone in central Mali, where medium-duration pearl millet is the appropriate cereal for light-textured soils under lower rainfall conditions.

For the sorghum/groundnut intercropping experiments, we used two benchmark sites, at Sotuba where the average annual rainfall is 1080 mm, and Kita where the long-term average annual rainfall is 1151 mm; and for pearl millet/groundnut, we used the benchmark site at Cinzana (where the average rainfall is 720 mm). The actual rainfall at these sites in 1985 was slightly to severely below average, being 957 mm at Sotuba, 641 mm at Kita, and 560 mm at Cinzana.

Sorghum/Groundnut Intercropping

Our experiments at both sites used a short-statured, short-duration sorghum (Malisor 84-7) and a locally recommended groundnut (cv 47-10).

Intercropping appreciably increased productivity at both sites. At Sotuba, the Land Equivalent Ratio (LER) was 1.30-1.40, and at Kita it was greater than 1.60. The three agronomic-management treatments—population of each component (sorghum, groundnut) and sowing date of sorghum—gave fairly consistent effects across the two sites (Tables 17 and 18). Higher groundnut density increased groundnut yields, but did not significantly ($P<0.05$) reduce sorghum yields. Higher sorghum populations decreased groundnut yields, but did not increase sorghum yield significantly. A delay in the sorghum sowing date increased groundnut yield at both sites ($P<0.05$); it increased sorghum yield slightly ($P<0.10$) at Kita, but severely reduced yields ($P<0.001$) at Sotuba. This contrasting effect between the two sites reflects the differences in

Table 17. Effect of population (plants ha^{-1}) and sowing date on performance of sorghum/groundnut intercrops, Sotuba, Mali, rainy season 1985.

	Sorghum			Groundnut			
Treatment	Population at harvest (plants ha^{-1})	Grain yield (kg ha^{-1})	LER[1]	Population at harvest (plants ha^{-1})	Pod yield (kg ha^{-1})	LER	Combined LER sorghum grain + groundnut pods
Groundnut population							
130000	38600	1710	0.72	86800	710	0.57	1.29
200000	36400	1630	0.68	113000	906	0.72	1.40
260000	35800	1460	0.61	161800	1018	0.82	1.43
SE	±2722	±180		±4318	±114		
Sorghum population							
26000	27500	1400	0.59	122700	970	0.78	1.37
52000	46400	1800	0.75	119100	785	0.63	1.38
SE	±1066	±141		±7272	±94		
Sorghum sowing date at							
groundnut sowing date	39700	2130	0.89	122700	695	0.56	1.45
4 weeks later than groundnut sowing date	34100	1070	0.45	119100	1060	0.85	1.30
SE	±2138	±98		±7272	±88		
CV (%)	29	44		29	53		

1. LER = Land Equivalent Ratio calculated using trial means for respective sole crops grown with locally recommended package of agronomic practices.

the sites and treatments. Although rainfall at Kita was much lower than at Sotuba, it was better distributed throughout the season; and, at Kita, sorghum sowing was only delayed by 2 weeks whereas it was delayed by 4 weeks at Sotuba.

These initial results showed good consistency across the two locations; intercropping gave substantial increases in productivity, and the best productivity was achieved by using higher populations of groundnut and lower populations of sorghum. We will continue these studies, to assess the reliability of treatments across years.

Pearl Millet/Groundnut Intercropping

In 1985 at Cinzana, we used a locally recommended pearl millet cultivar (M9 D3) with groundnut (cv 47-10). Rainfall was low (560 mm) and poorly distributed, and crops experienced drought stress. Yields, especially of pearl millet, were low (Table 19).

Groundnut yield was substantially increased by increasing the groundnut population and by delaying the pearl millet sowing by 2 weeks, but was not affected by an increase in pearl millet population. The low yields of pearl millet were not markedly increased by changes in pearl millet or groundnut populations, nor by the pearl millet sowing date.

Intercropping substantially increased productivity, ranging from 29% to 75% across the experiment, as shown by the high LERs. This, plus an interest in cash crops, such as groundnut in southern Mali, and good infrastructure for increasing groundnut production, encourages us to continue these studies.

Evaluation of Sorghum Genotypes under Intercropping

We evaluated nine sorghum cultivars obtained from the sorghum improvement programs of Nigeria, Burkina Faso, and Mali for their performance under sole-cropping and intercropping with cowpea. Normal plant population of 50000 plants ha^{-1} was maintained in both cropping systems. About 30000 plants ha^{-1} of cowpea was sown in a cereal/cowpea row arrangement of 2:1. Table 20 shows the performance of sorghum cultivars under sole and intercropping with cowpea. CSM 388, a Malian-improved local sorghum cultivar, which is long-duration and tall-statured, suffered due to late-season drought resulting in poor grain yields. S 34, S 35, Malisor 84-1, and Malisor 84-7—which are all short-duration and short-statured—yielded more than 2000 kg ha^{-1}. Cowpea productivity was assessed by fodder weights, as the crop was not treated with insecticides to ensure grain production. Intercropping greatly reduced cowpea fodder yields to 12-32% of its sole-crop yield. Cowpea fodder yield was lowest with CSM 388, and highest with Malisor 84-7. CSM 388, the tallest cultivar, provided excessive shading; Malisor 84-7, the shortest cultivar, competed minimally with cowpea.

The intercropping advantage, indicated by LERs, reflected the extent of competition offered by sorghum to cowpea. Total LER values did not reflect the grain yield potential of sorghum cultivars since S 35 and 82-S-50 yielded more when intercropped, resulting in a larger total LER. But the two top-yielding sorghum cultivars Malisor 84-1 and S 34 yielded 8-10% less when intercropped.

Table 18. Effect of population (plant ha^{-1}) and sowing date on performance of sorghum/groundnut intercrops, Kita, Mali, rainy season 1985.

	Sorghum			Groundnut			
Treatment	Population at harvest (plants ha^{-1})	Grain yield (kg ha^{-1})	LER[1]	Population at harvest (plants ha^{-1})	Pod yield (kg ha^{-1})	LER	Combined LER sorghum grain + groundnut pods
Groundnut population							
130000	22800	960	1.07	69200	1340	0.62	1.69
200000	23300	890	0.99	89400	1530	0.71	1.70
260000	21700	850	0.95	116100	1840	0.85	1.80
SE	±1580	±63		±4580	±87		
Sorghum population							
26000	16900	940	1.05	91700	1740	0.80	1.85
52000	28100	860	0.96	91700	1400	0.65	1.61
SE	±550	±51		±5280	±74		
Sorghum sowing date at							
groundnut sowing date	22500	830	0.93	90800	1380	0.63	1.56
2 weeks later than groundnut sowing date	22500	970	1.08	92500	1760	0.81	1.89
SE	±1280	±50		±9780	±72		
CV (%)	27	27		28	25		

1. LER = Land Equivalent Ratio.

Table 19. Effect of population (plants ha⁻¹) and sowing date on performance of pearl millet/groundnut intercrops, Cinzana, Mali, rainy season 1985.

Treatment	Sorghum Population at harvest (plants ha^{-1})	Sorghum Grain yield (kg ha^{-1})	Sorghum LER[1]	Groundnut Population at harvest (plants ha^{-1})	Groundnut Pod yield (kg ha^{-1})	Groundnut LER	Combined LER sorghum grain + groundnut pods
Groundnut population							
130000	38000	550	1.07	35000	510	0.34	1.41
200000	34500	520	1.01	53000	950	0.63	1.64
260000	33000	430	0.83	75000	1160	0.77	1.60
SE	±1720	±70		±1800	±73		
Millet population							
26000	30000	450	0.83	53000	850	0.56	1.39
52000	40500	550	1.06	55000	890	0.59	1.65
SE	±1030	±57		±3600	±81		
Millet sowing date at groundnut sowing date	35900	450	0.83	54000	700	0.46	1.29
2 weeks later than groundnut sowing date	34500	550	1.06	54000	1040	0.69	1.75
SE	±1440	±57		±3600	±73		
CV (%)	20	56		33	45		

1. LER = Land Equivalent Ratio calculated using trial means for respective sole crops grown with locally recommended package of agronomic practices.

Sole Crops

We commenced agronomic studies on individual sole crops using improved breeding material in the 1984 rainy season.

Sorghum. We evaluated three improved sorghum cultivars developed by the ICRISAT/Mali breeding program with CSM 388 as the local control. Table 21 shows the performance of these four cultivars at Sotuba. There were significant differences among the grain yields of different cultivars, of these CSM 388 yielded the least. The rains stopped early and this adversely affected the late-flowering CSM 388. Malisor 84-1 and Malisor 84-7 also outyielded Malisor 84-3, which was found to be highly sensitive to leaf diseases and mid-season drought. Adding fertilizer-N, or increasing the crop populations did not significantly increase yields.

Pearl millet. We evaluated five pearl millet cultivars suggested by our pearl millet breeding program for their agronomic responses under varying levels of density and added fertilizer-N at Cinzana. Although pearl millet growth was good, early in the season, following heavy rains during August, birds severely reduced grain yields later in the season (Table 22). However, ITMV 8304, IBV 8001, and Souna × Sanio outyielded the local cultivar (Pool 4). Among the high-yielding cultivars IBV 8001 produced the most panicles but being the earliest to flower it was found to be susceptible to bird damage.

Table 20. Performance of improved sorghum genotypes sole cropped, and intercropped with cowpea, Sotuba, Mali, rainy season 1985.

Genotype	Sorghum grain yield (kg ha^{-1})		Intercrop cowpea fodder yield[1] (kg ha^{-1})	Sorghum LER[2]	Cowpea LER	Combined LER
	Sole	Intercrop				
Malisor 84-1	2500	2310	780	0.92	0.25	1.17
E 35-1	1870	1460	840	0.78	0.27	1.05
82-S-50	2150	2360	740	1.10	0.24	1.34
83-F_6-222	1000	1340	880	1.30	0.28	1.58
S 35	2360	2630	740	1.11	0.24	1.35
Malisor 84-7	2020	1740	1240	0.86	0.40	1.26
Malisor 84-3	2010	1790	810	0.89	0.26	1.15
S 34	2660	2380	650	0.90	0.21	1.11
CSM 388	1100	930	360	0.83	0.12	0.95
SE	±130		±149			
CV (%)	40		43			

1. Sole cowpea fodder yield = 3120 kg ha^{-1}.
2. LER = Land Equivalent Ratio.

Table 21. Effect of plant population and fertilizer-N on time to 50% flowering (d), plant height (cm), number of panicles, and grain yield (kg ha^{-1}) of four sorghum cultivars, Sotuba, Mali, rainy season 1985.

Treatment	Time to 50% flowering (d)	Plant height (cm)	Number of panicles (ha^{-1})	Grain yield (kg ha^{-1})
Cultivar				
Malisor 84-3	66	188	61300	1630
Malisor 84-1	65	246	52000	2330
Malisor 84-7	68	149	70000	2100
CSM 388	81	448	68000	810
SE	±0.6	±4.3	±3733	±145
Population (plants ha^{-1})				
50000	71	256	55300	1820
100000	69	260	70700	1620
SE	±1.2	±20	±2866	±144
N applied (kg ha^{-1})				
0	70	257	65300	1660
50	69	259	60700	1780
SE	±1.2	±20	±2866	±144
CV (%)	11	32	24	40

Table 22. Effect of plant population and fertilizer-N on time to 50% flowering (d), plant height (cm), number of panicles, and grain yield (kg ha^{-1}) of five pearl millet cultivars, Cinzana, Mali, rainy season 1985.

Treatment	Time to 50% flowering (d)	Plant height (cm)	Number of panicles (ha^{-1})	Grain yield (kg ha^{-1})
Cultivar				
Composite Précoce	56	221	41300	770
IBV 8001	55	228	48700	800
Souna × Sanio	57	224	40700	830
Pool 4	59	232	49300	680
ITMV 8304	56	230	42000	870
SE	±1.0	±6.5	±2600	±78
Population (plants ha^{-1})				
33000	56	228	42000	860
66000	56	226	46700	720
SE	±0.6	±4.0	±1666	±48
N applied (kg ha^{-1})				
0	57	227	38000	720
50	56	227	50700	860
SE	±0.6	±4.0	±1400	±48
CV (%)	7	11	33	40

Increasing the pearl millet density reduced grain yield, and adding fertilizer-N increased grain yields. There was no significant interaction among treatments. IBV 8001 responded better to added fertilizer-N than the other four cultivars.

Central America and Mexico

ICRISAT's agronomy program in Central America involves an agronomist based at Centro Internacional de Mejoramiento de Maïz y Trigo (CIMMYT) in Mexico working cooperatively with national programs throughout the region. The major objective is to improve the productivity of cropping systems by introducing improved sorghum cultivars. Associated agronomic studies are needed to assess the requirements for improved management. Flexibility is required in our approaches, because the range in altitudes in the region creates a large range in agroclimates, to the extent that cold tolerance is an important consideration for cultivars in the highlands.

In 1985, our experiments were mainly directed towards comparing cultivars for intercropping, and determining some of the agronomic management factors that are important to improve the productivity of intercrops.

Mexico

We compared the performance of two sorghum cultivars in three intercrop systems in fields of subsistence farmers in the highlands. The two sorghum varieties were the red-seeded VA 110, and the white-seeded BTP 28; other attributes of these varieties include duration, stature, and cold tolerance. The cropping systems were sorghum with barley as a component intercrop of either a single row (system S_1), or a double row (system S_2), or with a single row of beans (*Phaseolus* spp) in a similar configuration to system S_1 (system S_3). We sowed the barley and bean intercrops 6 weeks after sorghum.

The sorghum/barley intercrops all gave a LER of less than 1, indicating that separate sole crops of barley and sorghum would be more efficient than intercropping. However, the sorghum/bean intercrop (S_3) gave an LER of about 1.25, which is equivalent to an increased return of US$ 150 ha^{-1}, and a 46% return on invested capital.

Guatemala

In subsistence farmers' fields in southeastern Guatemala, we compared ICRISAT's improved sorghum cultivars and tested agronomic management techniques in various intercropping systems involving sorghum, maize, and beans that had earlier been identified as the most pertinent for the region (ICRISAT Annual Report 1984, p. 73).

Fertilizer-N, applied at 40 kg N ha^{-1} at physiological maturity of maize, increased ($P<0.10$) the yield of improved sorghum varieties grown in relay. However, sorghum grain yield varied according to variety and sowing density. The introduction of improved sorghums increased the return on invested capital from 143% to 166% for the system using local photosensitive sorghums. The nutritive quality of the improved varieties will be compared with that of the local varieties in subsequent studies.

We also studied the effects of sowing date and the introduction of beans into a sorghum/maize intercropping system. In system S_1 maize was intercropped with local photosensitive sorghums sown 25 days later; in system S_2, both components of a maize/bean intercrop were sown simultaneously, and the same varieties of sorghum as in S_1 were sown 10 days later. Although sorghum yields did not vary between the systems, maize yield decreased considerably ($P<0.01$) when beans were included in the system and sorghum sown 15 days earlier.

Honduras

Maize/sorghum intercropping, by association within the same hill ("casado" system), is very popular on small steep hillside farms in southern Honduras. We studied the fertilizer-N needs in farmers' fields. Applying 20 kg N ha^{-1} at sowing increased the sorghum yields more ($P<0.05$) than maize; applying fertilizer-N 25 days later helped the maize component further. Since maize is the locally preferred grain, the latter application of fertilizer-N may be more useful.

Regional Cropping Systems in Central America

Four maize/sorghum intercropping systems were studied in a similar trial conducted in Guatemala, Haiti, Honduras, Mexico, and Nicaragua from 1983 to 1985. The yields of maize and sorghum depended on the level of competition between the two crops. In system S_1, maize and sorghum in simultaneous association within the same row, where sorghum imposed its maximum competition, maize yielded the least, and sorghum the highest of the four systems. This resulted in minimum total grain yield and the lowest profitability of the systems. For these reasons it was recommended that subsistence farmers in the region should be discouraged from using system S_1.

The two best systems are now under more intensive study in each country. ICRISAT's varieties play a prominent role in one of the systems. Research is aimed at increasing yield of these varieties so as to improve the system's profitability.

India

Insect Control

In 1984/85, light traps at ICRISAT Center indicated that populations of several major pests were greater than in previous year. For example, the total catch of *Heliothis armigera* in our Vertisol watershed trap was 28 164 in 1984/85, compared with 2326 in 1983/84. A similar increase was evident in our *H. armigera* pheromone traps, but these traps catch fewer moths than the light traps for most of each year. *Spodoptera* *litura*, which is a sporadic pest on groundnuts, is also monitored in light and pheromone traps at ICRISAT Center. We catch far more moths of this species in our pheromone traps than in our light traps, throughout each year. While large trap catches of *H. armigera* are almost always associated with large populations of larvae on crops in our fields, we often find that large catches of *S. litura* moths are not associated with any detectable populations of larvae on nearby hosts.

A pheromone and light trap combination caught more *H. armigera* moths than independently operated pheromone and light traps. However, for *S. litura*, a pheromone and light trap combination caught far fewer moths than a pheromone trap alone. We will continue to investigate such differences, for they may be important in helping us to understand the behavior and ecology of these pests.

We have been augmenting our pest/parasitoid survey data to determine the potential contribution of natural enemies to pest control if integrated pest management is to be implemented. Table 23 gives the average rates of egg and larval parasitism recorded in *H. armigera* over the past 8 years on ICRISAT mandate crops at ICRISAT Center. Many of the eggs laid on sorghum, pearl millet, and groundnut are parasitized by *Trichograma* spp but such parasitism is rare on pigeonpea and totally absent on chickpea.

Most parasitism occurs in the early larval instars of *H. armigera* on pearl millet, sorghum, and chickpea whereas most parasitism on pigeonpea and groundnut occurs in the late instars. *Campoletis chlorideae* is the predominant parasite in the 1-3 instar larvae and *Carcelia illota* predominates in the 4-6 instar larvae on all crops except groundnut. On that crop the mermithid nematode *Ovomermis albicans* is an equally or more prevalent parasitoid during the rainy season. Although *H. armigera* generally causes little or no yield loss in groundnut, the crop acts as an important reservoir for *H. armigera* populations when other hosts are not available.

Insecticide application techniques. Although commonly recommended, high-volume (HV) spraying is not the ideal means of applying pesticides to crops, particularly in the SAT. Such spraying can give good coverage of the plants and the relatively dilute pesticide spray mix that is used reduces the toxicity hazard to the user. However, the problem of providing 600 L ha^{-1} or more of water, and the physical work involved in such spraying discourage many farmers from

Table 23. Average parasitism (%) of *Heliothis armigera* eggs and larvae sampled from ICRISAT mandate crops, ICRISAT Center, 1977-85.

Crops	Egg parasitism (%)	Larval parasitism (%) 1-3 instars by *Campoletis chlorideae* Total	Alone	4-6 instars by *Carcelia illota* Total	Alone
Sorghum	33.2 (23511)[1]	49.5 (7877)	45.7	5.8 (8537)	3.9
Pearl millet	10.5 (2986)	50.7 (584)	39.9	5.1 (355)	4.8
Groundnut	15.8 (2778)	14.3 (3492)	6.5	11.5 (3230)	1.5
Pigeonpea	0.3 (21787)	9.9 (10354)	3.4	16.4 (28171)	8.1
Chickpea	0.0 (3700)	31.9 (12969)	31.6	6.1 (13283)	5.7

1. Figures in parentheses are total numbers of eggs or larvae collected and examined over 8 years.

pesticide use. We previously reported (ICRISAT Annual Report 1984, pp. 273 and 292) the development of low volume (LV) and ultra-low volume (ULV) sprayers mounted on bullock-drawn wheeled tool carriers. Such sprayers required far less water and physical effort.

In 1984/85, we compared these two sprayers in a trial at ICRISAT Center. Sprays of endosulfan (2 L ha^{-1} of 35% emulsifiable concentrate) were applied to pigeonpea, that had been intercropped with sorghum, when 10 eggs and/or 3 *H. armigera* larvae were recorded per plant. This crop required two sprays. The summarized data of pod damage and yields are shown in Table 24. There were no significant differences between the data recorded from the two sprayer treatments but both gave substantial yield increases over the nonprotected treatment. The LV sprayer suffered from nozzle blockage, a problem that can be overcome by improvements in filtration.

We also tested the ULV sprayer in farmers' fields at Farhatabad. Here this sprayer was compared with a farmer's traditional HV sprayer mounted on a bullock cart, in two replicates of 0.1 ha plots. The results of this comparison are summarized in Table 25. It can be seen that the ULV sprayer required less labor, time, and cost than the traditional sprayer, and gave at least equal protection to the crop. The benefits were so obvious that all the farmers on the Farhatabad watershed opted to use the ULV sprayer, and it was used to spray 40 ha. One farmer arranged for a copy of this machine to be fabricated locally, and used it successfully.

Table 24. Results of pod damage analysis and yields (kg ha^{-1}) of intercrop pigeonpea (plot size 0.8 ha) sprayed twice with endosulfan (2 L 35% EC ha^{-1}) using wheeled tool carrier with ultra-low (ULV) and low-volume (LV) sprayers, ICRISAT Center, 1984/85.

	Pod damage (%)			
Treatment	Borer	Podfly	Total insects	Yield (kg ha^{-1})
Ultra-low volume	9.1	10.7	21.6	1020
Low-volume	44.5	9.9	27.3	970
Nonsprayed	51.8	11.4	62.7	450
SE	±4.23	±0.72	±4.10	±47

Safety precautions. ULV spraying has many advantages over HV spraying and is thus likely to be popular with farmers. However, such spraying has an increased toxicity hazard, for a more concentrated spray mix is used, and if the sprayer is used incorrectly or in the wrong wind

Table 25. Results of evaluation of the Tropicultor mounted ultra-low volume (ULV) and traditional bullock-cart mounted high-volume (HV) sprayer assemblies in pigeonpea, Farhatabad Vertisols watershed, 1984/85.

Evaluation parameter	Tropicultor mounted ULV sprayer	Bullock-cart mounted HV sprayer	SE
Laborers required (ha^{-1})	1	4	
Time required (h ha^{-1})	1	8	
Labor cost (Rs ha^{-1})[1]	1.25	40	
No. of applications exceeded to threshold	3	4	
Total expenditure including insecticide[2] cost (Rs ha^{-1})	556	889	
Pod damage (%)	5.4	12.3	±0.16
Yield (kg ha^{-1})	1390	1070	±68

1. Labor cost = Rs 10 d^{-1}
2. Endosulfan (2 L 35% EC ha^{-1}) applied wherever counts of *H. armigera* eggs and larvae exceeded the economic threshold.

conditions the drift of the small droplets can contaminate the body of the user and his bullocks. Research at ICRISAT on this problem has been intensified, and a video film that stresses safety precautions in pesticide use has been made.

In studies of droplet drift from a hand-held ULV sprayer used on pigeonpea (Fig. 19), an average of less than one droplet cm^{-2} was recorded on the clothing of the operator when the wind (average velocity 8.5 km h^{-1}) direction was at an angle of 70° or more to the line of walking. However, when the wind was about 45° to the line of walking, the contamination increased to 3 droplets cm^{-2}, and more than 12 droplets cm^{-2} were recorded when the angle was less than 20°. Such spraying is safest when the wind is at right angles to the crop rows and farmers are advised not to spray when winds are very strong or at an angle of less than 70° to the crop rows. Farmers are also advised to wear protective clothing and face masks. It is likely that few farmers will observe such precautions and there is little doubt that ULV spraying is more hazardous than HV spraying when carried out by untrained operators. It is therefore essential that ULV sprayers should only be used to apply relatively safe pesticides.

Figure 19. Technician testing the contamination hazard from droplet drift using a hand-held ULV sprayer on a pigeonpea crop. The spray contains a dye so that droplets drifting onto the body of the operator can be counted on the cards fixed to his clothing. ICRISAT Center, 1985.

Intercropping studies. We continued to monitor pests and parasitoids in sole- and intercrops of pigeonpea with sorghum and maize on Vertisols and with pearl millet and groundnut on Alfisols. As in the previous year, we did not find any large differences in insect activity between sole and intercrop of any crop. However, in 1984/85 a damaging incidence of the groundnut leaf miner *Aproaerema modicella* was recorded on groundnut; an average of 68% leaves were mined in both sole and intercrops. Groundnut cultivar Robut 33-1 used in our trials is highly susceptible to this pest, but this pest is not normally prevalent during the rainy season. This year's problem was considered to be related to the long dry spell which occurred in August and September during the rainy season.

As in 1984 pigeonpea pod damage was higher on Vertisols (65%) than on Alfisols (39%). The parasitism rates recorded from the larvae of *H. armigera* collected from sole and intercrops of any crop, and from the two soil types, did not differ greatly.

Weed Control

Intensive cropping on both Alfisols and Vertisols at ICRISAT Center has led to severe nut grass (*Cyperus rotundus*) and Bermuda grass (*Cynodon dactylon*) infestations. The severity of the problem created by these perennial weeds is highlighted by the fact that tillage has not controlled these weeds, although it is effective under less-intensive systems. Therefore, we have recently commenced studies on the use of herbicides.

We conducted an experiment in 1981 and 1982 (ICRISAT Annual Report 1982, pp. 260-261) to study the effects of different tillage systems on the control of Bermuda grass on broadbeds and furrows (BBF) on a medium-deep Vertisol. The treatments included strip tillage, complete tillage (or split-strip tillage), and deep plowing and rebuilding of beds every year, all with sorghum/pigeonpea intercropping. The traditional system of cropping only in the postrainy season with traditional tillage on flat land was also included as a treatment.

The experiment was modified in 1984 to include, in addition to the above tillage systems, three herbicide treatments—pre-emergence application of atrazine to the rainy season crop, postemergence application of glyphosate (Roundup®) directed between rows, and postemergence application of fluazifop butyl. Maize-chickpea sequential cropping was followed except that cowpea was substituted for maize in the rainy season in the fluazifop butyl treatment because cereal crops are sensitive to this chemical. Double cropping was used in the traditional flat cultivation system and in a nonweeded control. We made the studies in field-sized plots (300 m^2 to 400 m^2) using animal-drawn equipment for all operations.

Double cropping on the BBF system gave 1.7 to 2.6 times greater returns than single-season cropping on flat land (Table 26). Yields from double cropping on flat land with traditional tillage methods were low (Table 27); nevertheless returns were good because of lower operational expenses. However, where no efforts were made to control Bermuda grass, double cropping made a loss. Of the three tillage systems on BBF, cross plowing and remaking of beds every year was most effective in controlling Bermuda grass. Though it involved some additional expenses, it still gave 51% higher returns in sorghum/pigeonpea and 33% in maize-chickpea over other tillage systems. There was no significant difference in net returns between strip tillage and complete tillage. Atrazine, generally recommended for weed control in maize, controlled all annual weeds but not Bermuda grass. In the absence of competition from other weeds, Bermuda grass flourished well in this herbicide treatment and reduced the yield of the low-canopy chickpea (Table 27). This indicates the need for specific herbicides to control this perennial weed. Glyphosate controlled Bermuda grass very well; this was reflected in the high chickpea yield but not in maize because the herbicide was applied about 4 weeks after the maize emerged by which time maize growth was already reduced by competition. For directed postemergence application of this chemical in a standing crop, suitable equipment (e.g., a wick applicator, or normal sprayers with protective hoods) is a prerequisite. Fluazifop butyl was as effective as glyphosate.

We conducted experiments on both Vertisols and Alfisols to evaluate the efficacy of glyphosate in controlling nut grass. Treatments included

Table 26. Effect of different tillage systems on the control of Bermuda grass (*Cynodon dactylon*), crop yields, and net returns of sorghum/pigeonpea intercrop on Vertisols (mean of 2 years 1981/82, 1982/83).

Treatment	Crop yield ($kg\ ha^{-1}$)		Net returns ($Rs\ ha^{-1}$)	Dry matter of Bermuda grass ($g\ m^{-2}$)		
	Sorghum	Pigeonpea		At first interculture	At sorghum harvest	At pigeonpea harvest
Strip tillage	3170	570	4780	49	319	119
Complete tillage	3540	600	5090	31	239	114
Deep plowing and rebuilding of beds	4030	1030	7470	12	135	82
Traditional	1110	-	2890	30	259	54
SE	±200	±92	±507	±12	±32	±16

Table 27. Effect of different herbicide and tillage systems on the control of Bermuda grass (*Cynodon dactylon*), crop yields, and net returns of maize-chickpea sequential cropping system on Vertisols, ICRISAT Center, 1984-85.

Treatment	Crop yield (kg ha⁻¹)		Net returns (Rs ha⁻¹)	Dry matter of Bermuda grass (g m⁻²)		
	Maize	Chickpea		At first interculture	At maize harvest	At chickpea harvest
Strip tillage	1260	430	3770	6	8	64
Complete tillage	880	460	3370	21	24	76
Deep plowing and rebuilding of beds	1170	630	4750	4	17	58
Atrazine (1.5 kg a i ha⁻¹)	1270	340	2990	10	37	159
Glyphosate (Roundup® at 1.5% V/V)	900	730	4490	2	12	34
Fluazifop butyl (0.3 kg a i ha⁻¹)	830	560	5650	4	5	73
Traditional (Double cropping)	860	340	3740	4	30	61
Nonweeded control	170	30	-330	10	23	22
SE	±132	±92	±565	±1.3	±5.5	±10.0

different concentrations of the herbicide, single deep plowing with disc or moldboard plows, and fallowing the land during the rainy season followed by repeated applications (three) of glyphosate. Sequential crops of sorghum-chickpea were grown on Vertisols, and pearl millet-groundnut on Alfisols; these are appropriate rotations on these soils. Nut grass counts (Table 28) together with crop yields (Table 29) indicate the weed control achieved by different treatments. Glyphosate was very effective in controlling nut grass on both soils. There was no signifi-

Table 28. Effect of glyphosate (Roundup® 2%) on nut grass (*Cyperus rotundus*) counts in comparison with discing, moldboard plowing or zero-tilled fallow, ICRISAT Center, rainy season 1984/85.

Treatment	Nut grass counts (number m⁻²)							
	Vertisols							
	24.5.84	18.6.84	12.7.84	9.8.84	28.9.84	12.10.84	17.12.84	21.1.85
Glyphosate 2%	126	46	34	30	30	11	11	2
Discing	96	5	60	124	221	189	135	59
Moldboard plowing	124	8	90	104	91	75	74	20
Fallow control	26	7	71	93	92	161	91	48
	Alfisols							
	15.6.84	10.7.84	3.8.84	10.10.84	14.12.84	19.1.85	14.3.85	
Glyphosate 2%	143	33	17	7	6	4	8	
Discing	20	188	83	135	57	102	209	
Moldboard plowing	5	72	166	59	63	143	288	
Fallow control	52	173	157	209	127	143	283	

Table 29. Effect of glyphosate (Roundup®) on the control of nut grass (*Cyperus rotundus*) on Vertisols cropped to sorghum-chickpea and on Alfisols cropped to pearl millet-groundnut, ICRISAT Center, rainy season 1984/85.

	Yield (kg ha^{-1})			
	Vertisols		Alfisols	
Treatment	Sorghum	Chickpea	Pearl millet	Groundnut
Glyphosate 3% + interculture	5080	550	2540	1590
Glyphosate 2% + interculture	4230	710	2190	1690
Glyphosate 1% + interculture	3990	610	2460	1020
Glyphosate 2%	3960	510	280	760
Discing + interculture	4010	680	1450	1470
Moldboard plowing + interculture	3830	720	2240	800
Fallow and repeated applications of glyphosate in rainy season				
Glyphosate 3%		440		1770
Glyphosate 2%		550		1870
Glyphosate 1%		390		1560
SE	±820	±152	±139	±232
CV (%)	19.5	26.7	7.5	16.7

cant difference between the different concentrations used, except that herbicide sprays of 2% and 3% concentration whether applied once or more than once, gave a higher yield of groundnut than the 1% concentration applied once or twice. Glyphosate application alone did not give adequate control of annual weeds; for these, it should be supplemented with intercultures or hand weedings. Repeated glyphosate sprays within a year did not improve the nut grass control over that achieved with one spray applied when nut grass is at the 7-8 leaf stage. The final counts of nut grass were affected slightly by plowing, but the weed appearance was delayed in the moldboard-plowed area by about 3 weeks. Soil inversion, by moldboard plowing, buries the nut-grass nuts originally on the soil surface and exposes those at lower depths, so that they are dessicated. However, the effect of tillage on crop yields was less consistent. The similarities between weed counts after both the plowing methods, and those under zero-tilled or the nonsprayed control conditions indicate that plowing does not effectively control this weed.

Agroforestry

Agroforestry is an alternate land-use system in which multipurpose woody perennials are grown in association with arable crops. Agroforestry systems have special significance in the context of the whole farm development concept as they meet several demands of the farm such as food for man, forage for livestock, fuel for cooking, and timber for shelter. These systems may be appropriate for any soil type but they may be more attractive economically for shallow soils where arable crops may be less productive. Our involvement in agroforestry research is considered as a natural extension of our intercropping work to further exploit the association amongst species by introducing perennials into annual cropping systems. In 1984 we started agroforestry work on *Leucaena leucocephala*, a fodder and fuel-yielding perennial introduced into the annual cropping systems. Emphasis was placed more on research methodology, particularly on experimental designs and characterization of resource use, than on developing different systems.

Experiments in this initial phase included a geometrical design to study the competition between leucaena and annual crops and to examine whether row orientation would influence the productivity of their association, a 2-way systematic design to determine the optimum proportion of leucaena and the annual crop, and the proximity at which they can be planted, and a multidisciplinary experiment involving agronomists, soil scientists, and engineers to monitor biological production, long-term changes in soil chemical and physical properties, and runoff and soil erosion in alley-cropping systems with leucaena.

Leucaena established very well in all the experiments and did not show any noticeable competition in the 1st year (1984) on annual crops such as sorghum, sorghum/pigeonpea, and pearl millet/pigeonpea intercrops grown in this order in the above experiments. In 1985, sunflower, sorghum/pigeonpea, and castor were the annual crops. Leucaena growth was little affected by the annual crops and by the end of the 1985 rainy season, had been harvested 4 or 5 times. But leucaena was very competitive to the annual crops causing significant reduction in their growth. The competition in this year when rainfall was 30% below average was obviously for moisture, and the detrimental effect of leucaena on a moisture-sensitive crop such as sunflower extended up to a maximum of 3.0 m. A preliminary examination of leucaena's rooting system indicated that its roots spread out laterally beyond 2.0 m. More information is required to devise suitable spacing for leucaena/annual cropping systems.

Experimental leucaena plants at ICRISAT Center with roots exposed to show extent of rooting system.

Technology Assessment and Policy Analysis

On-farm Tests of Residual Effects of Phosphorus Fertilizer on Pearl Millet Yields in Niger

We determined the residual effect of phosphorus fertilizer in four villages in western Niger. Two of the villages, Fabidji and Gobery, are in the Dollol Bosso region, south of Niamey. Soils in these village are of the Tanchia series. The other two villages, Samari and Sadeize Koira are in the Zarmaganda region, north of Niamey. Soils are uniformly sandy with an irregular topography.

Mean annual rainfall of the two regions and the rainfall in the villages between 1982 and 1985 are shown in Table 30. Rainfall in 1985 was higher than in 1984 in all the villages except Sadeize Koira. In Samari the rainfall was substantially higher than in 1984 and was very well distributed.

In 1984 we tested phosphorus fertilizer on about 30 farmers' fields in each study village (ICRISAT Annual Report 1984, pp. 325-327). Two sources of phosphorus, single superphosphate (SSP), and partially acidulated (50%) Niger Parc-W rock phosphate (PARP 50) were compared at four levels of 0, 12, 24, and 36 kg P ha^{-1}, using farmers' local varieties of pearl millet.

The treatments consisting of no fertilizer, one level of SSP, the same level of PARP 50, and a different dose of either SSP or PARP 50 were applied in 250 m^2 plots by each farmer.

Because of the drought in 1984 the tests in the two northern villages (Sadeize Koira and Samari) produced no yield. Millet grain yields were low

Table 30. Annual rainfall (mm) in four villages where farmers' tests were conducted in western Niger, 1982-85.

Villages	Long-term average	1982	1983	1984	1985
Dallol Bosso	600				
Fabidji		517	410	369	413
Gobery		540	392	422	425
Zarmaganda	400				
Sadeize Koira		240	361	215	215
Samari		210	345	160	345

in the other two villages, but they were 44-130% higher for all treatments with fertilizer compared to treatments without fertilizer. But the increases were only significant ($P<0.05$) at the 24 kg and 36 kg P ha^{-1} level, except for the 36 kg P as PARP 50. Using partial budget analysis to examine the profitability of fertilizer use under the conditions prevailing in 1984, we concluded that, provided farmers sow their pearl millet crops on time and there is sufficient rainfall to harvest a crop, phophorus fertilizer application up to the 24 kg P ha^{-1} level is likely to be economical.

This year we used the same farmers and the same plots to measure the residual effect of the phosphorus fertilizer applied in 1984 on pearl millet yields in 1985. No fertilizer was applied to the plots in 1985.

Because farmers did not plant some of their 1984 fields this year, and because of difficulties in identifying plot borders, only a total of 57 trials out of a potential of 120 (14 in Samari, 21 in Sadeize Koira, 10 in Gobery, and 12 in Fabidji) could be successfully completed. Because of the unbalanced design the number of plots varied per treatment as shown in Table 31. Apart from those in Samari, all 36 kg P ha^{-1} treatments gave 10-75% higher grain yields than the treatments without fertilizer (Table 31). But in only one case (36 kg P ha^{-1} as SSP in Gobery) was the increase significant ($P<0.05$). The 24 kg P ha^{-1} as PARP 50 treatments generally gave no higher yields than the treatments without fertilizer,

Table 31. Residual effect of phosphorus fertilizer on mean yield (kg ha^{-1}) of local pearl millet varieties. Farmers' test results from four villages in western Niger, 1985.

		Treatments[1]						
Village		1	2	3	4	5	6	7
Fabidji	Plots	12	7	5	8	8	-	7
	Mean	300	280	240	380	210	-	360
	SE	±86.3	±58.2	±111.8	±60.8	±47.0	-	±72.2
Gobery	Plots	10	3	5	5	5	5	7
	Mean	140	150	160	250	230	250	300
	SE	±25.3	±43.3	±58.6	±47.0	±38.9	±68.0	±73.3
Samari	Plots	14	8	7	8	6	8	5
	Mean	270	340	260	220	370	230	300
	SE	±46.0	±53.4	±58.2	±30.8	±79.6	±43.1	±31.3
Sadeize Koira	Plots	21	9	11	11	11	12	9
	Mean	110	110	180	150	120	200	170
	SE	±17.2	±21.0	±32.0	±26.5	±17.8	±29.2	±22.0

1. P applied (kg ha^{-1} basis) per treatment: 1 = 0, 2 = 12 as partially (50%) acidulated rock phosphate (PARP 50), 3 = 24 as PARP 50, 4 = 36 as PARP 50, 5 = 12 as single superphosphate (SSP), 6 = 24 as SSP and 7 = 36 as SSP. All plots received 30 kg N ha^{-1}.

except in Sadeize Koira where they gave 60-90% higher yields. These increases were significant at $P<0.05$.

Given that there is some residual effect of phosphorus, two questions arise. First, where there was a harvest in 1984 (and we have shown that 24 kg P ha^{-1} was the most profitable dose in Gobery and Fabidji), is the additional yield increase, due to the residual effect of phosphorus, sufficient to increase total returns to the 36 kg P ha^{-1} treatment above that for the 24 kg P ha^{-1} treatment? Secondly, in those villages with no harvest in 1984 (Sadeize Koira and Samari), were the yield increases in 1985 sufficient to cover the costs of the fertilizers applied in 1984?

Table 32 presents the results of partial budget analyses used to examine these questions. The addition of 1985 returns increased net financial benefits further at both the 24 and 36 kg P ha^{-1} levels in both Fabidji and Gobery. Although in contrast to 1984, when total net benefits at 36 kg P ha^{-1} were positive even when unsubsidized fertilizer prices were used, they were still less than those at 24 kg P ha^{-1}.

The sum of 1984 and 1985 benefits were positive using both subsidized and unsubsidized fer-

Table 32. Pearl millet grain yields (kg ha^{-1}) and economic returns in 1984 and 1985 at different levels of phosphorus applied in 1984 for farmers who sowed their crops on time in four study villages in western Niger,[1] 1985.

	1984			1985			R/P[4]		
Phosphorus level[2]	No[3]	Mean	SE	No	Mean	SE	1984	1985	Total[5]
Fabidji									
0	17	160	±15.5	12	300	±85.4	-	-	-
12	14	220	±37.7	15	240	±36.7	3.3	-8.6	-3.6
24	17	260	±24.0	6	400	±178.8	3.1	6.0	7.9
36	20	230	±23.7	15	370	±45.2	1.6	1.5	2.8
Gobery									
0	20	150	±25.7	10	140	±25.3	-	-	-
12	16	210	±24.5	8	200	±30.4	3.3	8.4	10.0
24	23	260	±28.8	10	200	±44.9	3.5	3.8	6.5
36	36	290	±22.5	12	280	±45.9	2.8	4.6	6.5
Samari									
0	-	0	-	14	270	±46.0			
12	-	0	-	14	350	±44.1	0	5.2	4.2
24	-	0	-	15	240	±34.6	0	-1.6	-1.8
36	-	0	-	13	250	±24.1	0	-0.6	-0.6
Sadeize Koira									
0	-	0	-	21	110	± 6.3	-	-	-
12	-	0	-	20	120	±13.2	0	1.1	0.9
24	-	0	-	23	190	±21.3	0	3.9	3.1
36	-	0	-	20	160	±17.0	0	1.6	1.3

1. Prices used are the average prices paid by farmers in the study villages and were 130 F CFA kg^{-1} for millet grain in 1984 and 200 F CFA kg^{-1} in 1985, 8 F CFA kg^{-1} for millet straw in 1984 and 12 F CFA kg^{-1} in 1985, 109 F CFA kg^{-1} for N and 200 F CFA kg^{-1} for P.
2. Nutrient base (kg P ha^{-1}).
3. No =Number of plots.
4. Net returns (F CFA) per F CFA spent on phosphate fertilizer.
5. 1985 net returns discounted at 25 %.

tilizer prices at 12 kg P ha^{-1} in Samari and 24 kg P ha^{-1} in Sadeize Koira.

We therefore amplify our conclusion of last year by adding that even when there is total crop failure in the year of application of phosphorus fertilizer, use of up to 24 kg P ha^{-1} is likely to be economical, since phosphorus fertilizer has a residual effect that is likely to increase yields sufficiently in the following year to allow full recovery of the fertilizer cost.

Rock Bunds for Erosion Control in Burkina Faso

In 1985, we began a pilot-scale 2-year test of a system of rock bunds for water harvesting in farmers' fields in Burkina Faso. A simple rock bund water-harvesting system was introduced in Burkina Faso by the Oxford Famine Relief Agency (OXFAM). The bunds are approximately 0.3 m high and are placed about 20 m apart along the contour lines of the field. Bunds are expected to increase yields in the short term because they improve available soil moisture and reduce loss of fertilizer. Additional benefits from rock bunds can be expected in the longer term because they help to control soil erosion. In our trials, rock bunding was combined with fertilizer application, seed of sorghum ICSV 1002, and tied ridges. The objectives of the trials are to assess the effect of bunds on sorghum yield in different rainfall zones, to determine complementarities of bunds with the other treatments, to identify important constraints to adoption, and to explore potential design improvements.

In 1985 our tests included trials that were managed by researchers as well as by farmers. The researcher-managed trials were conducted in one village each of the Sudanian and Northern Guinean bioclimatic zones of Burkina Faso. In the farmer-managed trials, eight farmers from each of our four study villages selected a section within their sorghum fields where they believed bunding to be appropriate. The farmers were provided with rocks for the bunds, fertilizer, and sorghum seed. Draft animals were owned by 16 of the farmers. These farmers could obtain equipment on loan to establish tied ridges. Only 10 farmers used this equipment on all their test sites. The contour lines on each test site were traced by ICRISAT field staff, but farmers constructed the bunds themselves and carried out all cultural operations.

Our results from the researcher-managed pilot trials indicated that the bunding package can increase yields by more than 500 kg ha^{-1} in both zones. Average yield increases from the package in trials managed by farmers varied considerably and appear to be associated with total rainfall and runoff intensity. Table 33 suggests that particularly high yield increases may be obtained from the package in regions where rainfall is low but runoff is high, and where higher rainfall levels are combined with occasional heavy or moderate runoff. Bunding has only a moderate effect on yield where moderate runoff prevails in low rainfall zones. Virtually no additional yields can be expected in moderate rainfall zones with infrequent or light runoff.

The costs of establishing rock bunds are commensurate with alternative investment opportunities, the package based on rock bunds would have to result in a sorghum yield increase of at least 150 kg ha^{-1} at present price and wage levels.

We gained important insights from interviews to find out farmers' perceptions of, and experiences with, the rock bunds and the ancilliary treatments. Farmers from both zones mentioned that their terminology for land types clearly distinguishes those that receive runoff and that would benefit from water harvesting. Farmers agreed that transport, and not availability of rocks, would be the major constraint to large-scale adoption of rock bunding. The IITA/SAFGRAD tied ridger that we supplied to the farmers was found to be unsatisfactory. Farmers complained about its size and weight, that it is prone to breakage, and that it is difficult to operate in the presence of bunds. Farmers regarded our sites for researcher-managed trials as inappropriate. According to them, neither site received sufficient runoff from upslope catchments. Nearly all farmers reported substantial accumulation of soil and organic matter at the bunds, and at some sites there was an accumula-

Table 33. Effects of rock bunding and sorghum variety ICSV 1002 on grain yield (kg ha^{-1}) in farmers' fields in four villages in two agroclimatic zones, Burkina Faso, 1985.

Yield and other aspects	Agroclimatic zone			
	Sudanian		Guinean	
	Kolbila	Ononon	Koho	Sayero
Number of fields	8	7	8	8
Rainfall in 1985 (mm)	514	487	922	715
Fields receiving heavy runoff	5	1	0	1
Fields receiving moderate runoff	2	5	2	1
Sorghum grain yield (kg ha^{-1}) with				
bunding and ICSV 1002	730	350	670	1010
Control	230	160	650	600
SE	±118	±67	±206	±233

tion of 0.20 m of top soil. Either higher bunds will have to be constructed at some sites or substantial maintenance work will be necessary.

We will repeat our package tests with more farmers and on more carefully chosen sites for researcher-managed trials. We will also try a group action approach to facilitate transporting bunding material with locally available resources.

Earthen Bunds for Erosion Control in Burkina Faso

The Fond de l'eau et de l'equipement rural (FEER) is the agency responsible for a contour-bunding program in Burkina Faso. We have collaborated with this agency since 1982 to evaluate short-term effects of earthen bunds for water management. Compared to the rock-bund systems described earlier, earthen bunds are less stable and their objective is to eliminate runoff rather than collect it and control its flow. Our method of evaluation was described earlier (ICRISAT Annual Report 1983, p. 314). We now have results from tests conducted during 3 years in 25 villages spread from the Northern Sahelian to the Southern Sudanian bioclimatic zones.

Bunds increased sorghum grain yields by 30% and pearl millet grain yields by 43% (Table 34). Absolute increases in grain yields were greatest in the central and southeastern regions of Burkina Faso.

Regression analysis showed that earthen bunds have significant positive effects on grain yields when combined with fertilizer and when used on fields with a steep slope in high rainfall areas.

Table 34. Effect of earthen contour bunds on sorghum and pearl millet grain yields (kg ha^{-1}) from farmers' fields in 25 villages, Burkina Faso, 1982/84.

Treatment	Crop		Region		
	Sorghum	Pearl millet	North	Central	Southeast
Plots within bund system	740	300	180	590	580
Control plots outside bund system	570	210	130	430	440
Percentage yield increase over contour plots	+30	+43	+38	+37	+32
SE	±68	±21	±22	±56	±53
Number of observations	100	234	126	103	105

Table 35. Internal rates of return from 30 000 F CFA investment in earthen bunding at different levels of annual maintenance costs in three regions of Burkina Faso.

Annual maintenance cost (F CFA ha^{-1})	Region		
	North	Central	Southeast
0	12.4	47.9	41.8
750	9.1	45.3	39.2
1500	5.6	42.8	36.7
3000	-3.4	37.7	31.5

Those results further indicated that with judicious site selection (emphasizing higher rainfall zones, and within these zones selecting fields with steeper slopes), through the complementary use of fertilizer, and with adequate maintenance, the short-term benefits of contour bunds, already important, can be substantially improved.

Average construction costs are estimated by the FEER at approximately 30 000 F CFA ha^{-1}. We calculated the internal rate of return to bunding for this level of construction costs, under the assumption that average observed yield increments for the regions can be obtained over 15 years and sold at the current official price of 90 F CFA kg^{-1}. Furthermore, we assumed levels of maintenance costs to vary between zero and 3000 F CFA ha^{-1} a^{-1}. The estimated internal rates of return show that earthen bunds are not an economically viable alternative for farmers in the northern region (Table 35). In that region economic viability, as indicated by an internal rate of return of 30%, would require that construction costs are reduced to between 15 000 F CFA ha^{-1} and 5000 F CFA ha^{-1}, depending on the level of annual maintenance costs. Bunding appears to be economically attractive in the central and southeastern regions.

New Cultivars and Production Variability in Sorghum and Millet in India

Several economists have documented increasing cereal production variability following the introduction of green-revolution technical change in the mid- and late-1960s in India. For example, researchers at the International Food Policy Research Institute (IFPRI) estimated that the coefficient of variation (CV) of total cereal production increased from 4.0 to 5.9%—a 50% increase—between 1954/55 to 1964/65 and 1967/68 to 1977/78.

Hybrids first released in the late 1960s presently account for about 50% of sorghum and 60% of pearl millet sown area in India. Usually they are sown in rainfed fields where small doses of fertilizers are applied. To what extent have improved hybrid technologies been responsible for increased variability in sorghum and pearl millet production?

To address this question, we analyzed data for grain production in 48 sorghum and 40 major pearl millet producing districts in India. We used a statistical decomposition method developed by IFPRI researchers. Two 12-year periods (1956/57 to 1967/68 and 1968/69 to 1979/80), corresponding to before and after the release and early diffusion of the sorghum and pearl millet hybrids, were selected to represent the pre- and post-green revolution eras.

Instability in sorghum and pearl millet production increased in terms of both total variance and CV from the first 12-year period to the second (Table 36). For sorghum, the CV of linearly detrended production increased from 8 to 16%; for pearl millet the change was even more marked, i.e., from 11 to 34%.

Increased production variance stemmed overwhelmingly from increased production covariance among major producing regions for both sorghum and pearl millet. More than 90% of the increase in production variance for both crops was attributed to changes in interdistrict production covariances. What was surprising was the strength of yield covariances in conditioning those changes (Table 36).

For sorghum, changes in yield covariance between the first and second period for each district pair were positively and significantly linked to the level of HYV adoption, changes in rainfall covariance, and extent of irrigated area (Table 37). For pearl millet, the level of HYV

Table 36. Characteristics and sources of increased sorghum and pearl millet production variability between pre- and post-green revolution periods in India.

Characteristics and sources[1]	Crop	
	Sorghum	Pearl millet
Characteristics		
Total production variance ('000 000 t)		
1956/57–1967/68	28	63
1968/69–1979/80	1017	1043
Coefficient of variation (%)		
1956/57–1967/68	8	11
1968/69–1979/80	16	34
Sources of increase in production variance (%)		
Within-district production variance	5	8
Interdistrict production covariance	95	92
Yield covariance	84	54
Other interregional sources	11	38

1. Based on detrended data.

Table 37. Estimated regression coefficients (R^2) of the determinants of changes in interdistrict yield covariance in sorghum and pearl millet production between 1956/57-1967/68, and 1968/69-1979/80, India.

Variable[1]	Crop	
	Sorghum[2]	Pearl millet[3]
Summed rate of hybrid adoption (%)	89** (±16.9)[4]	110** (±23.9)
Difference in hybrid area (%)[5]	-59* (±26.3)	-113** (±29.4)
Summed irrigated area (%)	100* (±43.9)	-462** (135.9)
Difference in irrigated area (%)[5]	214** (±59.3)	108 (±166.2)
Change in rainfall covariance	70** (±15.8)	14** (±2.9)
Intercept	2295	7162
R^2	0.07	0.04

1. The unit of observation for all variables is a district pair.
2. Based on 1128 district-paired observations.
3. Based on 780 district-paired observations.
4. Figures in parentheses are SE values.
5. Expressed in absolute value.

diffusion and irrigated area were positively and significantly associated with changes in yield covariance.

In other words, the results indicate that production and genetic environments are becoming more similar over time, and it is this growing similarity that is mainly responsible for increasing production variability at the national level for each crop. Increased yield covariances are to be expected because hybrids have a narrow genetic background. For example, the bulk of modern cultivar sorghum area in India is sown to four hybrids, CSH 1, CSH 5, CSH 6, and CSH 9. The latter three have the same male parent, CS 3541. Most of the commercially available pearl millet hybrids in the period under study were produced on the same seed parent.

The first-generation pearl millet hybrids HB 1, HB 3, and HB 4 became extremely susceptible to downy mildew, resulting in significant economic losses in the early 1970s, after inoculum had built up in farmers' fields. In response to those losses, many farmers in several major producing regions reverted to local types. Hybrid adoption rates plummeted. In the mid- and late-1970s, hybrid adoption again picked up as farmers accepted the second-generation hybrids which, at that

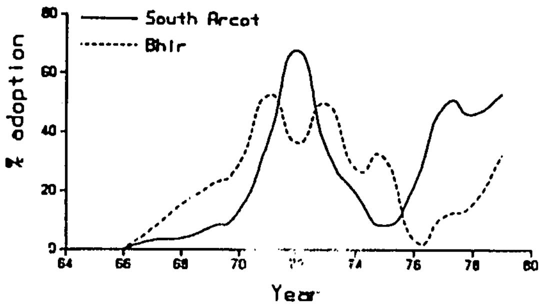


Figure 20. Adoption of pearl millet hybrids in Bhir (Maharashtra) and South Arcot (Tamil Nadu), India from 1966 to 1980.

time, were much less susceptible to downy mildew. Similar, atypical adoption patterns in producing regions as far away as Tamil Nadu and Maharashtra bear ample testimony to the problem of increasing production covariance caused by the use of super-susceptible cultivars (Fig. 20)

A judicious and more regionally oriented varietal release strategy and sound trade and storage policies can cost-effectively offset most, if not all, the instability costs arising from increasing yield covariance. In the absence of such efficient policies, investing in crop research to maintain and enhance resistance to yield reducers and to broaden genetic variation will have stability benefits at the national level, over and above returns to increased production. In any case, more covariate regional yields and the resulting increased production variability were a small price to pay for the growth in productivity attributed to the sorghum and pearl millet hybrids.

Yield Stability, Crop Insurance, and Household Income Variability in India's SAT

Much of the investment in breeding, pathology, entomology, and physiology at ICRISAT is aimed at developing higher- and more stable-yielding varietal technologies that increase output and improve equity and nutrition. Could these technologies also enhance the welfare of farm households by generating substantial reductions in variability in household income and consumption? Could stabilization policies like crop insurance that are triggered by shortfalls in yield significantly and cost-effectively reduce income variability and hence substitute for yield-stabilizing technical change? The answers to those questions hinge on the nexus between variability in crop yield and fluctuations in household income. We examined that relationship for resource-poor farm households in India's SAT.

We relied on household panel data from three ICRISAT study villages which are broadly representative of three soil, climatic, and cropping regions of India's SAT and which were thoroughly described in ICRISAT Annual Report 1982, pp. 313-320. Income data from the "continuous", cultivator households, who remained in the panel from 1975/76 to 1983/84, were analyzed. For those 81 households, information on income fluctuations was summarized by the CV of net household income. A CV was estimated for each household based on 9 years of income data deflated by a village-specific consumer price index.

Risk benefits were estimated under scenarios of perfect yield stabilization and simulated crop insurance designs for the common crops in each village (Table 38). Risk benefits were measured in terms of the mean proportional risk premium which reflects what a household would be willing to sacrifice in mean income to gain a reduction in income variability achieved by either perfect yield stabilization or by participation in a crop insurance scheme.

To assess the range of risk benefits potentially offered by crop insurance, two contrasting designs were investigated. One was a conventional individual approach where the basis for both premia and indemnity assessment is individual farmer's yield; the other was a homogeneous area approach which has been tested on a pilot scale in India since 1979 and uses regional (in our case village) yields as a basis for assessing indemnity claims and premia charges.

Although the mean household income CVs for the producers of these crops ranged from 33

Table 38. Simulated risk benefits (%) from perfect crop yield stabilization and crop insurance.

		Mean proportional risk premium[1]		
		Perfect crop yield stabilization	Crop insurance design	
Crop	Village		Homogenous area	Individual
Irrigated rice	Aurepalle	2.9	0.9	0.8
Castor	Aurepalle	1.3	1.0	0.6
Local sorghum	Aurepalle	0.2	0.1	0.1
Rice, sorghum, and castor[2]	Aurepalle	NA[3]	0.5	0.5
Local sorghum	Shirapur	-0.2[4]	0.3	0.3
Desi cotton	Kanzara	0.2	0.1	0.2
Hybrid sorghum	Kanzara	0.3	0.1	0.0
Cotton and sorghum[2]	Kanzara	NA[3]	0.2	0.2

1. Percentage of mean household income from 1975/76 to 1983/84.
2. For households that sowed at least one crop in 5 or more years.
3. NA = Not applicable.
4. A negative sign indicates increased household income variability.

to 47% in Table 39, the risk benefits from perfect commodity yield stabilization or crop insurance were modest to negligible (Table 38). Ironically, risk benefits from perfect commodity yield stabilization were largest in irrigated rice, the crop with the lowest yield CV in Table 39.

Removing the variability in the yield of only one crop was simply not an effective way to reduce income variability for the vast majority of farm households in the villages under study. For the rainfed crop with the largest risk benefits, perfect yield stabilization would only reduce household income variability by about 5%. Such a modest change would be worth less than 3% of mean household income. Stabilizing the yield of one crop only taps at most 25% of the potential risk benefits from perfect crop income stabilization.

Likewise, crop insurance did not offer much protection from income fluctuations. Of the common cropping patterns, apparent risk benefits would be derived from insuring castor and

Table 39. Common crops sown in three Indian study villages and coefficients of variation of household income, yields, and prices, 1975-1984.

		Number of		Percentage of gross cropped area	Coefficient of variation (CV)%[2]		
Crop	Village[1]	Farm households	Mean years cropped		Household income	Yield	Price
Irrigated rice	Aurepalle	9	8.1	12	47	31	7
Castor	Aurepalle	23	7.6	34	45	68	22
Local sorghum	Aurepalle	21	7.3	18	41	66	12
Local sorghum	Shirapur	21	8.3	58	34	69	17
Desi cotton	Kanzara	26	8.2	51	33	44	15
Hybrid sorghum	Kanzara	18	7.2	8	34	66	13

1. Those that sowed the crop for at least 5 years from 1975/76 to 1983/84.
2. Simple means across those households that sowed the crop in at least 5 years from 1975/76 to 1983/84.

rice in Aurepalle. But insurance would only reduce the CV of household income by 3-4%; such a modest reduction would be worth only about 1% of mean household income.

Perfect crop yield stabilization or crop insurance do not buy much in the way of risk benefits because most farm households rely on multiple income sources, particularly earnings in the local labor market. Diversified cropping patterns are also the norm in dryland agriculture in India's SAT; hence, farm households are not overly dependent on revenue from a single, dominant crop. Lastly, area variability in dryland agriculture severely erodes the effectiveness of policies or technologies that work through yield to reduce variability in household income and consumption. Mean area variability exceeded mean yield variability for each of the common crops listed in Table 39.

Comparative analysis of the results across the three regions suggests that five necessary and often conflicting conditions have to be satisfied for crop insurance to generate measurable risk benefits. An ideal region for crop insurance would be characterized by the following features:

1. Crop income should loom large in household income.
2. Farm households should specialize in few crops.
3. Output prices should be stable to ensure that price variability does not unduly influence revenue variability directly or indirectly through fluctuations in area.
4. Crop supply response should not depend heavily on agroclimatic conditions so that the link between weather-induced fluctuations in area and crop income could be broken.
5. Yields from the insured crops should be exposed to at most a few and not multiple sources of risk so that indemnity assessment based on a homogeneous area approach could be efficient in stabilizing income for most farmers in the region.

Conditions (4) and (5) conflict. To satisfy (4) we need relatively assured production regions. To meet (5), we require drought-prone regions. Suppose we map those five necessary conditions and delineate geographic areas where they are fulfilled in India's SAT. We believe that the intersecting set either in terms of geographic area or number of households would be very small.

Our results also support the notion that little, if any, economic value should be attached to the supposed risk-reducing attributes of improved varietal technologies for resource-poor households in India's SAT. Such technologies should be evaluated with regard to their impact on mean yield or output levels, equity, and nutrition. Likewise, we should not be overly concerned that improved varietal technologies, which farmers have adopted, may have accentuated yield variability. Increased yield variability is unlikely to manifest itself in markedly heightened fluctuations in household income.

Risk benefits from technologies which dampen yield variability may be more substantial in Africa's SAT because resource-poor households may rely more heavily on crop income than similar households in India's SAT. Also, those households are most likely to have fewer effective private and institutional means to compensate for shortfalls in current income. Comparative research on household risk benefits is needed in Africa's SAT.

More research is also needed on stabilization policies that can efficiently deliver measurable risk benefits to poor rural households in India's SAT. For example, rainfall lotteries appear to offer several advantages over crop insurance.

Preliminary analysis of evidence from the study villages also indicates that flexible and locally available public works programs have a large potential to protect a considerable number of poor rural households from the ravages of income variability in India's SAT. Landless labor households that relied almost entirely on earnings in the daily agricultural labor market in Shirapur and Kanzara, where the Maharashtra Employment Guarantee Scheme operated since 1977, had about 50% less variable income streams than those in Aurepalle, where rural public work opportunities were not locally available.

Resource Characterization and Use

Natural Resources

Soil Erosion: Slope Steepness and Length

Soil loss by erosion and water loss through runoff reduces the agricultural productivity of land in the SAT. Land management planners need to know the average annual erosion rates for a wide range of rainfall, soil, slope, crop, and management conditions in order to select an alternative land use and practice combination that will limit erosion rates to acceptable levels. A relatively simple technique for predicting the most likely soil loss rates for specific situations is to use the Universal Soil Loss Equation (USLE) that groups six major parameters important for soil loss prediction.

The equation has the form:

$$A = RKLSCP$$

where:

A = soil loss in tons per unit area, determined by rainfall erosivity
R = rainfall erosivity in erosivity units
K = soil erodibility in tons per unit area per erosivity unit
L = normalized slope length (dimensionless)
S = normalized slope gradient (dimensionless)
C = cropping management (dimensionless)
P = land practices per configuration (dimensionless).

The dimensionless factors are quantified by using as a base, a unit standard plot whose slope steepness is 9% (S=1), slope length is 22.1 m (L=1), and which is strictly fallow (C=1), with straight row cultivation practices directed along the prevailing slope (P=1).

To determine the values for the parameters L and S in the USLE for land with slopes less than 3%, we established runoff plots at ICRISAT Center before the 1984 rainy season. We installed runoff plots 3 m wide of three different lengths, 11, 22, and 44 m, on a range of natural land slopes on both Vertisols and Alfisols at ICRISAT Center. These slopes were 0.4%, 0.8%, 1.6%, and 2.0% for Vertisols. We monitored runoff and soil loss for individual storms. The soil surface was maintained bare, without protection from vegetation or mulch, so that we could evaluate the potential erodibility of a given treatment.

During the first 2 years, slope did not appreciably influence (Table 40) runoff losses on Alfisols even though the slopes ranged from 0.42 to 3.0%. We assume that this result means that runoff from a bare Alfisol is primarily governed by soil infiltration rate as effected by surface sealing. Runoff from Vertisols increased up to 1.6% with slope. While making these plots, they were cut and filled to obtain the required slope.

Table 40. Effect of slope on runoff (mm) from 22-m long bare-fallowed plots on Alfisols and Vertisols, ICRISAT Center, 1984 and 1985.

	Runoff (mm)			
	Alfisols		Vertisols	
Slope (%)	1984	1985	1984	1985
0.4	233	154	69	71
0.8	249	161	104	106
1.6	246	150	136	118
2.0	-	-	128	112
3.0	282	189	-	-
SE	±32.0	±18.9	±10.4	±3.6

Table 41. Effect of slope on soil loss (t ha^{-1}) from 22-m long bare-fallowed plots on Alfisols and Vertisols, ICRISAT Center, 1984.

	Soil loss (t ha^{-1})	
Slope (%)	Alfisols	Vertisols
0.4	3.0	0.9
0.8	2.9	2.8
1.6	3.7	3.5
2.0	-	3.8
3.0	7.3	-
SE	±1.06	±0.23

Table 42. Effect of slope length (m) on runoff (mm) and soil loss (t ha⁻¹) from bare-fallowed plots, on Alfisols and Vertisols, ICRISAT Center, 1984.

	Gentle[1] slope length (m)				Steep[2] slope length (m)			
	11	22	44		11	22	44	
Alfisols								
Runoff (mm)	367	250	114	±18.7	38	283	113	±35.7
Soil loss (t ha^{-1})	4.2	2.9	1.5	±0.59	5.2	7.3	6.1	±1.01
Vertisols								
Runoff (mm)	219	69	31	±4.1	188	128	93	±12.3
Soil loss (t ha^{-1})	5.5	0.9	0.6	±0.10	4.8	3.8	2.3	±0.48

1. Gentle slope—Alfisols 0.8%; Vertisols 0.4%.
2. Steep slope—Alfisols 3.0%; Vertisols 2.0%.

After soil settling the 0.4% slope plots are much flatter than originally planned; this has resulted in a marked reduction in runoff from these Vertisol plots.

Soil losses (Table 41) differed between the two soils. Losses from Alfisols in the 1984 rainy season were much higher from the 3.0% slope than from the three gentler slopes, whereas on Vertisols the losses were much smaller from the gentlest slope (0.4%) than from the steeper ones.

Slope length markedly affected runoff (Table 42). On both soils runoff per unit area was greater on the shorter slope than on the longer ones. The 11-m long plots had three times more runoff than 44-m long plots on Alfisols. Runoff from 11-m long plots was seven times more than that from 44-m long plots on the gentlest Vertisol slope. Soil loss was similarly affected by slope length except in the steeper slope (3.0%) on Alfisols. We need to collect data for a few more years to develop relationships between slope, soil loss, and runoff.

Simulating Sorghum Yields and Fertilizer Requirements for Different Agroclimates in the Indian SAT

We used the revised SORGF model to compute the probabilities of sorghum grain yield for four selected locations in India using climatic data from 1941 to 1970. Mean annual rainfall is 527 mm at Anantapur, 792 mm at Patancheru, 889 mm at Dharwad, and 1001 mm at Indore. The available water-holding capacity of soils is 50 mm at Anantapur, and 150 mm at the other three locations. Simulated sorghum grain yields under adequate management (e.g., timely field operations, using a high-yielding cultivar, applying recommended doses of nutrients, and plant protection measures) in 70% of the years were more than 2200 kg ha^{-1} for Anantapur, 4500 kg ha^{-1} for Patancheru, 5500 kg ha^{-1} for Dharwad, and 6200 kg ha^{-1} for Indore (Fig. 21). We calculated

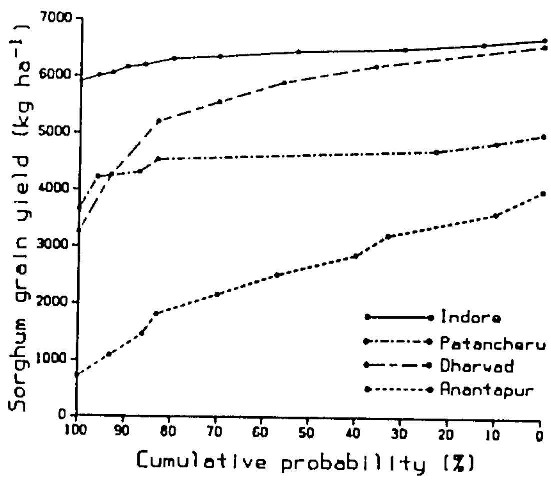


Figure 21. Cumulative probability (%) of simulated sorghum grain yield (more than a given amount) based on climatic data from 1941 to 1970 for four selected locations in India.

fertilizer requirements on the assumption that 20 kg N ha⁻¹ is needed to produce 1000 kg grain yield ha⁻¹, and that a plot without added fertilizers contains 30 kg N ha⁻¹. Based on the simulated sorghum yields, the nitrogen requirement in 70% of the years would have been at least 15 kg N ha⁻¹ for Anantapur, 60 kg N ha⁻¹ for Patancheru, 80 kg N ha⁻¹ for Dharwad, and 95 kg N ha⁻¹ for Indore. Such analyses are useful to estimate the potential yields, and to identify the N-responsive areas based on climate and soil data. These studies can be extended to assess the risks involved in allocation of resources in different agroclimatic environments.

Cropping Patterns and Farm Incomes in the Southern Sahelian Zone

Data derived from our on-going village surveys in Gobery and Samari in western Niger were used to examine cropping patterns and their contribution to farm incomes between 1982 and 1984.

Average gross crop area per farm ranged from 9.4 ha in Gobery in the drought year of 1984 to 15.4 ha in Samari in 1982 (Table 43). But these differences were not statistically significant ($P > 0.5$). The mean gross crop area of 11.6 ha per farm or about 1.0 ha per person is much greater than that usually reported for the wetter Sudanian zone of West Africa. This is because farmers in the study area generally practice minimum tillage. Except for low-lying areas the land is not plowed before sowing, and weeding involves scraping only the top few mm of soil. Animal traction is not used in the villages we studied.

Intercropping is the most prevalent cropping system in both villages. The average proportion of gross cropped area intercropped ranged between 50 and 70% except in Samari in 1984. The proportion of area intercropped in Samari decreased significantly ($P < 0.05$) during that year as the drought prevented farmers from sowing

Table 43. Cropping patterns and crop incomes in two villages in the Southern Sahelian zone of western Niger, 1982-84.

	Gobery			Samari		
	1982	1983	1984	1982	1983	1984
Rainfall (mm)	54	392	423	210	345	153
Household size (persons)	NA[1]	NA	11.3	NA	NA	11.1
Crop income (1000 F CFA farm⁻¹)	150	150	180	180	300	-70
Crop area (ha farm⁻¹)	11.6	11.7	9.4	15.4	11.0	10.5
Cropping pattern (% of gross cropped area)						
Sole crop pearl millet	46	29	42	39	30	59
Other sole crops	1	1	1	1	1	1
Pearl millet/cowpea	34	49	35	9	21	24
Pearl millet/cowpea/sorrel	5	9	6	31	23	6
Groundnut intercrops	12	1	0	0	0	0
Sorghum intercrops	3	11	17	20	25	10
Crop incomes (% of total)						
Sole crop pearl millet	36	33	29	23	16	84
Other sole crop	-[2]	1	2	-[2]	1	-[2]
Pearl millet/cowpea	35	27	52	15	25	11
Pearl millet/cowpea/sorrel	6	11	10	33	27	1
Other intercrops	22	28	7	31	30	4

1. NA = Not available.
2. Less than 0.5%.

cowpea after pearl millet had been sown. Pearl millet/cowpea or pearl millet/cowpea/ sorrel (*Hibiscus sabdariffa*) are the most prevalent intercrops, usually occupying about a third of the gross cropped area. Sorghum and cowpea are only sown as intercrops. Groundnut, once a major cash crop in the area, has virtually disappeared from the cropping system.

Household crop incomes were calculated by deducting variable costs (mainly the costs of seed, fertilizer, and hired labor) from the value of crop output. They represent the returns to land, capital, and family labor. Prices used were those actually paid by farmers.

Net crop income per farm ranged from a loss of 70 000 F CFA in Samari in the drought year of 1984 to a positive return of 300 000 F CFA the preceding year in the same village. As we stated earlier, there was a total crop failure in Samari in 1984. In 1983 rainfall was much higher (Table 43). Gobery is in a higher rainfall zone and is close to a large regional market (ICRISAT Annual Report 1983, p. 315). Farmers there generally receive higher prices and obtain higher yields. They therefore have higher values of crop output. But net crop income is usually higher in Samari as a result of lower use of hired labor.

Net income ha^{-1} averaged about 12 000 F CFA across villages and years. Intercrops contributed about 75% of the total net crop income. This was higher than the 55 % of land area occupied by intercrops. Net incomes ha^{-1} were generally higher for the intercrops than for sole-cropped pearl millet. These data therefore confirm the findings from other zones in Sub-Saharan Africa that in traditional farming systems, intercrops generally produce higher returns than sole crops.

Extent and Characteristics of Intercropping in the Indian SAT

Intercropping is widely practiced by farmers in the Indian SAT. Using data from several years of our village studies in different agroclimatic zones of India, we measured the extent and determinants of intercropping.

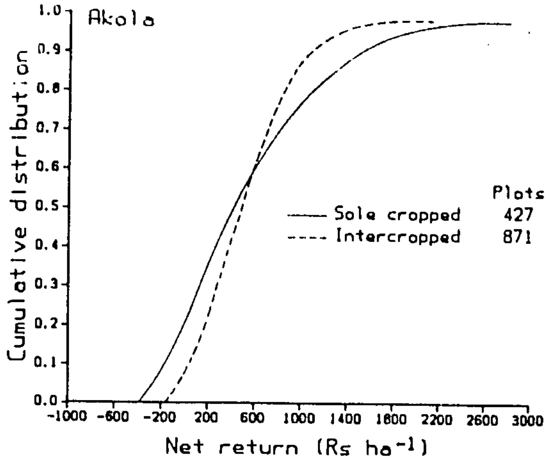
There is substantial interregional variation in intercropping (Table 44). In most zones, the intercropped area accounts for about one-third to one-half of farmers' gross cropped area. The notable exception is the Akola region, with its medium-deep Vertisols and reliable rainfall, where more than three-quarters of the gross cropped area is intercropped.

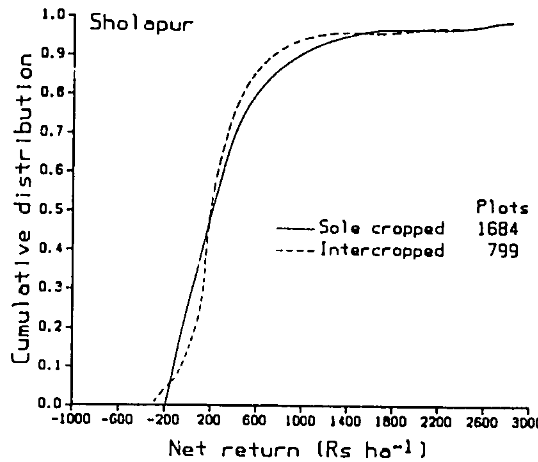
Contrary to general belief, intercropping is not the exclusive domain of traditional varieties. Pearl millet hybrids are intercropped extensively in the Sabarkantha region and sorghum hybrids are finding wider farmer acceptance in intercropping systems in Akola.

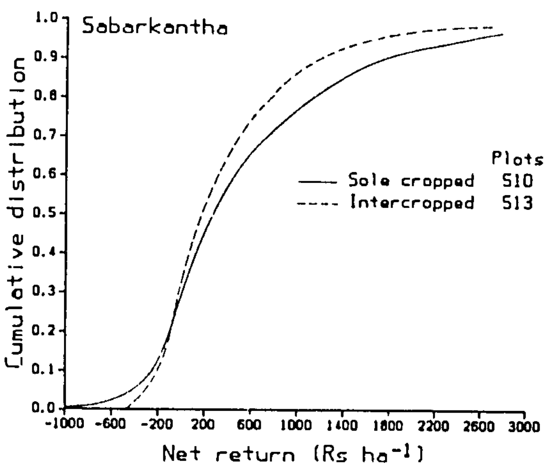
Access to irrigation, land value, and cropping season are the main factors conditioning the interhousehold variation in intercropping within the study regions (Table 45). Controlling for those variables, we find that farm size, as measured in gross cropped area, does not significantly influence the extent of intercropping. Tabular analysis usually shows that subsistence farmers intercrop proportionally more of their land than large farmers, but those differences largely disappear when we account for the effects of irrigation, land quality, and cropping season. Likewise, differences among households in family labor and livestock endowments do not appear to influence intercropping decisions.

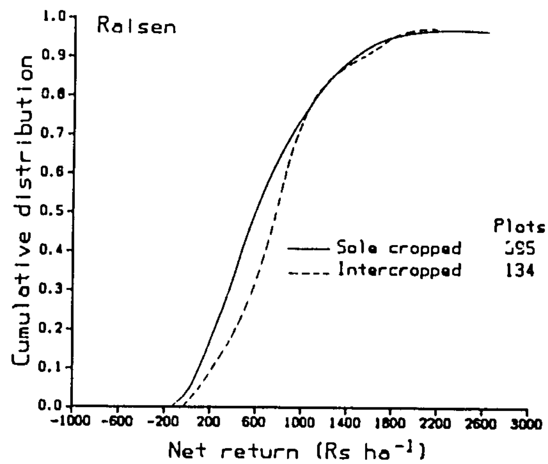
In the postrainy season, farmers have more information on soil moisture availability than in the rainy season, which to some extent explains the popularity of sole cropping in that season. Additionally, within each region plots that are cropped in the postrainy season are usually characterized by a lower-lying topography or are deeper than those cultivated in the rainy season. Differences in soil quality and topographic position not captured by the land value variable in Table 45 undoubtedly explain why postrainy-season cropping is so obviously a determinant of intercropping. Moreover, much rainfed postrainy season cropping occurs under a receding soil moisture regime severely curtailing the potential for farmers to derive species compensation benefits from intercropping.

The regression results suggest that farmers in dryland regions where rainy-season cropping is









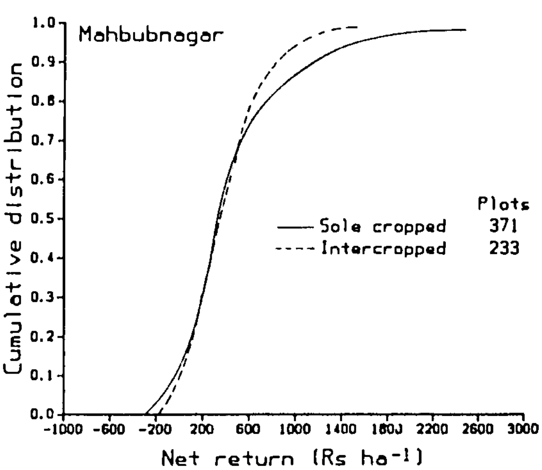


Figure 22. Cumulative net returns (Rs ha^{-1}) from sole and intercropped plots in five regions of the Indian SAT.

Table 44. Extent of intercropping in five agroclimatic zones of the Indian SAT.

Regional characteristics and extent of intercropping	Districts representative of agroclimatic zones				
	Mahbub-nagar[1]	Sholapur[1]	Akola[1]	Sabar-kantha[2]	Raisen[3]
Average annual rainfall (mm a^{-1})	759	665	885	760	1200
Rainfall CV (%)	35	34	23	33	39
Predominant soil type	Alfisols	Deep Vertisols	Medium deep Vertisols	Entisols	Deep Vertisols
Gross Cropped Area (GCA) per farm (ha)	3.6	7.7	6.2	4.2	4.6
Percentage of GCA irrigated (%)	43	11	3	34	2
Percentage of GCA intercropped (%)	32	35	83	45	33
Percentage of farmers with some area intercropped (%)	55	84	97	90	65
Percentage of farmers with total area intercropped (%)	7	4	51	10	4
Major crops in intercrops[4]	S,M,P, OP	M,P,MC, OP	S,C,P, B	M,GN, LD,P	W,CP,LL,

1. Based on data in two study villages from 1975/76 to 1979/80.
2. Based on data in two study villages from 1980/81 to 1983/84.
3. Based on data in two study villages from 1981/82 to 1983/84.
4. S = Sorghum, M = Pearl millet, P = Pigeonpea, C = Cotton, W = Wheat, OP = Other pulses, MC = Minor cereals, CP = Chickpea, LL = Lentil, LD = Linseed, GN = Groundnut, B = Mung bean.

extensively practiced will benefit most from intercropping research. Within those regions, benefits from such research should be accessible to all households irrespective of how much land, labor, and livestock they own.

Intercropping is often viewed as offe‑ing considerably more protection against production risk than sole cropping. Risk benefits in the form of crop compensation or reduced disease and pest incidence from intercropping can only be quantified in controlled agronomic experiments. Comparing net returns from sole- and intercropped dryland fields in the five study regions in Figure 22 provides a rough approximation of the crop diversification benefits that are available from intercropping. In Raisen, intercropping is superior to sole cropping at almost all levels of net return. In Sholapur and Mahbubnagar, the cumulative distribution of net returns does not differ substantially between the two competing systems. In Akola and Sabarkantha, the classic tradeoff is obtained; intercropping systems perform better at lower levels of net returns while sole cropping offers more favorable prospects for higher net returns. As a risk reducing strategy, crop diversification through intercropping would appear to be most efficient in those two regions.

Social and Economic Conditions

Trends in Income, Real Wages, and Poverty in the Indian SAT

After 10 years of household panel data collection in three villages in different agroclimatic zones of the Indian SAT, we can now discern some trends in per capita income, real wages, and poverty levels. Nominal income, representing returns to own capital, land, family, labor, owned bullocks, and management was calculated for each of the 104 "continuous" households in the sample and deflated by a village-specific consumer price index to arrive at estimates of real income.

Table 45. Determinants of the interhousehold variation in intercropping in five agroclimatic zones of the Indian SAT.

Explanatory variable	Agroclimatic zones				
	Mahbubnagar	Sholapur	Akola	Sabarkantha	Raisen
Size of family	-0.21	-0.35	-0.66	-0.37	0.43
	(-0.33)[4]	(-0.59)	(-1.51)	(-0.74)	(0.60)
Livestock	0.47	-0.33	-0.10	1.01	0.51
	(0.96)	(-0.44)	(-0.23)	(1.14)	(0.75)
Gross cropped area (GCA)	-0.11	-0.15	-0.02	0.06	-0.81
	(-0.43)	(-1.05)	(-0.16)	(0.11)	(-0.19)
Irrigated area	-0.49**	-0.12	-0.66**	-0.44**	-0.72
	(-8.37)	(-1.38)	(-4.04)	(-6.44)	(-1.50)
Land quality	0.01	0.06	-0.23***	0.05	-0.06
	(0.05)	(0.56)	(-2.98)	(0.94)	(-0.41)
Postrainy season cropping	-0.29***	-0.20**	-0.97**	-0.33**	0.18
	(-3.38)	(-2.32)	(-8.31)	(-2.46)	(1.51)
Village dummy[1]	4.75	30.50**	3.01	-33.92**	34.72**
	(1.07)	(8.70)	(1.33)	(-8.42)	(6.40)
Year dummy[2]					
1976/77	-3.75	4.58	-1.45	-	-
	(-0.87)	(0.94)	(-0.43)	-	-
1977/78	0.55	17.93**	4.08	-	-
	(0.13)	(3.52)	(1.22)	-	-
1978/79	-8.71	8.17	-4.09	-	-
	(-1.91)	(1.64)	(-1.20)		
1979/80	-7.25	0.63	5.98	-	-
	(-1.60)	(0.11)	(0.17)		
1981/82	-	-	-	3.92	-
				(0.96)	-
1982/83	-	-	-	2.87	7.24
				(0.68)	(1.24)
1983/84	-	-	-	-1.58	16.94**
				(-0.37)	(2.76)
Intercept	50.68	32.87	100.75	71.05	-6.26
R^2	0.43	0.27	0.45	0.51	0.26
F ratio	20.53	10.93	22.29	22.44	6.93
Intercropping (% of GCA)[3]	26.17	35.06	82.70	43.65	35.41
Number of observations	287	291	283	209	150

1. Village dummy refers to Dokur in Mahbubnagar, Kalman in Sholapur, Kinkheda in Akola, Rampura in Sabarkantha, and, Rampura Kalan in Raisen. The reference villages are Aurepalle, Shirapur, Kanzara, Boriya, and Papda in their respective zones.
2. Refers to 1975/76 as the reference year in Mahbubnagar, Sholapur, and Akola, 1980/81 in Sabarkantha, and 1981/82 in Raisen.
3. Dependent variable.
4. Figures in parentheses are t values.

The growth in real income over the analysis period has been slow but perceptible (Figure 23a). Relatively stable food prices have had the largest influence on improvement in rural welfare. Over the 9-year period of analysis from 1975/76 to 1983/84, real income has registered a positive and significant trend ($P<0.05$) in Kanzara and Shirapur but has stagnated in Aurepalle, a village on Alfisols in an erratic rainfall tract where technical change has been limited to improved varieties of rice and castor. Growth in income and consumption expenditure has been most marked in Kanzara, a village on Vertic soils with relatively assured rainfall. The expansion of the mung bean area, diffusion of new sorghum hybrids, and intensification of fertilizer and pesticide use has been fairly rapid throughout the period in Kanzara. In Shirapur, the rise in real income in the late 1970s is largely attributed to the Maharashtra Employment Guarantee Scheme (EGS), an ambitious rural public works program. In the late 1970s and early 1980s, the EGS employed about 15% of male and 25% of female labor in Shirapur. During the analysis period, households in Shirapur were still recovering from a prolonged drought during 1971-73.

To accurately identify the beneficiaries of income growth within each village, we stratified the households into quartiles, based on relative income position in the initial 3-year period from 1975/76 to 1977/78, and estimated trends in income for each quartile (Table 46). We found that the poorest households received more, or as much income growth as the richest households in each village. In both Aurepalle and Shirapur, the richest households in the mid-1970s, i.e., those in quartile 4, registered no significant change in per-person income during the analysis period. Meanwhile, real income grew annually by about Rs 20 per person in 1975 prices for the poorest households in Aurepalle, and by about Rs 34 per person for comparable households in Shirapur. Only in Kanzara, where technical change was marked over the 9-year period, did household income expand for the larger cultivator households in quartile 4.

These encouraging trends were largely derived from a tightening village labor market, illustrated in Figures 23b and 23d for men's and women's wages. Despite large fluctuations—e.g., rainfall in Aurepalle in 1978 was more than 40% above average resulting in a large increase in village labor demand—real wages displayed a pronounced upward trend, particularly for men in Kanzara and Aurepalle after 1981.

Table 46. Annual growth in real household income per person (in 1975 Rs) by village and income quartile from 1975/76 to 1983/84.

	Income quartile[1 2]			
Village	1	2	3	4
Aurepalle	20.0** (±4.44)[3]	18.7** (±7.0)	34.1** (±12.6)	4.4 (±25.9)
Shirapur	33.7** (±6.2)	13.0 (±8.6)	34.7** (±11.9)	-4.7 (±19.6)
Kanzara	38.1** (±7.3)	24.0** (±7.9)	20.4 (±11.0)	35.5* (±16.9)

1. 1 indicates the poorest household quartile, 4 the richest.
2. Estimates from a linear fixed effects model with household income by cropping year as the dependent variable, and household and time trend as independent variables.
3. Figures in parentheses are SE values.

The growth in men's wages in Aurepalle and in men's and women's wages in Shirapur is primarily attributable to an increase in off-farm employment opportunities. The demand for agricultural labor in both villages has remained constant over the analysis period. In contrast, in Kanzara, the demand for men's and women's labor in the daily-rated agricultural labor market has increased. Heavier yields, requiring more harvesting labor and stimulated by greater adoption of modern cultivars and pesticides use, and the widespread diffusion of labor-intensive mung bean as an intercrop with cotton partially explain rising real wage rates for men and women since 1980. The upward trend in labor use ha^{-1} and real wages was sustained even with widespread introduction of mechanical threshing for sorghum, wheat, and mung bean in the late 1970s in Kanzara.

The analog to the favorable real wage picture

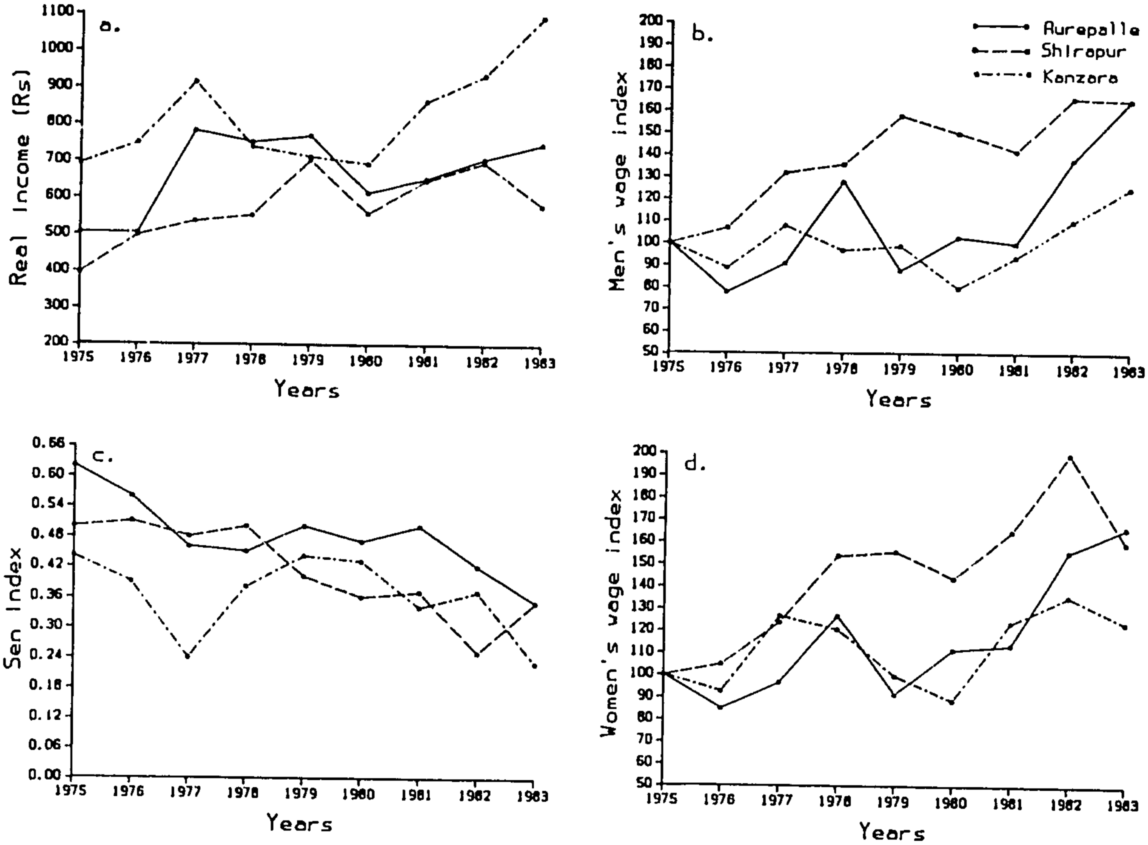


Figure 23. Trends in a. mean per person real income (Rs), c. poverty (Sen Index), b. men's, and d. women's wage indices in three villages of the Indian SAT.

conveyed by Figures 23b and 23d is the fall in poverty charted in Figure 23c. In Aurepalle and Shirapur, the poorest villages, poverty, declined from 1975/76 to 1983/84. This was measured using an income criterion as well as the Sen Index, which accounts for the proportion of poor people as well as how poor they actually are. In Kanzara, poverty dropped until 1980; since then below-average rainfall has resulted in an abrupt rise in the poverty incidence.

These encouraging trends in real wages and in the incidence of poverty demonstrate that technical change is only one (albeit an important) determinant of rural village welfare in the Indian SAT. These favorable trends should also not delude us from recognizing that the vast majority of households in the study villages are still very poor.

Income and Fuel Supply from Common Property Resources in India

Common property resources (CPRs) including village pastures, forests, wasteland, ponds etc., play a significant role in the sustenance of the rural poor. Building on research reported earlier (ICRISAT Annual Report 1983, p. 335), in 1985 we completed studies on their contribution to employment and income generation.

To estimate the income from CPRs, we prepared an inventory of CPR-products collected by respondent households during different seasons and evaluated it using village prices. Another component of CPR-based income is of livestock returns, attributable to animal grazing on CPRs. Income generated from processing and marketing CPR-products was not included,

Table 47. Annual household income (Rs a^{-1}) derived from common property resources (CPRs) in villages in arid or semi-arid zones in seven Indian states, 1983/84.

	Average annual household CPR income (Rs a^{-1})			
State	No. of study districts	No. of study villages	Labor and small farm household	Large farm household
Gujarat	2	4	774	185
Rajasthan	2	4	770	412
Tamil Nadu	1	2	738	162
Madhya Pradesh	2	4	732	385
Karnataka	1	2	649	170
Maharashtra	3	4	557	177
Andhra Pradesh	1	1	534	171

so our income estimates understate the total household income derived from CPRs.

Income estimates for different areas (represented by states) are presented in Table 47. For landless labor and small farm households, per household income from CPRs during the reference year 1983/84 ranged from Rs 534 to Rs 774, equivalent to household income shares ranging from 13 to 22%. Large farm households depended much less on CPR-based income than landless labor and small farm households.

In all study villages the Gini Coefficients of income distribution decline, indicating greater equality, once imputed returns from CPRs are added to other sources of household income (Table 48).

Poor people's reliance on CPRs when they are willing to work but cannot find employment is the reason why CPRs enhance equity. On approximately 25% of the days when individuals in the study villages reported involuntary unemployment, they derived full-time work from CPRs. They also obtained partial employment from CPRs, on 1 day in 5 when they were willing to work but unable to find a job.

Fuelwood from CPRs, crop residues, and dung are major sources of energy supply for farm households in India. We studied fuel consumption for a small sample of households in the ICRISAT study villages to determine the dependence of two groups of households on different sources of fuel. We stratified the sample

Table 48. The effect of common property resources (CPRs) on income inequality in seven Indian study villages, 1983/84.

			Gini Coefficient[1]	
State	District	Village	With CPR income	Without CPR income
Gujarat	Sabarkantha	Rampura	0.47	0.57
Gujarat	Sabarkantha	Boriya	0.27	0.34
Madhya Pradesh	Raisen	Papda	0.27	0.36
Madhya Pradesh	Raisen	Rampur Kalan	0.20	0.42
Maharashtra	Akola	Kanzara	0.45	0.48
Maharashtra	Sholapur	Shirapur	0.32	0.37
Andhra Pradesh	Mahbubnagar	Aurepalle	0.44	0.50

1. Larger values denote greater inequality in household incomes.

Table 49. Fuel consumption by households in villages of the Indian SAT, 1984/85.

Household[1] group	Average per household consumption of fuel during 3 weeks (kg)	Proportion of fuel (%) received from			
		Common property resources	Own sources		
			Crop by-product	Dung	Fuelwood and others
Labor and subsistence farmers	142	74	10	13	3
Large farmers	202	15	33	31	21

1. Based on data from panel households covered by ICRISAT Village-Level Studies during 1 week in each season.

households into landless and small farm households, who own few productive resources, and large farmers, who while not rich are generally much better off than their resource-poorer counterparts. We observed the fuel consumption of the sample households for 1 week in each of the rainy, postrainy, and summer seasons.

Levels of fuel consumption appear to be heavily influenced by household income (Table 49). While poor households use most of their fuel to prepare food only once in a day, richer, large farm households consume fuel for a variety of uses several times during a day, e.g., to prepare food and animal feed, heat bath water, and make tea.

Small farm and landless labor households rely to a much larger extent on CPRs for their fuel supply; large farm households obtain their fuel mainly from owned resources. Increasing the availability of fuel from commonly or privately owned trees may reduce the wasteful use of dung for fuel by the rural poor.

Productivity Consequences of Tenancy in the Indian SAT

Tenancy, mainly sharecropping, is fairly widespread in the Indian SAT, and the ICRISAT study villages are no exception. In eight study villages representing four broad agroclimatic zones, about 81% of the plots were owner-operated, 18% sharecropped, and 1% leased-in on a fixed rent during the analysis period (Table 50). As in much of South Asia, mixed tenancies, i.e., where farmers cultivate their own land and sharecrop or lease-in others' land, were more numerous than pure tenancies. The ratio of mixed to pure tenancy in the eight villages in the late 1970s and early 1980s was about 3.9 : 1.0. The incidence of tenancy remained fairly constant over time. We found no evidence that tenancy was declining in our study villages.

We reported earlier (ICRISAT Annual Report 1979/80, pp. 240-242), our research on some of the determinants of tenancy. Recently, a scholar from Stanford University, USA, used the VLS data to evaluate the popular perception that sharecropping is productively inefficient because there is less incentive to apply variable inputs in sharecropping contracts relative to fixed renting or owner operation.

The core results of that comparative analysis are presented in Table 51 where the third line shows the mean percentage difference in average input intensity and in output productivity on sharecropped plots relative to owner-operated plots for the same household. These mean differences in average input use and output are truly large, but there was considerable variation from village to village.

Controlling for the effects of soil quality and use of irrigation, tenancy significantly explains differences in the use intensity of family labor, hired female labor, bullock draft, and seeds and output productivity between sharecropped and owned fields within the same household in the same cropping year. The relative contribution of tenancy, to these differences is also substantial (Table 51). Sharecropping accounted for an

Table 50. Incidence of tenancy in eight Indian study villages in four agroclimatic zones expressed as percentage of gross cropped area[1].

Zones and villages	Owner-operated	Sharecropped	Fixed rent
Alfisol and low rainfall			
Aurepalle[2]	96.4	0.5	3.1
Dokur[3]	84.0	15.0	1.0
Medium-deep Vertisol and undependable rainfall			
Shirapur[2]	64.5	35.5	0.0
Kalman[3]	77.6	22.1	0.3
Medium-deep Vertisol and dependable rainfall			
Kanzara[2]	83.9	12.3	3.8
Kinkheda[3]	92.2	7.7	0.1
Deep Vertisol and high rainfall			
Boriya[4]	67.1	25.5	7.4
Rampura[4]	80.7	16.1	3.1

1. Based on cropping season observations for 9389 cultivated plots.
2. Refers to 8 cropping years, 1975/76–1982/83.
3. Refers to 5 cropping years, 1975/76–1979/80.
4. Refers to 3 cropping years, 1980/81–1982/83.

Table 51. Contribution of tenancy to differences in factor intensity and output on owned and sharecropped land.

Mean differences, tenancy effect, and percentage shares[1]	Factor intensities							
	Family labor		Hired labor		Bullock draft	Seed	Fertilizer	Output
	Men	Women	Men	Women				
Mean difference[2]	12.1	10.2	2.9	12.0	3.8	4.3	2.6	77.8
Tenancy effect[3]	20.6	21.3	3.4	14.0	7.6	7.6	-0.5	101.5
	(±3.9)[4]	(±3.4)	(±2.8)	(±6.3)	(±1.4)	(±3.3)	(±3.4)	(±25.0)
Percentage mean difference[5]	33.2	55.2	19.1	32.1	22.7	26.5	20.6	32.6
Irrigation share	25.4	21.5	48.5	58.4	13.9	44.2	92.8	43.3
Soil quality share	5.7	-5.7	3.1	-5.7	6.8	-16.3	14.6	-0.5
Tenancy share	68.9	84.2	48.4	47.3	79.3	72.1	-7.4	57.2

1. Based on 352 observations of mixed tenancy from the eight Indian study villages listed in Table 50.
2. Difference in intensity of input between owned and sharecropped land. Labor and draft power are measured in h ha^{-1} seed, fertilizer, and output are in Rs ha^{-1}.
3. Estimated regression coefficient for tenancy holding Rs ha^{-1} soil quality and irrigation differences constant. Positive values indicate that factor intensities or output were greater on owned relative to sharecropped land.
4. Figures in parentheses are SE values.
5. The share represents the percentage of the mean difference that can be attributed to each variable. The mean difference is calculated relative to owned land.

18.7% reduction in output and a sizeable decline in the average use of family labor and bullock draft. Differences in fertilizer use were almost entirely due to differences in access to irrigation. These results indicate that farmers are apt to apply less labor and draft power to the same cropping system and to sow more extensive, lower-valued crops on land they sharecrop. Additional analysis of mixed tenancy showed that differences in input ratios were not large between owner-operated and fixed-rented fields.

The data clearly support the popular perception that sharecropping does result in fairly sizeable efficiency losses in dryland agriculture. Landlords cannot cost-effectively monitor the work performance of tenants.

What do these efficiency losses documented in Table 51 imply? Firstly, it is important to emphasize that they stem primarily from underutilization of labor and bullock draft per unit of land. Allocations of purchased inputs such as inorganic fertilizer, at these relatively low-use levels were not sensitive to alternative tenurial forms and were largely conditioned by access to irrigation. Secondly and more importantly, it would be wrong to infer that banning or legally restricting sharecropping in these villages would yield significant gains to society. If the option of sharecropping was made less available, we suspect that some of the owners would have had to fallow land that was subsequently sharecropped. Others would have cultivated land (that otherwise would have been destined for sharecropping) as or even more extensively than did the prospective tenants. To the extent that the primary motivation for tenancy comes from risk sharing and resource adjustment, the inefficiency cost associated with sharecropping should be assigned to seasonally incomplete bullock rental and insurance markets.

Determinants of Labor Supply

There is growing concern that in the process of generating technological change in developing countries it should combine growth with equity. In countries like India where labor:land and labor:capital ratios are generally much higher than in other developing countries, this concern translates into a call for labor-using, and land- and capital-saving technological change. Assessment of the consequences of such technological changes on employment and wages requires knowledge of the parameters of the labor market.

We earlier reported (ICRISAT Annual Report 1982, pp. 318-320) research on the determinants of wages in the daily-rated casual labor market in six ICRISAT study villages. To estimate labor supply and subsequently simulate the impact of improved technologies on labor earnings and household income, we also need to know the determinants of labor market participation and hours worked.

The estimated results from a probit analysis of the decision to participate by men and women in the daily labor market are presented in Table 52. The probability of participation was primarily influenced by nutritional status, health, wealth, skill, and caste for both men and women.

Women who were adequately nourished (100% of standard) had a probability of participation, which was 0.08 higher than those who had average levels of nutrition (83% of standard). For men, nutritional status had little effect on their probability of participation both statistically and numerically.

The elasticity of the probability of participation with respect to the value of farm assets was -0.75 for men and -0.43 for women. These elasticities are the major explanation for the relatively low probabilities of participation for men from large and relatively affluent farm households, rather than their caste status per se. Indeed, those men from the second to highest caste group had a significantly higher participation probability than any other caste group. Caste plays a more dominant role for women, with those from the lowest caste group having a much higher probability of participation than women from the higher caste groups.

Primarily because of family division and land subdivision, farm size has declined by about 50% from 10.7 ha in 1962/63 to 5.3 ha in 1982/83 in five of the six villages. The asset elasticities derived above suggest that labor market participation by landowning families in five villages may have increased by up to 38% for men and 22% for women as a result of the secular reduction in farm size.

The "direct costs" of participation of women in terms of household confinement and child care had little effect on their decision to participate in the hired labor market. A woman's participation in market work in these rural villages would not be affected by the demands on her time for 'household activities'. Going out to work in the labor market apparently means additional hours of work which women accept rather than curtail their market participation.

Table 52. Determinants of the probability of participation by men and women in the daily hired-labor market in six southern Indian villages, 1975–78.

Variables affecting participation probability[2]	Probability			
	Men		Women	
	Initial[1]	Changes[2]	Initial[1]	Changes[2]
Continuous variables				
Weight-for-age index	0.25	-0.10	0.56	0.46
Height-for-age index	0.25	0.26	0.56	-0.46
Education in years	0.25	-0.01	0.56	-0.02
Years of experience[3]	0.32	0.00	0.56	0.00
Own children aged 5-12 in household	0.25	-0.05	-	-
Value of household's farm assets ('000 Rs)	0.25	-0.07	0.56	0.09
Other able men in household	0.25	-0.04	0.56	-0.04
Disabled men in household	0.25	0.25	-	-
Able women in household	0.25	0.01	0.56	0.02
Young children aged 1-4 years in household	-	-	0.56	0.00
Births per woman	-	-	0.56	0.00
'Babysitters' in household	-	-	0.56	0.02
Discrete (dummy) variables				
If not a household head	0.17	0.20	0.54	0.03
If caste 2	0.21	0.15	0.50	0.01
If caste 3	0.21	0.01	0.50	0.01
If caste 4	0.21	0.08	0.50	0.28
If a tradesman or tradeswoman	0.29	-0.22	0.57	-0.12
If a craftsman	0.29	-0.01	0.57	-0.35
If a professional	0.29	-0.28	0.61	-0.31
If unable to do hard field work	0.27	-0.24	0.61	-0.31
If illiterate	0.24	0.03	0.59	-0.04
If married now	0.18	0.10	0.57	-0.01
If never been married	0.18	0.02	0.57	-0.06
If 'peak' season	0.25	0.02	0.56	0.01

1. Probability at mean level of all variables other than when considering the dummies of interest which are set to zero. The (village × year) dummies have not been included here.
2. When continuous variables are increased by one unit, i.e., partial derivative of the probit probability and dummies are set to a value of 1 after the initial probability has been estimated with the dummies of interest set to zero instead of at their mean levels in the data.
3. These had both linear and quadratic terms in the probit. Before calculating the partial derivative of the probability function, the mean of the linear term was used in the quadratic term.

Table 53. Scenario analysis of effect of increased labor demand on labor market participation, wages, and household labor income for a representative household in the Indian SAT.

	Existing situation 1975-78	After 50% increase in effective labor demand
Average family size	8.37	8.37
No. of labor market participants		
Men	2.00	2.00
Women	2.00	2.00
Participation rates		
Men	0.54 (0.44)[1]	0.81
Women	0.58 (0.45)[1]	0.87
Wage rates (Rs d^{-1})		
Men	3.39	5.65
Women	1.90	2.80
Household labor income (Rs a^{-1})		
Men	1089	3341
Women	624	1778
Total	1713	5119
Total household net income (Rs a^{-1})	4300	7706

1. Figures in parentheses are the participation rates adjusted for the probabilities of market employment of 0.81 for men and 0.77 for women. It is assumed there is no resultant unemployment after the increased labor demand.

Combining information on the determinants of wages, participation, and hours worked, we found short-run elasticities of labor supply with respect to real daily wages in these six villages to be 0.75 for men and 1.05 for women. We encountered little evidence of a backward-bending labor supply response often speculated on and occassionally reported in the literature.

Some prospective technologies for the Vertisol regions of SAT India show promise of increasing labor requirements per hectare by between 40 and 260% (ICRISAT Annual Report 1982, pp. 309-313). Using the derived supply elasticities of 0.75 for men and 1.05 for women, the short-run effects of a 50% increase in effective labor demand from such technological change on a representative household are to increase wage rates of men by 67% and those of women by 48% (Table 53).

These results suggest that for a typical family of eight people with four labor market participants in these south Indian villages, the elasticity of household labor earning with respect to shifts in labor demand is 4.0. The equivalent elasticity of total household net income is 1.6. These parameters illustrate the potential that programs aimed at creating employment and employment-enhancing technological change can have on the welfare of low-income households who rely on wage earnings for their livelihood.

Consumer Preferences for Groundnut Quality Characteristics

Earlier, (ICRISAT Annual Reports, 1977/78, pp. 239-240, and 1979/80, p. 245) we reported our findings on the relationship between market prices and quality characteristics for sorghum cultivars. We extended that analysis to groundnut to obtain a quality index that can be used to rank modern groundnut varieties according to their likely acceptance in the market.

We collected 163 pod samples from an assembly market in Andhra Pradesh where groundnuts from the postrainy season are traded and 207 samples from four markets in Gujarat where rainy-season groundnuts are marketed. We recorded the market prices and measured seven characteristics of the groundnut samples that were perceived by traders and groundnut breeders to determine groundnut quality. These characteristics were: shelling percentage, 100-seed mass, oil content, moisture content, and percentages of shrivelled seed, damaged seed, and infested pods.

We estimated a regression equation where the logarithm of groundnut price was expressed as a function of the seven quality characteristics and binary variables for each of the four Gujarat markets. The estimated coefficients indicate that shelling percentage, oil content, and 100-seed mass are the most important quality characteristics (Table 54). The coefficients of percentage of damaged seed and percentage of infested pods, although statistically significant, are small. Within the range of observations in our samples, those two quality characteristics did not markedly reduce groundnut prices.

We used the estimated coefficients of the quality characteristics to rank 15 groundnut varieties bred by ICRISAT. We compared our ranking with the ranks assigned to the varieties by 14 traders from groundnut markets in Andhra Pradesh. The two rankings showed only a weak correlation (rank correlation coefficient 0.48). Traders admitted having difficulties assessing new varieties unknown to them, or cultivars that have unfamiliar colors or pod shapes. To validate the relationship in Table 54, we plan to collect a new set of market samples, predict prices based on our regression results, and compare those predicted prices with actual market prices. If we obtain a good fit between forecast and

Groundnut buyers at a market in India assessing produce quality.

Table 54. Market price as a function of groundnut quality characteristics.

Variable description	Regression coefficient	SE
Intercept	3.442	
Log shelling (%)	0.368**	±0.053[1]
Log kernel oil (%)	0.230**	±0.071
Log 100-seed mass (g)	0.085**	±0.026
Log pod (%)	-0.024	±0.048
Shrivelled seed mass (% total seed)	-0.001	±0.001
Damaged seed mass (% total seed mass)	-0.009**	±0.001
Infested pods (% total pods)	-0.015*	±0.007
Amreli market[1]	0.062**	±0.015
Savarkundla market[1]	0.126**	±0.012
Gondal market[1]	0.061**	±0.015
Rajkot market[1]	0.025	±0.015
R^2	0.65	
F ratio (df = 11358)	62***	
Number of observations	370	

1. Evaluated with reference to the Adoni market.

actual prices, the regression results reported in Table 54 can be used to screen cultivars for consumer preferences.

Cooperative Activities

Collaborative Projects with National Programs

West Africa

In the area of resource characterization, the agroclimatology program at ISC has established links with the national meteorological services of Burkina Faso, Mali, Niger, and Senegal for climatological analysis of historical rainfall data.

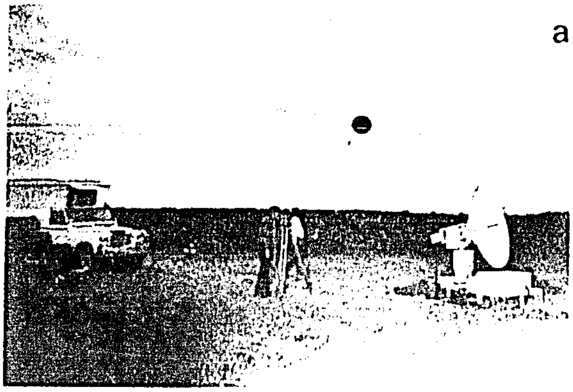
The multinational water-balance studies in Niger are conducted in cooperation with the national meteorological service and the Centre régional de formation et d'application en agrométéorologie et hydrologie opérationelle (AGRHYMET), Niamey.

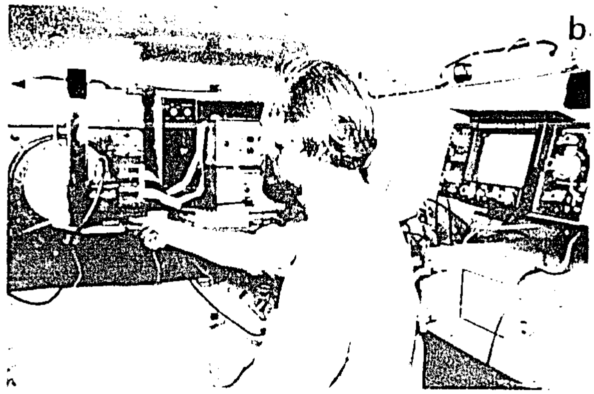
The soil fertility program conducts cooperative studies in villages with the Laboratory of Soils, Institut national de recherches agronomiques du Niger (INRAN) and the Institut burkinabè de la recherche agronomique et zootechnique (IBRAZ) in Burkina Faso. The IITA/ICRISAT cowpea program at ISC has conducted two joint trials with INRAN. One trial tested cowpea entries from ISC and the national program as sole crops at five locations in Niger with annual rainfall ranging from 300 to 800 mm. The second was an evaluation of three contrasting cowpea and pearl millet cultivars at three locations. We also have cooperative linkages with SAFGRAD in Burkina Faso, and with the national programs of Mali and Senegal.

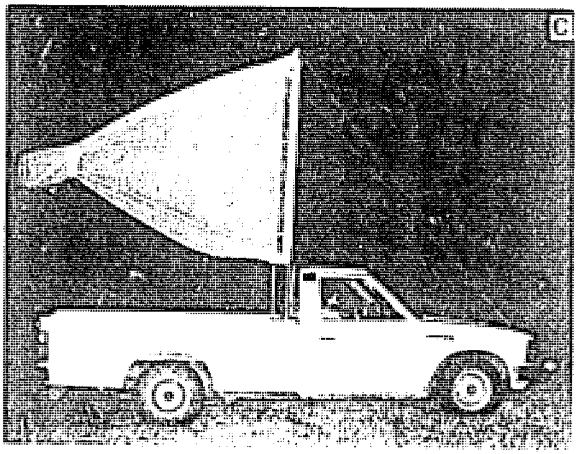
Collaboration with Mentor Institutions

Tropical Development and Research Institute, UK

The Tropical Development and Research Institute (TDRI), of the Overseas Development Administration (ODA), UK has been collaborating with ICRISAT on research on *Heliothis armigera* since April 1984. This work covers two main areas: studies of behavior and ecology, with special emphasis on adult movement and flight behavior; and investigations into farmers' perception and management of *H. armigera.* Assistance has also been given to ICRISAT pulse entomologists on the artificial rearing of *H. armigera.* Specialists from TDRI on biometeorology, flight physiology, and crop protection economics have visited ICRISAT at various times for periods of up to 2 months to work on specific aspects of the project. In late 1985, a three-man radar entomology unit set up their equipment at ICRISAT to study flight behavior of *H. armigera* over crop areas. In addition, ecological studies of field populations were carried out on chickpea and pigeonpea crops; battery-operated light traps, set in a range of crops and cropping systems, were used to study changes in adult populations and female reproductive status. A major aim of this work is to assess the extent and







Radar studies by TDRI of *Heliothis armigera* flight ICRISAT Center 1985.

a. Radar site showing mobile laboratory (left) and radar reflector dish (right); kiteborne balloon (center) is released and tracked by theodolite to determine wind speed and direction at different altitudes.

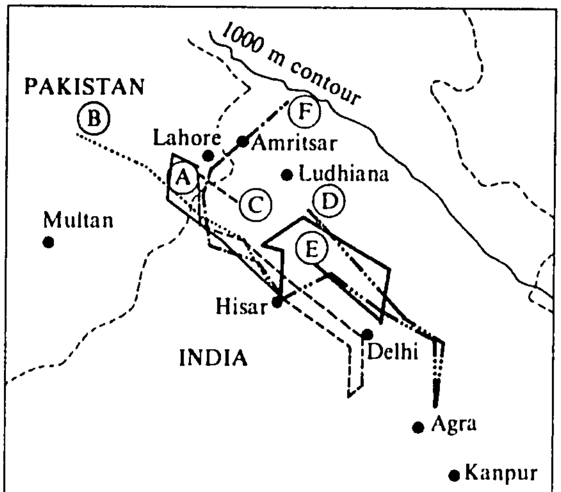
b. TDRI scientist inside mobile laboratory, showing radar plan position indicator with camera attachment and other equipment.

c. A net, mounted on a moving vehicle, collecting *H. armigera* moths and other flying insects in its path.

importance of long-distance, as against local, movement of *H. armigera* moths, and the importance of factors such as diapause, reproductive potential, and larval mortality under various environmental conditions on its status as a pest.

Biometeorological Studies. Capacity for dispersal is an important aspect of insect ecology and has implications for the control strategies directed against it. *Heliothis armigera* is known to be very mobile and there is evidence for its long distance migration or dispersal in India and other parts of its distribution range. Migration is most likely to occur at the end of the crop-growing season when hosts are maturing and food is scarce. From studies made of other noctuid moths, the distance and direction of migration are likely to be strongly influenced by winds at elevations over 100 m.

We used ICRISAT records of light-trap catches at Patancheru, Gwalior, and Hisar and data from pheromone traps at other locations to find occasions when sudden increases in captures suggested immigration. Trajectories were calculated on the assumption that moths were carried by winds for at least 3 successive nights, and using charts of wind fields at altitudes of 600 and 900 m at 0000 and 1200 GMT prepared by the India Meteorology Department. In northern India trajectories calculated for increases between January and March indicated that the origin of moths was predominantly to the northwest and occasionally from the southeast, although never further south than 24°N (Fig. 24). At Patancheru, during March-May, trajectories indicated origins of moths to be from the southeast as far as the coastal regions, or from the west-north-west.



Backtrack	Start of trajectory	Arrival date at Hisar
—— A	7 Feb	9 Feb
········ B	8 Feb	10 Feb
---- C	7 Feb	11 Feb
—···— D	8 Feb	12 Feb
━━ E	9 Feb	13 Feb
—·—· F	11 Feb	14 Feb

(from ICRISAT data).

Figure 24. Backtracks from Hisar, 9-14 February 1982, showing possible source of *Heliothis armigera* moths and the effect of a weather disturbance.

Flight physiology. There is evidence from the literature that both the quality of larval food and adult feeding influence the flight behavior and reproductive performance of *H. armigera.* In view of the likely implications for long-distance movement, we studied the flight behavior of *H. armigera* at ICRISAT Center using 'flight mills' to measure flight times and distances.

A 'flight mill' consists of a freely rotating arm to which a moth is tethered; the revolutions are automatically recorded. Sixteen mills were set up in near-natural conditions. The day-old adults used in the tests were reared from a variety of hosts in the field, and provided with either a honey diet, water, or no food. Concurrent studies were made of the longevity and fecundity of both flown and unflown moths. Although the results were variable, most-prolonged flight was shown by moths which had received a pigeonpea diet as larvae but were not fed as adults, and by moths fed on dough-stage sorghum as larvae, and on a honey diet as adults. Sustained flights of over 30 km were recorded, indicating a considerable potential for dispersal. This work is continuing.

Farmers' perception survey. We made a survey of farmers' perception of *H. armigera* to gain information on farmers' recognition of *H. armigera* as a pest, their views on its importance on their crops relative to other production constraints, and on what measures they take to combat it.

Nearly all of the farmers (95%) in five VLS-villages in Andhra Pradesh and Maharashtra recognized the caterpillars and 30% regarded *H. armigera* as the most important production constraint on pigeonpea and chickpea. Insecticides were recognized as being the most effective means to control larvae, although the proportions of farmers using them varied greatly between villages (37-93%). Just under 50% did not apply insecticide until damage was seen, even though over 70% were able to detect larvae before they were big enough to cause much damage.

Institute of Hydrology, UK

We started a new project at ISC in the 1985 cropping season to study the detailed processes of evaporation from a sparse dryland pearl millet crop. In this type of vegetation much of the rainfall is lost as direct evaporation from the soil and conventional methods of calculating crop-water use could be inaccurate. The principal aim of this study is to make measurements of soil evaporation, transpiration, and total evapotranspiration and to use these to develop models that will give more accurate predictions of sparse-crop evaporation. A model that quantifies the amounts of water used by the plants, and lost as soil evaporation should prove useful in assessing different crop-management practices that attempt to make more efficient use of the limited soil water supply.

In September and October 1985, we made

preliminary measurements of evaporation on a 4-ha plot of pearl millet to assess the performance of a number of techniques. Total evaporation was measured using two "Hydras", micrometeorological devices designed at the Institute of Hydrology, UK. An early version of the Hydra (MK 1) had previously been found to underestimate evaporation by about 30% in a hot, arid climate. The instrument has since been redesigned and the prototype of this new version (MK 2) was compared with MK 1 (Fig. 25). We calculated transpiration from measurements of stomatal conductance and leaf area index (LAI) using the Penman-Monteith equation. The soil component of evaporation was estimated using small portable soil lysimeters weighed hourly throughout the day.

Comparison between Hydras MK 1 and 2 showed that the improvements incorporated into the new design had removed the systematic errors found in the MK 1 instrument. The sum of the outgoing fluxes of heat and water vapor measured by the MK 2 on average, balanced the incoming available radiational energy. This indicates that, within the limits of experimental error (approximately ±10%), the MK 2 Hydra can successfully make direct measurements of the evaporation in this environment.

Figure 26 shows an example of the components of evaporation on a day (19 September) when the soil was wet (17 mm of rain had fallen in the previous 2 days). Despite the high evaporative demand, transpiration was only 0.9 mm on this day, primarily due to the very low LAI

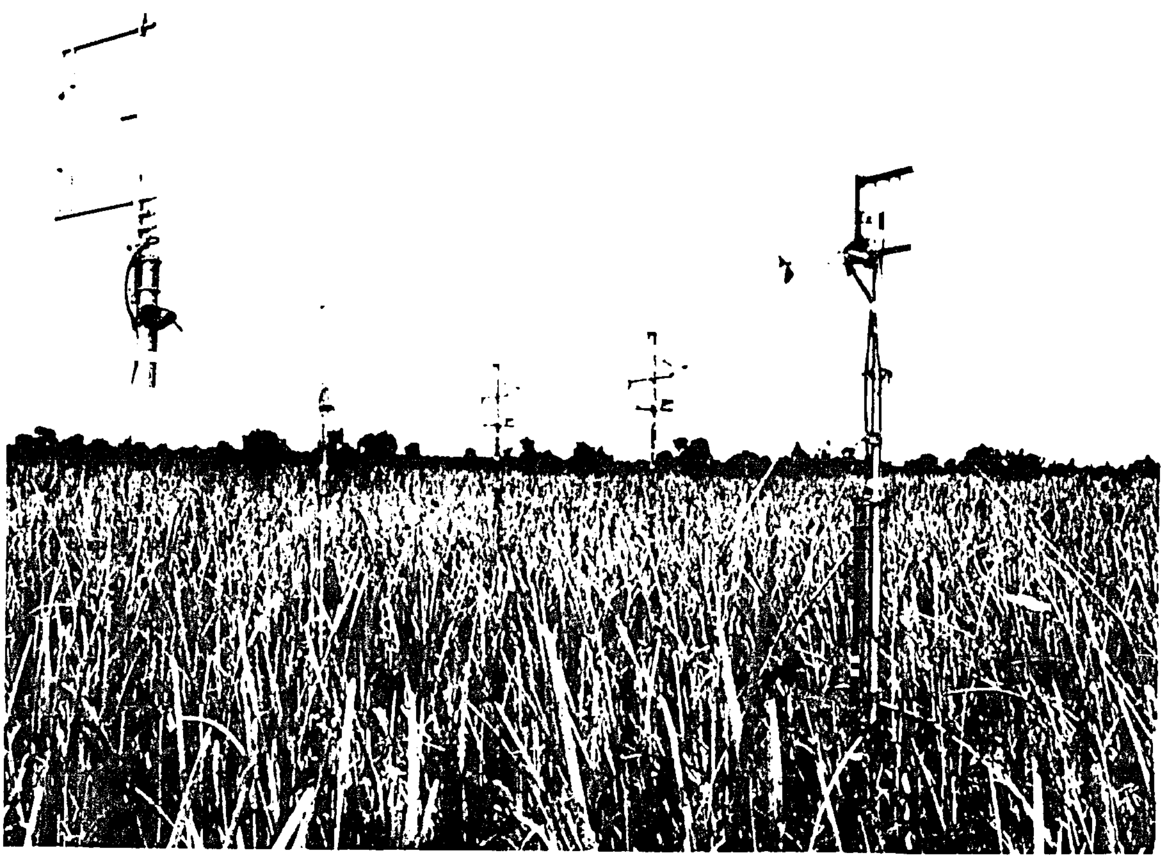


Figure 25. Measurement of evaporation from a pearl millet crop. Micrometeorological instrumentation from left to right, Hydra 2, two automatic weather stations, Hydra 1 (insert, enlarged Hydra 2). ISC, Niger, rainy season 1985.

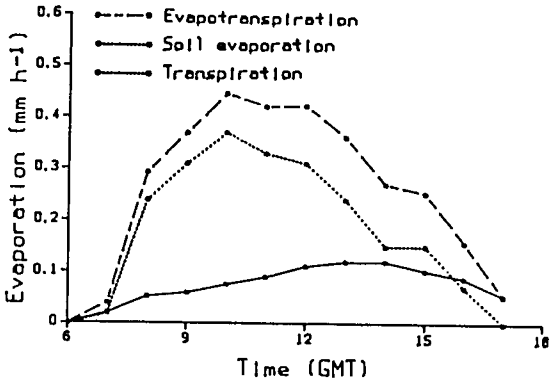


Figure 26. Diurnal trends in transpiration, soil evaporation and evapotranspiration from a pearl millet crop on 19 September, a clear dry when the soil was wet, ISC, Niger, rainy season 1985.

(0.26) at the time. In contrast, soil evaporation was high (2.1 mm), indicating the important contribution that direct soil evaporation can make on days following rain. The total evaporation, calculated as the sum of transpiration and soil evaporation, was 3.0 mm, in good agreement with that given by the Hydra MK 2 (2.9 mm).

Soil evaporation decreased rapidly as the soil dried, so that 5 days later, on 24 September, only 0.2 mm of water was lost directly from the soil, whereas transpiration remained at 0.9 mm.

These preliminary results are very encouraging since they suggest that the Hydra MK 2 can now provide reliable measurements of evaporation in extremely hot arid climates. The results also demonstrate the importance of soil evaporation in the water balance of sparse crops. With a cumulative soil evaporation of around 5 mm after each substantial rainstorm, it is feasible that some 15-20% of rainfall is lost by direct soil evaporation over an entire cropping season in the Sahelian region.

Training

During 1985, 19 persons worked in the Resource Management Program as part of their training program at ICRISAT. One International Intern completed a 2-year postdoctoral program on Vertisol technology and on-farm research. Another intern finished the first year of her program, and is continuing in 1986, working on problems of fertilizer use in farmers' fields. Four Research Scholars, three from India and one from the Netherlands, worked on well irrigation on Alfisols, supply response of oilseeds, input marketing, and new technologies in Vertisols. An Inservice Fellow from Mexico worked with our agronomists on problems of intercropping sorghum and pigeonpea. Ten Research Scholars and two Research Fellows will continue their work with us during 1986

At ISC we had four students from l'Ecole d'agronomie, University of Niamey working with us during 1985. Two worked with our agroclimatologist on transpiration patterns in pearl millet and cowpea, and pearl millet production under normal and assured rainfall. The other two worked on effects of fertilizers on pearl millet, and on the interaction of organic manure and natural phosphate on pearl millet. In addition, graduate students from the Agricultural Training School, Niger came to ISC for a one-week course to gain practical experience as agricultural technicians in such aspects as animal traction, tractor and equipment operations, agricultural surveying, and the use of the rainfall simulator. A scientist from Togo visited ISC for 2 weeks training with the IFDC program.

In-service Economics Training Course

We held our second 6-week in-service training program for economists working in national agricultural research programs in the SAT. The objectives of the program were to strengthen the ability of participants to identify constraints to agricultural production in the SAT, propose and evaluate means for alleviating or removing production constraints, infuse a farming systems perspective into agricultural research, and familiarize participants with microcomputers and their use in economics research.

The program was attended by 11 participants, mainly from African national agricultural research agencies. Six African countries were represented: Burkina Faso, Ethiopia, Kenya, Malawi, Nigeria, and Sudan. We hope that the attendance of two women participants reflects an increasing role of women in agricultural research.

In the syllabus, considerable emphasis was placed on surveys. The topics covered comprised informal as well as formal survey methods, sample and questionnaire design, and survey management. The trainees had a chance to exercise their surveying abilities during a visit to an ICRISAT study village. This excursion also provided an opportunity for trainees to compare village life and production conditions in the Indian SAT with those in their home countries.

A special feature of the program was the introduction to microcomputers and their uses in agricultural economics research. A core section of the program was concerned with technology assessment. The trainees were taught budgeting analysis and whole-farm modeling and they were helped to solve small problems on microcomputers. They were introduced to ICRISAT's marketing studies in order to enhance their awareness of factors affecting the adoption and profitability of agricultural technologies that lie outside the realm of farms. A substantial amount of time was devoted to response function analysis, particularly the analysis of fertilizer response. Following a request from several trainees, we introduced a section on regression analysis.

Since the best research results are likely to have only a diminished impact when they are poorly communicated, a small section on report writing and graphical data presentation was included in the program.

In response to feedback we obtained from the

In-service trainees watching an Indian housewife preparing food during their visit to an ICRISAT study village.

trainees, we will offer similar training programs in the future when more emphasis will be given to data collection, data processing, and analysis.

Improved Vertisol Technology Training Program

During 1985, six training courses were conducted on various aspects of ICRISAT's improved deep-Vertisol technology. These programs trained a total of 153 officers, who represented the state departments of agriculture of Andhra Pradesh, Karnataka, Maharashtra, and Madhya Pradesh; the State Bank Institute of Rural Development; and the Syndicate Bank. The initial training organized at ICRISAT worked well in terms of providing the necessary background and exposure to the basic elements of the technology.

Workshops, Conferences, and Seminars

Inaugural IBSRAM Workshop on Management of Vertisols for Improved Agricultural Production

An inaugural workshop on the management of Vertisols for improved productivity was held at ICRISAT Center on 18-22 February, 1985 attended by over 60 participants from more than 26 countries, and sponsored jointly by ICRISAT and the Soil Management Support Services (SMSS). It was cosponsored by the Australian Centre for International Agricultural Research (ACIAR), the Australian Development Assistance Bureau (ADAB), the Agency for International Development (AID), the International Development Research Centre (IDRC), and the Institut francais de recherche scientifique pour le développement en coopération (ORSTOM). The main objective of the workshop was to determine the extent of support for the formation of a Vertisols Soils Network, whose aim is to assist national agricultural research programs in developing their own research capabilities to improve productivity on Vertisols. The Vertisols network is one of four that are being initiated by the International Board for Soil Research and Management (IBSRAM).

The workshop was structured to provide a series of papers that discussed the properties of Vertisols in some important agroclimatic zones, examples of improved management systems (or components of these), and the advantages of networks. Group discussions were held to determine participants' views on the needs for characterization of soils, management under irrigated as well as rainfed agriculture, and validation of improved or promising technologies. Participants vigorously discussed the ways in which networks could be formed and operated; they strongly supported the proposal to form networks, and assisted in developing an outline to develop project proposals.

Network formation was originally proposed because it was seen as an efficient means to rapidly transfer improved management practices amongst member countries of the network, and thus accelerate improvement in productivity on these greatly underutilized soils. However, the participants also indicated the need to identify high-priority areas of research.

Copies of the summary report are available from Information Services, ICRISAT. Full proceedings are in preparation.

Training Needs for Dryland Agriculture

A workshop on the training needs of dryland agriculture, with particular reference to the deep Vertisol technology was held at ICRISAT Center, 17-18 July 1985. The objectives of the workshop were to focus on area-specific problems of dryland agriculture and the production potential of Vertisols and Alfisols and to discuss the training requirement for implementing the watershed-based technology. Participants included 16 directors of agriculture, directors of research and extension education from the agricultural universities of Andhra Pradesh, Karnataka, and Maharashtra and scientists from ICAR, ICRISAT, the Central Research Institute for Dryland Agriculture (CRIDA), and the National Institute of Rural Development (NIRD).

The workshop drew attention to the problems of dryland agriculture and discussed the various aspects of improved technologies developed for Vertisols by ICRISAT and for Alfisols by ICAR institutions (including agricultural universities). Emphasis was laid on the management of a watershed as an ecological and functional unit. The problems and experiences gained in the planning and implementation of watershed-based land-and-water-management and crop-production technologies in different states were discussed and attention focused on the training needs for effective extension of improved dryland agriculture technology.

Copies of the proceedings are available from Information Services, ICRISAT.

Working Group Meeting on Agroforestry Research in the Semi-Arid Tropics

Agroforestry workshop participants visiting ongoing experiments at ICRISAT Center.

The objectives of the meeting were to review agroforestry research in the SAT, especially in India, to establish links and collaboration among institutions doing agroforestry research, and to develop a network for agroforestry research in India and Africa. The meeting was held at ICRISAT Center on 5-6 August 1985 and the 30 participants represented research institutions such as the Indian Council of Agricultural Research (ICAR), the International Council for Research in Agroforestry (ICRAF), and ICRISAT, the funding agency (Ford Foundation), industry, and voluntary organizations.

Working groups recommended that the agroforestry research must aim to increase and stabilize the income of the small farmer in the SAT. Specific socioeconomic recommendations include studies of market demand and supply of agroforestry products, identifying potentially appropriate agroforestry systems and to assess long-term effects on soil and water conservation. Priority areas for agronomic research were listed and an inventory of the existing research in India was made. It was agreed that it would be advantageous for ICRISAT and ICAR to collaborate closely on agroforestry research and common experiments should be installed to ensure that the generated information is widely adapted.

Copies of a report on the meeting are available from Information Services, ICRISAT.

Symposium and Training Workshop on the Agrometeorology of Groundnut

Agricultural researchers and agrometeorologists from 16 countries joined ICRISAT scientists in Niamey, Niger, 14-26 August, to review and discuss our present knowledge of climatic factors that primarily influence groundnut yields in the semi-arid dryland agriculture of the tropics. The techniques and methods to describe the weather risks to crop production was the central theme of discussions.

The Training Workshop and the Symposium were jointly sponsored by ICRISAT, the World Meteorological Organization (WMO, an agency of the United Nations), the Peanut Cooperative Research Support Program (Peanut CRSP) of the U.S. Agency for International Development, and the Food and Agriculture Organization of the United Nations (FAO). Other cosponsors were the Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (AGRHYMET), Niamey, and the Institut national de recherches agronomiques du Niger (INRAN).

There were 80 participants in the sessions which began with a series of training workshop meetings 14-20 August and ended with a 5-day symposium 21-26 August. The meeting was opened by His Excellency the Minister for Higher Education, Government of Niger, who also chaired the closing session.

The presymposium training workshop was attended by 12 agroclimatologists drawn from 10 African countries. During the workshop, the participants were given 'hands on' training in the use of computers for agrometeorological data storage, retrieval, and analysis. They also made field visits to study crop phenology, soil and plant water status, and automatic data acquisition systems.

At the symposium the participants reviewed the recent climatic changes that are occurring in the Sub-Saharan region and their impact on Sahelian agriculture. The gaps in our current knowledge on the response of groundnut to its growing environment were identified. Priority research areas for collaborative research were noted, and an action plan for national and international research formulated. AGRHYMET in association with ICRISAT and Kansas State University, USA has launched a project to assist further understanding of rainfall variability in Sahelian groundnut-growing areas. WMO and AGRHYMET in association with the National Agrometeorological Service of Niger have made plans to provide operational weather information to farmers and agriculturists on the occurrence of droughts, pests, and diseases.

Copies of the symposium proceedings are available from Information Services, ICRISAT.

Looking Ahead

Following the formation of the new Resource Management Program in 1985, a year or two will be required to consolidate our research results. At the same time new modes for conducting interdisciplinary research in so-called task teams, which will operate on specifically assigned budgets will be developed by the program.

Most of the ongoing research projects should be completed by 1987, to make way for new, largely interdisciplinary projects. Such new projects will ensure maximum collaboration with national programs and institutions.

Research thrusts in India will emphasize the Vertic soils in low, medium, and high rainfall areas, the shallow Alfisols under low and medium rainfall and the deep Vertisols under low rainfall.

For the Vertisols where rainfall is assured, our efforts in India are being reduced, our on-farm testing has been completed and this activity has been taken up by national programs. Component research is now confined to those aspects important to the long-term stability of the new system (e.g., rotations), or aspects on which problems arise in on-farm testing. However, some countries outside India with similar soils and environment have indicated an interest in the double-cropping technology. For these countries, new component research will be initiated to handle the different problems that will arise in these similar, but not identical, environments to those in India.

For the Vertisols where rainfall is not assured, diagnostic and new component research is needed. We will initiate new programs for this target area in 1986.

In Africa, the sandy soils of West Africa in low and medium rainfall zones rank highest; work on these will be undertaken at ISC. In view of the overriding importance of efficient use of water resources to achieve yield stability in the West African Sahel, we will continue to emphasize our agroclimatic studies aimed at resource characterization. A description of drought probabilities in the sorghum- and millet-growing regions of West Africa will receive emphasis. We will continue our studies on water balance at three locations in Niger, and will start a similar study in Mali in 1986.

In the area of soil fertility, we will continue our research on phosphorus, nitrogen, and sulfur and will expand our studies on crop residues. We will continue the long-term soil management experiment, plant establishment studies, and physical characterization of sandy soils. We will contribute to the operational-scale research effort in wnich we will study soil management aspects in conjunction with animal traction. We hope to expand our collaborative efforts into the wetter part of the Sahelian zone.

With the availability of high-yielding, short-duration cowpea, new cropping systems are likely to develop. There is already interest in growing short-duration crops under limited irrigation and on residual soil moisture, as well as in rotation with rice along the rivers. Growing cowpea in pure stands is also becoming attractive. Therefore, work at ISC will continue to evaluate short-duration cultivars suitable for the various cropping systems. Closer collaboration with national programs will be intensified to evolve feasible and economically viable alternatives for the region, through the use of high-yielding, drought-tolerant cultivars, improved fertility, plant-protection measures, and increased plant population.

The Vertisol areas of eastern Africa (Ethiopia, Sudan) under low and medium rainfall zones, fall under the mandate of ICRISAT Center.

Alfisols and Entisols in low-rainfall areas in southern Africa represent a third category, and research for these areas will be conducted by scientists at ICRISAT Center until a resource-management group can be established in our southern African regional project in Zimbabwe. For these areas, collaborative research projects will be developed with national and international institutions to which ICRISAT can contribute its experience on Vertisol management in India.

We recognize the importance of particular aspects of resource management research in each region including the remaining SAT regions and we have made initial contacts with national programs for collaborative work on such aspects. In the Asian region (other than India), for instance, we plan to make a collaborative study on the comparative production cost of pulses and regional demand, to identify the potentials for both production and interregional exchange of pulses. We have been asked to help in formulating a master plan for the Research Institute for Food Crops at Maros, Indonesia, that will address the problems of rainfed agriculture in eastern Indonesia.

In Latin America, we have contributed a consultant's report to plans for agricultural research in northeastern Brazil, and we are in contact with scientists there about collaborative work in cropping systems and water management.

Publications

Institute Publications

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Agricultural markets in the semi-arid tropics. Proceedings of the International Workshop, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Training needs for dryland agriculture with particular reference to deep Vertisol technology. Proceed'ngs of the workshop, 17-18 July 1985. ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Report of the Inaugural Workshop on Management of Vertisols for Improved Agricultural Production. 18-22 February 1985, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Other Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. The Tropicultor operator's manual: field operations. Patancheru, A.P. 502 324, India: ICRISAT. (English and Telugu)

Journal Articles

Awadhwal, N.L., and **Thierstein, G.E.** 1985. Soil crust and its impact on crop establishment: A review. Soil and Tillage Research 5: 289-302.

Behrman, J.R., and **Murty, K.N.** 1985. Market impacts of technological change for sorghum in Indian near-subsistence agriculture. American Journal of Agricultural Economics 67(3): 539-549.

Bhatnagar, V.S., **Pawar, C.S.**, **Jadhav, D.R.**, and **Davies, J.C.** 1985. Mermithid nematodes as parasites of *Heliothis* spp. and other crop pests in Andhra Pradesh, India. Proceedings of the Indian Academy of Sciences (Animal Sciences) 94(5): 509-515.

El-Swaify, S.A., **Pathak, P.**, **Rego, T.J.**, and **Singh, S.** 1985. Soil management for optimized productivity under rainfed conditions in the semi-arid tropics. Advances in Soil Science 1(1): 1-64.

Huda, A.K.S., **Sivakumar, M.V.K.**, and **Rego, T.J.** 1985. An analysis of agro-climatic data in relation to fertiliser use in dryland farming areas of India. Fertiliser News 30(2): 35-41.

Huda, A.K.S., **Virmani, S.M.**, and **Sekaran, J.G.** 1985. Simple models for predicting sorghum grain yield using environmental factors. Journal of the Indian Society of Agricultural Statistics 37(2): 184-191.

Jadhav, D.R., **Bhatnagar, V.S.**, and **Pawar, C.S.** 1985. The species status of *Heliothis armigera* (Hub.) (Lepidoptera: Noctuidae) in Andhra Pradesh, India on the basis of aedeagal cornutal spines. Current Science 54(5): 239-240.

Jodha, N.S. 1985. Population growth and the decline of common property resources in Rajasthan, India. Population and Development Review 11(2): 247-264.

Jodha, N.S., and **Mascarenhas, A.C.** 1985. Adjustment in self-provisioning societies. Pages 437-464 *in* Climate Impact Assessment, studies of the interaction of climate and society (Kates, R.W., Ausubel, J.H., and Berberian, M., eds.). Chichester, UK: John Wiley and Sons.

Nageswara Rao, R.C., **Sardar Singh**, **Sivakumar, M.V.K.**, **Srivastava, K.L.**, and **Williams, J.H.** 1985. Effect of water deficit at different growth phases of peanut. I. Yield responses. Agronomy Journal 77(5): 782-786.

Natarajan, M., **Kannaiyan, J.**, **Willey, R.W.**, and **Nene, Y.L.** 1985. Studies on the effects of cropping system on fusarium wilt of pigeonpea. Field Crops Research 10(4): 333-346.

Natarajan, M., and **Willey, R.W.** 1985. Effect of row arrangement on light interception and yield in sorghum-pigeonpea intercropping. Journal of Agricultural Research 104(2): 263-270.

Ntare, B.R. and **Aken'Ova, M.** 1985. Yield stability in segregating populations of cowpea. Crop Science 25(2): 208-211.

Pawar, C.S., **Bhatnagar, V.S.**, and **Jadhav, D.R.** 1985. *Heliothis* species and their larval parasitoids on sole and intercrop safflower in India. Insect Science and its Application 6(6): 701-704.

Pawar, C.S., **Bhatnagar, V.S.**, and **Jadhav, D.R.** 1985. Some predatory insects and their parasites. Science and Culture 51(3): 101-102.

Singh, B.B., and **Ntare, B.R.** 1985. Development of improved cowpea varieties in Africa. Pages 105-115 *in* Cowpea Research, Production and Utilization, (Singh, S.R. and Rachie, K.O., eds.). John Wiley and Sons Interscience Publications.

Sivakumar, M.V.K., and **Huda, A.K.S.** 1985. Solar energy utilization by tropical sorghums. Agricultural and Forest Meteorology 35: 47-57.

von Oppen, M., **Ghodake, R.D.**, **Kshirsagar, K.G.**, and **Singh, R.P.** 1985. Performance and transfer constraints of improved Vertisol technology. Entwicklung + Landlicher Raum 19(6): 11-14.

Walker, T.S., and **Kshirsagar, K.G.** 1985. The village impact of machine threshing and implications for technology development in the semi-arid tropics of peninsular India. Journal of Development Studies 21(2): 215-231.

Conference Papers

Jodha, N.S. 1985. Market forces and erosion of common property resources. Pages 263-277 *in* Proceedings of the International Workshop on Agricultural Markets in the Semi-arid Tropics, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Mueller, R.A.E. 1985. Plant breeders' rights and the multilevel seed system. Pages 3-14 *in* Proceedings of the International Workshop on Agricultural Markets in the Semi-arid Tropics, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Murty, K.N. and **von Oppen, M.** 1985. Nutrients distribution and consumer preferences in India: some policy implications. Pages 179-200 *in* Proceedings of the International Workshop on Agricultural Markets in the Semi-arid Tropics, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Parthasarathy Rao, P. 1985. Marketing of fodder in rural and urban areas of India. Pages 97-107 *in* Proceedings of the International Workshop on Agricultural Markets in the Semi-arid Tropics, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

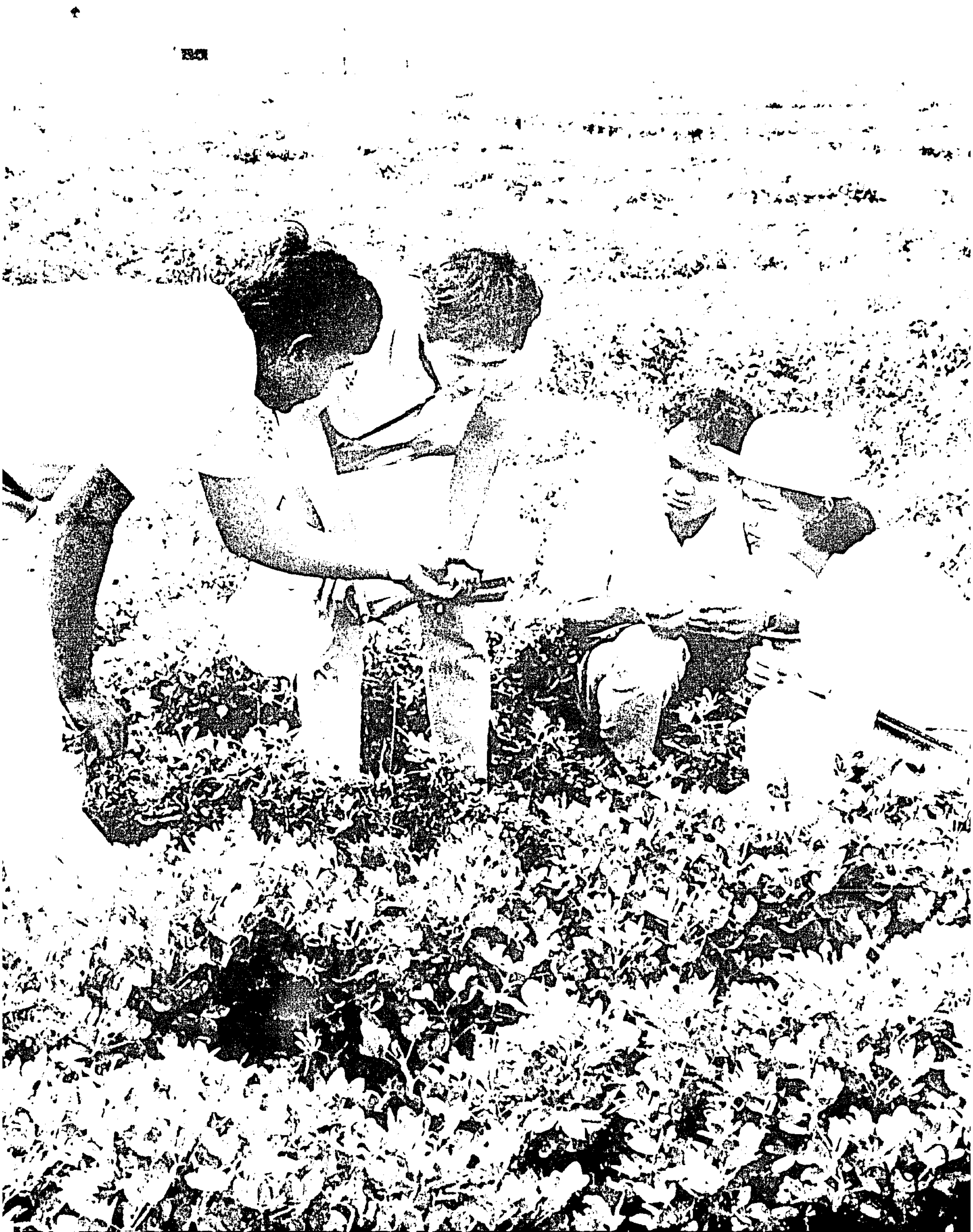
Pathak, P., **Miranda, S.M.**, and **El-Swaify, S.A.** 1985. Improved rainfed farming for semiarid tropics—implications for soil and water conservation. Pages 338-354 *in* Soil Erosion and Conservation, Proceedings of International Conference, 16-22 Jan 1983, University of Hawaii and East-West Center, Honolulu, Hawaii, USA: Soil Conservation Society of America.

Renard, C. 1985. "Exploitation des ressources et conservation" de l'ICRISAT au Centre sahélien au Niger. Pages 35-45 *in* Actes du séminaire sur un réseau international de recherche sur la résistance à la sécheresse, 23-26 septembre 1985, Ouagadougou, Burkina Faso. Wageningen, Pays-Bas: Centre technique de coopération agricole et rurale, Convention ACP-CEE de Lomé, et Paris, France: Centre de coopération internationale en recherche agronomique pour le développement.

Serafini, P.G. 1985. Intercropping Systems: the ICRISAT/Mali experience 1979-1983. Pages 154-179 *in* Les cultures associées dans les zones sahélienne et sahélo-soudanienne de l'Afrique de l'Ouest. Liaison Sahel No. 3. Bamako, Mali: Institut du Sahel.

von Oppen, M., **Parthasarathy Rao, P.**, and **Subba Rao, K.V.** 1985. Impact of market access on agricultural productivity in India. Pages 159-168 *in* Proceedings of the International Workshop on Agricultural Markets in the Semi-arid Tropics, 24-28 October 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

TRAINING



Contents

Cover photo: Trainees from Thailand and the Philippines discussing groundnut foliar disease resistance screening trials with ICRISAT groundnut pathologist.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Training Program, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

TRAINING

The requests from Ministries of Agriculture and National Programs for ICRISAT to provide training for research scientists, technicians, extension personnel, and students continued to increase. This resulted in an increased number of participants (22%) and increased weeks of training (31%) at ICRISAT Center (Table 1). The participants represented 49 countries (Table 2). With these participants the number of countries, which have sent participants for an ICRISAT long-term training program, increased to 70. The requests to assist students were greater than the staff could accommodate at ICRISAT Center and in the regional stations.

British international intern assembling a pheromone trap used in his studies on the migration of *Heliothis armigera* moths.

Postdoctoral Fellowships

Three international interns completed 2-year study programs related to optimizing the use of light and water by groundnut plants improving on-farm research techniques for deep Vertisols and the identification of insect migration patterns to potentially identify techniques that would reduce insect damage to crops. Research fellows reported on their studies related to the epidemiology of pigeonpea blight, environmental effects

Table 1. Numbers of trainees in long-term training programs, ICRISAT Center, 1985.

Category	Number	Weeks	Countries
International Interns	3+ 6[1]	376	3
Research Fellows	4+ 5	394	1
In-service Fellows	32	140	21
Research Scholars	10+20	934	11
In-service Trainees	109+ 1	2646	38
Apprentices	3+ 2	76	4
Total present	161+34	4566	49[2]

1. + = the number continuing into 1985.
2. Different countries.

344

Table 2. Participants by region, country, and category who completed long-term programs at ICRISAT Center during 1985.

Country	II[1]	RF	IF	RS	IT	Ap	Total
Western Africa							
Benin					2		2
Burkina Faso			1		3		4
Burundi					1		1
Chad					1		1
Ghana				0+1[2]	2		2+1
Guinea					4		4
Mali				0+1	3		3+1
Mauritania					1		1
Morocco			1				1
Niger					2		2
Nigeria					4		4
Senegal			1		5		6
Eastern Africa							
Ethiopia			1	0+1	4		5+1
Kenya				2	2		4
Rwanda			1		1		2
Somalia				0+3	3		3+3
Sudan			1		7		8
Uganda					2		2
Southern Africa							
Botswana					4		4
Malawi					4		4
Mozambique				0+1	1		1+1
Tanzania					6		6
Zambia					2		2
Asia							
Bangladesh			4		1		5
Burma					4		4
China			1		5		6
Fiji			1				1
India		4+5	5	5+7	2	1	17+12
Indonesia					4		4
Iran			1		1		2
Iraq					1		1
Korea (South)			1				1
Nepal			1				1
Pakistan			2				2
Philippines			2		5+1		7+1
Sri Lanka			2		4		6
Syria			1		1		2
Thailand			1		11		12
Yemen Arab Republic					1		1

Continued.

Table 2. *Continued.*

Country	II[1]	RF	IF	RS	IT	Ap	Total
Southern America							
Chile			1				1
Dominican Republic					1		1
Guatemala					1		1
Honduras					1		1
Mexico			2		2		4
Others							
Australia	0+1					0+1	0+2
Federal Republic of Germany			1	2+4			3+4
Netherlands				1		2	3
UK	3+2			0+1		0+1	3+4
USA	0+3			0+1			0+4
Total	3+6	4+5	32	10+20	109+1	3+2	161+34

1. II = International Intern, RF = Research Fellow, IF = In-service Fellow, RS = Research Scholar, IT = In-service Trainee, Ap = Apprentice.
2. + = the number continuing into 1986.

on nitrogen fixation in groundnuts, the genetics of wilt resistance in pigeonpea, and characterization of nematodes in pulses and other crops.

In-service Fellowships

The increased nomination of senior scientists employed in Ministries of Agriculture, Universities, and research development agencies resulted in 32 scientists from 21 countries completing 140 man-weeks of intensive study. They were associated with ICRISAT scientists to study specialized research methods and techniques in microbiology, physiology, pathology, plant breeding and genetics, research-farm design, development and management, climatology, entomology, systems of inter-, relay, and sequential cropping, and management of natural resources in relation to improved food production.

An intensive 2-week pulse pathology training course stressed the current methodologies for identifying causal pathogens and screening germplasm accessions for sources of resistance to be used in plant populations in farmers' fields.

Research Scholarships

Master of Science students from four countries were successfully guided by scientists on eight theses, related to the study of wilt-resistance breeding methods in pigeonpea, relations of credit availability, interspecies competition and optimum plant type in sorghum, markets for commercial inputs and their influences on farm production, water management and its supply response to production influence of drought stress on groundnut seed quality, development of methods for optimally dehulling sorghum grain, and the effects of intercropping systems on sorghum genotypes. Two students worked on their Doctoral (PhD) theses. They studied the influence of photoperiod on groundnut growth, and the identification of chemicals in pulse plants related to insect-pest resistance.

Six students from Niger and one from Togo were supervised by ICRISAT scientists in Niger, four in Burkina Faso, and four in Senegal. Their BSc or Ingénieur Agronome degree thesis topics were related to screening for *Striga* resistance, entomology, drought and yield, millet and sorghum agronomy, and agroclimatology.

Clockwise from top left: In-service fellow from Burkina Faso (right) discussing his work on stemborer resistance with a member of the ICRISAT Sorghum Improvement Program; research fellow from India working in the pulse pathology laboratory; in-service trainees from Sudan, Ethiopia, and Burma collecting threshed grain from experimental plots; Ethiopian research scholar comparing chickpea genotypes.

In-service Training Programs

Requests for ICRISAT's 6-month training programs resulted in the acceptance of the largest group in the history of our training programs. This year we provided experience in research planning and management for effective evaluation of technology being tested, data collection and its evaluation, effective methods for communication of improved techniques, and basic agronomy for increased and stabilized food crop production in rainfed conditions. Individualized schedules in the cereals, pulses, and groundnut programs involved conducting field and laboratory experiments in population improvement methods, variety testing and selection for environmental adaptation for yield, identifying disease and insect resistances, and the influences of management on selection and yield responses. The crop production agronomy and extension methods participants studied the influences of various types and rates of fertilizer material on crop responses, plant density influence on yield, methods of demonstrating improved varieties and techniques, and methods for successfully transferring improved technology to food producers in rainfed-farming areas. The remaining participants received practical experiences related to their interests in cropping systems, land and water management, development and use of improved animal-drawn equipment, and the economics of improved technologies. They received limited training and experience in research farm development and management techniques.

Six scientists from Central American regional programs (two from Mexico, two from Guatemala, one from El Salvador, and one from Costa Rica) received 5 months training in sorghum improvement and production at CIMMYT.

Apprenticeships

Self-sponsored apprenticeships were provided for a few participants during their university holidays, or as a part of their required work-study programs. Each participant was assigned to an ongoing research project to collect and handle data, gain work experience, and subsequently write a report. Participants were provided experience in a semi-arid agricultural research environment, which is expected to be of benefit when they return to their undergraduate degree course, enter employment, or undertake postgraduate studies in semi-arid agriculture programs.

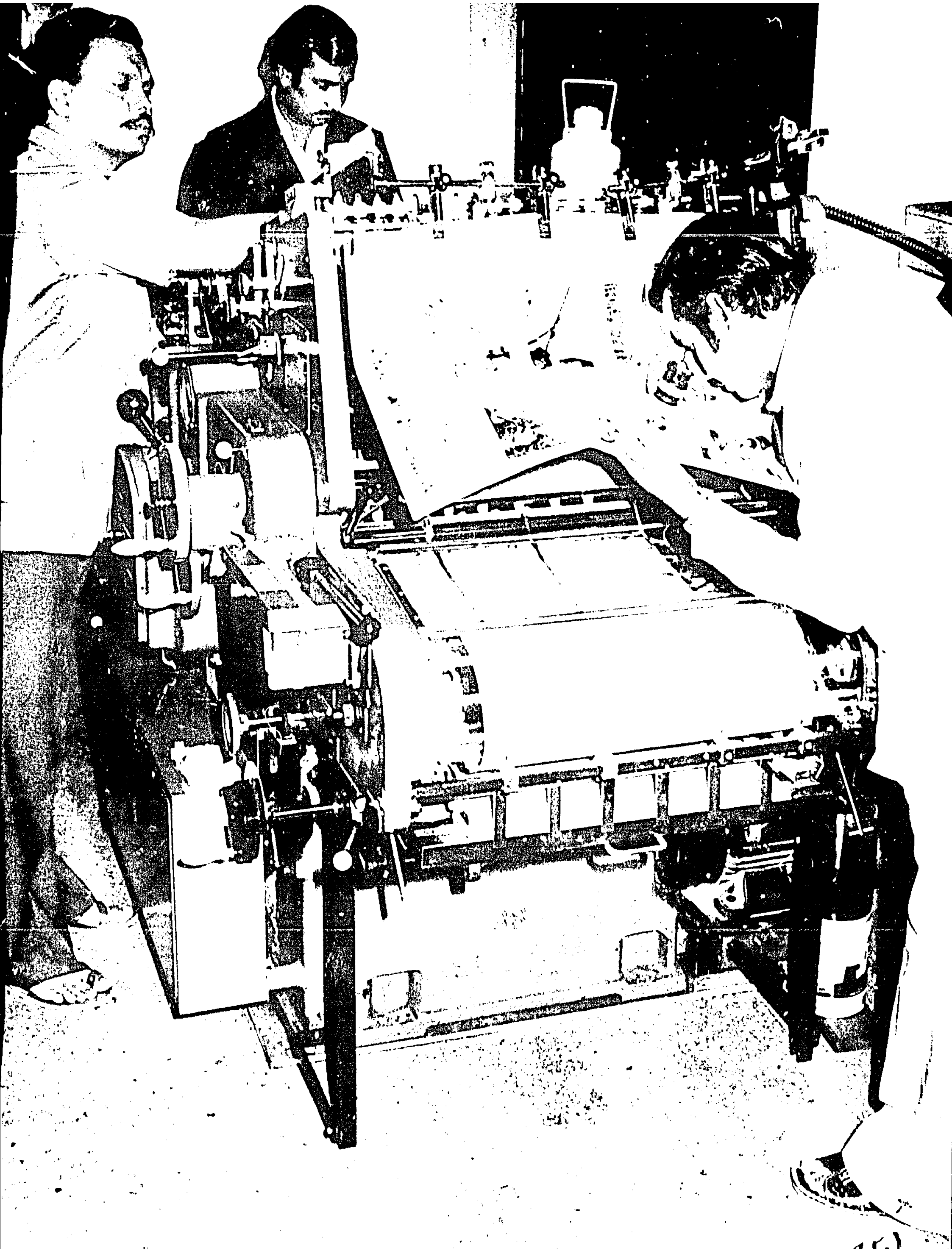
Apprentice from the Netherlands working on groundnuts.

Short-term Courses

Two-day intensive courses were held for 15 employees of State Banks and 18 State Department of Agriculture employees. The courses were designed to transfer technology for increasing the production of crops during the rainy season on the rainfed deep Vertisols of India. The participants were selected to be associated with State deep Vertisol watershed development projects for the implementation of the broad-bed-and-furrow technology in their village crop improvement programs.

Looking Ahead

Postdoctoral fellowships and student research thesis scholarships will be available (10-20 per year) on research topics related to plant breeding, physiology, microbiology, pathology, cytogenetics, entomology, agronomy, land and water management, agricultural economics, agroclimatology, and resource management within ongoing research projects. One to 6 months specialist training for national research scientists (15-20 per year) will be available in research disciplines as in-service fellowships. The crop improvement, crop production, and resource management's 6-month in-service training programs will be able to accommodate the increased requests for training of technicians, scientists, and extension personnel. Intensive courses in legume pathology and agricultural economics are planned for 1987.



Contents

Cover photo: An ICRISAT publication on press in Information Services' printshop.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Information Services, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh 502 324, India.

RESEARCH SUPPORT ACTIVITIES

Plant Quarantine

The Plant Quarantine Unit is responsible for the phytosanitary examination of ICRISAT mandate crop seeds for export. It also carries out surveillance for pests and diseases in the postentry quarantine isolation area in conjunction with the Government of India National Plant Quarantine Services, and helps in the harvest of healthy first-generation seeds for release to ICRISAT scientists.

While exporting seeds, all samples leaving ICRISAT are examined and certified to be substantially free from pests and diseases by the quarantine authorities of the Government of India before dispatch. The plant quarantine rules and regulations of the importing countries are strictly followed in cooperation with Central Plant Protection Training Institute (CPPTI) and the National Bureau of Plant Genetic Resources (NBPGR).

Plant Material Exports

During 1985 there was a 37% increase in seed exports. A total of 65450 seed and plant samples of our mandate crops and minor millets were exported to scientists and cooperators in 99 countries (Table 1). Seeds comprising 510 sets of various international trials and nurseries supplied by crop improvement programs for multilocational testing were dispatched to 184 collaborative research stations in 74 countries. Other material exported included germplasm accessions from the ICRISAT gene bank, breeding and segregating lines, genotypes for chemical analysis, and physiological and nitrogen-fixation studies. We also exported 83 units of *Rhizobium* strains as peat inoculants or agar slopes to 17 institutions in 14 countries, and six samples of *Striga* seeds to collaborating scientists in the UK.

Table 1. Plant material exports of ICRISAT mandate crops during 1985.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
AFRICA						
Angola					59	
Benin				47		
Botswana	218	5		40		
Burkina Faso	6186	203		3	128	
Burundi	263			3		
Cameroon	823	110		28		
Cape Verde Islands			222	5		
Chad	141	57				
Congo				20	154	
Egypt	194		202	16	57	
Ethiopia	454	11	342	73	33	15
Gabon					25	
Gambia	86	4			40	
Ghana	346	196		3	54	

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
Guinea	72	18		72	15	
Guinea Bissau			19	20	20	
Ivory Coast				10	6	
Kenya	130	32	359	83	12	
Liberia	50	50	64	8		
Malawi	372	18	99	208	237	
Mali	728	50		61	120	
Mozambique	621	66			59	
Niger	884	976	10	7	104	
Nigeria			8	2		
Rwanda	395		100	20	19	
Senegal	532	393			44	
Sierra Leone	867	119			56	
Somalia	460					
Sudan	391	350	152	23	94	
Swaziland			64	22		
Tanzania	440			64		
Togo				3		
Tunisia			256			
Uganda	351					
Zaire	4				19	
Zambia	1 157	1 847	93	88	33	
Zimbabwe	5 780	1 082	120	145		
ASIA						
Bangladesh			891	60	549	
Bhutan						
Burma	72	50	565	390	156	
China	788	65		43	302	
Indonesia	77		5	40	159	
Iran	765		662			
Iraq	3		152			
Israel	122		9			
Japan	154	50	50	50	52	
Korea	75	221		79	100	100
Malaysia				6	37	
Nepal	72	10	1 031	20	49	
Pakistan	1 150	343	2 509	11	76	
Philippines	1 536	48	64	264	233	
Saudi Arabia	51					
Sri Lanka	72	1	16		24	
Syria			527			
Taiwan	24	7	1	31	110	
Thailand	978	37	13	107	306	
Turkey		25	65			
Yemen (AR)	1 630	114	152			

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
THE AMERICAS						
Argentina	1 253		152	117		
Belize			248			
Bolivia	122			53		
Brazil	32			27	2	
Canada	249		322		63	
Caroline Islands				20		
Chile			156	4		
Colombia	329	145	264		32	
Costa Rica	172	8				
Dominican Republic	182					
Ecuador	114	50	50	123	50	
El Salvador	481			16		
Guatemala	602					
Guyana			6			
Haiti	72	5			29	
Honduras	696	7				
Jamaica		25				
Mexico	1 141	247	825	30	19	
Nicaragua	174					
Panama	72					
Peru	11		152	56	19	
Puerto Rico				70	1	
Surinam	72					
Trinidad			64			
Uruguay	100					
USA	773	15	184	157	347	
Venezuela	712			3		
EUROPE						
Belgium	71	19	8			
Canary Islands				10		
Cyprus					30	
Federal Republic of Germany	39		10			
France	188					
Greece			152			
Italy	98	25	16	21		
Portugal					41	
Spain			152			
UK	1 164	200		29	24	50
USSR	36					
AUSTRALASIA						
Australia	247	109	152	150	55	
Fiji				2		
New Zealand			4			
	38 716	7413	11 739	3 063	4 354	165

Plant Material Imports

The National Plant Quarantine Service released 35 consignments comprising 4338 samples of seed and plant materials from 27 countries (Table 2) to ICRISAT.

The Government of India's plant quarantine unit located at CPPTI, Hyderabad, released 4056 healthy seed samples of sorghum, pearl millet, chickpea, pigeonpea and its wild relatives, and 273 groundnut plants. The groundnut plants were subjected to growing-on tests against

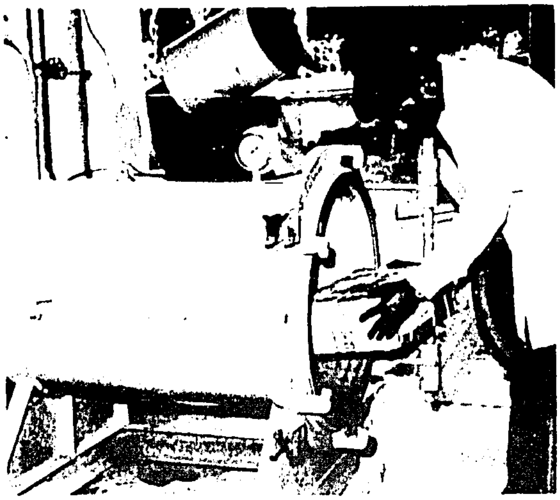
Table 2. Plant material imports of ICRISAT mandate crops during 1985.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
AFRICA						
Burkina Faso		87				
Kenya				49		
Lesotho	250					
Malawi						
Niger		350				
South Africa	32					
Swaziland	184					
Tanzania	5	12			90	
Zimbabwe	647	263				
ASIA						
Bangladesh			131	6		
China	51					
Indonesia				18		
Syria			1241			
Yemen (AR)	329	34				
THE AMERICAS						
Barbados				17		
Brazil				10		
Dominican Republic				56		
Grenada				13		
Mexico		1				
Puerto Rico				42		
St.Lucia				18		
St.Vincent	1			19		
Trinidad and Tobago	1			70		
USA	1	13	76		183	
EUROPE						
Italy			3			
USSR						9
AUSTRALASIA						
Australia				26		
	1501	760	1451	344	273	9

viruses in an insect-proof screen house. Nine samples of minor millets were released by NBPGR, New Delhi, and forwarded to the Genetic Resources Unit (GRU). The Plant Quarantine and Fumigation Station at Sahar, Bombay, released 81 samples of *Rhizobium* nodules, collected in Malawi.

Postentry Quarantine Isolation Area (PEQIA)

Before seed and plant samples are released officially they are grown in isolation. We raised 3660 accessions of our mandate crops and wild legumes such as *Flemingia strobilifera*, *F. macrophylla*, *F. lineata*, *F. bracteata*, *Rhyncosia minima*, and *Atylosia scarabaeoides* in the PEQIA at ICRISAT Center. This included 366 chickpea lines



Imported seed consignments are vacuum fumigated on arrival at the Central Plant Protection and Training Institute (CPPTI), Hyderabad, before the seeds are examined for signs of disease or insect infestation.

After crops are harvested in the postentry quarantine isolation area (PEQIA), the crop residue is burned to avoid any possible spread of diseases, insect pests, or other contaminants.

from the International Center for Agricultural Research in the Dry Areas (ICARDA) that were grown under shelters during the rainy season.

The crops were regularly inspected by Government Plant Quarantine officials and any plants showing incipient symptoms of potentially serious diseases were promptly rogued and incinerated. In addition, a regular spraying program was undertaken to ensure healthy crop. Seeds from healthy plants were harvested and released to the GRU and Crop Improvement Programs.

Looking Ahead

The Plant Quarantine Unit will be moving to new permanent accommodation soon, in a building that will provide better facilities for strengthening quarantine inspection of outgoing seed material.

Computer Services

The Computer Services Unit provides timesharing to ICRISAT research personnel on a VAX-11/780 computer system and to ICRISAT administration on a VAX-11/750 computer system. Both systems use the VMS operating system. We develop interactive systems, provide data-entry services, install software packages, install microcomputer hardware and software, and conduct seminars and individualized instruction on computer usage to all ICRISAT staff members.

State of Development

The major thrust of software development in 1985 was on systems for administrative applications, i.e., personnel management, supplies management and procurement, assets management, and financial accounting. We also made revisions in existing systems for payroll, fuel management, and tracking work orders to facilitate integration with the new systems. We initiated ancillary systems for the travel office and field medical unit. We have released the systems for supplies management, assets management, and Phase I of the financial accounting for regular use. Besides these administrative applications, we developed and released an institute-wide mailing-list system to Information Services, developed a new version of an online research project management information system, added a French language capability to the interface software that links our VAX-11/780 computer system to a phototypesetter, developed a conversion program to permit microcomputer-based word-processor files to be used on the VAX and phototypesetter, and implemented data capture software for the Epson HX-20 hand-held microcomputer.

All systems, with the exception of financial accounting, are being designed and implemented in-house. The financial accounting system, designed by A.F. Ferguson and Co., Madras, is being implemented in-house. Software development was hindered during the first half of the year by the heavy interactive load on the VAX-11/780. The progress on these projects accelerated with the installation of the VAX-11/750 for administrative use in early July 1985, allowing all development terminals to be transferred to this lightly loaded machine.

The Statistical Analysis System (SAS), a popular statistical package in North America, was under evaluation during the last half of the year and a decision to purchase this software was taken in December. REF-11 software used to maintain small lists of references was purchased and installed on the research VAX-11/780 system in April.

An Assistant Manager for Administrative Software Development was appointed in July 1985, and two additional programmer/analysts joined in late September and late December. Two Computer Services Assistants have also joined the service, freeing senior assistants to help with software development projects. An attendant has also joined us to help with routine computer operations.

Several Digital Equipment Corporation (DEC) Rainbow microcomputers were installed during 1985 for word processing, spreadsheet applications, small database management, and training. Many of these systems are able to gain access to one of the central computers for data exchange.

ICRISAT is a member of CGNET, a computer-based messaging network that links the TAC and CGIAR secretariats, CIAT, CIMMYT, CIP, IBPGR, ICRISAT, IFPRI, IIE, IRRI, and ISNAR. CGNET is implemented using the ITT Dialcom Electronic Mail Service that permits messaging with several other institutes throughout the world. In addition to mail messages, CGNET is being used to exchange experimental data with a cooperating university in the UK. The use of the electronic mail service has required the operation of our computer systems 24 hours per day, thus providing improved access for our user community. In October, the ICRISAT Sahelian Center (ISC), in Niamey, Niger, was added to CGNET using a DEC Rainbow microcomputer, a modem, and an international telephone link to the USA. This link has greatly facilitated the exchange of information between ICRISAT Center and ISC.

There was an emphasis on training during 1985, both for our computer users and the Computer Services staff. A 5-day course on basic computer usage, text editing and formatting was offered in-house during January to 15 members of the ICRISAT Center administrative staff. Sixty-two administrative staff members attended a 1-week computer familiarization course during June and July, and 22 staff members attended a course on Database Management during August. Both courses were conducted by CMC, Ltd., who also presented a 2-day seminar entitled "Computers: a management tool" for the ICRISAT directors and administrative division heads. Hinditron Computers Private Ltd., Secunderabad, conducted two courses, a 5-day introduction to VMS, the operating system used on our VAX systems, in December to the staff members who had taken the familiarization course, and a 5-day introduction to Datatrieve, DEC's data retrieval system, in November to the staff members who had attended the database course earlier.

Three Computer Services staff members attended a 2-week course on BASIC programming offered by CMC, Ltd., Secunderabad, in January. One staff member participated in a 3-day seminar on the IBM PC microcomputer in Hong Kong, during September. Two staff members attended a 5-day advanced course on database management systems in Bombay during September, and two others attended a 5-day advanced course on office information systems in Bombay in October. The assistant manager for operations was trained for 6 weeks on the latest versions of system software and system programming techniques at Digital Equipment Corporation in the USA.

The Department Head attended the Spring DEC-Users' Society (DECUS) meeting in June in New Orleans, Louisiana, USA, followed by a 3-day meeting of six IARC computer center directors at CIMMYT. He also attended the Fall DECUS meeting in December in Anaheim, California, USA. Four staff members attended the Computer Society of India annual meeting in Delhi in February.

Looking Ahead

The two VAX computer systems will be connected as a network providing a base for online access to administrative systems to all program offices and divisions in the Institute. We will complete the integration of the primary administrative applications: financial accounting, personnel database management, purchase order tracking, and supplies management. A new payroll system that will make use of the new personnel and financial accounting systems, a system to monitor vehicle usage, a system to help track the progress of manuscripts through the Editorial Committee review process, a record-keeping system for experimental plots, and a new system to maintain genetic resources accessions records are all planned for 1986. We will encourage more use of microcomputers for word processing to help offload the VAX systems, and we will evaluate the use of microcomputers as nodes in the proposed VAX network. We will implement international electronic mail services for the SADCC/ICRISAT Sorghum and Millet Improvement Project in Bulawayo, Zimbabwe.

Statistics Unit

The Statistics Unit provides services to ICRISAT staff and scientists from collaborative projects at various stages of their research. This includes providing experimental designs, analyzing results, and drawing inferences. We review scientific papers for the Editorial Committee and reports for programs and scientists. We also participate in visits to experimental trials. Our principal statistician visited ICRISAT's research programs in West and eastern Africa to discuss design and analysis of trials and their results, gave seminars on experimental methods and nearest neighbor (NN) techniques, and had useful discussions with national scientists. One staff member received training on Crop Experimentation in Developing Countries at the University of Kent at Canterbury, UK.

Our consultancies with scientific staff and collaborators during the year averaged over 70 per month. Data sets were processed for scientists at ICRISAT and cooperative programs. A number of GENSTAT and FORTRAN computer programs were written to generate randomized plans and statistical analyses to meet the specialized needs of scientists.

The Institute benefitted from a consultant's visit on the application of NN techniques in field experiments. Several pearl millet and sorghum data sets were subjected to NN analyses which indicated marked increases in precision of effects estimated by having a better adjustment for trend in the field.

Discussions with scientists stimulated us to develop techniques to solve the following problems.

Analysis of harvest indices. This advocates the estimation of harvest indices as the ratio of the mean grain (pod) yield to the total yield as against the mean of the ratios of the two characters. The performance of the two types of estimates were compared for their bias and mean squared error (MSE). The assumptions of analysis of variance are not tenable on the classical estimate which is less efficient than the proposed one.

The analysis of land equivalent ratios (LERs) using the approximation for MSE of the ratio of random variables. The MSE of the component and total LER estimates were evaluated and a test for their comparisons over a number of treatments obtained.

Application of the Edgeworth Series distribution function for the dose and binary response relationship. This function takes into account the departure from normality by making adjustment for the skewness and kurtosis parameters of the real data.

Approximations to the first two moments of the sample Gini's Coefficient and its distribution. Using the properties of order statistics the results are obtained for a general distribution function and simplified for a few used to study income distribution.

A design to monitor and analyze data for screening genotypes for *Striga* resistance. The use of frequent control plots throughout the trial area enables the intensity of *Striga* pressure at different locations in the field to be monitored and allows neighboring test entries to be assessed with more confidence. The data on sorghum using the checkerboard layout were analyzed with plot assessment and nearest neighbor comparison methods.

We participated in several conferences, symposia, and scientific and administrative meetings and prepared technical reports for scientists' use.

Looking Ahead

We plan to assess various spatial methods available for field experiments and construct some experimental designs with particular emphasis on adjustment for one-dimensional local trends. We shall also examine data analysis methods robust for mild departure from (assumed) normality.

Library and Documentation Services

Acquisition

We developed a microcomputer-based book acquisition system and implemented it during the year. The system enables data-entry, duplication checking, placement of purchase orders, follow-up of pending orders, budgeting, etc., and has enabled increased efficiency of operations. This is reflected in the 32% increase in book acquisitions achieved during 1985 as compared to 1984. Data on acquisitions during 1985 are given in Table 1.

Table 1. Status of acquisition, ICRISAT Library, 1985.

Documents	Additions during 1985	Total holdings (Dec 1985)
Books and reports	1063	20045
Bound volumes of periodicals	784	12085
Annual Reports	132	1061
Reprints, photocopies, etc.	996	5623
Microforms	116	763

We assisted in identifying, selecting, ordering, classifying, and cataloging a core collection of books for the ISC library. Such assistance to ISC will continue until ISC moves to permanent facilities at Sadoré and appoints trained library staff.

Documentation Services

The Selective Dissemination of Information (SDI) service was expanded to include more scientists from Africa. The service now goes to 140 scientists in 26 countries representing a 27% growth in the number of scientists receiving the service during 1985.

We conducted 12 on-line searches on computer-readable databases and 68 manual searches to meet specific requests for comprehensive, and/or problem-oriented information. The availability of search results was announced in the SMIC Newsletter enabling more users to benefit from this service.

The Central Reprography Unit attached to the Library provides Institute-wide photocopying and offset printing services. In 1985, the unit produced 968955 pages of photocopies and 12690 masters used to print program-level publications.

We started to input conventional and nonconventional literature produced at ICRISAT to the AGRIS database. This will enable wider and easier access to information produced at ICRISAT by readers in developing countries, who receive the AGRIS database free of cost. We are negotiating with the Commonwealth Agricultural Bureaux (CAB) International to input ICRISAT literature to the CAB database, and to use computer-readable CAB products.

Sorghum and Millets Information Center (SMIC)

Bibliographies. We published annotated Millets bibliographies for 1981 (641 entries) and 1982

(991 entries). All components of SMIC bibliographies are now computer-produced enabling much faster compilation.

Traveling Workshop in West Africa. Two information scientists from SMIC, and the French editor from ISC conducted workshops from 12-31 March 1985 in four West African countries, namely, Burkina Faso, Mali, Niger, and Senegal. The workshops aimed to improve the awareness of agricultural scientists in those countries to the resources, services, and capabilities of SMIC. As a result of the workshops, there has been an increase in requests for SMIC services and improved contact between ICRISAT and libraries and documentation centers in West Africa.

Document delivery services. SMIC provided copies of 4878 papers in its collection to scientists from all over the world. This represents a threefold increase in the demand for this service in 1985 over that of the previous year.

Looking Ahead

A comprehensive project proposal to expand SMIC's resources and services to all five crops of ICRISAT's mandate was submitted to International Development Research Centre (IDRC) for funding. The new project envisages the use of machine-readable subsets of the CAB and AGRIS databases for information retrieval and selective dissemination services. Our database of information on ICRISAT's mandate crops will include subsets of the two databases together with locally generated input.

A data management software package suited to bibliographic applications has been identified and will soon be acquired. This will enable our database to become interactively searchable by ICRISAT scientists. The package will also enable the library to automate some of its routines and plan for a more integrated management of its resources and services.

Information Services

Information Services is responsible for the publication and dissemination of information about our research to a wide audience of national scientists and policymakers in developing countries, the international scientific community, donors, and informed readers. In addition, the division provides support services to scientists in the preparation of tables, figures, posters, photos, and slides, and in editing journal articles, conference papers, and other materials for publication or presentation outside ICRISAT. We also provide a French translation service to ICRISAT administrative and scientific staff.

This year ICRISAT published 52 institute-level publications including the second edition of A Guide to Sorghum Breeding, 2 Information Bulletins, 6 Workshop Proceedings, 3 Bibliographies, and 9 issues of various newsletters. Two issues of Nouvelles de l'ICRISAT were published and distributed from the ICRISAT Sahelian Center. Institute publications are listed at the end of the relevant Program's section of this report, and copies are available from Information Services.

Information Services also provides the secretariat to the Editorial Committee, which operates an internal peer-review system for manuscripts authored for international scientific publications. During 1985, a total of 153 manuscripts by ICRISAT authors were submitted to the Committee. Sixty manuscripts were approved for submission to journals and 47 to workshop or conference proceedings. Information Services staff edited 61 of these during the review process. Listings of papers published in 1985 are printed at the end of the relevant Program's section of this report, and reprints can be obtained from the appropriate Program Office.

During 1985 we revised the ICRISAT Style Guide designed to help authors in the presentation of externally and internally published manuscripts. We also ran a week-long workshop for staff members on the use of the Style Guide. The workshop sessions gave scientists, clerical staff, Computer Services, Statistics Unit, Library, and Information Services staff a chance to meet and discuss many topics of mutual interest. Excerpts from the Style Guide were used to produce a Guide for Authors that can be sent to scientists preparing papers for publication in ICRISAT workshops.

In addition to institute-level publications, the Art Unit handled 1100 pieces of artwork such as line figures, photo page layouts, poster presentations, maps, forms, overlays, page pasteups, and brochures. The Art Unit staff spend considerable time visualizing, evaluating transparencies for their reproduction value, and preparing rough layouts of cover designs and other graphic illustrations. The Photographic Unit handled 1462 jobs, comprising almost 30000 exposures in 1985. In addition to printing the major institute-level publications, the Printshop ran 784825 impressions from 875 pages during 1985. The Distribution Unit dispatched 30813 copies of publications during the year, a substantial increase over 1984. More than 85% of our publications were sent gratis to libraries and scientists engaged in agricultural research pertaining to the SAT, and the remainder were sold.

Looking Ahead

With our increasing involvement in francophone West Africa, Information Services is attempting to produce more French editions of ICRISAT publications. We intend to revise the Style Guide in the coming year and incorporate many modifications that resulted from our workshop for staff. We will also produce a revised Guide to Authors to incorporate the Style Guide modifications and hope to issue a French version of this useful document.

Finally, expanding information technology, especially advances in machine translations, graphic media, and telecommunications will surely affect the way Information Services responds to producers and audiences in the future.

Publications

Institute Publications

Annual Progress Reports

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Research Highlights 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Progrès de la recherche 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Annual Report 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT R&D Leaflets

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Improved seeds from ICRISAT: plant material descriptions nos. 1-9. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Fertilizer use in semi-arid tropical India. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Individual diets and nutritional status in Southern India. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Proceedings of the regional groundnut workshop for Southern Africa, Lilongwe, 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Early and late leaf spots of groundnut. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. ICRISAT R&D Leaflet. Retrospective literature searches on research subjects relating to ICRISAT's mandate. Patancheru, A.P. 502 324, India: ICRISAT.

Bibliographies

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). Sorghum and Millets Information Center. 1985. Millets Bibliography 1981. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Sorghum and Millets Information Center. 1985. Millets Bibliography 1982. Patancheru, A.P. 502 324, India: ICRISAT.

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. At ICRISAT nos. 9, 10, 11, and 12. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Sorghum and Millets Information Center, 1985. SMIC Newsletter nos. 16 and 17. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Nouvelles de l'ICRISAT nos. 6 et 7. Centre sahélien de l'ICRISAT, B.P. 12404, Niamey, Niger (via Paris): ICRISAT.

Other Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Hyderabad-Secunderabad: A guide and directory. Patancheru, A.P. 502 324, India: ICRISAT.

Journal Articles

Gilliver, B., Vasudeva Rao, M.J., and Venkateswarlu, P. 1985. A design and methods of analysis to monitor crop growth conditions illustrated with sorghum screening trials for resistance to *Striga*. Experimental Agriculture 21(3): 233-240.

ICRISAT Governing Board—1985

366

ICRISAT Senior Staff—as of December 1985

Administration

L.D. Swindale, Director General
J.S. Kanwar, Director of Research
C.R. Jackson, Director of International Cooperation (until October)
M.G.Wedeman, Assistant to Director General
S.P. Ambrose, Principal Government Liaison Officer and Principal Administrator
B.C.G. Gunasekera, Principal Soil and Water Scientist (International Cooperation)
S.J. Phillips, Special Assistant to Director General for Educational Affairs
V. Balasubramanian, Senior Executive Officer (Director General's Office)
Joyce Gay, Senior Administrative Secretary to Director General
M.S.S. Reddy, Scientist (from May, on contract)
Sunetra Sagar, Senior Administrative Secretary to Director of Research
S. Krishnan, Senior Administrative Officer (International Cooperation)
S. Ramachandran, Administrative Officer (International Cooperation)
D. Mitra, Fiscal Manager
A. Banerji, Assistant Manager (Fiscal)
V.S. Swaminathan, Senior Accounts Officer
A.N. Venkataswamy, Accounts Officer
C.P. Rajagopalan, Accounts Officer
P.A.V.N. Kumud Nath, Accounts Officer (from March)
B.K. Johri, Personnel Manager
Y. Bharadwaja, Assistant Personnel Manager (until July)
N.S.L. Kumar, Senior Personnel Officer
P. Suryanarayana, Senior Personnel Officer
R. Vaidyanathan, Purchase and Stores Manager (on sabbatic leave from October)
C.R. Krishnan, Assistant Manager (from June)
K.P. Nair, Senior Purchase Officer
D.K. Mehta, Senior Stores Officer
D.V. Rama Raju, Senior Purchase Officer
K.C. Saxena, Stores Officer
K.R. Natarajan, Shipping and Purchase Officer
S.K. Dasgupta, Senior Scientific Liaison Officer (Visitors' Services, until February)
A. Lakshminarayana, Scientific Liaison Officer (Visitors' Services)
Harish Sethi, Scientific Liaison Officer (from May)
K.K. Sood, Senior Security Officer
A. Ekbote, Security Officer
K.K. Vij, Senior Administrative Officer (Delhi Office)
V. Lakshmanan, Assistant Manager (Administration)
N. Surya Prakash Rao, Resident Medical Officer
R. Narsing Reddy, Transport Officer (on study leave)
G. Vijayakumar, Transport Officer
K. Jagannadham, Administrative Officer (Transport)
A. Rama Murthy, Travel Officer (from March)

International Cooperation

ICRISAT Sahelian Center, Niger

C.R. Jackson, Director, ISC and West African Programs (from November)
K.F. Nwanze, Principal Millet Entomologist and Acting Director (until November)
K. Anand Kumar, Principal Millet Breeder and Team Leader, Millet Improvement Program
B.B. Singh, Principal Millet Breeder, (Maradi)
M.V.K. Sivakumar, Principal Agroclimatologist
D.S.C. Spencer, Principal Economist
M.C. Klaij, Principal Soil and Water Management Scientist
C.A. Giroux, French Writer/Editor
B.D. Marvaldi, Project Development Officer
P.G. Serafini, Research Farm Manager
D.C. Goodman Jr., Regional Administrative Officer
L.K. Fussell, Principal Millet Agronomist
C. Renard, Principal Agronomist and Team Leader, Resource Management Program (from April)
J. Werder, Principal Millet Pathologist (from February)
A. Batiano, Principal Soil Chemist (ICRISAT/IFDC)
Maimouna S. Dicko, Principal Animal Nutritionist (ICRISAT/ILCA)
B.R. Ntare, Principal Cowpea Breeder/ Agronomist (ICRISAT/IITA)
R.C. Chase, Principal Soil Scientist (Texas A&M University)
L. Marchais, Principal Geneticist (ORSTOM)
S. Tostain, Principal Geneticist (ORSTOM)
A. Tekete, Principal Agronomist (University of Hohenheim, from April)
T.J. Stomph, Research Assistant

P. Ouedraogo, Research Assistant (from February)
Solange D. Gabriel, Executive Assistant, Liaison

Burkina Faso

C.M. Pattanayak, Principal Sorghum Breeder and Team Leader
K.V. Ramaiah, Principal Cereal Breeder—*Striga* (on sabbatic leave from December)
S.N. Lohani, Principal Millet Breeder
P.J. Matlon, Principal Production Economist
Helga Vierich, Principal Social Anthropologist (until August)
M.D. Thomas, Principal Sorghum Pathologist
D.S. Murty, Principal Sorghum Breeder (from June)
S. Lingani, Administrative Assistant, Accounts
B. Ouedraogo, Administrative Assistant, General Services

Mali

J.F. Scheuring, Principal Cereals Breeder and Team Leader
S.V.R. Shetty, Principal Agronomist
S. Toure, Administrative Officer
I. Kassambara, Computer Analyst (from April)

Nigeria

S.O. Okiror, Principal Millet Breeder

Senegal

S.C. Gupta, Principal Millet Breeder (until October, on sabbatic leave, April-August)

Kenya

Brhane Gebrekidan, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern and Southern Africa

Sudan

R.P. Jain, Principal Millet Breeder

Malawi

Regional Groundnut Improvement Program for Southern Africa

K.R. Bock, Principal Groundnut Pathologist and Team Leader
S.N. Nigam, Principal Groundnut Breeder

Zimbabwe

SADCC Regional Sorghum and Millet Improvement Project

L.R. House, Project Manager
W. Williams, Administrative Officer
A.B. Obilana, Principal Sorghum Breeder (from July)
S.C. Gupta, Principal Millet Breeder (from October)
E.W. Nunn, Farm Development Specialist (until May)
D.S. Bisht, Farm Development Specialist (from June)
W.A.J. de Milliano, Principal Cereals Pathologist (from December)

Syria

K.B. Singh, Principal Chickpea Breeder
M.V. Reddy, Principal Chickpea Pathologist (until February)

Pakistan

M.S. Rahman, Principal Chickpea Breeder/Plant Pathologist

Mexico

V.Y. Guiragossian, Principal Sorghum Breeder
C.L. Paul, Principal Sorghum Agronomist

Research Programs

Sorghum

S.Z. Mukuru, Principal Plant Breeder and Program Leader
L.K. Mughogho, Principal Plant Pathologist

J.M. Peacock, Principal Plant Physiologist
K. Leuschner, Principal Cereals Entomologist
D.S. Murty, Plant Breeder
(on sabbatic leave from June)
Belum V.S. Reddy, Plant Breeder
(on sabbatic leave until April)
B.L. Agrawal, Plant Breeder
P.K. Vaidya, Plant Breeder (from April)
N. Seetharama, Plant Physiologist
(on sabbatic leave until August)
R.K. Maiti, Plant Physiologist (until January)
P. Soman, Plant Physiologist
Suresh Pande, Plant Pathologist
R.Bandyopadhyay, Plant Pathologist
S.L. Taneja, Entomologist
H.C. Sharma, Entomologist
H.D. Patil, Senior Research Associate
S.P. Jaya Kumar, Administrative Officer
P. Ramesh, Research Fellow
N.F. Beninati, International Intern (from October)

Pearl Millet

S.B. King, Principal Plant Pathologist
and Program Leader
F.R. Bidinger, Principal Plant Physiologist
J.R. Witcombe, Principal Plant Breeder
K.K. Lee, Principal Cereals Microbiologist
K.N. Rai, Plant Breeder
B.S. Talukdar, Plant Breeder
Pheru Singh, Plant Breeder
S.B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist
(on sabbatic leave until October and
on secondment from November)
V. Mahalakshmi, Plant Physiologist
S.D. Singh, Plant Pathologist
R.P. Thakur, Plant Pathologist
S.P. Wani, Microbiologist
K.R. Krishna, Microbiologist
Nirmala Kumar, Administrative Officer
P.Q. Craufurd, International Intern (from February)

Pulses

Y.L. Nene, Principal Plant Pathologist
and Program Leader
D.G. Faris, Principal Plant Breeder, Pigeonpea
W. Reed, Principal Entomologist
(on sabbatic leave until April)
C. Johansen, Principal Agronomist
H.A. van Rheenen, Principal Plant Breeder, Chickpea
J. Arihara, Associate Physiologist (from May)
N. Ae, Associate Microbiologist (from May)
K. Okada, Assistant Microbiologist (from December)
K.C. Jain, Plant Breeder, Pigeonpea
K.B. Saxena, Plant Breeder, Pigeonpea
S.C. Gupta, Plant Breeder, Pigeonpea
Harjit Singh, Plant Breeder, Pigeonpea
(until October)
D.M. Pawar, Senior Agricultural Officer
(Cooperative Trials)
M.D. Gupta, Senior Research Associate
(on study leave)
Onkar Singh, Plant Breeder, Chickpea
C.L.L. Gowda, Plant Breeder, Chickpea
S.C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea
(on sabbatic leave until July)
J.H. Miranda, Senior Research Associate, Chickpea
O.P. Rupela, Agronomist (Microbiology)
J.V.D.K. Kumar Rao, Agronomist (Microbiology)
N.P. Saxena, Agronomist (Physiology)
Y.S. Chauhan, Agronomist (Physiology)
N.V. Ratnam, Senior Research Associate
S.S. Lateef, Entomologist
S. Sithanantham, Entomologist
M.P. Haware, Plant Pathologist
M.V. Reddy, Plant Pathologist (from March)
A.M. Ghanekar, Plant Pathologist
V.S. Bisht, Research Fellow (until September)
D.R. Dent, International Intern (until December)
I.S. Dundas, International Intern
S. Dwivedi, Research Fellow (until October)
S.B. Sharma, Research Fellow (until November)
P.K. Anand Rao, Research Fellow

Groundnut

R.W. Gibbons, Principal Plant Breeder
and Program Leader
D. McDonald, Principal Plant Pathologist
D.V.R. Reddy, Principal Plant Virologist
J.H. Williams, Principal Plant Physiologist
J.P. Moss, Principal Cytogeneticist
(on sabbatic leave until October)
J.A. Wightman, Principal Entomologist
L.J. Reddy, Plant Breeder
(on sabbatic leave from July)
P. Subrahmanyam, Plant Pathologist
(on sabbatic leave until April)

M.J. Vasudeva Rao, Plant Breeder
V.M. Ramraj, Plant Physiologist
V.K. Mehan, Plant Pathologist
P.T.C. Nambiar, Microbiologist
P.W. Amin, Entomologist
A.K. Singh, Cytogeneticist
D.C. Sastri, Cytogeneticist
S.L. Dwivedi, Plant Breeder
R.C. Nageswara Rao, Plant Physiologist
G.V. Ranga Rao, Entomologist (from July)
P. Subrahmanyam, Administrative Officer
S.N. Azam Ali, International Intern (until October)
K.M. Dick, International Intern
M. Dutta, Research Fellow (until December)
H.A. Hobbs, International Intern
S. Nahdi, Research Fellow

Resource Management

M. von Oppen, Program Leader (from October) and Program Leader, Economics (until September)
R.P. Singh, Program Leader, Farming Systems (February-October)
S.M. Virmani, Principal Agroclimatologist (on sabbatic leave until August)
J.R. Burford, Principal Soil Chemist
C.W. Hong, Principal Soil Scientist (ICRISAT/IFDC)
C.K. Ong, Principal Agronomist, Cropping Systems
A.B.S. King, Cropping Systems Entomologist (ICRISAT/TDRI)
R.J. Van Den Beldt, Principal Agronomist, Agroforestry (from March)
A. Schutt, Assistant Engineer, Soil Fertility Unit, (ICRISAT/University of Hamburg, from December)
K.B. Laryea, Principal Soil Physicist (from November)
T. Takenaga, Principal Agricultural Engineer
T.S. Walker, Principal Economist (from June)
R.A.E. Mueller, Principal Economist
D. Sharma, Coordinator, On-farm Research
Piara Singh, Soil Scientist
A.K.S. Huda, Agroclimatologist
K.L. Sahrawat, Soil Chemist
T.J. Rego, Soil Scientist (on sabbatic leave until October)
K.P.R. Vittal, Soil Scientist (until June)
M.R. Rao, Agronomist
M.S. Reddy, Agronomist (on leave from November)
M. Natarajan, Agronomist
C.S. Pawar, Entomologist
A.A.H. Khan, Engineer
Sardar Singh, Soil Scientist
K.L. Srivastava, Agricultural Engineer
R.K. Bansal, Agricultural Engineer
R.C. Sachan, Agricultural Engineer
Prabhakar Pathak, Agricultural Engineer
N.K. Awadhwal, Agricultural Engineer/Soil Physicist
S.K. Sharma, Senior Research Associate
V.M. Mayande, Engineer
N.S. Jodha, Senior Economist
R.N. Athavale, Senior Hydrologist (from June, on contract)
R.D. Ghodake, Economist (on leave from September)
R.P. Singh, Economist
K.G. Kshirsagar, Senior Research Associate
K.V. Subba Rao, Senior Research Associate
M.J. Bhende, Senior Research Associate
R.S.Aiyer, Senior Administrative Officer
Surendra Mohan, Senior Administrative Officer
R.T. Hardiman, International Intern (until May)
K.A. Dvorak, International Intern (from January)
N.V. Narasimhan, Research Fellow
V. Ballabh, Research Fellow

Support Programs

Biochemistry

R. Jambunathan, Principal Biochemist
Umaid Singh, Biochemist (on sabbatic leave until September)
V. Subramanian, Biochemist
S. Sivaramakrishnan, Plant Biochemist/Physiologist (from June)
T.A. Krishnamurthi, Senior Administrative Officer (from August)
Santosh Gurtu, Senior Research Associate
M.S. Kherdekar, Senior Research Associate

Electron Microscopy

A.K. Murthy, Engineer

Genetic Resources

M.H.Mengesha, Principal Germplasm Botanist and Program Leader (on sabbatic leave)

W.H. Skrdla, Germplasm Botanist and Acting Program Leader
K.E. Prasada Rao, Senior Botanist
R.P.S. Pundir, Botanist
V. Ramanatha Rao, Botanist
S. Appa Rao, Botanist (on sabbatic leave)
P. Remanandan, Botanist

Plant Quarantine

B.K. Varma, Chief Plant Quarantine Officer
Upendra Ravi, Senior Research Associate
N. Rajamani, Senior Administrative Officer

Fellowships and Training

D.L. Oswalt, Principal Training Officer
A.S. Murthy, Senior Training Officer
B. Diwakar, Senior Training Officer
T. Nagur, Senior Training Officer (on sabbatic leave from November)
S.K. Dasgupta, Senior Training Officer (from February)
Faujdar Singh, Training Officer (from March)
T.A. Krishnamurthi, Senior Administrative Officer (until July)
V.S. Raju, Senior Secretary (from August)

Information Services

H.L. Thompson, Head
J.B. Wills, Research Editor
Susan D. Feakin, Research Editor
S.R. Beckerman, Visiting Research Editor (until August)
S.M. Sinha, Assistant Manager, Art and Production
D.R. Mohan Raj, Editor
Madhu Reddy, Editor
J.J. Abraham, Editor (from August)
H.S. Duggal, Senior Photographic Supervisor
G.K. Guglani, Senior Art Visualizer
T.R. Kapoor, Senior Composing Supervisor
A. Antonisamy, Printshop Supervisor
N.V.N. Chari, Administrative Officer

Statistics

B. Gilliver, Principal Statistician (on sabbatic leave from July)
Murari Singh, Statistician

Computer Services

J.W. Estes, Computer Services Officer
S.M. Luthra, Assistant Manager (Computer Services)
J. Sai Prasad, Assistant Manager (Computer Services)
T.B.R.N. Gupta, Senior Computer Programmer/Analyst
C. Kameswara Rao, Computer Programmer/Analyst
J. Gnanasekharan, Computer Programmer/Analyst (from October)
S.V. Nanda Kishore, Computer Programmer/Analyst (from December)

Library and Documentation Services

L.J. Haravu, Manager
P.K. Sinha, Senior Documentation Officer
P.S. Jadhav, Library Officer
S. Prasannalakshmi, Library Officer

Housing and Food Services

G.W. Conover, Manager
S. Mazumdar, Assistant Manager (Food Services)
B.R. Revathi Rao, Assistant Manager (Housing)
D.V. Subba Rao, Assistant Manager (Warehouse)

Physical Plant Services

V.P. McGough, Manager (from May)
P.M. Menon, Assistant Manager (Administration)
Sudhir Rakhra, Chief Engineer (Civil)
D. Subramaniam, Chief Engineer (Electrical)
C.K. Belliappa, Assistant Manager (Workshop, from May)
S.K.V.K. Chari, Senior Engineer (Electronics and Instrumentation, on study leave)
N.S.S. Prasad, Senior Engineer (Electronics and Instrumentation)
A.R. Das Gupta, Senior Engineer (Communication)
D.C. Raizada, Senior Engineer (Airconditioning)
N.V. Subba Reddy, Horticulture Officer (until August)

D.V.S. Verma, Engineer (Machineshop)
R. Thiyagarajan, Engineer (Automobiles)
A.N. Singh, Engineer (Heavy Equipment and Tractors)
S.W. Quadar, Engineer (Office Equipment)
K.R.C. Bose, Engineer (Civil)
V.S. Raju, Senior Secretary (until July)

Farm Development and Operations

D.S. Bisht, Manager (until May)
S.N. Kapoor, Manager (Farm Operations)
S.K. Pal, Senior Plant Protection Officer
K. Ravindranath, Senior Engineer (Farm Machinery)
M. Prabhakar Reddy, Senior Agricultural Officer
M.C. Ranganatha Rao, Senior Engineer
S. Abid Ali Khan, Agricultural Officer
N.V. Subba Reddy, Horticulture Officer
(from August)
K.Santhanam, Senior Administrative Officer

Acronyms and Abbreviations Used in this Annual Report

ACIAR	Australian Centre for International Agricultural Research (Australia)
ACT	Arhar Coordinated Trial
ACT 1	Early Maturity Arhar Coordinated Trial
ACT 2	Medium Maturity Arhar Coordinated Trial
ACT 3	Late Maturity Arhar Coordinated Trial
ADAB	Australian Development Assistance Bureau
ADB	Asian Development Bank
AGRHYMET	Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (Niger)
AICMIP	All India Coordinated Millet Improvement Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICPIP	All India Coordinated Pulses Improvement Project
AICSIP	All India Coordinated Sorghum Improvement Project
AID	Agency for International Development (USA)
AMYT	Advanced Millet Yield Trial
APAU	Andhra Pradesh Agricultural University (India)
ARA	Acetylene-Reduction Activity
ARSHAT	Asian Regional Sorghum Hybrid Adaptation Trial
ARSVAT	Asian Regional Sorghum Variety Adaptation Trial
AWHC	Available Water-Holding Capacity
BARI	Bangladesh Agricultural Research Institute (Bangladesh)
BND	Bud Necrosis Disease
BP	Bristled Population
CAB	Commonwealth Agricultural Bureaux (UK)
CBMS	Computer-Based Messaging System
CCS	Combined Carbon Source
CEC	Cation Exchange Capacity
CILSS	Comité permanent interétats de lutte contre la sécheresse dans le Sahel (Mali)
CIMMYT	Centro Internacional de Mejoramiento de Maïz y Trigo (Mexico)
CIP	Centro Internacional de la Papa (Peru)
CISN	Chickpea International Screening Nursery (ICARDA)
CIVT	Composite Inter-Varietal de Tarna
CIYT	Chickpea International Yield Trial
CLAIS	Comision Latinoamericano de Investigadores en Sorgo (Guatemala)
CMI	Commonwealth Mycological Institute (UK)
CPPTI	Central Plant Protection Training Institute (India)
CPRs	Common Property Resources
CRIDA	Central Research Institute for Dryland Agriculture (India)
CRSP	Collaborative Research Support Program (USA)
CV	Coefficient of Variation
cv	cultivar
CVT	Coordinated Varietal Trial
DAE	Days After Emergence
DAR	Days After First Rain
DAS	Days After Sowing
DEC	Digital Equipment Corporation (USA)

DM	Downy Mildew
DMR	Downy Mildew Resistant
DTF	Days To 50% Flowering
EACSSN	Eastern Africa Cooperative Sorghum Screening Nursery
EACT	Extra-early Arhar Coordinated Trial
EC	Electrical Conductivity
EC II	Early Composite II
EGS	Employment Guarantee Scheme
ELISA	Enzyme-Linked Immunosorbent Assay
ELPN	Elite Products Nursery
EPIT	Early Maturity Pigeonpea International Trial
ER	Ergot Resistant
ERC	Ergot Resistant Composite
ET	Evapotranspiration
EXACT	Extra-extra-early Arhar Coordinated Trial
F CFA	Franc Communauté financière africaine
FAO	Food and Agriculture Organization of the United Nations (FAO)
FDRVT	Foliar Disease Resistant Varietal Trial
FEER	Fonds de l'eau et de l'équipement rural (Burkina Faso)
FESPO	Fertilizer Seed Pora
FYM	Farmyard Manure
GCVT	Gram Coordinated Varietal Trial
GIET	Gram Initial Evaluation Trial
GLM	Groundnut Leaf Miner
GRU	Genetic Resources Unit
GRV	Groundnut Rosette Virus
HAU	Haryana Agricultural University (India)
HLS	Hairy Leaf Surface
HYV	High Yielding Variety
IAR	Institute for Agricultural Research, Ahmadu Bello University (Nigeria)
IAR	Institute of Agronomic Research (Cameroon)
IARI	Indian Agricultural Research Institute (India)
IBPGR	International Board for Plant Genetic Resources (Italy)
IBRAZ	Institut burkinabè de recherche agronomique et zootechnique (Burkina Faso)
IBSRAM	International Board for Soil Research and Management (Thailand)
ICAR	Indian Council of Agricultural Research (India)
ICARDA	International Center for Agricultural Research in the Dry Areas (Syria)
ICAT	International Chickpea Adaptation Trials
ICCT	International Chickpea Cooperative Trials
ICCT DL	International Chickpea Cooperative Trial Desi Long-duration
ICCT DS	International Chickpea Cooperative Trial Desi Short-duration
ICMPES	ICRISAT Millet Pathology Ergot Sib-bulk
ICRAF	International Council for Research on Agroforestry (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
ICRRWN	International Chickpea Root Rots Wilt Nursery
ICSN	International Chickpea Screening Nursery
IDRC	International Development Research Centre (Canada)
IET	Initial Evaluation Trial

IFDC	International Fertilizer Development Center (USA)
IFPRI	International Food Policy Research Institute (USA)
IIE	International Institute of Education (IIE)
IITA	International Institute of Tropical Agriculture (Nigeria)
IIUCWRRN	ICAR/ICRISAT Uniform Chickpea Root Rots Wilt Nursery
IIUTPPBR	ICAR/ICRISAT Uniform Trials for Pigeonpea Phytophthora Blight Resistance
IIUTPSMR	ICAR/ICRISAT Uniform Trials of Pigeonpea Sterility Mosaic Resistance
IIUTPWR	ICAR/ICRISAT Uniform Trials for Pigeonpea Wilt Resistance
ILCA	International Livestock Center for Africa (Ethiopia)
IMD	India Meteorological Department
IMMLT	ICRISAT Millet Multilocational Trial
IMZAT	ICRISAT Pearl Millet African Zone A Trial
INRAN	Institut national de recherches agronomiques du Niger (Niger)
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
IPDR	Institut pratique de développement rural (Niger)
IPM	Integrated Pest Management
IPMAT	ICRISAT Pearl Millet Adaptation Trials
IPMAT	International Pearl Millet Adaptation Trial
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery
IPMRN	International Pearl Millet Rust Nursery
IPMSN	International Pearl Millet Smut Nursery
IPWN	International Pigeonpea Wilt Nursery
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (France)
IRRI	International Rice Research Institute (Philippines)
ISC	ICRISAT Sahelian Center (Niger)
ISC	International Sorghum Conversion
ISHAT	International Sorghum Hybrid Adaptation Trials
ISNAR	International Service for National Agricultural Research (The Netherlands)
ISRA	Institut sénégalais de recherches agricoles (Senegal)
ISSBN	International Sorghum Stem Borer Nursery
ISSFN	International Sorghum Shoot Fly Nursery
ISSN	International Sorghum *Striga* Nursery
ISVAT	International Sorghum Variety Adaptation Trial
IVC	Inter Varietal Composite
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya (India)
LAI	Leaf Area Index
LER	Land Equivalent Ratio
LON	Line Observation Nursery
LPSMWRY	Late-maturity Pigeonpea Sterility Mosaic and Wilt Resistant Yield Trial
LPSRY	Late-maturity Pigeonpea Sterility Mosaic Resistant Yield Trial
MC	Medium Composite
MFR	Multifactor Resistant
MLT	Multilocational Trial
MPAY	Medium-duration Pigeonpea Adaptation Yield Trial
MPN	Most Probable Number

MPSMWRY	Medium-duration Pigeonpea Sterility Mosaic Wilt Resistant Yield Trial
MPSRY	Medium-maturity Pigeonpea Sterility Resistant Lines Yield Trial
MPUB	Medium-maturity Pigeonpea Unselected Bulk
MPWRY	Medium-maturity Pigeonpea Wilt-Resistant Yield Trial
MSE	Mean Squared Error
N	Nitrogen
NARC	National Agricultural Research Centre (Pakistan)
NBPGR	National Bureau of Plant Genetic Resources (India)
NEC	New Early Composite
NELC	New Elite Composite
NET	National Elite Trial
NIRD	National Institute of Rural Development (India)
NN	Nearest Neighbor
NPV	Nuclear Polyhedrosis Virus
NR	Nitrate Reductase
NRA	Nitrate Reductase Activity
ODA	Overseas Development Administration (UK)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
OXFAM	Oxford Famine Relief Agency (UK)
P	Phosphorus
PARP	Partially Acidulated Rock Phosphate
PCV	Peanut Clump Virus
PEQIA	Postentry Quarantine Isolation Area
PGMR	Panicle Grain Mold Rating
PMADT	Pearl Millet Advanced Drought Trial
PMAHT	Pearl Millet Advanced Hybrid Trial
PMAVT	Pearl Millet Advanced Variety Trial
PMIVT	Pearl Millet Initial Variety Trial
PMMDT	Pearl Millet Multilocational Drought Trial
PMNT	Pearl Millet National Trial
PMV	Peanut Mottle Virus
PMXN	Pearl Millet Exchange Nursery
PON	Pigeonpea Observation Nursery
PYSV	Peanut Yellow Spot Virus
RBD	Randomized-Block Design
RH	Relative Humidity
RLWC	Relative Leaf-Water Content
RMP	Resource Management Program
ROCAP	Oficina Regional de los Programas Centroamericanos (USAID)
RP	Rock Phosphate
RR	Rust Resistant
RRL	Regional Research Laboratories (India)
rse	residual standard error
S	Sulfur
SADCC	Southern African Development Coordination Conference (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SAS	Statistical Analysis System

SAT	Semi-Arid Tropics
SCA	Specific Combining Ability
SDI	Selective Dissemination of Information
SLS	Smooth Leaf Surface
SMIC	Sorghum and Millets Information Center
SMK	Sound Mature Kernel
SMSS	Soil Management Support Services
SR	Smut Resistant
SRC	Smut Resistant Composite
SSP	Single Superphosphate
TADD	Tangential Abrasive Dehulling Device
TARO	Tanzanian Agricultural Research Organization (Tanzania)
TDM	Total Dry Matter
TDRI	Tropical Development and Research Institute (UK)
TGMR	Threshed Grain Mold Rating
TNAU	Tamil Nadu Agricultural University (India)
TSP	Triple Superphosphate
TSWV	Tomato Spotted Wilt Virus
ULV	Ultra-Low Volume
UNDP	United Nations Development Programme
UPN	Uniform Progeny Nursery
USDA	United States Department of Agriculture (USA)
USG	Urea Super Granules
USLE	Universal Soil Loss Equation
VAM	Vesicular Arbuscular Mycorrhizae
VLP	Virus-Like Particles
VLS	Village-Level Studies
WAE	West African Early
WMO	World Meteorological Organization (Switzerland)
WSARP	Western Sudan Agricultural Research Project (Sudan)
WUE	Water-Use Efficiency

ICRISAT plant material named or under naming process by the Plant Material Release Committee (PMRC)

Crop	Type of material	Original name	New name	Remarks
Pearl millet	Variety	WC-C75	ICMV 1	High-yielding variety released for general cultivation in India by Government of India, Ministry of Agriculture, Department of Agriculture and Cooperation.
Pearl millet	Variety	IBV 8001	ICMV 2	High-yielding cultivar in pre-release stage in Senegal.
"	"	IBV 8004	ICMV 3	"
Pearl millet	Male-sterile lines (A and B)	2068A 8A(843A)	ICMA 2	New male-sterile line for the production of new hybrids.
"	"	2068B 8B(843B)	ICMB 2	"
"	"	2221A 1A(842A)	ICMA 3	"
"	"	2221B 1B(842B)	ICMB 3	"
"	"	S10A (834A)	ICMA 4	"
"	"	S10B (834B)	ICMB 4	"
Pearl millet	Inbred line	ICMPE 13-6-27	ICML 1	Source of resistance to ergot (*Claviceps fusiformis*).
"	"	ICMPE 13-6-30	ICML 2	"
"	"	ICMPE 134-6-25	ICML 3	"
"	"	ICMPE 134-6-34	ICML 4	"
Pearl millet	Inbred line	SSC PS 252-S-4	ICML 5	Source of resistance to smut (*Tolyposporium penicillariae*).
"	"	ICI 7517-S-1	ICML 6	"
"	"	EBS 46-1-2-S-2	ICML 7	"
"	"	EB 112-1-S-1-1	ICML 8	"
"	"	NEP 588-5690-S-8-4	ICML 9	"
"	"	P 489-S-3	ICML 10	"
Pearl millet	Population (sibs of sister lines)	ICMPES 1	ICMP 1	Source with combined resistance to ergot (*Claviceps fusiformis*), smut (*Tolyposporium penicillariae*), and downy mildew (*Sclerospora graminicola*).
"	"	ICMPES 2	ICMP 2	"
"	"	ICMPES 28	ICMP 3	"
"	"	ICMPES 32	ICMP 4	"

Continued

Crop	Type of material	Original name	New name	Remarks
Pearl millet	Inbred line	IP 2696-1-4	ICML 11	Source of resistance to rust (*Puccinia penniseti*) controlled by a single dominant gene.
Sorghum	Pure line	SPV 351	ICSV 1	Released cultivar in India.
Chickpea	Pure line	ICCC 4	ICCV 1	Released cultivar in Gujarat State, India.
Chickpea	Pure line	ICCL 82001	ICCV 2	Combines acceptable kabuli seed-type with wilt resistance and short duration.
"	"	ICCL 83006	ICCV 3	"
"	"	ICCL 83004	ICCV 4	"
"	"	ICCL 83009	ICCV 5	"
Pigeonpea	Line	ICP 8863	ICPV 1	Recommended by AICPIP as source of resistance to wilt (*Fusarium udum*).
Pigeonpea	Population	MS4A	ICPM 1	Source of translucent anther-type of male sterility.
Pearl millet	Inbred line	P 7	ICML 12	Source of resistance to downy mildew (*Sclerospora graminicola*).
"	"	SDN 503	ICML 13	"
"	"	700251	ICML 14	"
"	"	700516	ICML 15	"
"	"	700651	ICML 16	"
Pearl millet	Inbred line	700481-21-8	ICML 17	Source of resistance to rust (*Puccinia penniseti*).
"	"	IP 537 B	ICML 18	"
"	"	IP 11776 (Souna Mali)	ICML 19	"
"	"	IP 2084-1	ICML 20	"
"	"	P 24	ICML 21	"
"	"	D 212-P1	ICML 22	"
Sorghum	Pure line	SPV 386	ICSV 2	Released cultivar in Zambia.

Continued

Crop	Type of material	Original name	New name	Remarks
Sorghum	Pure line	PM 11344	-[1]	Submitted by Sorghum Entomology (in process).
Pearl Millet	Variety	ICMS 7703	-	Submitted by Pearl millet Breeding (in process).
"	"	ITMV 8001	-	"
"	"	ITMV 8002	-	"
"	"	ITMV 8304	-	"
"	Male-sterile lines (A and B)	DSA 105-	-	Submitted by Genetic Resources Unit (in process).
"	"	DSA 118	-	"
"	"	DSA 134	-	"
"	"	PMC 23	-	"
Chickpea	Pure line	ICCC 32	-	Submitted by Chickpea Breeding (in process).
"	"	ICCX 730008-8-1-1P-BP-8EB	-	"
Pigeonpea	Variety	ICPL 87 (Pragati)	-	Submitted by Pigeonpea Breeding (in process).
"	"	ICPL 151 (Jagriti)	-	"
Groundnut	Variety	Robut 33-1-18-8-B1	-	Submitted by Groundnut Breeding (in process).
"	"	Robut 33-1-7-4	-	"

1. - indicates naming in process.