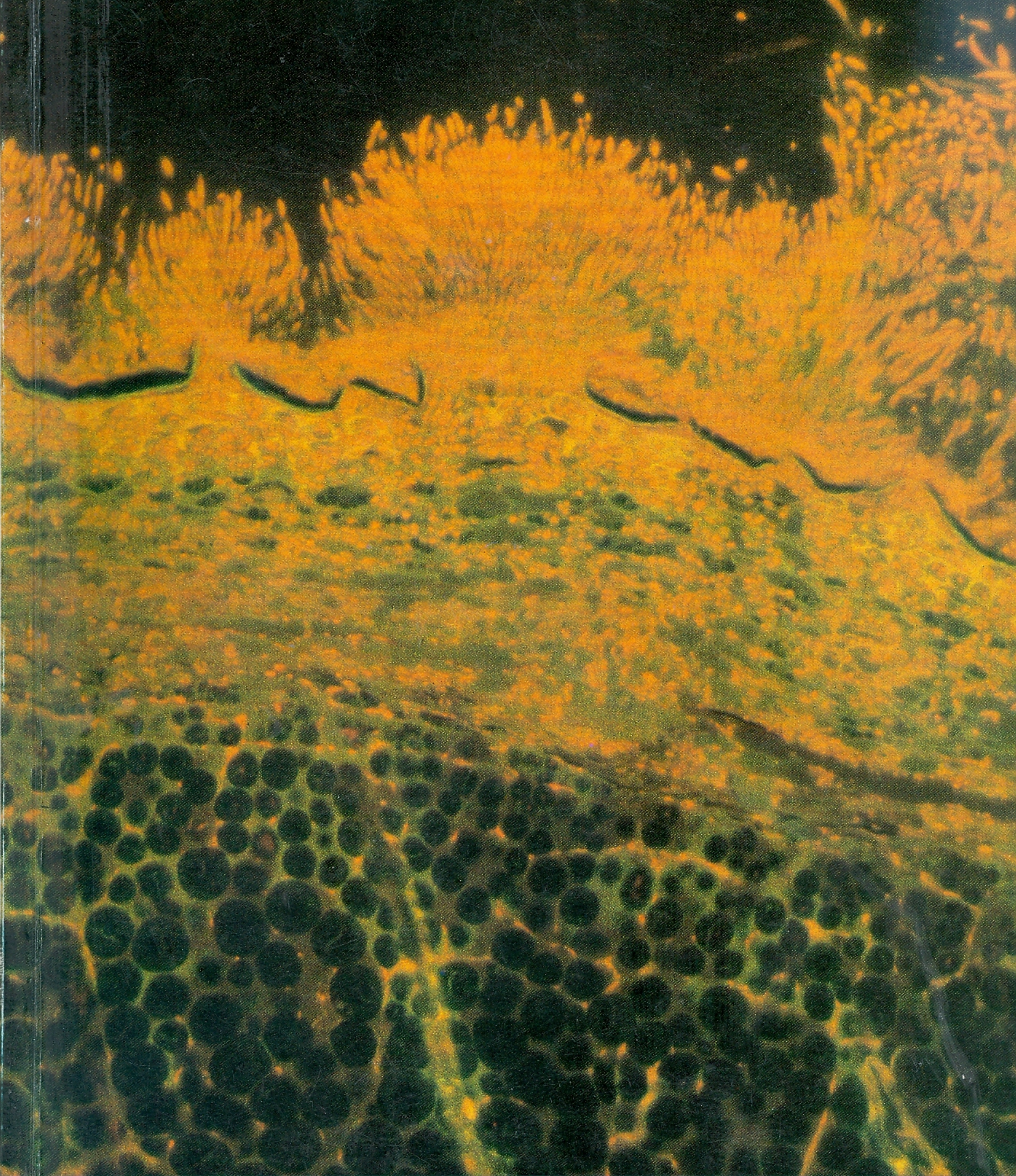
ICRISAT
ANNUAL REPORT 1987



Cover photo: Fluorescence micrograph (×1200) of a section through a moldy sorghum grain showing *Fusarium pallidoroseum*, (Cooke) Sacc., one of several grain-mold pathogens, colonizing the endosperm, aleurone layer, and pericarp, and sporulating on the surface after breaking through the epidermis. Sorghum grain mold is a major disease that affects sorghum crops throughout the SAT, limiting both production and utilization, and is one of ICRISAT's main research thrusts.

ICRISAT ANNUAL REPORT 1987

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

1988

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.

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

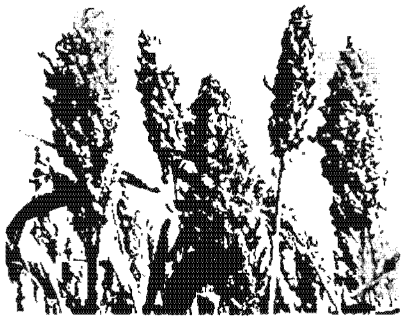
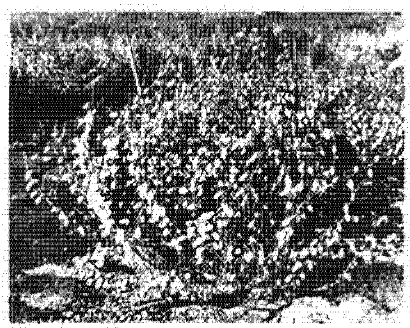
The International Crops Research Institute for the Semi-Arid Tropics is a nonprofit, scientific, research and training institute receiving support from donors through the Consultative Group on International Agricultural Research. Donors to ICRISAT include governments and agencies of Australia, Belgium, Canada, Federal Republic of Germany, Finland, France, India, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, United Kingdom, United States of America, and the following international and private organizations: Asian Development Bank, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), International Development Research Centre, International Fund for Agricultural Development, The European Economic Community, The Opec Fund for International Development, The World Bank, and 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.

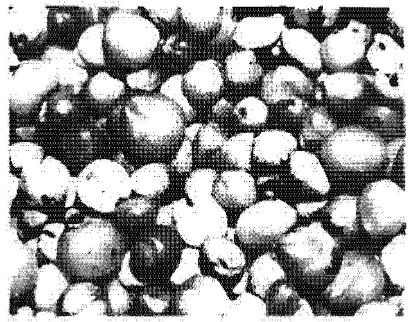
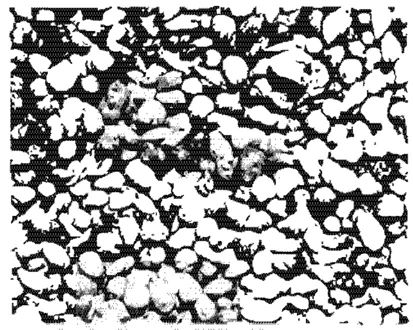
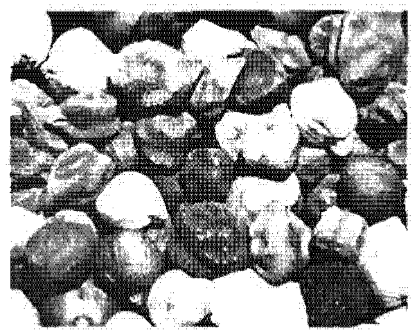
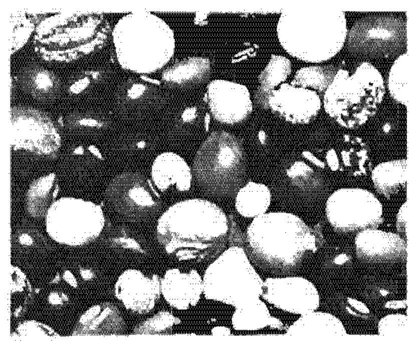
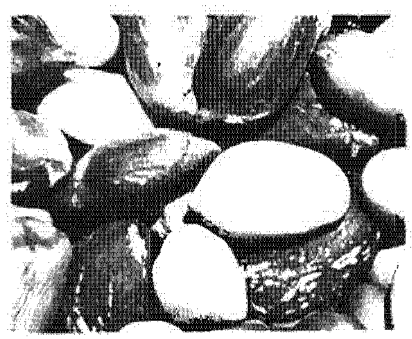
The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

ISSN 0257-2478 ICR 88-0038

Contents

ICRISAT's Five Crops

	Latin	English	French
	*Sorghum bicolor* (L.) Moench	Sorghum, durra milo, kafir corn, Egyptian corn.	Sorgho
	*Pennisetum glaucum* (L.) R.Br.	Pearl millet, bulrush millet, cattail millet, spiked millet.	Mil
	*Cicer arietinum* L.	Chickpea, Bengal gram, caravance, garbanzo bean.	Pois chiche
	*Cajanus cajan* (L.) Millsp.	Pigeonpea, red gram.	Pois d'Angc
	*Arachis hypogaea* L.	Groundnut, peanut.	Arachide

Portuguese	Spanish	Hindi	
Sorgo	Sorgo, zahina	Jowar, jaur	
Painco, perola.	Mijo perla, mijo.	Bajra	
Grao-de-bico	Garbanzo, garavance.	Chana	
Guando, feijao-guando.	Guandul	Arhar, tur.	
Amendoim	Mani	Mungphali	

About This Report

This Annual Report covers the 1987 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 six countries of Africa, and in Mexico, Syria, and Pakistan, where ICRISAT scientists are posted. Pertinent agroclimatic information is presented in the Agroclimatic Environment section.

In this Report, research achievements in respect of the Institute's five mandate crops are presented by crop, in the form of interdisciplinary reports on problem areas that reflect the interactive nature of our scientists' work.

Research by ICRISAT scientists in cooperative programs outside India is reported under relevant crop or discipline headings. Detailed reporting of the extensive activities of ICRISAT's research support units is precluded by the space available in this volume, but comprehensive coverage of ICRISAT's core research programs is given. Further information about the work reported here is provided in individual program publications, available from the research programs concerned. Offprints of sections of this Report are also available on request from program offices.

ICRISAT uses the Systéme international d'unitès (SI units). Throughout this Report, the variability of estimates is shown by including the standard error (SE); on graphs representing the mean of several observations the standard error is shown by a bar (I). Where levels of probability are discussed in the text, significance is generally mentioned at the 5% level; where the level differs, it is indicated parenthetically. In tables, levels of probability are shown 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.

The latin name for pearl millet has been changed; *Pennisetum americanum* (L.) Leeke is now referred to as *Pennisetum glaucum* (L.) R. Br. in this Report and in other ICRISAT publications.

A list of elite ICRISAT plant materials issued by the Institute's Plant Material Identification Committee during 1987 appears at the end of this Report, together with a listing of previously named material that are now in cultivation. In the text the ICRISAT designation of each plant material is given first, followed by its released designation or name in parentheses (where different) or its original name.

Introduction

For ICRISAT, 1987 marked an important milestone with the completion of 15 years of international service. The Institute continued to use its developed concepts and technologies to mitigate the effects of drought during this year when parts of India were afflicted by the worst drought of the century. At ICRISAT Center, rainfall to the end of September was about 27% below normal. But our crops did well. The drought did not significantly affect yields or the success of the experiments, indicating that the effects of moderate droughts can be partially offset by utilizing ICRISAT-developed breeding lines and management practices.

ICRISAT celebrated its 15th anniversary this year, on 16 October, World Food Day, dedicated this year by the Food and Agricultural Organization of the United Nations to resource-poor farmers, who constitute ICRISAT's major target group. Mrs Kumudben Joshi, Governor of Andhra Pradesh, was the chief guest. The Governor noted that ICRISAT had 'rendered very distinguished service to the international farming community.' During the cerem-

On ICRISAT Day the Governor of Andhra Pradesh released a commemorative catalog of publications by ICRISAT scientists.

ony, 334 regular employees received certificates for their 10 years' service,and 194 received awards for 15 years' service.

This has been an important year for the expansion and consolidation of ICRISAT's activities in West Africa. With the provision of special capital funds from many of the CGIAR donors, the construction of facilities at the ICRISAT Sahelian Center (ISC) is proceeding on schedule, and should be completed in mid-1988. The regional groundnut program, started in late 1986, became fully staffed with the addition of a breeder and a pathologist in January 1987. This permitted experimentation over a full crop season at Sadoré, and at Bengou in southern Niger in collaboration with the Institut national de recherches agronomique du Niger (INRAN).

The Resource Management team at ISC was strengthened by the addition of an agroforester, who began studies on the phenology of *Acacia albida* and initiated working relationships with national and international programs. An entomologist was appointed to work on pearl millet. Interaction with other CGIAR institutes has grown, with scientists from the International Food Policy Research Institute (IFPRI) and the International Board for Plant Genetic Resources (IBPGR) being attached to the ISC. In Burkina Faso, a *Striga* agronomist joined the sorghum team through an agreement with the French Ministry of Cooperation.

In Niger, ICRISAT forewarned the Government that the 1987 rainy season in the Sahel would be short, and crop yields would probably be below average. The prediction was generally accurate, but unseasonal rain in October helped remove the spectre of yet another year of food shortages. Nevertheless, the production of some crops was low. In the Sahelian zone, yields of pearl millet were 33% lower and cowpea yields 21% lower than in 1986. On the other hand, sorghum growing in the moister Sudanian zone, was little affected by drought. Good progress was made in all areas of research in the region, despite inadequate rainfall.

The ICRISAT Sahelian Center developed and strengthened its cooperation with national, regional, and international organizations in West Africa. Operational scale trials, involving an improved package of practices for millet and cowpea in the drier agroecological zones, were extended to the Birni N' Konni INRAN station in Niger, and we hope to extend these trials to other countries in 1988. The improved cropping systems developed by our bilateral program in Mali are being rapidly adopted by farmers in the southern parts of the country.

A number of new collaborative agreements were entered into during the year. ICRISAT signed a Memorandum of Understanding with Sri Lanka during the year, providing for mutual cooperation and collaboration in agricultural research under the auspices of the Asian Grain Legumes Network (AGLN). ICRISAT also signed a Memorandum of Understanding with Nepal, along with developing Work Plan for 1987/88. Memoranda of Agreement were also signed with the Republic of Mali, at Bamako, for the establishment of a West African regional sorghum and millet project in that country, and with the Federal Republic of Nigeria, at Lagos, for the establishment of a West African subregional research and training program on sorghum, operating from a central base in Nigeria. Under a new arrangement with Malawi, ICRISAT will expand its groundnut research activities at Chitedze Agricultural Research Station, Lilongwe, and construct offices and houses there for additional staff.

During this year, at the request of the Government of India, we set up a new unit, called the Legumes On-Farm Testing and Nursery (LEGOFTEN), a multidisciplinary unit that works with state scientists to compare the state-recommended, local farmers', and ICRISAT's methods of growing legumes. Initially, this unit will focus on groundnuts. Other important functions will be: prompt dispatch and follow-up of requests for seed; on-farm testing of elite material of all three legume crops in ICRISAT's mandate; identification of lines for minikit trials and their monitoring; seed multiplication of identified lines; and monitoring of all-India trials that contain ICRISAT legume materials.

This unit conducted groundnut yield-maximization trials, in collaboration with the Union Ministry of Agriculture and Departments of Agriculture of five Indian states. ICRISAT's technology was closely monitored and compared with the existing technology in individual states. In general, ICRISAT methods produced higher yields than the state-recommended or local ones, and have generated enthusiasm among farmers and extension personnel. In the state of Maharashtra, a special Groundnut Day was organized to observe the trials, attended by over 200 farmers, the State Minister of Agriculture, Members of Parliament, other government officials, and the media. The Government of Maharashtra has issued a directive that the technology should be transferred to at least 30% of the state's farmers by 1988.

Sorghum and pearl millet genotypes produced by ICRISAT are already in wide use by national breeding programs in Asia, Africa, Central and Latin America, and the Caribbean. However, to help speed up screening and testing, and to reduce delays in improved varieties reaching farmers, we set up a Cooperative Cereals Research Network (CCRN). This Network will enable regional programs to gain access to the full range of research material available in the entire ICRISAT system, and to bring back to ICRISAT scientists information on field problems faced by national programs.

ICRISAT continued its on-farm research on the improved Vertisol technology, and this had lasting impact in several areas. A recent study on the adoption of this technology in Madhya Pradesh 2 years after on-farm trials, showed that most farmers adopted double cropping and used improved seeds and fertilizers. Some had also adopted dry seeding and drainage improvements.

We established a new Nematology laboratory during the year. Nematodes will be isolated and identified from soil and root samples for further laboratory, greenhouse, and field experiments.

ICRISAT's Library and Documentation Services were further refined this year. A Compact Disk Read-Only-Memory (CD-ROM) facility was installed in the Library, and will be used to provide information retrieval services to scientists at ICRISAT and national programs. A new service replaced the Sorghum and Millets Information Center. The Semi-Arid Tropical Crops Information Service (SATCRIS) is funded jointly by ICRISAT and the International Development Research Centre (IDRC), Canada. It is designed to provide efficient and wide access to information on all of ICRISAT's mandate crops, and on aspects such as agroclimatology, soils, food and feed quality, and farming systems of the SAT.

In 1987, in addition to 30 Institute-level publications that included books, Research and Information Bulletins, workshop proceedings and progress reports and 11 issues of various newsletters, ICRISAT issued a new slideset and our scientists published 64 journal articles and 69 conference papers in the open scientific literature.

Several crop varieties and hybrids developed from ICRISAT material were released tofarmers during the year. ICSV145 (SAR 1), a *Striga asiatica*-resistant ICRISAT sorghum variety, has been released in India as ICSV 145, and has been recommended for cultivation in *Striga*-endemic areas of Andhra Pradesh during both rainy and postrainy seasons. It gives a grain yield of 2.2 t ha^{-1} under extensive field infestation by *Striga*; and matures in around 110 days with a fodder yield of

ICSV 112 (SPV 475) a high-yielding sorghum variety that has been recommended for use in most states in India for cultivation in the rainy season. In addition to high grain yields, this variety can also produce over 10 t of fodder per hectare.

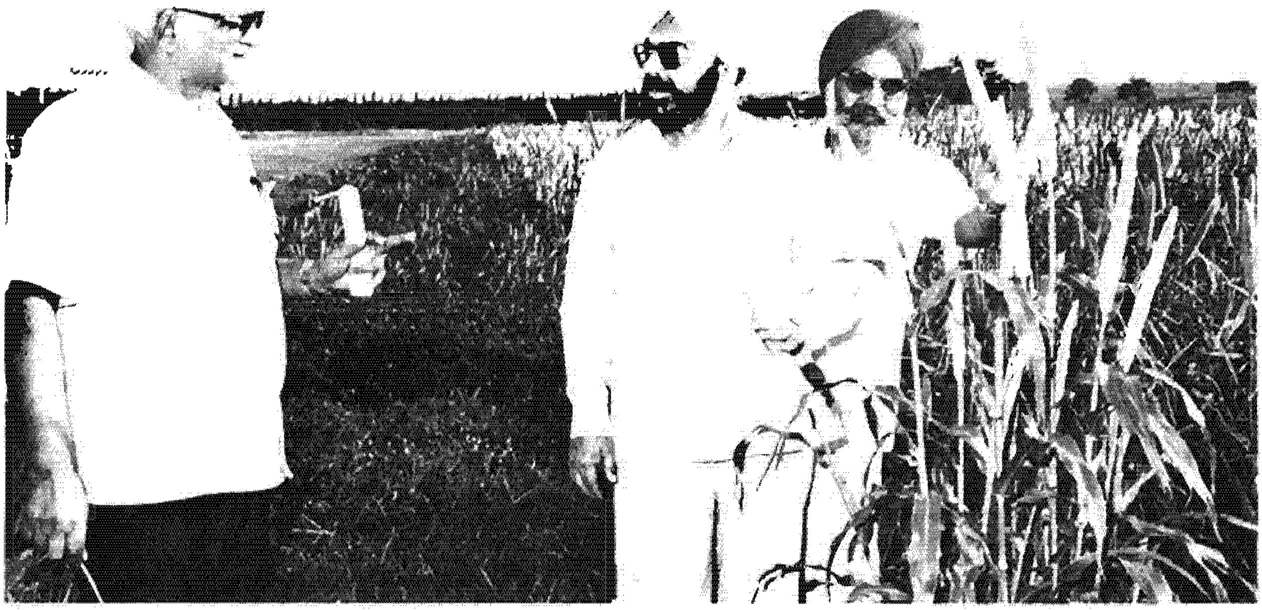
about 12.2 t ha^{-1}. ICSV 112 (SPV 475), a rainy-season, high-yielding sorghum variety (3.4 t ha^{-1}) was recommended for use in most states of India. It matures in 115-120 days and gives a fodder yield of around 11.8 t ha^{-1}. Three ICRISAT pearl millet hybrids ICMH 451 (MH 179), ICMH 501 (MH 180), and ICMH 423 were released for general cultivation in India. They are highly resistant to downy mildew. Hybrid ICMH 423 matures in about 85 days at ICRISAT Center, and is well adapted for cultivation in northern India. ICRISAT male-sterile lines are the seed parents of two other pearl millet hybrids released at the 1987 AICPMIP workshop for general cultivation in India—HHB 50 from Haryana Agricultural University, whose seed parent is 81 A, and Pusa 23 from IARI, New Delhi, whose seed parent is 841 A. Furthermore, ICRISAT pearl millet variety ICTP 8203 has been cultivated in Maharashtra in 1987 on a fairly wide scale. There has been much interest in ICRISAT's chickpea varieties from many states, particularly from Maharashtra, where chickpea has good potential in limited-irrigation areas. In response to several requests for improved varieties, 75 kg of desi (ICCC 37 and ICCC 42) and 180 kg of kabuli (ICCV 2, ICCV 5, and ICCV 6) varieties were dispatched.

Several ICRISAT cultivars were also released in other parts of the semi-arid tropics during this year. Improved sorghum varieties were released; two by the national program in Zimbabwe, one in Ethiopia, and two in Malawi. A hybrid based on an ICRISAT-bred female parent was released in Zambia. A pearl millet variety has been released and two others are in the prerelease stage in Zambia, and in Burkina Faso, an ICRISAT-produced pearl millet variety is being distributed to farmer. An ICRISAT groundnut germplasm line, ICG 7886 (Tifrust 2) developed in collaborative research on rust disease by ICRISAT and the USDA-ARS, University of Georgia, USA, has been released in Jamaica under the local name Cardi-Payne. The line, the original germplasm for which was collected in Peru, has a high degree of resistance to rust and moderate resistance to late leaf spot. It has been cited as an ideal variety, suited to all Jamaican requirements, and yielded, on average, 1.7 t ha^{-1} on farmers' fields, 75% more than the local valencia variety. One cultivar of chickpea has been released in Bangladesh, one in Nepal, two in Morocco, and two ICRISAT-ICARDA developed lines were released for general cultivation in Turkey.

Exchange of ideas and research perspectives continued during the several workshops, conferences, and meetings sponsored or cosponsored by ICRISAT during 1987. The potential of biotechnology to stabilize and increase crop production and to improve crop nutritional quality received the attention of 20 scientists in an International Workshop on Biotechnology held at ICRISAT Center. Over 35 agricultural scientists from 12 nations conferred with scientists at ICRISAT Center on insect pest management strategies relating to stem borers on sorghum. An international workshop on Aflatoxin Contamination of Groundnut brought some 50 scientists from 26 countries to ICRISAT Center for discussions on this important topic. Nearly 100 agronomists, soil scientists, representatives of governments, professors, rural economists, hydrologists, and other specialists from Africa, Europe, India, and the USA gathered at the ISC to participate in a Soil, Water, and Crop Management Workshop devoted to rainfed agriculture in the Sudano-Sahelian Zone. A Conference on Livestock and the Improved Management of Dark Clay Soils in Africa was organized in Addis Ababa, Ethiopia by ILCA to review the current state of knowledge on the use of Vertisols in sub-Saharan Africa and to develop guidelines for future research, aimed at increasing food and feed production from these soils. In collaboration with the Institut d'economie rurale (IER), a workshop on Intercropping Systems in Mali was organized, where 50 scientists and extension workers reviewed the past cropping systems research in Mali. In addition, there were other conferences, meetings, scientists' meets, and field days.

During 1987, ICRISAT's Genetic Resources Unit (GRU) explored South America, eastern, southern, and western Africa, and South Asia, resulting in the addition of valuable germplasm accessions in our gene bank. This year, for

Postrainy-season trainees taking notes on a chickpea pathology experiment at ICRISAT Center, 1987.



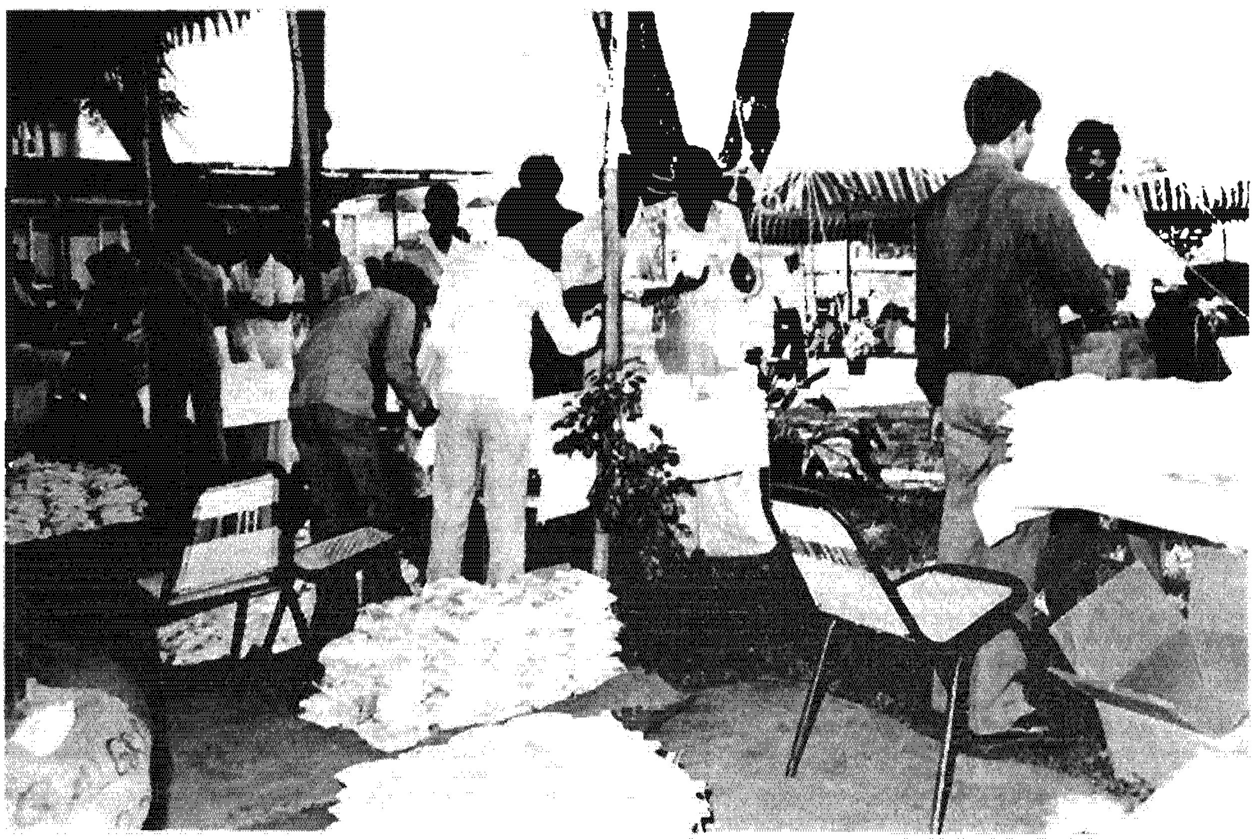
Union Minister of Agriculture G.S. Dhillon (center), Director General, Indian Council of Agricultural Research, N.S. Randhawa (right), and Deputy Director General J.S. Kanwar, visiting trials at ICRISAT Center.

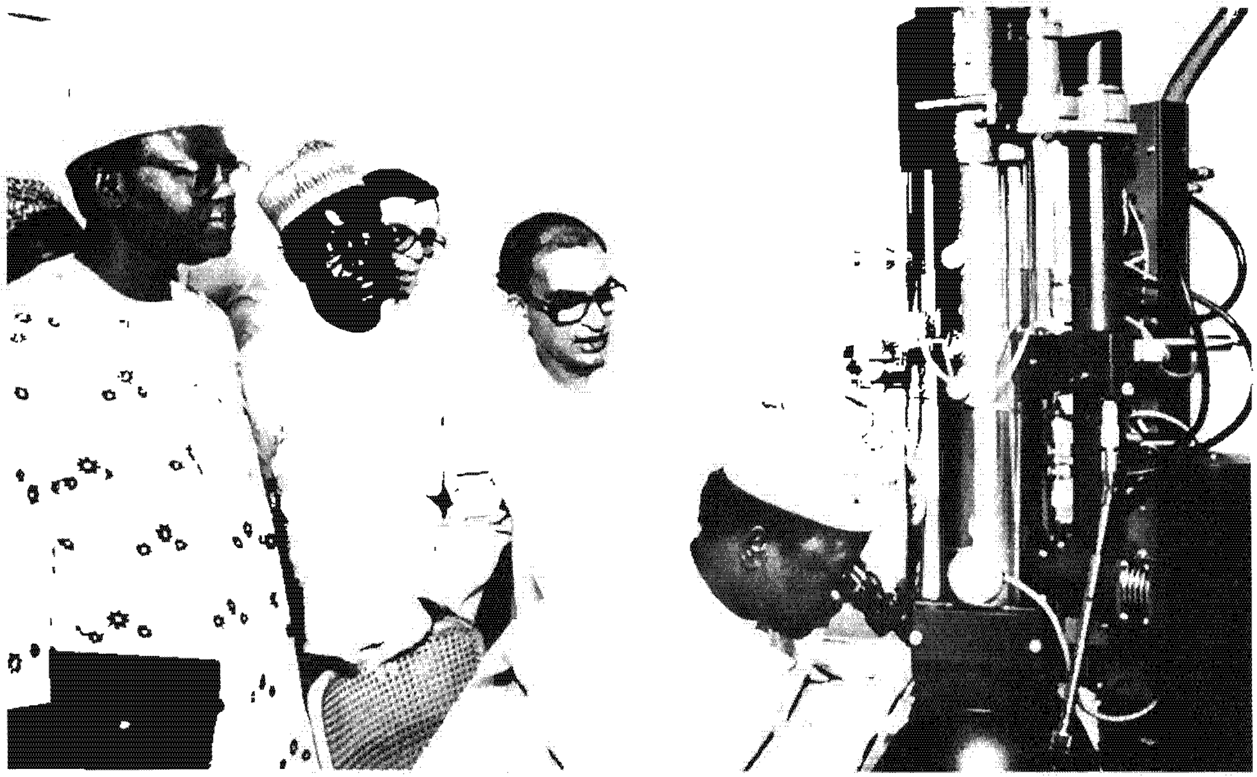
the first time, a germplasm collection trip was undertaken to Burma, as a part of the 1987/88 Burma-AGLN Work Plan. We added 3940 new accessions of our mandate crops to the ICRISAT gene bank, raising the total collection to 87 494. This year, 33 652 samples were sent to scientists in India and 20 869 samples to those in other countries, in addition to the 16 591 samples supplied to scientists at ICRISAT Center. The collaborative germplasm evaluation program with the National Bureau of Plant Genetic Resources, ICAR, India is going well. This program and similar work on pigeonpea in Kenya, and chickpea in Ethiopia, have made available several thousands of germplasm accessions available to national programs and are helping to identify desirable genotypes for crop improvement.

There was a record number of 210 trainees at ICRISAT Center during this year in various training programs, including for the first time trainees from Nicaragua, Vietnam, Tunisia, and Trinidad. This years' trainees had the highest record of achievements, with good yields in trainee experiments despite the drought. The seventh international training course in legume pathology dealt, for the first time with all three legumes on ICRISAT's mandate. Ten participants from eight countries attended this course. A socioeconomics training course was attended by 10 participants from nine countries. Twenty-four participants from six states of India and the Union Ministry of Agriculture

With the aid of their interpreter, the delegation from the USSR State Agro-Industrial Committee learn of ICRISAT's work on sorghum hybrids for the postrainy season.

Farmers receiving seeds of released ICRISAT cultivars on Farmers Day, when over 1200 farmers visited the Institute.





Research Directors of national agricultural programs in West and equatorial Africa examining samples under the electron microscope during a tour of Indian agricultural research institutions that included a visit to ICRISAT.

attended a training workshop on the Transfer of Technology for Rabi (postrainy-season) Groundnut. In West Africa, where the planned training facilities are not yet ready, an increased number of students and cooperators were trained by our scientists in Niger, Mali, and Burkina Faso.

Over 11 000 persons visited ICRISAT Center during 1987. Prominent among them were eight research directors of national agricultural programs in West and equatorial Africa, who visited ICRISAT Center to observe current research programs. Other important visitors included Mr J.G.Harris, the Canadian High Commissioner to India; Mr J.Cuendet, the Swiss Ambassador to India; Mr G.S.Dhillon, Union Minister for Agriculture, Government of India; Major General Mohammadu Gado Nasko, Federal Minister of Agriculture, Water Resources and Rural Development, Federal Republic of Nigeria; Dr Manmohan Singh, Deputy Chairman, Planning Commission, New Delhi; Mr V.Nageshwar Rao, Minister for Agriculture and Mr G.Muddukrishnama Naidu, Minister of Forests, Government of Andhra Pradesh; Dr J. W. Mellor, Director General, International Food Policy Research Institute, Washington D.C., USA; Dr Kamla Chowdhry, Chairman, National Wastelands Development Board, New Delhi; Mr Hoang Dinh Phu, Vice-President, State Committee for Science and Technology, Government of Vietnam, Hanoi; Dr Nicole

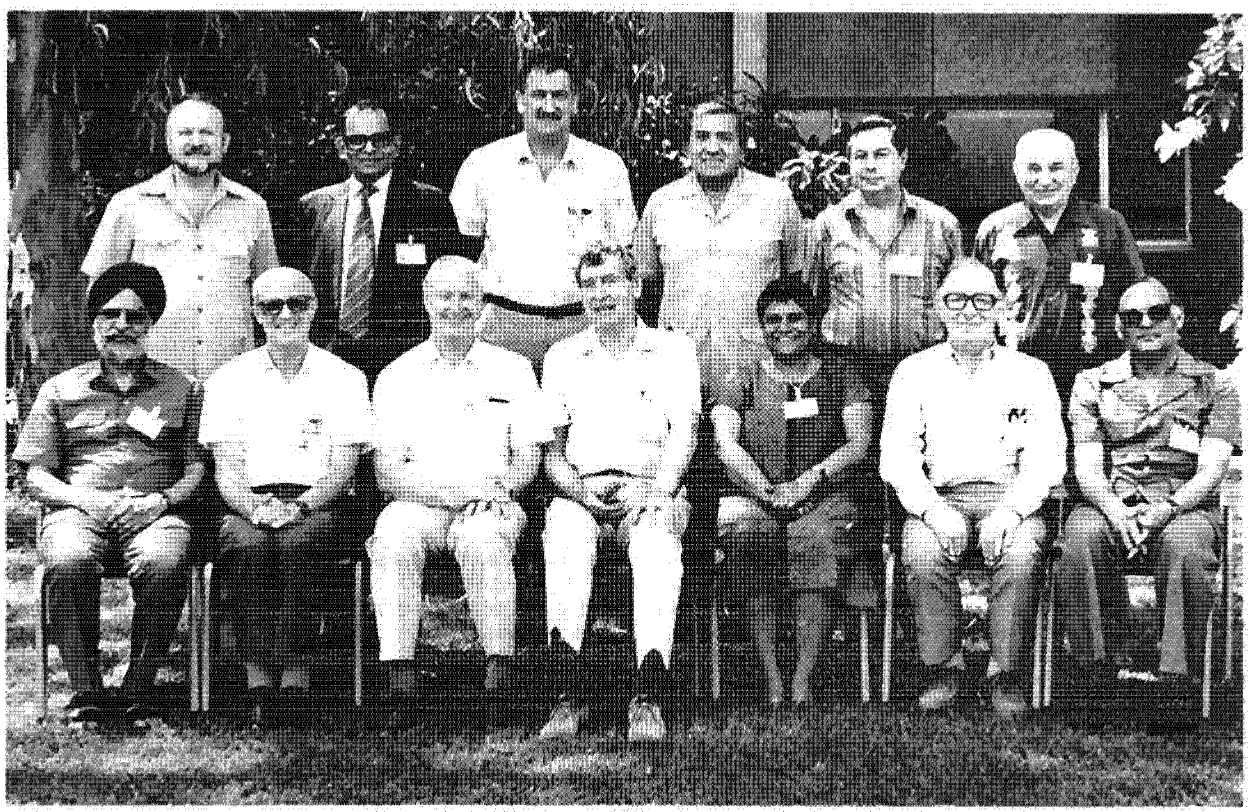
Senecal, Director General, Multilateral Programs Branch, Canada International Development Agency; a six-member high-level delegation from the USSR State Agro-Industrial Committee, USSR; and a nine-member Agricultural Task Force from Uganda. Over 1200 farmers from Andhra Pradesh, Maharashtra, and Tamil Nadu visited ICRISAT Center on Farmers' Day. A notable feature this year was that each farmer was given seeds of released ICRISAT cultivars of sorghum, pearl millet, pigeonpea, and chickpea, with literature describing the cultivars and the recommended package of practices.

Having reached the 15-year milestone, with continuing support from our donors and the CGIAR, which the Institute gratefully acknowledges, ICRISAT marches ahead in its quest to improve food production in the semi-arid tropics of the world.

F.V. MacHardy
Chairman, Governing Board

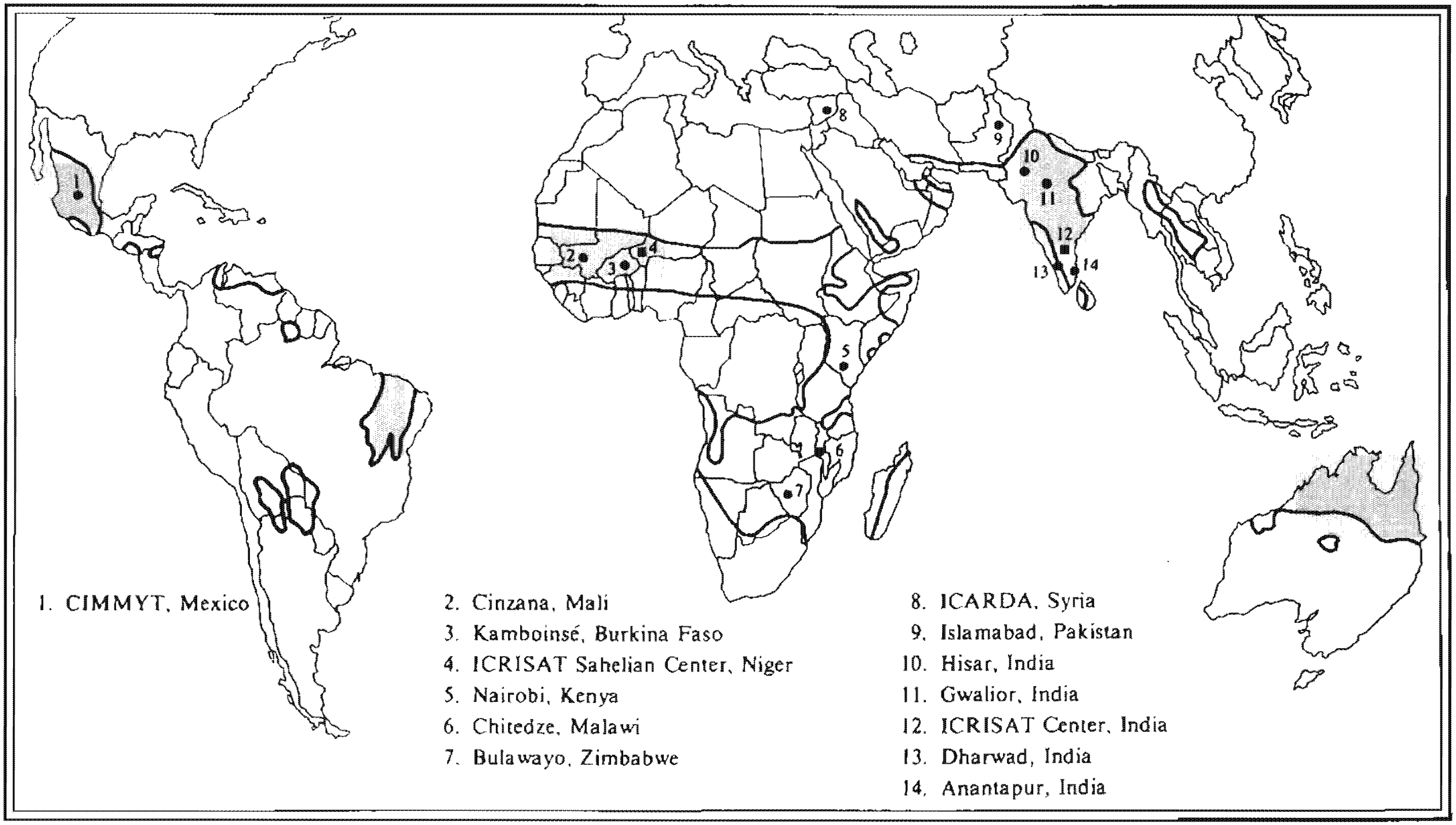
L.D. Swindale
Director General

ICRISAT Governing Board Members: Starting left to right: P.M.A. Tigerstedt, C.S. Sastry, L. Brader, J. Moncada, C. Charreau, P.L. Adkisson; Seated, left to right: N.S. Randhawa, L.D. Swindale, N.L. Innes, F.V. MacHardy, B.K. Patel, W.T. Mashler, Shravan Kumar.



AGROCLIMATIC ENVIRONMENT

Semi-arid tropical regions of the world (shaded). Numbers indicate locations where ICRISAT staff worked in 1987.



Cover photo: Participants in a groundnut modeling workshop, analyzing agroclimatic data from various cooperative stations to predict crop performance, ICRISAT Center, 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1988. Annual report 1987. Patancheru, 502 324, India: ICRISAT.

For offprints, write to: Resource Management Program, Internationl Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Patancheru, A.P. 502 324, India.

AGROCLIMATIC ENVIRONMENT

Most of the research reported in this volume was done 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 these environments and includes monthly rainfall and temperature for most locations.

ICRISAT Center, Patancheru

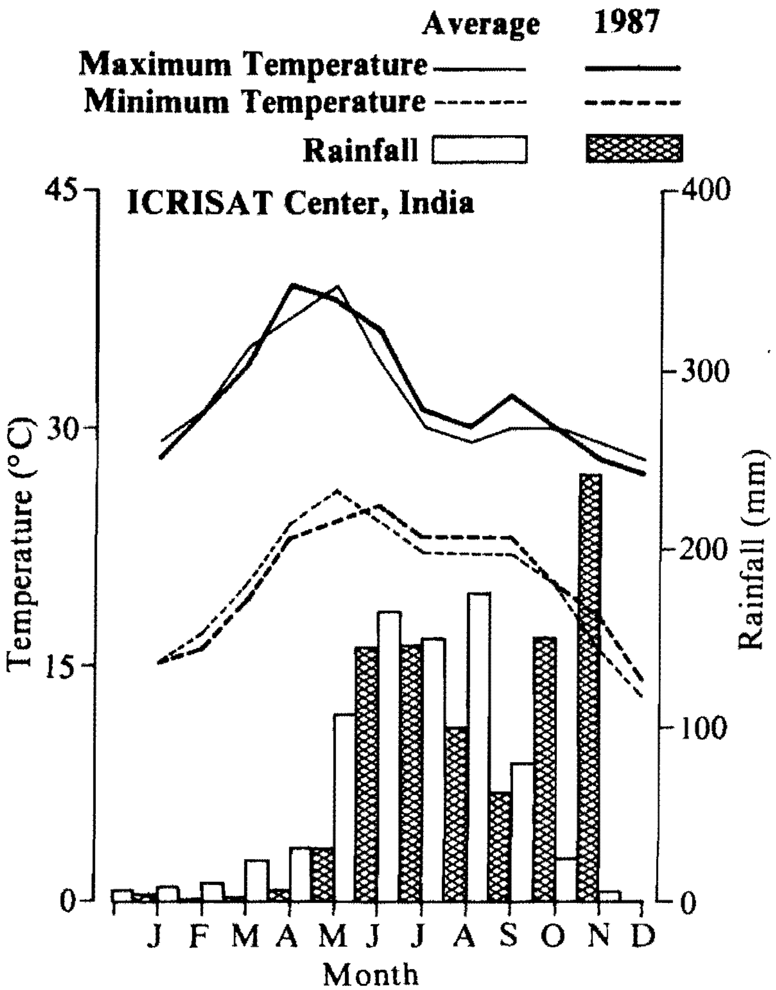
The Institute is located at 18°N, 78°E near Patancheru village, Andhra Pradesh, 26 km northwest of Hyderabad. The experimental farm, extending over 1400 ha includes two major soil types found in the semi-arid tropics: Alfisols (red soils), which are light and drought-prone, with an available water-holding capacity (AWHC) of 60-100 mm, and Vertisols (black soils), which have high AWHCs of 180-230 mm. Access to 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 the average annual rainfall (764 mm) is received 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 relatively 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 this 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 sow an irrigated crop of short-duration pigeonpea in December. As in normal farming practice, two sorghum crops a year can be grown at the Center, one on Alfisols during the rainy season and the other on Vertisols in the postrainy 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 1987 at Patancheru was 879 mm, 12% above average. Rainfall during the monsoon was 24% below average but because October and November were exceptionally wet, prospects for the postrainy-season crops were good. Daily maximum and minimum air temperatures were within ±2° C of the average for all months.

The below-average rainfall at the start of the season inhibited growth of the nonirrigated, short-duration pigeonpea, while sorghum sown in mid June experienced drought stress. However, unusually heavy rains during October/November resulted in a normal crop yield for sorghum and the postrainy season (1986/87) chickpea, and the medium-duration pigeonpea was revived to the extent that no drought stress was measurable in this season. Water was generally adequate for pearl millet, except during the early part of the season on shallower soils. Pearl millet growth and yield (3.5-4.0



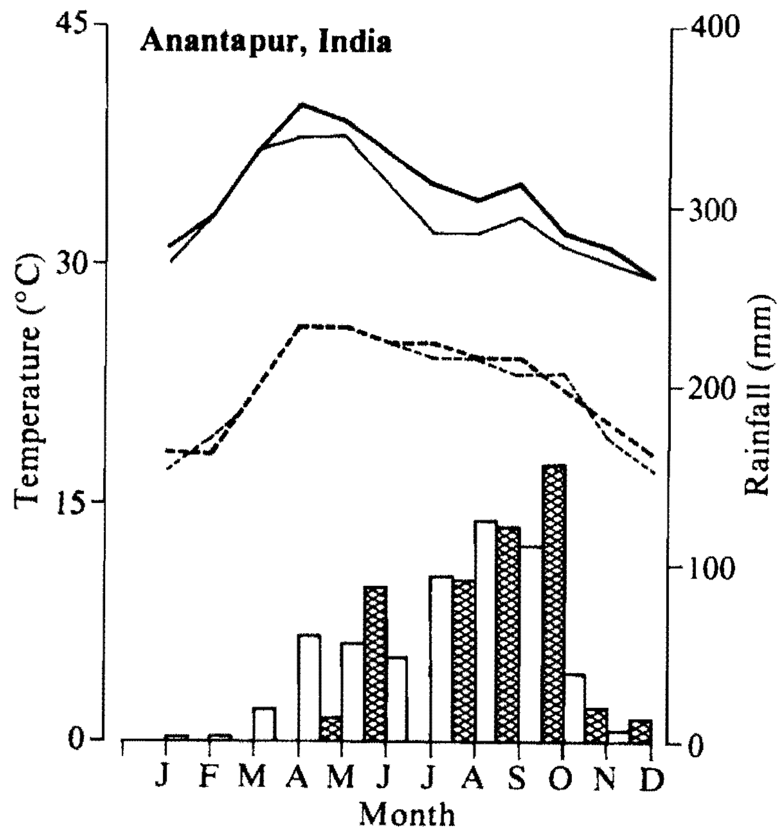
t ha⁻¹) were good on heavier soils where there was no significant stress. Yields on shallower soil fields were about average. The groundnut crop was affected by a severe epidemic of early leaf spot, though late leaf spot and rust were less than usual. Groundnut experienced drought stress during pod filling, and medium- and long-duration cultivars reached maturity during heavy rainfall impairing seed quality.

Other Research Locations

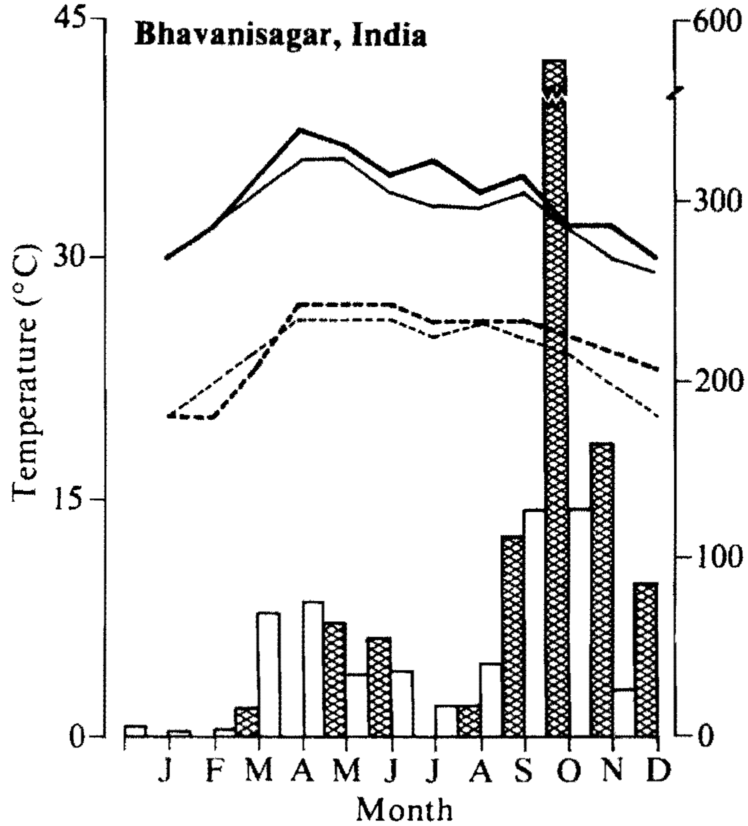
India

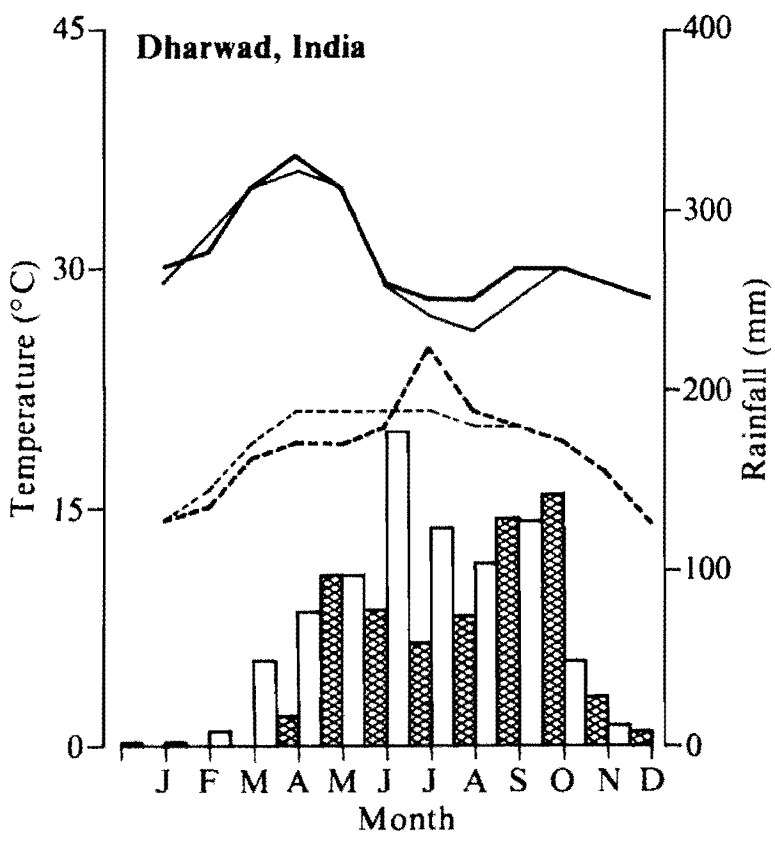
At five agricultural universities in India, ICRISAT has established stations and carries out cooperative research to test the performance of breeding material under a range climatic conditions and latitudes.

Anantapur (15° N, 562 mm rainfall)—a drought-prone area where we screen pearl millet, sorghum, and groundnut under low rainfall on Alfisols (AWHC 50 mm). Annual rainfall in 1987 was 501 mm, 11% below average. Crops sown soon after the 70 mm rain on 27 May suffered from severe drought stress in early August, but recovered to yield about 1.2 t ha^{-1} groundnut pods and 1.1 t ha^{-1} pearl millet grains. Crops sown after the rains on 4 and 5 August yielded better: 1.8 t ha^{-1} groundnut pods, 1.6 t ha^{-1} pearl millet grains and 2.0 t ha^{-1} sorghum. Late-sown sorghum suffered from severe terminal stress, yielded only 1.5 t ha^{-1} and lodged heavily. The late-sown pearl millet also experienced some stress during grain filling, as normal for this station.



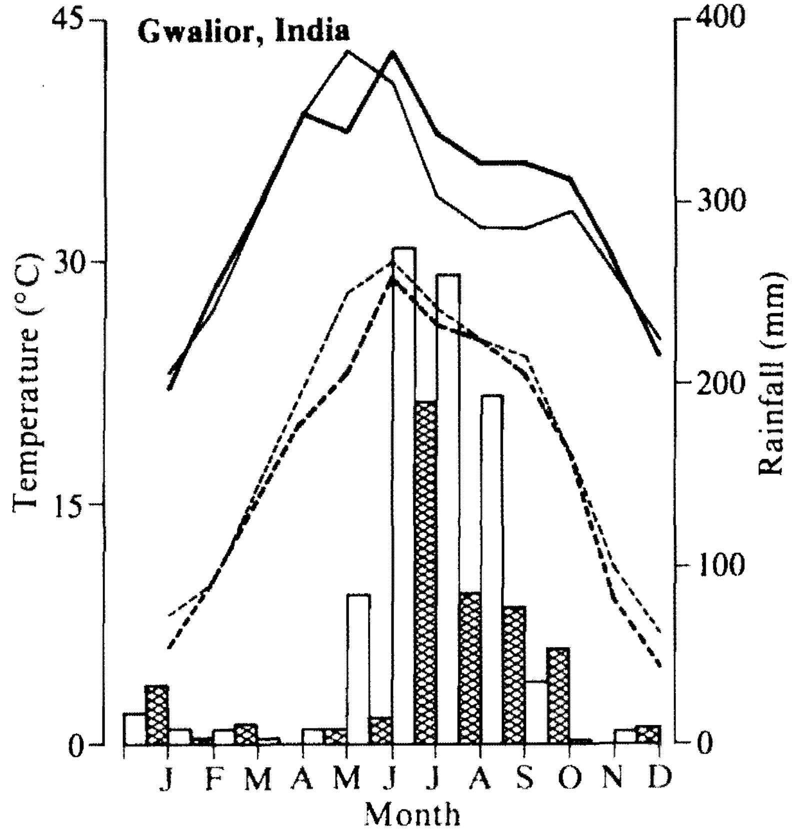
Bhavanisagar (11°N, 77°E, 574 mm rainfall)—where we screen sorghum for diseases and pests and test pearl millet on Alfisols (AWHC 80 mm), at a daylength similar to the Southern Sahelian bioclimatic zone of Africa. Annual rainfall was 1052 mm, 83% above average. Fifty-one percent of the annual rainfall fell in October. Sorghum sown on 12 and 22 June experienced drought stress during the early stages of growth (July to mid-September). Irrigation in August revived the crop to some extent, and growth was normal in the later stages. We obtained normal crop yields.

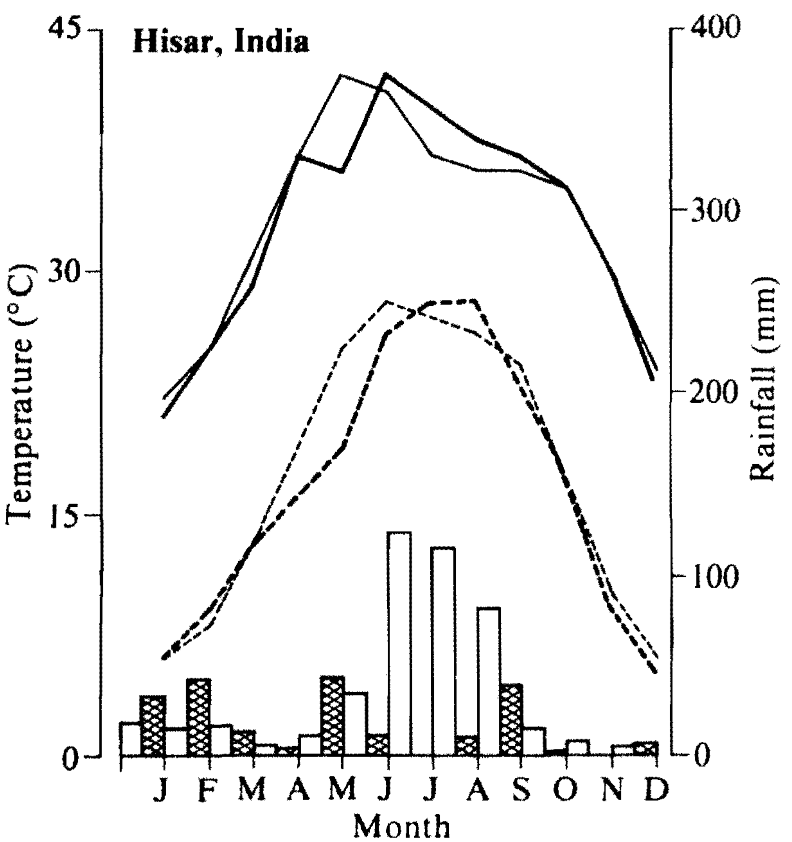




Dharwad (15°N, 75°E, 818 mm rainfall)—an especially good Vertisol site (AWHC 150 mm) for pest and disease screening, e.g., screening sorghum for downy mildew. The annual rainfall in 1987 was 627 mm, 23% below average. Daily minimum air temperatures in July were 4°C higher than average. The sorghum crop experienced an extended period of drought stress during its vegetative growth phase. However, intermittent showers later in the season provided adequate water during the reproductive stages, resulting in a normal crop year.

Gwalior (26°N, 78°E, 899 mm rainfall)—an area on Inceptisols (AWHC 150 mm), where most of India's long-duration pigeonpea crop is grown. Annual rainfall in 1987 was 481 mm, 46% below average. As a result of the low rainfall in both the 1986 and 1987 seasons, unirrigated chickpea crop experienced drought stress. However, above-normal rainfall early in the year ensured good yields of the 1986/87 long-duration pigeonpea crop. Heavy showers at the start of the 1987 rainy season led to poor plant stands. Low rainfall during the rest of the season necessitated regular irrigation to maintain normal growth of pigeonpea.





Hisar (29°N, 75°E, 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 1987 was 205 mm, 54% below average. Rainfall during June to October was only 63 mm, 83% below average. Daily maximum and minimum air temperatures in May were 6°C cooler than average. The below-average rainfall resulted in a complete failure of rainfed crops. However, the 1986/87 postrainy season chickpea crop was aided by good rains in January-March 1987. The vegetative growth of the irrigated short-duration pigeonpea crop was prolific, making insecticide spraying difficult, and resulting in severe damage by *Heliothis*.

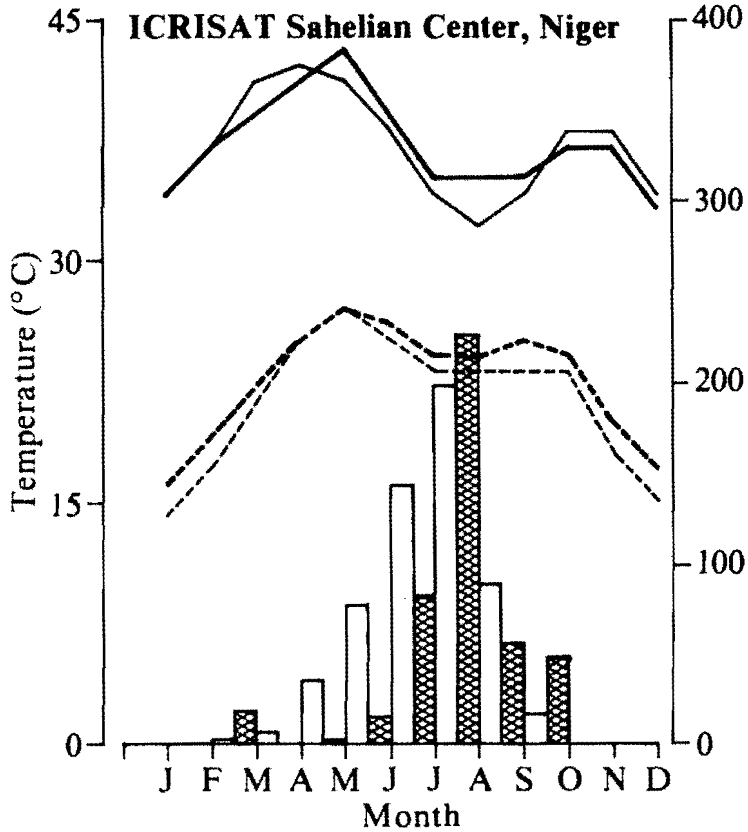
ICRISAT Sahelian Center, Niger

The ICRISAT Sahelian Center (ISC) is our principal research base for pearl 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 ha is covered by reddish colored, friable, sandy soils (AWHC 50-75 mm) with low native fertility and low organic matter.

Seasons. The climate is characterized by a June to September rainy season of about 90 days, often including long dry spells. The average annual rainfall (570 mm) at Niamey is irregular and normally comes in the form of convective storms. During the dry season 'harmattan' winds bearing dust from the north and east occur. The temperatures are warm year round and average 29° C.

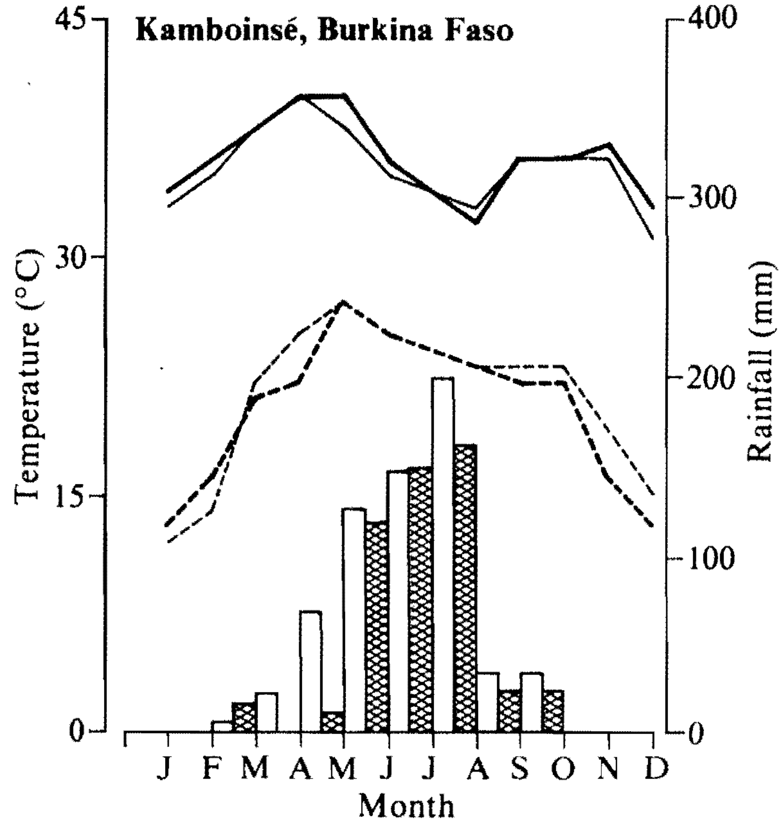
Crops. The main crop grown in the Niamey region is short-duration millet (90 to 110 days duration) which is sown with the first rains towards the end of May until the end of June. To advance generations and to help in seed multiplication, an irrigated off-season nursery is grown from January to April.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

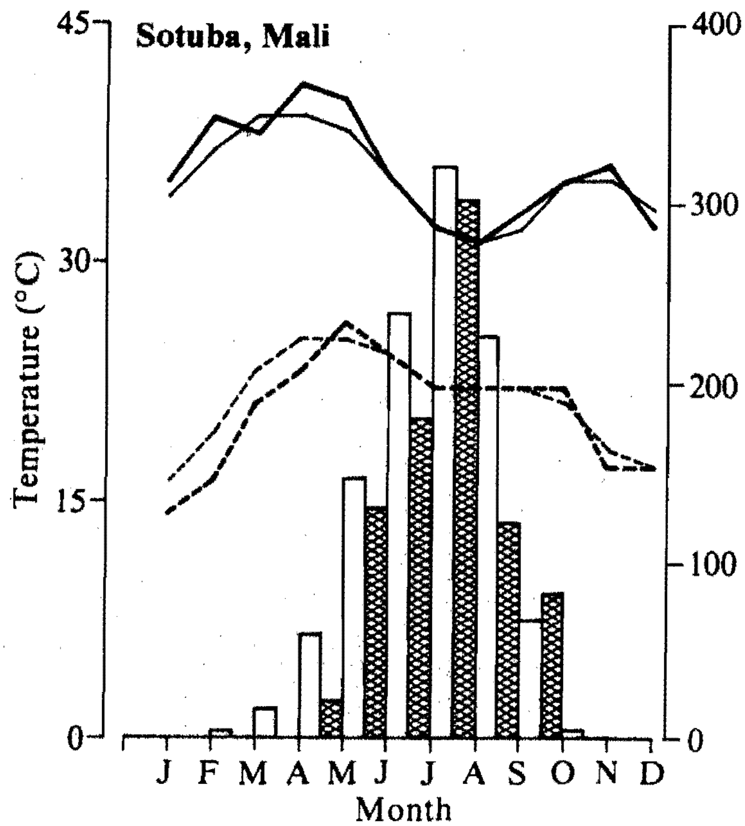
Weather. Rainfall in 1987 at ISC was 448 mm, 21% below average and several months were very dry. Rainfall in June and July totalled only 98 mm against the average of 220 mm. Rainfall in September was 37% below average, but October rainfall was 31 mm more than the average of 17 mm. In 1987, late-sown, short-duration varieties yielded better than long-duration varieties, as sowing was delayed by 6-8 weeks. Intercropped cowpea fared well, and both hay and grain were improved by the late rains. The late rains did not favor the development of pests so that populations, especially those of crickets were lower than usual. Erratic distribution of rainfall resulted in a lower incidence of *Striga*, especially in farmers' fields, compared to 1986. Disease incidence, however, was not affected.



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, and pearl millet breeding. The length of the cropping season is about 120 days from June/July to October/November. Sorghum, pearl millet, groundnut, 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 to 1.2 m on the lower slopes. The AWHC of the soils varies from 30 to 100 mm. The rainfall in 1987 was 606 mm, 15% below average. Ninety-two percent of the annual rainfall was received in the rainy season from June to September. The year was marked by early and mid-season drought stress, resulting in a very poor crop at the research station.





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 pearl millet are the major crops. Soils are tropical ferruginous, leached to hydromorphic types (loam and clay loam), with AWHC 150-200 mm. The total rainfall in 1987 was 828 mm, 23% below average. Rainfall in July was 25% below average and in September 46% below average.

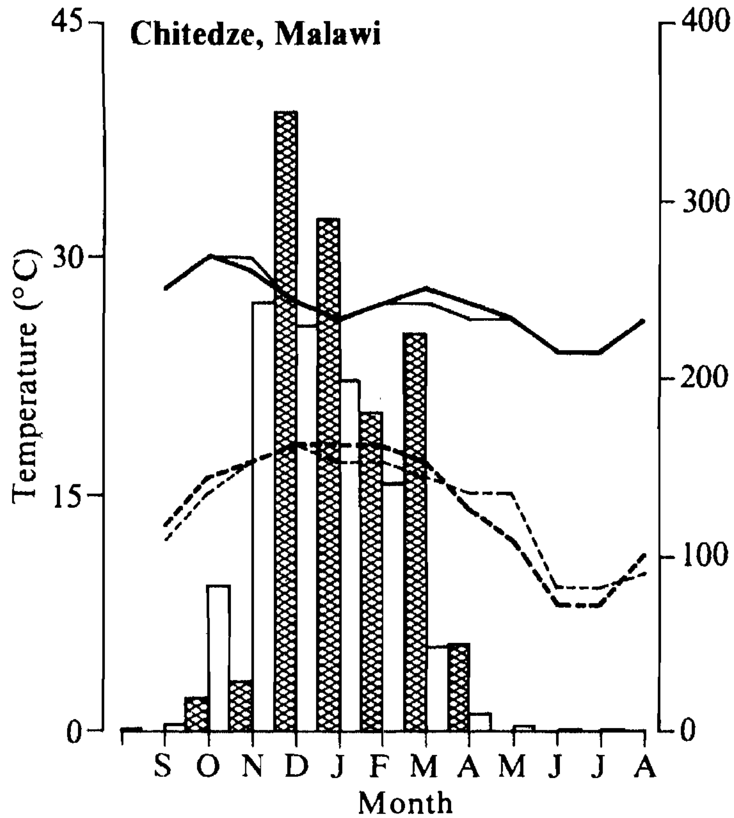
Cinzana (13°N, 6°W, 700 mm rainfall)—in the Southern Sahelian bioclimatic zone, where we conduct research on different crops and agronomic practices associated with these crops. The length of the cropping season is about 120 days from June/July to September/October. Pearl millet, cowpea, groundnut, and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

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.

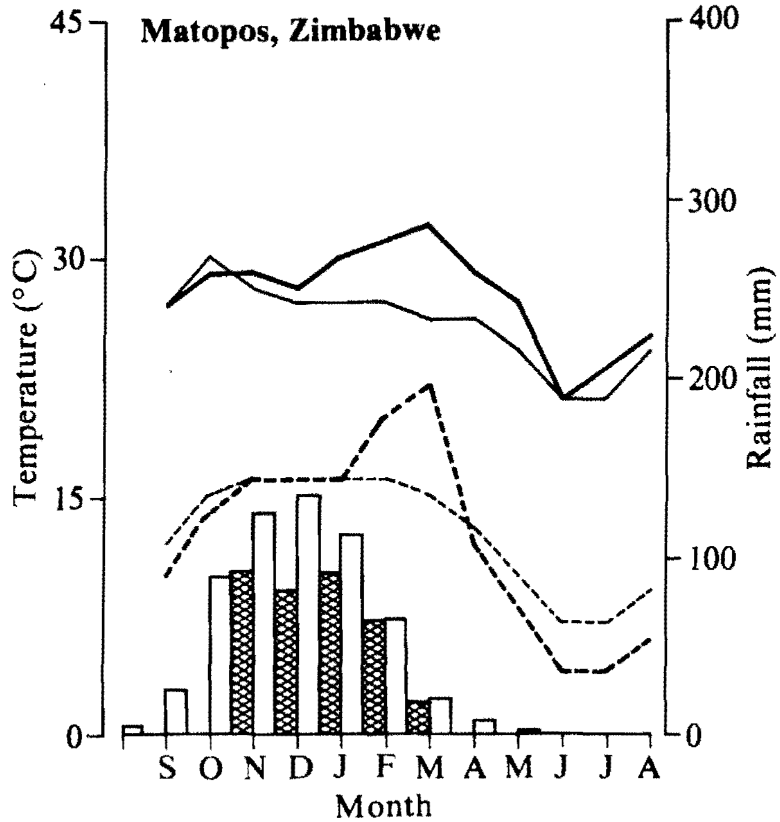
Malawi

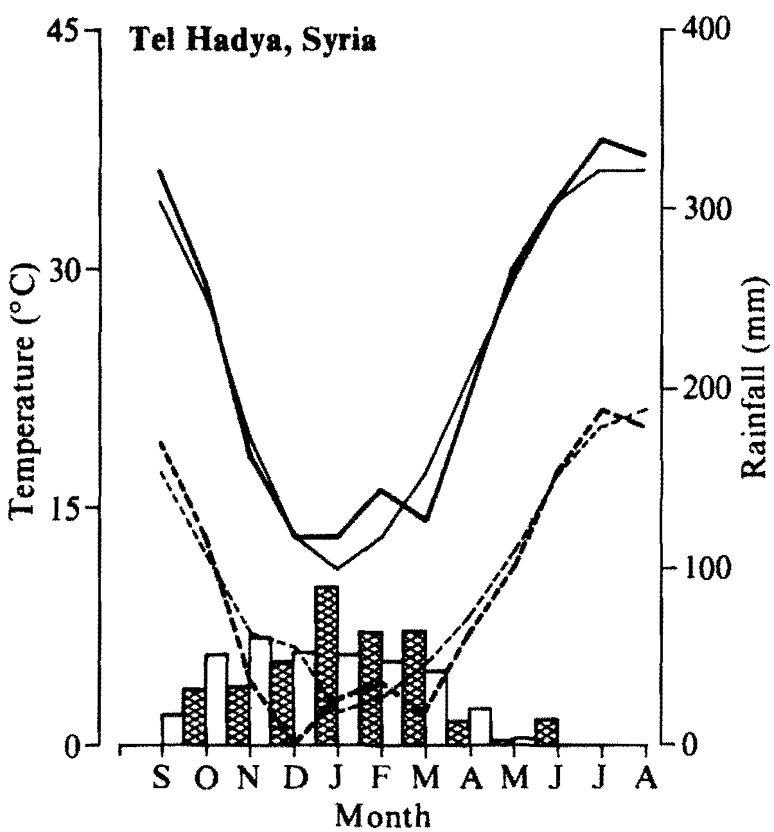
Chitedze (14°S, 34°E, 957 mm rainfall)—where our Regional Groundnut Improvement Program for Southern and Eastern Africa is based. Chitedze, located on the Lilongwe plain, has a tropical continental climate with one rainy season from October/November to March/April. Maize, tobacco, and groundnut are some of the important crops of the area. Rainfall during the growing season (November 1986 to April 1987) was 20% above the long-term average (936 mm). Distribution was poor, with prolonged dry spells interspersed with exceptionally heavy precipitation (638 mm of rain fell in December and January), which resulted in waterlogging. Yields were lower than expected.



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. Annual rainfall (September 1986 to August 1987) was 41% below average. Daily air temperatures in March were 6 (maximum) and 7 (minimum) °C higher than average. Considering the below-average rainfall, crop performance was very good at Matopos and at the other experiment station, Lucydale.



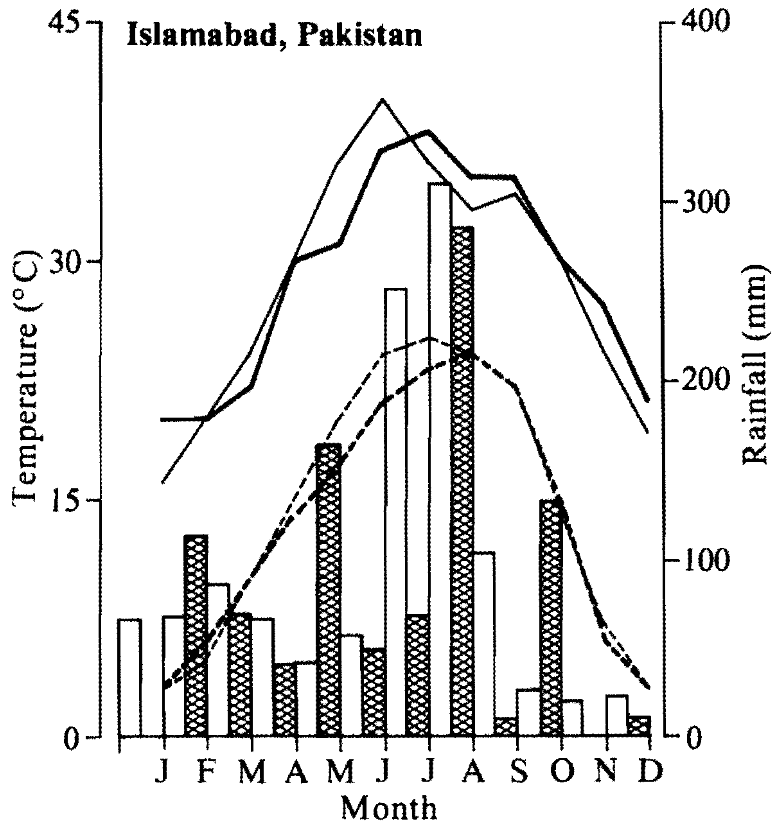


Syria

Tel Hadya near Aleppo (36°N, 37°E, 340 mm rainfall)—where our staff work with ICARDA on kabuli type chickpeas 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 fabia bean are important crops in the region. Rainfall in 1986/87 was near average.

Pakistan

Islamabad (34°N, 73°E, 1116 mm rainfall)—where the research emphasis is on developing chickpeas resistant to ascochyta blight. Annual rainfall in 1987 was 939 mm, 16% below average. Rainfall from June to October was 27% below the seasonal average, but in February and May was much higher than the corresponding averages. Rainfall in July was 73% below average and in September was only 10 mm against the average.



Mexico

El Batan (19°N, 99°W, 750 mm rainfall)—where our CIMMYT-based breeder and agronomist work on high-altitude, cold-tolerant sorghums and material adapted for low and intermediate elevations in Central and 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: A general view of the long-term storage facility of the ICRISAT gene bank.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. 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, A.P. 502 324, India.

GENETIC RESOURCES UNIT

The success of modern crop cultivars and changes in cropping systems resulting in the replacement of primitive variable landraces, population explosion and disturbance of the ecosystem have all been responsible for eroding plant genetic resources available to man. The genetic wealth in landraces and wild relatives of our crop plants is irreplaceable. The importance of genetic resources in crop improvement and for the development of new cultivars is well recognized. Hence collection, maintenance, evaluation, conservation, documentation, and distribution of genetic resources are given high priorities by crop improvement organizations around the world. In ICRISAT, the responsibility to handle these genetic resources activities for the five mandate crops: sorghum, pearl millet, chickpea, pigeonpea, and groundnut, and for six minor millets rests with the Genetic Resources Unit (GRU).

Germplasm Collection and Assembly

During 1987, we explored South America, eastern, southern and western Africa, and South Asia, and collected germplasm samples resulting in the addition of valuable germplasm accessions to our gene bank. We organized 10 collection missions and brief summaries of these are reported. This also gave us an opportunity to observe at first hand the genetic diversity, and the extent of genetic erosion in the areas we explored (Fig. 1). The material collected is well conserved and evaluated, and being distributed

Figure 1. Collecting pearl millet germplasm during a severe drought in Karnataka, India.

to scientists around the world, whenever we receive requests.

Priority areas for collecting germplasm of our mandate crops have been identified based on their representation in our gene bank, threat of genetic erosion, and available information on genetic diversity in the area. Discussions with the International Board for Plant Genetic Resources (IBPGR), and national scientists in source countries have also helped determine such areas. Priority countries/areas where germplasm of each crop is yet to be collected have been determined, and germplasm collection in those areas is progressing.

During the period under report, we added 3940 new accessions of mandate crops to the ICRISAT gene bank, thus raising the total collection to 87 494. An additional 606 sorghum, 649 pearl millet, 48 chickpea, 222 pigeonpea, and 399 groundnut samples have been harvested from plant quarantine fields and released to us, but are yet to be registered.

The total number of accessions assembled to date for each mandate crop and the number of countries represented in our gene bank are given in Table 1. Countrywise acquisitions are shown in Table 2. We have also assembled 6457 accessions of minor millets from 42 countries (Table 3). We will continue to collect our mandate crops from priority areas. Our collection efforts in India in collaboration with the National Bureau of Plant Genetic Resources (NBPGR) will also continue. During future collection missions, more emphasis will be given to wild relatives of our crops.

In March 1987, the West African office of IBPGR, our major collaborator in West Africa, was transferred from Ouagadougou, Burkina Faso, to the ICRISAT Sahelian Center (ISC), Niamey, Niger. The office organized joint collection missions in Chad, Mali, and Mauritania. Emphasis was given to collection of germplasm from the drier zones of West Africa because of the threat of genetic erosion due to desertification in that region. The collection missions were launched in collaboration with the national programs (Laboratoire de Farcha, N'Djamena, Chad, the Centre national de recherche agronomique et de développement agricole (CNRADA), Kaedi, Mauritania, and the Institut national de la recherche zootechnique, forestière et hydrobiologique (INRZFH), Mali. The Institut français de recherche scientifique pour le développement en coopération (ORSTOM) program at ISC participated in the mission to Mauritania. A total of 424 samples of cultivated and wild relatives of ICRISAT mandate crops were collected, including 231 samples of sorghum, 107 of *Pennisetum* spp, 3 of finger millet (*Eleusine coracana*), and 83 of groundnut.

A set of all the samples was left in the country where they were collected, and duplicates will be deposited with the base collections for long-term conservation. Samples of sorghum, pearl millet, and groundnut are available at ISC and will be deposited in the gene bank at ICRISAT Center after seed increase. Samples of wild millet are being analyzed by the ORSTOM program at ISC. Working collections of the forage and tree species used at ISC are held by ISC/IBPGR for multiplication, evaluation, and selection by the Resource Management Program.

Table 1. ICRISAT gene bank accessions in 1987 and to date, showing crop and number of countries represented.

	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Accessions in 1987	2205	937	371	216	211	3940
No. of countries	15	4	11	16	7	39
Total to date	30277	19085	15246	11034	11852	87494
No. of countries	87	42	41	50	89	132

Table 2. Additions to ICRISAT germplasm collection in 1987.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
AFRICA					
Algeria	21	-	-	-	-
Burundi	45	-	-	-	-
Cameroon	305	727	-	-	-
Kenya	-	-	-	3	1
Mali	-	2	-	-	130
Morocco	-	-	1	-	-
Mozambique	-	-	-	-	2
Rwanda	80	-	-	1	-
South Africa	-	-	-	1	
Sudan	-	-	1	-	-
Tanzania	-	-	-	-	3
Uganda	633	18	-	-	-
Yemen Arab Republic	563	-	-	-	-
Zaire	29	-	-	-	-
Zimbabwe	-	-	-	-	5
ASIA					
Bangladesh	-	-	2	6	-
India	248	190	321	64	8
Indonesia	-	-	-	2	-
Iran	-	-	30	-	-
Italy	-	-	7	-	-
Pakistan	-	-	1	-	-
People's Republic of China	163	-	-	-	-
Republic of Korea	75	-	-	-	62
Syria	-	-	-	-	-
Taiwan	1	-	-	-	-
EUROPE					
Socialist Republic of Romania	7	-	-	-	-
UK	-	-	-	3	-
USSR	18	-	5	-	-
Yugoslavia	-	-	1	-	-
AMERICA					
Brazil	-	-	-	9	-
Dominican Republic	-	-	-	24	-
Guyana	-	-	-	21	-
Jamaica	-	-	-	37	-
Puerto Rico	-	-	-	1	-
St. Lucia	-	-	-	11	-
St. Vincent	-	-	-	2	-
USA	-	-	1	-	-
Venezuela	1	-	-	29	-
OCEANIA					
Australia	13	-	-	2	-
Unknown	3	-	1	-	-
Total accessions	2205	937	371	216	211

Table 3. Additions to the ICRISAT minor millets collection in 1987 and cumulative totals, 1976–1987.

Species	Accessions in 1987	Cumulative total
Eleusine coracana (finger millet)	768	2761
Setaria italica (foxtail millet)	52	1380
Panicum miliaceum (proso millet)	74	831
Panicum sumatrense (little millet)	-	377
Echinochloa spp (barnyard millet)	-	582
Paspalum scrobiculatum (kodo millet)	-	526
Total	894	6457

Germplasm Maintenance

Our maintenance activities included the rejuvenation of 16 666 cultivated and 377 wild relatives of our mandate crops, and 1656 minor millet accessions, mainly during the postrainy season (Table 4). Seed viability monitoring and quality control were further improved in order to ensure effective germplasm conservation. We found that agar (0.5–0.8%) is a better and more cost-effective substrate for germination tests than the conventional paper medium that costs 40–50% more. The viability of 1674 sorghum, 729 pearl millet, 3698 chickpea, and 2651 groundnut accessions was tested. All conserved seeds are regenerated when their viability falls below 85%, this year 190 sorghum, 61 pearl millet, 484 chickpea, and 416 groundnut accessions were identified for immediate rejuvenation. For better day-to-day gene bank management we started using a microcomputer to store and retrieve seed viability data.

Table 4. Number of germplasm accessions grown for rejuvenation at ICRISAT Center during 1987.

Crop	No. of accessions Cultivated	Wild
Sorghum	6051	202
Pearl millet	1662	17
Chickpea	1927	22
Pigeonpea	1232	76
Groundnut	5794	60
Minor millets	1656	-
Total	18322	377

Germplasm Evaluation

During the year, a total of 27 613 accessions were sown at ICRISAT Center for rejuvenation and evaluation. These included 7520 sorghum, 5697 pearl millet, 4316 chickpea, 2256 pigeonpea, 5794 groundnut, and 1656 minor millet accessions. Seed of all the groundnut accessions sown were tested by legume virologists for the presence of viruses using the enzyme-linked immunosorbent assay (ELISA) technique.

Our collaborative germplasm evaluation program with NBPGR progressed further with the appointment of ICRISAT and NBPGR coordinators. A meeting between GRU and NBPGR was held in May in New Delhi when collaborative work plans for 1987/88 were finalized. Under this program, 16 207 germplasm accessions were sown during 1987 for evaluation in India (Table 5). A joint GRU/NBPGR workshop on germplasm evaluation and utilization will be held in October 1988 at ICRISAT Center. The continuation of joint germplasm evaluations in collaboration with NBPGR will provide information on the performance of our material in different regions of India; this will facilitate better utilization of the available diversity.

Our regional and multilocational evaluation work in Africa progressed further (Table 5). Under this program, pearl millet, chickpea, and pigeonpea germplasm accessions were evaluated in Africa, details are given under the respective crop headings. In future more emphasis will be given to regional germplasm evaluations in eastern, southern, and West Africa to identify material suited to those areas.

Table 5. Collaborators, locations, number of accessions, and type of material evaluated under joint evaluation programs, 1987.

Crop	Collaborator	Location	No. of accessions	Type of material
Sorghum	NBPGR, India	Trichur	2000	Photoperiod-sensitive
	NBPGR, India	Akola	99	Evaluation for mid-season drought resistance
	NBPGR, India	Issapur	4577	Entire Indian collection and promising forage types
Pearl millet	NBPGR, India	Issapur	2000	Diverse germplasm
	NBPGR, India	Akola	81	Selected germplasm
	SADCC/ICRISAT, Zimbabwe	Bulawayo	1996	Selected germplasm
	IAR, Cameroon	Maroua	870	Cameroon germplasm
Chickpea	NBPGR, India	Akola	1200	Long-duration accessions
	NBPGR, India	Gwalior	1200	Long-duration accessions
	NBPGR, India	Issapur	1200	Long-duration accessions
	PGRC/E, and ARC, Ethiopia[1]	Debre Zeit	1033	Selected accessions
Pigeonpea	NBPGR, India	Issapur	350	Short-duration accessions
	NBPGR, India	Akola	300	Medium long-duration, grain types
	NBPGR, India	Jorhat	200	Long-duration, vegetable types
	NDFRC, Kenya[2]	Katumani	500	Long-duration, vegetable type
		Kiboko	500	Long-duration, vegetable type
Groundnut	NBPGR, India	Jodhpur	1500	Selected accessions
	NBPGR, India	Akola	1500	Selected accessions

1. PGRC/E = Plant Genetic Resources Center/Ethiopia; ARC = Agricultural Research Center, Debre Zeit.
2. NDFRC = National Dryland Farming Research Center.

Germplasm Enhancement

There are a number of instances where the genetic resources assembled from different agro-ecological regions are not amenable to immediate utilization. Examples are tall and photoperiod-sensitive landraces of sorghum, and photoperiod-sensitive pigeonpea. In order to use such wide genetic diversity for crop improvement, we need to convert this germplasm to more useful forms so that it can be used in breeding programs. At GRU, we have an ongoing sorghum introgression program and we are working to identify less photoperiod-sensitive pigeonpeas.

Interest in the use of exotic germplasm for crop improvement has markedly increased. Exotic genetic resources differ widely in their capacity to contribute to crop improvement of this capacity also depends on their ability to freely intercross with indigenous or cultivated germplasm. At GRU, we are attempting to transfer useful genes available in the wild species into cultivated backgrounds; especially in sorghum, pearl millet, and chickpea. More emphasis will be given to the studies on genomic relationships in *Pennisetum* so that its wild species can also be used in genetic enhancement.

Documentation

The chickpea and pigeonpea germplasm catalogs were revised and reviewed during the year and will be published in 1988. We intend to complete compilation of the sorghum, pearl millet, and groundnut catalogs in 1988 so that these too can be published. Computer printouts of passport and/or evaluation data of sorghum (8), groundnut (2), and *Setaria* (1) were supplied on request. Evaluation data from all the recent seasons on all the crops, and passport data on new accessions have been entered into the computer.

We computerized the viability testing and seed distribution data for all crops using the dBASE III program on a microcomputer.

Germplasm Distribution

Providing ICRISAT scientists with the germplasm base for their work is one of our major activities. Accessions are screened for desirable traits that are potentially useful in breeding programs. Table 6 gives the distribution of each crop's accessions to various disciplines within ICRISAT during 1987.

In addition to the 16 591 samples supplied to scientists at ICRISAT Center, 33 652 samples were sent to scientists in India, and 20 869 samples to scientists in other countries (Table 7). This year, we were requested to transfer to Botswana and Malawi the entire sorghum germplasm we collected from those countries. Although a set of the original germplasm collected in those countries was left with them at the time of collection, we were glad to be able to replenish their germplasm stocks from the world collection held in our gene bank.

Sorghum

This year, 2205 new accessions were added to our gene bank raising the total to 30 277 (Table 1). The new accessions, assembled by collection and correspondence, came from 15 countries (Table 2).

In July 1987, we organized a collection expedition to southern Somalia in collaboration with the Ministry of Agriculture, Government of Somalia. Two hundred and twenty-seven samples of sorghum were collected from the Bay, Middle Juba, Gedo, Lower Shebelle, Middle Shebelle, and Hiran regions. The majority of

Table 6. Seed samples supplied to ICRISAT Crop Programs in 1987.

	Cereals		Legumes			
Discipline	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Physiology	323	391	118	36	42	910
Pathology	146	343	1 286	521	368	2 664
Entomology	6 517	-	7	60	92	6 676
Microbiology	11	30	-	-	-	41
Breeding	1 262	908	552	132	353	3 207
Biochemistry	19	-	1 103	1 504	355	2 981
Cytogenetics	-	-	-	5	60	65
Training	32	-	-	-	3	35
Nematology	-	-	-	-	2	2
Others	-	-	5	-	5	10
Total	8 310	1 672	3 071	2 258	1 280	16 591

Table 7. Germplasm samples distributed by GRU, ICRISAT, in 1987.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (1+2+3)	No. of countries
Sorghum	8310	13070	6046	27426	28
Pearl millet	1672	8047	3009	12728	12
Chickpea	3071	4663	1605	9339	16
Pigeonpea	2258	1647	1638	5543	24
Groundnut	1280	4993	7616	13889	14
Minor millets	-	1232	955	2187	9
Total in 1987	16591	33652	20869	71112	
Cumulative total to date	406569	171160	195698	773427	

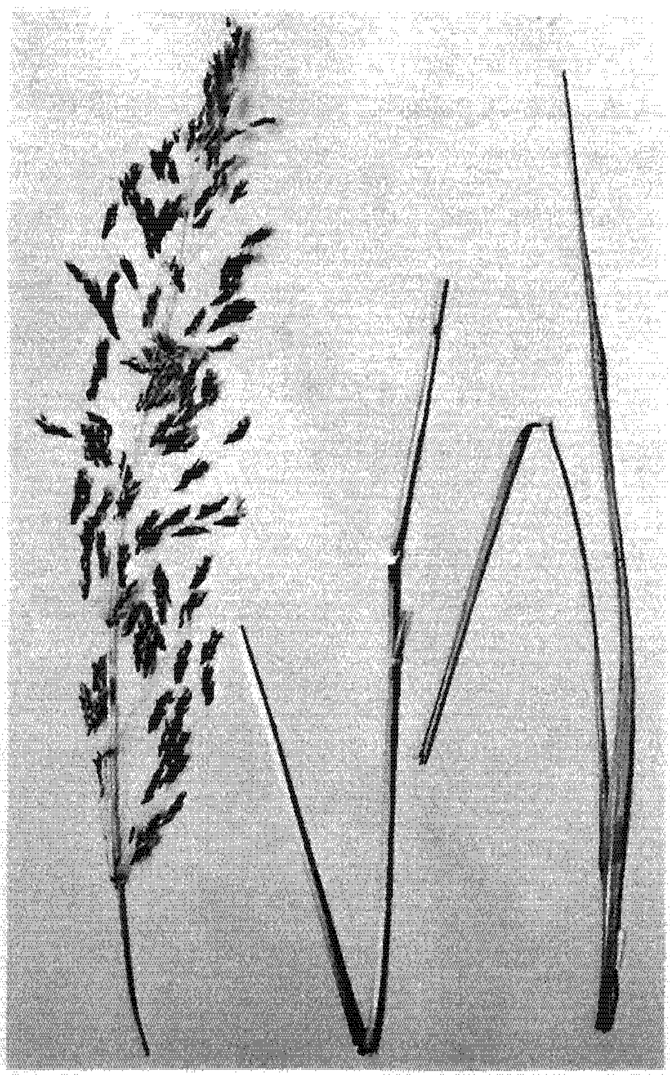
sorghums collected belong to race Durra and are short-duration types (maturing in about 100 days) with good forage value (Fig. 2). Local sorghums seem to be well adapted to the region for both grain and fodder yield even under biotic (stem borer, *Chilo partellus*) and abiotic (terminal drought) stresses. There is considerable variation in pericarp color in local sorghums, such as chalky white, pearly white, straw, light brown, brown, light red, red, and reddish brown. Sorghum samples collected in regions bordering Kenya and Ethiopia are slightly longer in dura-

Figure 2. Collecting short-duration durra sorghum landraces in southern Somalia, July 1987.

tion (110 days) with larger panicles and bold grain. Zerazera, Dabar, and Hegari sorghums are also cultivated in areas bordering Ethiopia. Another collection mission was organized in collaboration with NBPGR and Tamil Nadu Agricultural University (TNAU) to the Western Ghats of Tamil Nadu and Kerala, India, where 152 samples were collected. These include a rare wild species *Sorghum nitidum* (Fig. 3) and primitive cultivars belonging to races Guinea, Bicolor, and Durra.

We grew 606 accessions from Australia (1), Burundi (9), Guatemala (1), El-Salvador (2), Haiti (3), Honduras (3), Mozambique (6), Nicaragua (3), Somalia (298), Tanzania (269), and Zimbabwe (11) in the Post-Entry Quarantine Isolation Area (PEQIA) for inspection and release.

Figure 3. *Sorghum nitidum*, a rare wild sorghum species collected in the Western Ghats of Tamil Nadu, India, December 1987.



In collaboration with NBPGR, 4577 accessions of sorghum germplasm of Indian origin were evaluated at Issapur, New Delhi (Table 5). We identified the 182 most promising genotypes, mostly dual-purpose (grain and forage) types that will be of use in various forage breeding programs. We also evaluated 2000 photoperiod-sensitive tropical landraces at the NBPGR Regional Station, Trichur, (10°N and 76°E; altitude 53 m), Kerala. Interestingly, contrary to our expectation, there was an increase in days to 50% flowering, compared with that at ICRISAT Center for most of these landraces.

In the rainy and postrainy seasons, 1469 recently assembled accessions were characterized and evaluated at ICRISAT Center. These included the highly photoperiod-sensitive Sierra Leone collections and the local sorghums (Kaoliangs) received from the People's Republic of China, and the Yemen Arab Republic (Fig. 4). The final converted lines of zerazera landraces from Ethiopia on different maturity and height backgrounds were sown and characterized to assign International Sorghum Conversion (ISC) numbers and for utilization in breeding programs. From these, inservice trainees, and sorghum breeders from Ethiopia, Nicaragua, the People's Republic of China, Somalia, Zambia, and Zimbabwe selected lines of their choice for utilization in breeding programs. We rejuvenated 6051 cultivated and 202 wild sorghum accessions during 1987 (Table 4).

In order to augment the 'rabi program' in India, a basic collection constituted at ICRISAT was sent to Annigeri and Gulbarga research stations in Karnataka to be tested in the postrainy season. In an introgression program to transfer genes for sorghum shoot fly (*Atherigona soccata*) resistance from *S. dimidiatum*, F_2 populations of crosses involving wild and cultivated accessions were raised. Two hundred male-sterile lines were evaluated, and 20 were found to be agronomically suited to the postrainy season.

We supplied 454 accessions to the Southern African Development Coordination Conference

Figure 4. Director General, L.D. Swindale observing variation in the new sorghum germplasm collected in the Yemen Arab Republic.

(SADCC)/ICRISAT Sorghum and Millet Improvement Program, 838 to the ICRISAT Eastern Africa Program, and 378 to ICRISAT scientists working in Mexico. We also supplied 6198 accessions to national programs including Botswana (125), India (2807), Malawi (404), Qatar (204), Republic of Korea (198), Rwanda (265), and Zaire (2195) for use in their research programs. In all, we distributed 27426 samples to sorghum scientists (Tables 6, 7). Eight computer printouts of evaluation data were supplied to sorghum scientists in Cameroon (1), India (3), Kenya (1), Sudan (1), and USA (2) for use in their programs.

Pearl millet

This year we added 937 accessions (Table 1) consisting of 727 from Cameroon, 190 from India, 2 from Mali, and 18 from Uganda (Table 2), raising the total number of cultivated accessions to 19085, besides 68 accessions of wild relatives of *Pennisetum*. We sowed 649 accessions in the PEQIA in December for quarantine inspection and seed increase. These include 2 wild *Pennisetum* samples from Mali, 164 wild and weedy forms of *Pennisetum* from Niger, 53 wild and 288 cultivated samples from Tanzania, 29 cultivated samples from Togo, and 113 cultivated samples from Burkina Faso.

In collaboration with the Tanzania Agricultural Research Institute (TARI), Tanzania, and SADCC/ICRISAT, Zimbabwe, we collected 288 cultivated and 53 wild *Pennisetum* samples from Tanzania in May. *Pennisetum pedicellatum* and *P. polystachyon* were endemic throughout the country; *P. ramosum* and *P. purpureum* were found in heavy soils and low-lying areas. We organized collection missions in collaboration with NBPGR to the pearl millet growing areas of Karnataka and Tamil Nadu. In Karnataka, we collected 181 cultivated samples, and 5 wild relatives of *Pennisetum* from the northern districts during October and November. In December, we collected 278 samples from Tamil Nadu in collaboration with TNAU. *Pennisetum clandestinum* was collected for the first time from India in the Nilgiri hills during this expedition.

During the rainy season, we evaluated 3165 accessions at ICRISAT Center. The 527 germplasm samples from Cameroon were broadly classified into two forms, the short-duration 'Mouri' which flowers in 80-90 days and produces grey grains, and the long-duration 'Yadiri' which flowers in 115-130 days and generally produces white grain. Sweet stalks were found in both types. All the 18 accessions from Uganda flowered very late and produced many tillers and conical heads with large grain. All the 81 accessions from Togo and the 40 accessions from Benin were evaluated and classified into different cultivar groups based on flowering, spike, and grain characters.

Under the NBPGR/ICRISAT collaborative project, we evaluated 2000 diverse accessions at Issapur, New Delhi. During a field visit conducted by NBPGR in September 1987, millet scientists from Delhi, Haryana, and Rajasthan made selections for use in their programs. ICRISAT breeders selected 92 accessions. The 81 accessions that were selected by NBPGR/ICRISAT from the 2000 evaluated at Jodhpur during 1986, were evaluated at Akola and 17 accessions were selected; 14 for grain and 3 for forage purposes. During a field visit to the PEQIA, ICRISAT scientists selected 253 accessions, and the Coordinator, All India Coordinated Pearl Millet Improvement Program (AICPMIP), Pune selected 36 samples from Cameroon and Uganda.

We evaluated 1996 diverse accessions at Aisleby, Bulawayo, Zimbabwe, in collaboration with SADCC/ICRISAT. From this, 96 accessions for grain, 49 for fodder, and 21 for both grain and fodder were selected and then evaluated at ICRISAT Center. Nine accessions were also selected for inclusion in the Pearl Millet Late Variety Trial (PMLVT) for the SADCC region. All the 870 Cameroon germplasm accessions were jointly evaluated by the Institut de la recherche agronomique (IRA), Maroua, and ICRISAT (Fig. 5). In general, the differences between the types were more conspicuous at Maroua than at ICRISAT Center. Agronomically superior accessions were jointly selected for

Figure 5. Scientists from IRA, IITA, and ICRISAT recording evaluation data in an indigenous pearl millet germplasm trial, Maroua, Cameroon, October 1987.

use in the millet breeding program at Maroua.

The search for new genes continued. As a result of screening 16 480 accessions, we identified seven more 'glossy' lines. We found that three genes control glossiness and assigned the gene symbols gl_1, gl_2, and gl_3. Studies showed a segregation ratio of 3 glossy : 1 nonglossy and no reciprocal differences were observed. We found that the genes controlling purple plant color (*P*), long bristles (*Bl*) and trichomeless (*tr*) are independent of gl_1 and gl_2.

We constituted a large-seeded pearl millet germplasm pool, and studied the genetics of male-sterility in male sterile (ms) lines developed from Ghana and Botswana germplasm. These lines were improved for downy mildew (*Sclerospora graminicola*) resistance by growing them in sick plots for three generations.

We initiated studies on the genomic relationships in the polybasic genus *Pennisetum* (x=5,7,8, and 9), and pollen mother cells (PMC) meiosis to determine chromosome numbers. In x=5 type, 2x=10 was observed in *P. ramosum* (Fig. 6). In x=7 type, 2x=14 was observed in *P. glaucum* (cultivated), *P. violaceum*, *P. mollissimum*, and *P. schweinfurthii*, while 4x=28 was observed in *P. purpureum*. In x=8 type, 2x=16 and 4x=32 was observed in *P. mezianum*. In x=9 type, 2x=18 and 3x=27 was observed in *P. hohenackeri* while 3x=27 was observed in *P. setaceum*. 4x=36 was observed in species *P. mecrorum*, *P. cenchroides*, *P. divisum*, *P. pedicellatum*, and *P. orientale*, while 5x=45 was observed in *P. villosum*. *P. squamulatum*, and two subspecies of *P. polystachyon* (*polystachyon* and *setosum*) showed 6x=54 chromosomes while *P. macrostachyum* showed the highest chromosome number with 68 chromosomes.

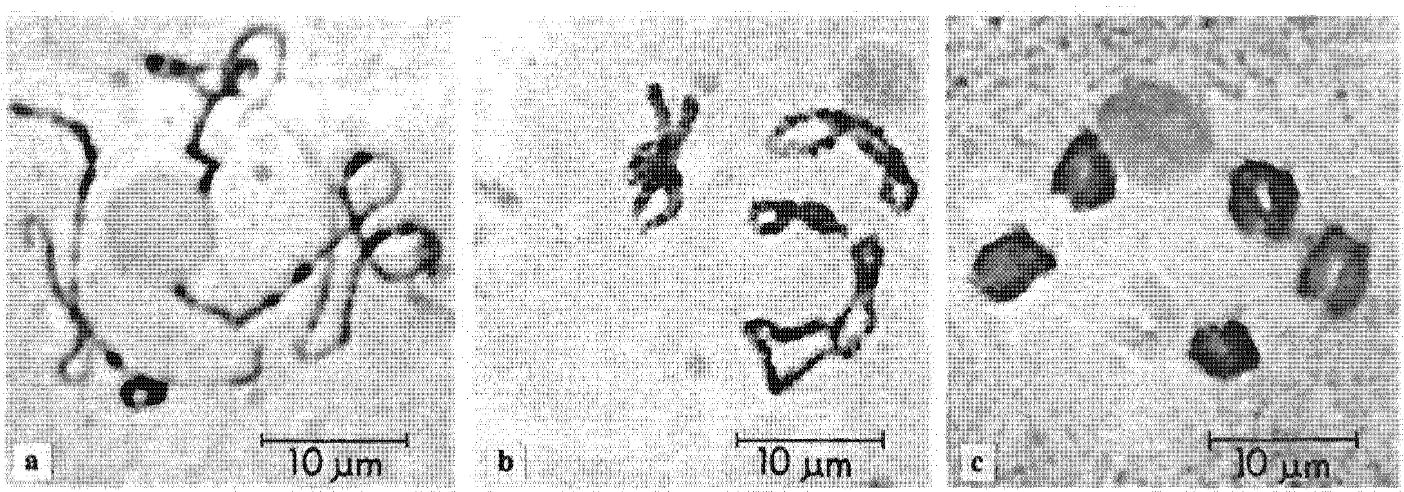
We identified a spontaneous triploid (3x) in *P. hohenackeri* in a population of 28 diploid plants and conducted cytomorphological studies. As a part of the introgression of useful genes from wild into cultivated pearl millet, we attempted 103 crosses using two cultivated accessions and 10 wild species, and obtained F_1 seed in 62 crosses.

Both passport and evaluation data on 19 085 accessions are being entered into the computer.

Chickpea

We organized a germplasm collection mission to Madhya Pradesh state in India during February in collaboration with NBPGR and Jawaharlal Nehru Krishi Vishva Vidyalaya (JNKVV), Jabalpur. The mission resulted in the collection of 157 chickpea samples, and with this the world collection has been further augmented with twin-podded, pink seeded, and tuberculated seed types. In another mission, collaborating with the Institut national de la recherche agrono-

Figure 6. a. Pachytene, b. diplotene, and c. diakinesis stages of pollen mother cell meiosis showing five bivalent chromosomes in *Pennisetum ramosum*, a distant wild relative of pearl millet (bar represents 10 μm).



mique (INRA), Morocco, and the International Center for Agricultural Research in Dry Areas (ICARDA), 122 chickpea samples were collected in Morocco, most of which were kabuli types (Fig. 7). The large-seeded, twin-podded kabuli types, and the desi type chickpeas from that region were also of interest.

In the gene bank, we registered 371 samples during the year (Table 1). These include 321 samples of Indian origin, 30 from Iran, 7 from Italy, 5 from USSR, 2 from Bangladesh, and 1 each from 6 other countries (Table 2). With the new additions, the present chickpea holding in the gene bank is 15246 accessions.

The evaluation of 1033 accessions, jointly by ICRISAT and Agricultural Research Center, Debre Zeit, Ethiopia, has resulted in the identification of 18 agronomically superior accessions. From the joint NBPGR and ICRISAT multilocational tests in India, we evaluated 1200 accessions each at Akola, Gwalior, Issapur, and Patancheru. In the test at Gwalior, crop performance was very good and five accessions namely, ICC 148, 327, 1034, 1083, and 1341 surpassed yield levels of either of the three control cultivars (K 850, L 550, and G 130) used in the study. This work will be continued in the postrainy season 1987 when a new set of germplasm accessions will be evaluated.

At ICRISAT Center, 1150 accessions were characterized, and seeds of 2200 accessions were rejuvenated. Monitoring of seed viability continued and we identified 484 accessions that showed <85% germination standard for rejuvenation.

The glabrous shoot mutant that was identified from progenies of Chafa seeds treated with ethyl methane sulphonate (EMS) proved useful in pathological, entomological, and physiological studies. Genetic studies revealed that the glabrous characteristic is governed by a single recessive gene. A gene symbol *gl* was proposed

Figure 7. Collecting chickpea germplasm in Morocco, in collaboration with scientists from the Institut national de la recherche agronomique (INRA), Morocco and ICARDA.

for this trait. We also completed inheritance studies on a naturally occurring polycarpy mutant. The twin-flower peduncles, polycarpy, and other associated features of the mutant were found to be the pleiotropic expression of one recessive gene. We proposed a gene symbol *tpc* for this character.

Crosses were made to transfer resistance to botrytis gray mold (*Botrytis cinerea*) disease from desi to kabuli backgrounds. Eight F_2 progenies were raised and their segregants will be tested for resistance to the disease. The induced mutant with thick branches and upright canopy was crossed to other types in an attempt to transfer this characteristic.

Pigeonpea

During this year, we added 216 new accessions, raising the total pigeonpea germplasm holdings in the gene bank to 11034 (Table 1). The new accessions are landraces collected from Guyana, Jamaica, India, and Venezuela during 1986 (Table 2). The wild pigeonpea gene pool now has 271 accessions consisting of 6 genera and 47 species. We received 150 samples from Thailand that are undergoing quarantine clearance. We raised 103 more exotic accessions in the PEQIA for release and seed increase. These were received from Italy (12), Kenya (30), and Zambia (61).

This year, we characterized and rejuvenated 924 accessions from 7 countries, including 139 new accessions from Brazil (10), Guyana (21), India (26), Jamaica (42), Kenya (2), Venezuela (30), United Kingdom (3), and lines developed at ICRISAT (5). The remaining 785 accessions were those with incomplete data. During this year, damage by fusarium wilt (*Fusarium oxysporum* f. sp *ciceri*) and pod borer (*Heliothis armigera*) was severe, and this affected the recording of observations. Several preliminary evaluations are in progress. These include a set of 16 medium-duration accessions with desirable agronomic traits, 20 vegetable types with high yield potential, and a set of 16 entries with high biomass potential.

We rejuvenated 1232 accessions, out of which 644 were accessions with low seed stock, 365 with germination standard below the critical level, and 223 for which there is high demand. We rejuvenated 76 accessions of wild species for seed increase in the botanical garden.

We continued the preliminary screening against photoperiodic insensitivity, and out of 528 accessions screened during 1986/87, 14 were found to be less sensitive. During 1987/88, a set of 556 accessions will be screened. Under extended daylength conditions, 269 accessions were screened during 1986/87 and 56 accessions were identified with little or no difference in days to flowering compared to the control.

We previously evaluated a working collection of 1000 large-seeded, long-duration accessions at Katumani and Kiboko in Kenya. From this trial a set of 500 accessions was characterized at these two locations during 1986/87, in collaboration with the National Dryland Farming Research Centre (NDFRC), Kenya. Katumani lies at about 2° S latitude at an altitude of 1570 m, its average annual rainfall is 659 mm, over 64 rainy days with year-to-year variation between 400–950 mm. Rainfall is bimodal, with peaks in April and November. Kiboko is located 130 km southeast of Katumani, at about 950-m elevation. Kiboko is much warmer than Katumani, but the rainfall pattern in both places is similar. We jointly identified 63 accessions at Katumani, and 51 at Kiboko with desirable agronomic traits and local adaptation. The breeders at NDFRC are evaluating the yield potential of these accessions in replicated trials at many locations in Kenya. ICRISAT breeders selected 39 accessions and these are being evaluated at ICRISAT Center. We identified several accessions with such specific traits as profuse flowering and podding, large pods with large and green seeds (Fig. 8), high ratoonability, and high biomass production (Fig. 9). These are being purified by breeders at NDFRC for further testing and utilization. The agronomists at NDFRC have included the high biomass-producing lines in their trials in 1987/88.

The passport data of the newly registered accessions, characterization data of 1986/87 rainy season at ICRISAT Center, and the 1986/87

Figure 8. Evaluation of eastern African pigeonpea germplasm in Kenya, June 1987.

joint germplasm evaluation data from two locations in Kenya are now available on computer. The photoperiodic insensitivity screening data on less-sensitive accessions from 1977/78 to 1986/87 have been documented and are being entered into the computer. The seed distribution and passport data on wild species have also been entered into a microcomputer.

Groundnut

During the year, we added 211 accessions from seven countries, thus raising the total groundnut accessions in the gene bank to 11852 (Table 2). The new additions included 130 accessions from Mali that we collected during 1986. In addition,

Figure 9. Pigeonpea genotypes, which are now much in demand, with potential for high biomass production identified in NDFRC/ICRISAT joint pigeonpea evaluation trial, Katumani, Kenya, June 1987.

Figure 10. EMBRAPA/ICRISAT *Arachis* germplasm collection team in northeastern Brazil, March 1987.

accessions obtained from Burma (41), Greece (14), and USA (709) are undergoing quarantine clearance.

In April, we collected *Arachis* germplasm in Brazil in collaboration with the Centro Nacional de Recursos Genéticos (CENARGEN) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) (Fig. 10). We explored northeastern Brazil, where *Arachis* species in sections *Extranervosae, Ambinervosae*, and *Triseminalae* are known to occur in the states of Bahia, Pernambuco, Ceara, Paraiba, Riogrande do Norte, and Piaui. We sampled a total of 41 *Arachis* populations including 7 cultivated groundnuts. During this mission, we covered large areas, previously unexplored or inadequately explored. As a result we extended our knowledge of the geographic distribution of *A. sylvestris* Krap. *et* Greg. *nom. nud.*, and species in section *Ambinervosae.*

A groundnut collection mission was undertaken in Burma during October-November in collaboration with the Asian Grain Legume Network (AGLN) and Agricultural Corporation (AC), Burma. We explored the central dry zone (mainly the provinces of Mandalay, Sagaing, and Magwe) and obtained 41 samples (Fig. 11). In collaboration with NBPGR, we explored the Palghat district in Kerala, and Tamil Nadu state and collected 126 samples of groundnut during November-December.

During May, we obtained 709 samples of wild (123), and cultivated (586) groundnuts from Texas Agricultural Experiment Station (TAES), Stephenville, USA. These accessions were part of previous collections in South America, in some of which ICRISAT had participated. We achieved this transfer of material after a considerable lapse of time and expect it to greatly enrich the ICRISAT groundnut collection.

We sowed 2987 accessions during the rainy season and 2807 during the postrainy season for rejuvenation (Table 4) and characterization using the IBPGR/ICRISAT descriptors. In collaboration with our legume virologists, all the 2987 accessions sown in the rainy season were tested for the presence of peanut mottle virus (PMV) before sowing, using the ELISA technique. Field inspection was also carried out so that we could harvest only from PMV-free plants. Accessions of 60 wild species were rejuvenated.

We repeated the bold-seeded accessions trial with 96 accessions in collaboration with the breeders this year (ICRISAT Annual Report 1986, p. 15). Data from two seasons has helped us select material for the Legumes Program to include in their groundnut breeding program.

Figure 11. Collecting local groundnut landraces from a Burmese farmer, November 1987.

Our collaboration with the NBPGR continued and 1500 accessions were sown at NBPGR Regional Station, Jodhpur, and 1500 accessions at Akola (Table 5), for joint evaluation. However, the trial at Jodhpur failed due to lack of rainfall. The results of the trial at Akola are being processed.

We examined the fresh-seed dormancy of 1038 accessions that were harvested in March-April and found 39 accessions belonging to ssp *fastigiata* with a dormancy period exceeding 30 days. These will be useful in breeding short-duration groundnut cultivars with fresh-seed dormancy since this avoids the problem of in situ germination in regions where rains may occur during the harvest period.

Over 5900 accessions were supplied to the Biochemistry Unit for collaborative screening and oil and protein content analyses. The results showed a wide range of variation, 31.8–55.0% in oil content, and 15.8%–34.2% in protein content in the undefatted meal. The accessions that gave the highest values are ICG 3670 with 55% oil, and ICG 5856 with 34.2% protein. These accessions, which are rich sources of oil and protein, will be added to the growing list of groundnut genetic stocks for utilization and distribution.

We distributed 13 889 samples during the year (Tables 4 and 5), including 1280 samples to ICRISAT scientists, 4993 to scientists in India, and 7616 to scientists outside India. We supplied a total of 6000 accessions to scientists in Indonesia to be screened for resistance to peanut stripe virus (PStV), in a collaborative project between the Central Research Institute for Food Crops (CRIFC), Bogor, Indonesia, Australian Centre for International Agricultural Research (ACIAR), and ICRISAT.

We completed computerization of passport data on 31 descriptors on 11 640 accessions. Data on 21 evaluation descriptors are now on computer for all accessions, and data on 21 more descriptors are being computerized. The seed stock position of all the accessions is also available on computer along with seed distribution data.

Minor Millets

We assembled 894 new accessions of three crop species of minor millets from Burundi (10), Republic of Korea (125), Uganda (577), USSR (1), and Zimbabwe (181) during the year, raising our total gene bank holdings to 6457 (Table 3). A total of 1606 accessions of six crop species, proso millet (834), barnyard millet (574), foxtail millet (103), little millet (27), finger millet (55), and kodo millet (13) were evaluated and rejuvenated.

We supplied 1196 accessions to NBPGR for evaluation at Akola, India. We also supplied 444 accessions to Nigeria, 192 to Republic of Korea, and 200 to Kenya for evaluation and use in their breeding programs. Two finger millet accessions, IE 2247 and IE 2929, sent to Zambia have been approved for prerelease in that country.

Publications

Institute Publications

Journal Articles

Appa Rao, S., Mazhani, L.M., and **Attere, A.F.** 1986. Collecting in Botswana. Plant Genetic Resources Newsletter 68:27-28. (JA 623)

Appa Rao, S., Mengesha, M.H., and **Rajagopal Reddy, C.** 1986. Pearl millet (*Pennisetum americanum*) germplasm from Senegal. Indian Journal of Genetics and Plant Breeding 46(2):413-422. (JA 352)

Appa Rao, S., Mengesha, M.H., and **Rajagopal Reddy, C.** 1986. Variation and adaptation of pearl millet germplasm in Tamil Nadu, India. Indian Journal of Genetics and Plant Breeding 46(3):449-455. (JA 480)

Appa Rao, S., Mengesha, M.H., and **Rajagopal Reddy, C.** 1987. Glossy genes in pearl millet. Journal of Heredity 78(5):333-335. (JA 579)

Appa Rao, S., Mushonga, J.N., and **Muza, R.F.** 1986. Collecting in Zimbabwe. Plant Genetic Resources Newsletter 67:41-43. (JA 664)

Mengesha, M.H., and **Appa Rao, S.** 1986. Genetic resources of pearl millet at ICRISAT. Journal d'Agriculture Traditionelle et de Botanique Appliquee 33:59-67. (JA 691)

Prasada Rao, K.E., and **Abdulla, Hamoud Ali.** 1986. Sorghum germplasm from the Yemen Arab Republic. Sorghum Newsletter 29:8-10. (JA 586)

Ramanatha Rao, V., and **Mwenda, F.F.** 1987. Collecting groundnut germplasm in Tanzania. Plant Genetic Resources Newsletter 70:35-37. (JA 592).

Conference Papers

Remanandan, P. 1987. Genetic variation in pigeonpea germplasm. Pages 320-321 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 280)

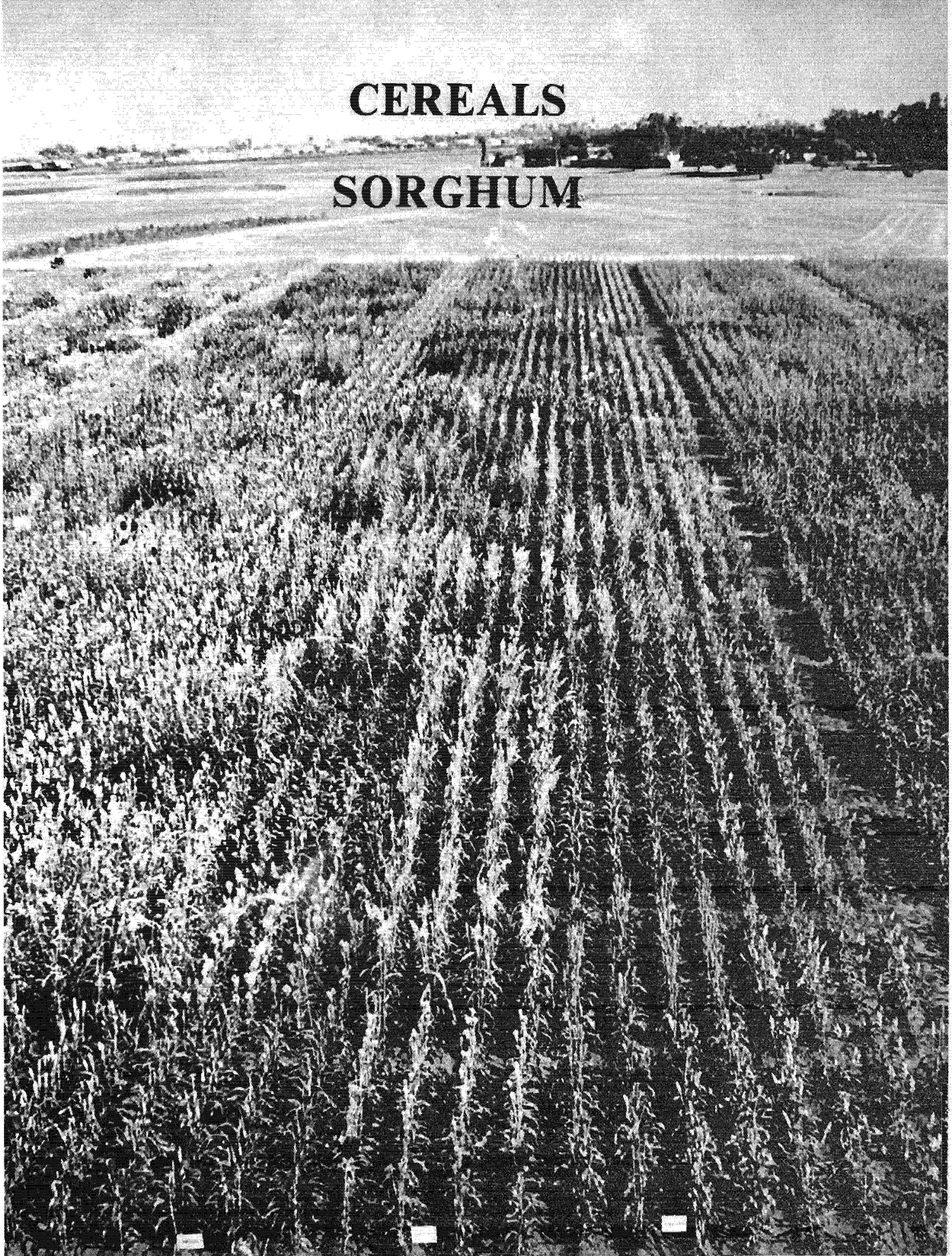
Ramanatha Rao, V. 1987. Origin, distribution and taxonomy of *Arachis* and sources of resistance to groundnut rust (*Puccinia arachidis* Speg.). Pages 3-16 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 403)

Seetharama, N., **Prasada Rao, K.E.**, **Subramanian, V.**, and **Murty, D.S.** 1987. Screening for sweet stalk sorghums, and environmental effect on stalk sugar concentrations. Pages 169-179 *in* Technology and applications for alternate uses of sorghum: proceedings of the National Seminar, 2-3 Feb 1987, Parbhani, India. Parbhani, Maharashtra 431 402, India: Marathwada Agricultural University. (CP 308)

Subramanian, V., **Jambunathan, R.**, and **Prasada Rao, K.E.** 1987. Dry milling characteristics of sorghum grains and their relationship to product quality. Pages 45-54 *in* Technology and applications for alternative uses of sorghum: proceedings of the national seminar, 2-3 Feb 1987, Marathwada Agricultural University, Parbhani, India. Parbhani, Maharashtra 431 402, India: Marathwada Agricultural University. (CP 346)

CEREALS

SORGHUM



Contents

Cover photo: Screening sorghum for midge resistance. Note the use of infestor rows, sprinklers, split sowing, and head cages to manipulate the midge population and ensure optimum levels of infestation necessary for the identification of midge-resistant genotypes. ICRISAT Center, postrainy season 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

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

SORGHUM

The sorghum improvement program extends across the semi-arid tropics (SAT). Regional responsibilities are divided among the cereals program at ICRISAT Center in India (Asia), research teams based in Burkina Faso (West Africa), and in Zimbabwe (southern Africa), a research network for eastern Africa based in Kenya, and a research network for Central America, Mexico, and the Caribbean based in Mexico. A cooperative cereals research network based at ICRISAT Center coordinates a global network of trials and nurseries to facilitate transfer of breeding material to National Programs.

A major objective of this program is to provide national agricultural research systems with breeding material having high yield potential under the environmental conditions prevailing in selected agroecosystems. Breeding material developed by the program has been entered into the sorghum improvement programs of countries across the SAT, and open-pollinated and hybrid cultivars produced by its various teams and networks are successfully grown in several countries of Asia, Africa, Central America, Mexico, and the Caribbean. Among the several ICRISAT-bred cultivars released in 1987, ICSV 112 (SPV 475) was recommended for release by the All India Coordinated Sorghum Improvement Project (AICSIP) in India; in Mexico it was released as UANL-I-V-187 by the University of Nuevo Leon, and it has been proposed for release in Malawi. Details of other ICRISAT-bred material that was released in 1987 are given in this report.

Research emphasis is placed on breeding for acceptable crop establishment under conditions of heat and drought stress, escape from mid- and late-season stress, and multiple resistance to insect pests and diseases. The results from our studies on the physiological basis of genotype differences, in their ability to emerge through soil crust and resistance to drought, will greatly enhance our work in this area. Although we have determined that flavan-4-ol is associated with mold-resistant sources used in the breeding program, we are yet to transfer grain mold resistance into high-yielding sorghum genotypes. Other major problems include lodging of high-yielding hybrids under conditions of terminal stress, and susceptibility of cultivars to shoot fly and stem borers. However, several midge-resistant genotypes have shown stable resistance in 4 years of testing. The feasibility of using biotechnological techniques to transfer shoot fly resistance from wild to cultivated sorghum is being investigated. Results accumulated over 10 years show that the associative N_2-fixation system does not have a significant agronomic impact on sorghum production. Our research emphasis has therefore shifted to the uptake and availability of mineral nutrients.

In West Africa, our team in Burkina Faso is breeding cultivars adapted to the Northern Guinean zone with annual rainfall between 900 and 1200 mm, and is developing cultivars for the Sudanian zone where the annual rainfall is 600–900 mm. The susceptibility of adapted cultivars to the parasitic weed *Striga hermonthica* remains a serious problem across West Africa. *Striga asiatica*-resistant genotypes have been identified and ICSV 145 (SAR 1) has been recommended for release in India, but the genetics of resistance remains poorly understood. At ICRISAT Center, we have associated the effects of soil fertility and water deficits on the production of stimulants by sorghum roots which trigger germination of *Striga* seeds. In West Africa, groundnut grown in association with sorghum suppresses *Striga*. A package of cultural practices to reduce the incidence of *Striga* germination in infested fields is being developed.

Our program in eastern Africa coordinates a research network that facilitates distribution of ICRISAT breeding material in the region, and helps transfer breeding and disease resistance screening technologies developed at ICRISAT to national agricultural research systems. Training of local staff is a major activity of the eastern Africa network. In 1987, we organized a short course on seed production for national program scientists, attended by over 50 participants from 13 countries of the region.

The sorghum improvement program team in southern Africa has, as its primary objective, the strengthening of national research capability for sorghum improvement in the region. This includes research, education, training, and research station development. Twenty-five students are currently pursuing undergraduate or postgraduate studies at universities in the USA. Several countries of the region have benefited from our efforts at research station development. Increasing the germplasm base for sorghum improvement in national programs is continuing. Emphasis on the utilization of sorghum for human consumption, industrial uses, and as a forage is increasing. Susceptibility to *Striga* remains a serious yield-limiting factor of hybrids and cultivars. The resistance of selected breeding lines to these parasitic weeds needs to be confirmed.

The Central American-Mexican-Caribbean research network endeavors to develop cultivars for the highlands (1800–2300 m) and lowlands (800–1800 m) of the region, and cropping systems to incorporate high-yielding cultivars into established farming practices. In 1987, three ICRISAT-improved sorghum cultivars were released in the region. Following a survey of over 200 farmers in southeastern Guatemala when we found that 87% of them grow the local photosensitive sorghum, we concluded that the National Program should concentrate on improving this type of sorghum and the agronomic practices that can increase its productivity in the local farming systems. The ICRISAT program has started a project on the improvement of local photosensitive sorghums in El Salvador which is central to the region where these sorghums are important.

Physical Stresses

Drought

Seedling Emergence through Soil Crust

The effect of soil crust on seedling emergence varies between genotypes. We compared the seedling growth response of a crust-tolerant genotype (IS 17605), with a sensitive one (IS 23317), using a field technique described earlier (ICRISAT Annual Report 1983, pp. 69-71).

We excavated whole seedlings from the soil for growth analysis in 2-m plots in both control and crust treatments every day until seedlings emerged [from one day after sowing (DAS) to 6 DAS] (Fig. 1). The seedlings of crust-tolerant IS 17605 accumulated dry mass faster than the susceptible entry, irrespective of crust treatments (Fig. 2). The average dry-matter utilization for new growth in the crusted soil was higher in IS 17605 (5.5 mg d^{-1} $seed^{-1}$), than in IS 23317 (3.1 mg d^{-1} $seed^{-1}$). However, on a percentage basis (to the grain mass), the sensitive genotype used more dry matter (15% d^{-1} $seed^{-1}$) compared to the tolerant gentoype (12% d^{-1} $seed^{-1}$).

From Figure 2a it can be inferred that the crop growth rate of seedlings was higher for the crust-tolerant IS 17605 (2.6 mg d^{-1} $seedling^{-1}$) than for IS 23317 (1.7 mg d^{-1} $seedling^{-1}$). The difference in growth between the genotypes was mainly in the plumule (Fig. 2b). The shoot extension rate of IS 17605 was 10.1 mm d^{-1} $seedling^{-1}$ as against 8.6 mm d^{-1} $seedling^{-1}$ in the case of IS 23317 (Fig. 2b). The radicle extension rates did not vary significantly betweeen the two genotypes—19.3 d^{-1} $seedling^{-1}$ for IS 17605 and 19.5 mm d^{-1} $seedling^{-1}$ for IS 23317.

These results indicate that faster plumule growth facilitates emergence. While the barrier imposed by the crust reduces growth of both genotypes, the tolerant genotype is able to emerge before the crust strength becomes too great.

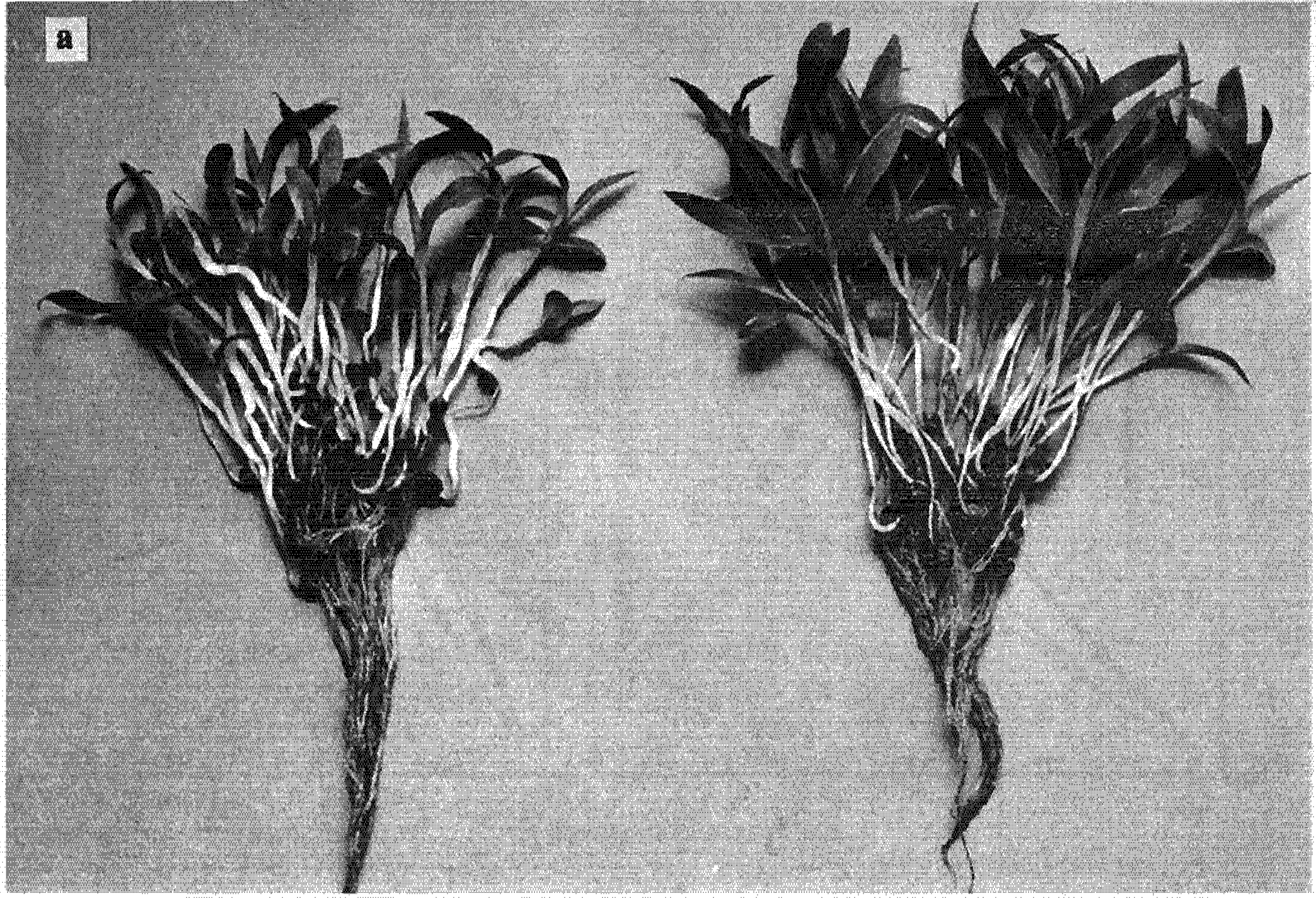


Figure 1. Seedling emergence through soil crust. (a) Seedlings of a tolerant genotype IS 17605, which emerged through the crust (left) and in the control (right). (b) Seedlings of a sensitive genotype IS 23317, which failed to emerge fully through the crust (left) but emerged in the control (right).

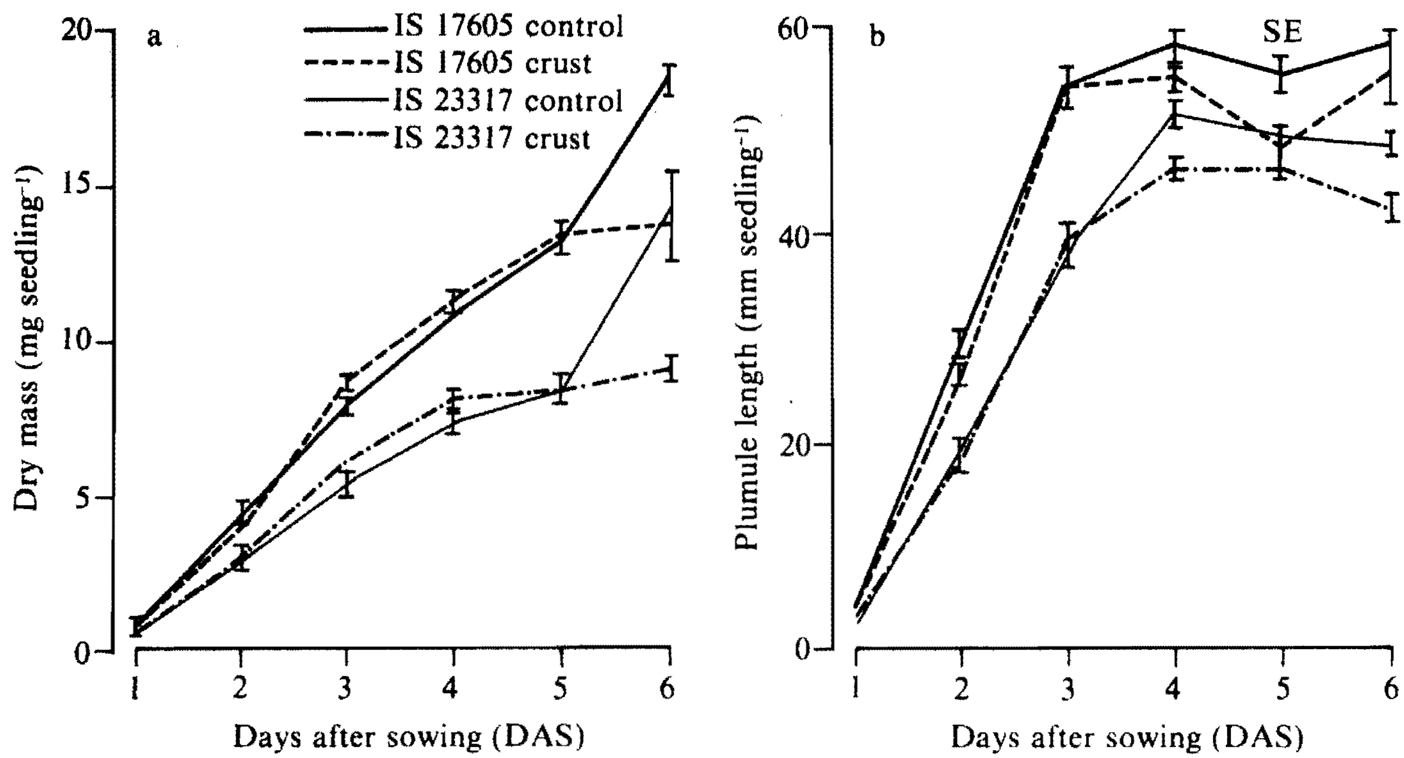


Figure 2a. Time course of dry mass accumulation. b. Increase in plumule length of crust-resistant (IS 17605) and sensitive (IS 23317) sorghum seedlings from crust and control treatments, ICRISAT Center, summer 1987.

Midseason Drought

Proline Accumulation and Drought Resistance

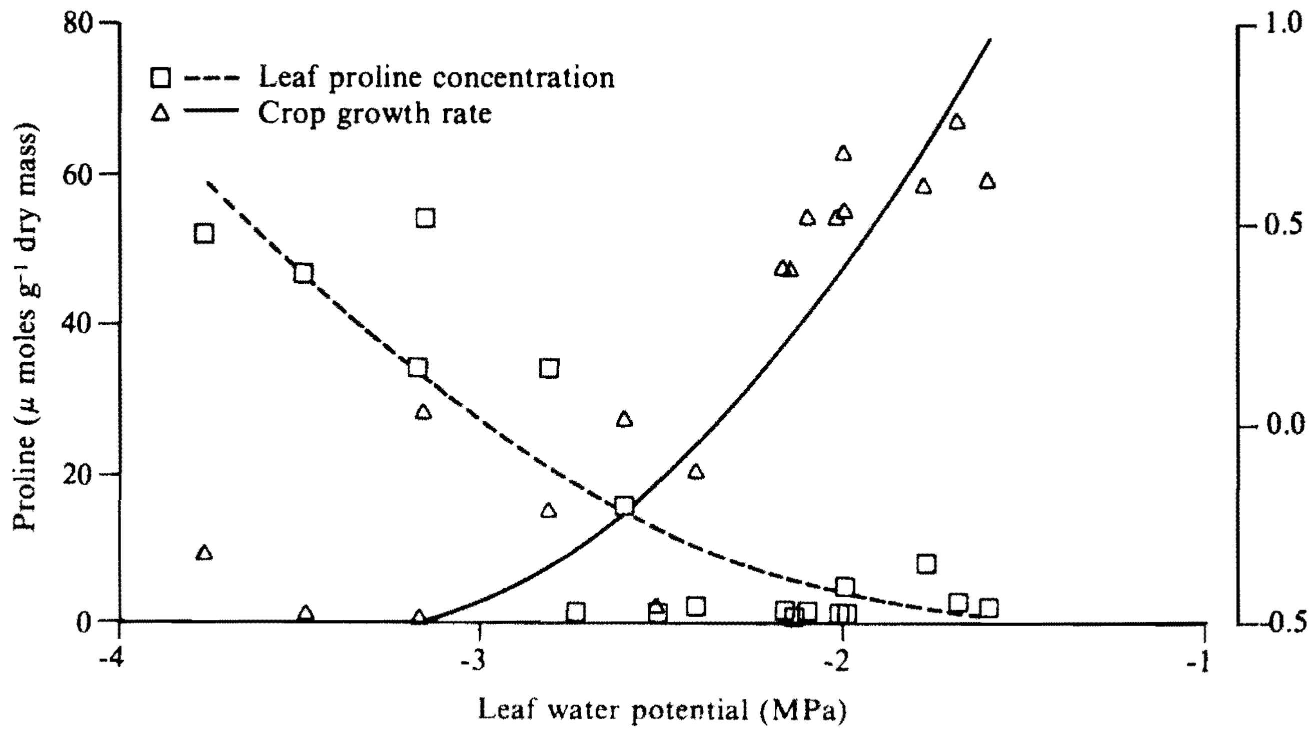
We measured the proline levels in the two youngest, fully expanded leaves by a colorimetric method in six sorghum genotypes differing in drought resistance; IS 22380, ICSV 213, IS 13441, and SPH 263—resistant; and IS 12379 and IS 12744—susceptible, when subjected to midseason drought stress under field conditions (ICRISAT Annual Report 1986, pp. 24-27). Both sets of genotypes accumulated less than 0.5 μ moles proline g^{-1} dry mass under control conditions. When subjected to drought, mean proline levels in the leaves of the resistant group were 41.6 μ moles g^{-1} dry mass (range 21.1–64.6) in contrast to the low levels in the susceptible group (mean = 1.2; range 1.0–1.5) The high proline levels in stressed plants of the resistant genotypes returned to the level of the control plants a few days after the stress was alleviated by watering.

Most of the proline in the resistant lines accumulated when leaf-water potentials (LWP) were lower than -2.5 MPa (Fig. 3); this low level of LWP was not reached in the susceptible genotypes during drought. Most of the proline accumulated after plant growth had ceased, thereby not contributing to plant productivity during stress. Furthermore, proline made little contribution to osmotic adjustment. However, there was a high correlation between the levels of proline (r^2 = 0.81) measured at the end of the stress period and the immediate recovery of resistant genotypes following rewatering, suggesting that proline might have a role in the immediate recovery of plants upon rewatering.

Terminal Drought

Root Growth in Postrainy-season Sorghum

We earlier reported the relative importance of nitrogen- and water-deficit stresses on the pro-



Regression equations:
Proline vs LWP $y = 36.0 + 43.3 + 13.3\ x^2\ (r^2 = 0.78)$
Growth rate vs LWP $y = 4.47 + 2.84\ x + 0.40\ x^2\ (r^2 = 0.63)$

Figure 3. Relationship between sorghum leaf proline concentrations (□) and crop growth rates (Δ) with leaf-water potentials (LWP). The negative values of crop growth represent loss of dry matter and absence of new growth even after release from stress in susceptible genotypes. ICRISAT Center, summer 1986.

ductivity of postrainy-season sorghum (ICRISAT Annual Report 1986, pp. 27-28). As we found little effect of N added at sowing on the total seasonal water use under terminal drought during the postrainy season, we studied the effect of both N and water (irrigation) levels on root growth during grain filling.

Nitrogen and water levels did not significantly affect root mass during grain filling. Plants seem to distribute the same amounts of dry matter to the roots, irrespective of stress conditions in the postrainy season. However, unlike N, soil water levels significantly influenced the distribution of roots in the soil profile during different stages of grain filling (Fig. 4). Under both water regimes, mean root length density (RLD) decreased with age. At all stages, the dryland I_0 treatment had higher RLD than the I_2 treatment, which received two irrigations before flowering.

The most significant aspect of the differences between root systems of crops under the two treatments was the distribution of RLD at various depths (Fig. 3). Plants in the I_0 treatment invariably showed higher RLD at a depth of >120 cm at all stages of grain filling than those in the I_2 treatment. The reverse was true for RLD in the near-surface soil layers (0–40 cm deep), as these layers were wetter in the I_2 treatment than in the I_0 treatment, especially at the beginning of flowering (65 DAS). Maximum water was extracted during grain filling in both the treatments in the layers between 40–120 cm. In these layers, the RLD increased, and subsequently decreased following uptake of water in a particular layer. Roots of plants in the I_0 treatment being drier than those in the I_2 treatment, they differed in root growth and senescenced earlier than the I_2 treatment. Thus, although the overall

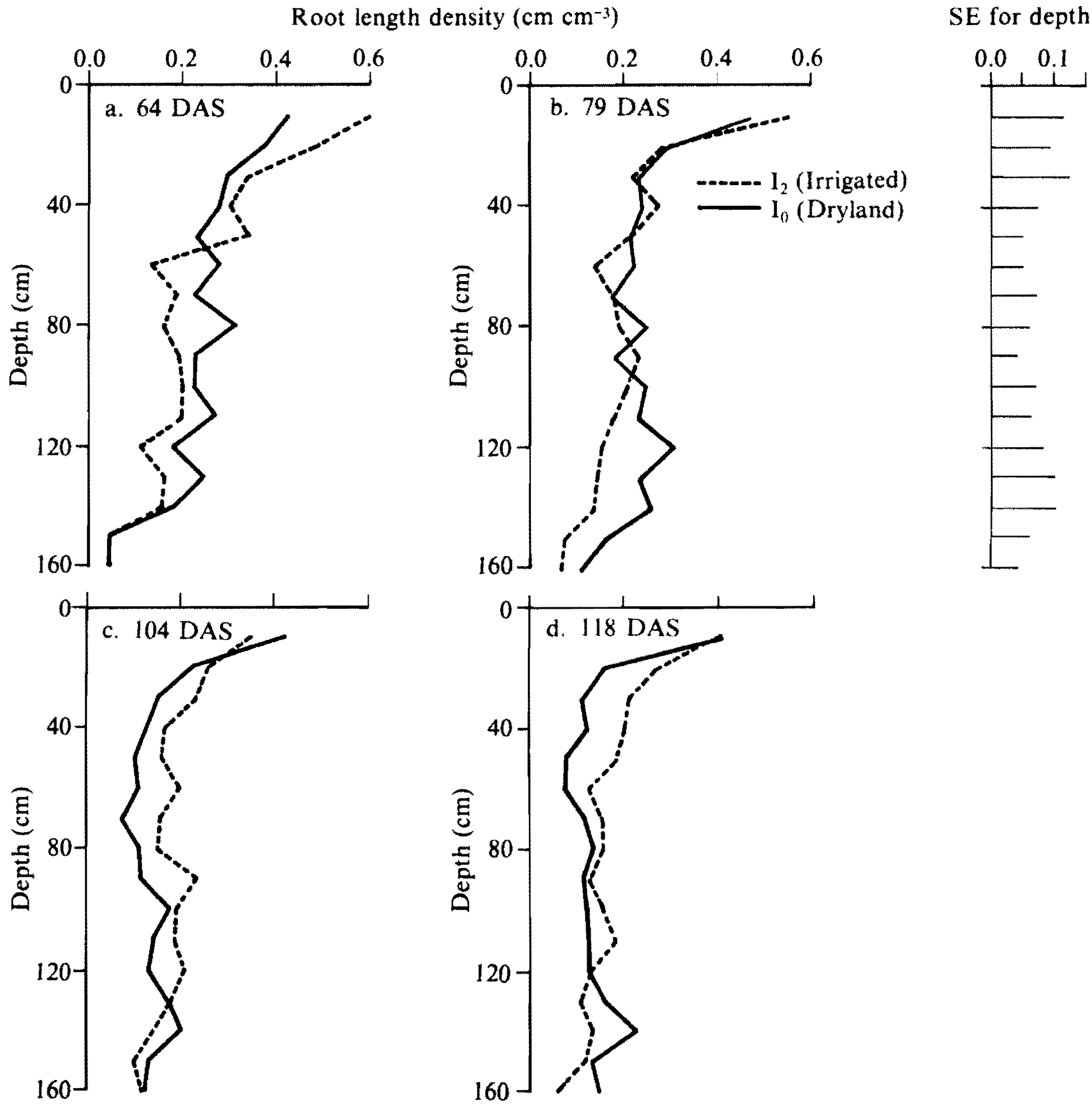


Figure 4. Root length density at different depths in dryland (I_0) and irrigated (I_2) sorghum crops at four stages: a. 64 days after sowing (DAS), b. 79 DAS, c. 104 DAS, and d. 118 DAS during grain filling. SEs for individual depths are shown on the right; all other SEs are less than 0.03. Vertisol, ICRISAT Center, postrainy season 1986/87.

differences in the mean RLD between the two irrigation treatments were barely significant ($P < 0.05$), the temporal variation in the root profile is very significant and should be noted while screening for root-growth characteristics. These data will also be used for modeling root growth and water uptake.

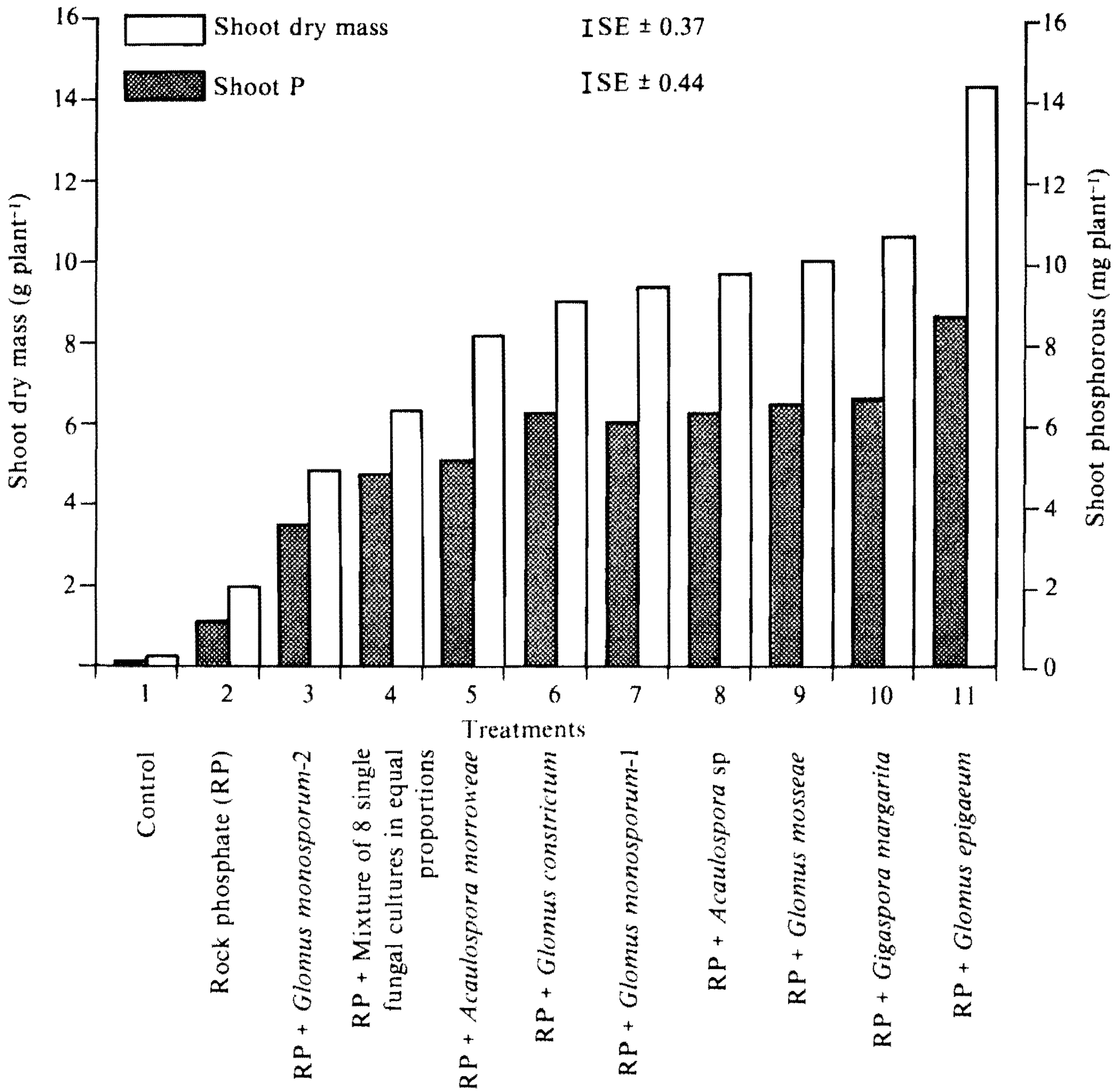


Figure 5. Response of sorghum cultivar CSH 5 to inoculations with various mycorrhizal fungi in an Alfisol amended with 50% acidulated Kodjari rock phosphate, ICRISAT Center, 1987.

Central America, Mexico, and the Caribbean

In Mexico, we grew four cold-tolerant genotypes (VA 110, BTP 28, IC/CI-4, and VA 130) under irrigated and dryland conditions with three levels of nitrogenous fertilizer—0, 60, and 120 kg N ha^{-1}. Irrigation increased ($P < 0.05$) grain yield by 52% and the harvest index by 50% by virtue of increased N utilization efficiency. Drought under dryland conditions affected the growth of all varieties, delaying flowering by as much as 13 days ($P < 0.01$) compared to irrigated plots.

We tested 25 of our best drought-tolerant lines in four countries of the region. Superior genotypes across locations were Sepon 77 bulk variety, M 90322 × M 90812, M 90812, M 90322, 79T 2846 (Lason) 80T 5058, 80L 27952-1 × M-91057, and M 90378 with an average yield of 3.7 t ha^{-1}.

Plant Nutrition

Vesicular-Arbuscular Mycorrhizae (VAM)

Earlier experiments with pearl millet have clearly indicated that mycorrhiza aids better phosphorus (P) uptake from rock phosphate sources, and that efficiencies differ among mycorrhiza strains (Annual Report 1983, p. 89-90). We further tested this phenomenon using sorghum CSH 5. Evaluation of eight different VAM fungi using 50% acidulated Kodjari rock phosphate indicated that their efficiency in stimulating plant growth differs (Fig. 5). *Glomus epigaeum* was the most efficient (14.3 g shoot dry matter $plant^{-1}$) and *G. monosporum* was the least effective (4.9 g shoot dry matter $plant^{-1}$), compared to the noninoculated control (1.9 g dry matter $plant^{-1}$). Rankings of these same VAM fungal cultures tested earlier on pearl millet and groundnut differed appreciably (ICRISAT Annual Reports 1984, p.103; and 1985, p.237), which indicates specificity for the host crop in terms of growth stimulation and P uptake.

From our trials in 1986, eight sorghum genotypes with higher VAM colonization and better ability to respond to VAM inoculation were selected. Their evaluation in Vertisols helped identify 6 promising cultures and 3 genotypes—ICSV 1 (SPV 351), IS 4769, and CSH 5. These genotypes showed a significant ($P<0.05$) increase in grain mass after inoculation.

Nitrogen Uptake

We studied the interaction between levels of N supplied as urea or potassium nitrate with irrigation levels on grain yield, dry matter accumulation, nitrate reductase activity (NRA) in leaves, N concentration in plant parts, and N uptake in sorghum SPH 218. During three samplings done in the later stages of crop growth (83, 97, and 104 DAS), total dry matter, N content (%) in leaves, and total N uptake increased significantly with the application of fertilizer-N, and also with irrigations. The mean specific NRA increased significantly with the addition of fertilizer-N over N treatments without applied N (Table 1).

Grain yield marginally increased with the application of fertilizer-N above 40 kg N ha^{-1}, and with irrigation. The source of N fertilizer had no effect on any of the plant parameters studied.

These results show that sorghum SPH 218, grown during the postrainy season, produced

Table 1. Effect of different N and irrigation levels on total dry matter (TDM) (g $plant^{-1}$), total N uptake (mg $plant^{-1}$), N content in leaves (%), and nitrate reductase activity (n mol NO_2 cm^{-2} leaf h^{-1}) of sorghum SPH 218, ICRISAT Center, postrainy season 1986/87.[1]

Irrigation levels[2]	Nitrogen (kg ha^{-1}) 0	40	80	120	Mean
	Dry matter (g $plant^{-1}$)				
I_1	75.8	80.1	89.3	85.3	82.6
I_2	79.3	90.3	98.2	98.8	91.7
I_3	88.1	100.2	99.8	103.2	97.8
SE			±3.40		±1.70
Mean	81.1	90.2	95.8	95.8	
SE			±2.0		
CV (%)			16		
	Total N uptake (mg $plant^{-1}$)				
I_1	552	607	639	691	622
I_2	500	692	838	902	732
I_3	653	858	915	1125	883
SE			±38		±19.1
Mean	568	719	797	906	
SE			±22		
CV (%)			21		

Continued

Table 1. *Continued.*

Irrigation levels[2]	Nitrogen (kg ha^{-1}) 0	40	80	120	Mean
	N content in leaves (%)				
I_1	1.06	1.12	1.01	1.11	1.07
I_2	1.13	1.34	1.52	1.49	1.37
I_3	1.51	1.60	1.87	2.10	1.77
SE			±0.060		±0.027
Mean	1.23	1.35	1.46	1.57	
SE			±0.032		
CV (%)			17		
	Nitrate reductase activity (n mol NO_2 cm^{-2} leaf h^{-1})				
I_1	30.6	34.6	34.6	40.0	35.0
I_2	24.6	33.0	37.4	41.2	34.0
I_3	34.8	40.0	40.8	57.4	43.2
SE			±1.70		
Mean	30.1	36.0	37.6	46.3	0.84
SE			±0.97		
CV (%)			38		

1. Average of 18 replications. Means of samplings at 83, 97, and 104 DAS.
2. I_1 = No irrigation, I_2 = Irrigation at 36 DAS, and I_3 = Irrigation at 36 and 68 DAS.

significantly more total plant dry matter and grain yield when provided with 40 kg N ha^{-1} either as urea or potassium nitrate, along with irrigations at 36 and 68 DAS, over the treatment without N.

Biotic Stresses

Diseases

ICRISAT Center

Grain Molds

Relationship between polyphenols and mold resistance. Our preliminary greenhouse experiments at Purdue University, USA, indicated that flavan-4-ols may be associated with mold resistance (ICRISAT Annual Report 1984, p.22). We further investigated the role of flavan-4-ols in mold resistance in field experiments during the rainy seasons of 1984, 1985, and 1986, using cultivars belonging to the following groups: white-grain, mold-susceptible, with testa (WST^{++}; (cultivars IS 2433 and IS 2516); colored-grain, mold-resistant, without testa (CRT^{+-}; cultivars IS 14375, IS 14380, and IS 14384); colored-grain, mold-resistant, with testa (CRT^{++}; cultivars IS 625, IS 9353, and IS 18759); and colored-grain, mold-susceptible, without testa (CST^{+-}; cultivars IS 402 and IS 417). These cultivars were grown in a randomized block design (RBD) with three replications. We analyzed leaf samples from the 1985 and 1986 experiments for flavan-4-ols. Leaves were harvested at 56, 63, and 70 days after emergence (DAE) and extracted with methanol and acidified methanol. Results obtained from methanol extracts were similar to those obtained from acidified methanol extracts. Flavan-4-ols concentration in group CRT^{+-} was at least 3–4 times higher than in other groups at 70 DAE.

We collected grain samples at 10, 20, 30, 40, 50, and 60 days after 50% flowering (DAF) from the 1984 and 1985 experiments, extracted them in methanol and acidified methanol, and analyzed them for flavan-4-ols. Results indicated that flavan-4-ols concentration was high up to 20 DAF but gradually decreased as the grains developed. The resistant cultivars always had higher amounts of flavan-4-ols than the susceptible ones. At 30 DAF, cultivars belonging to the CRT^{+-} group had 2–3 times more flavan-4-ols than the CST^{+-} group. The WST^{+-} group had negligible flavan-4-ols.

These experiments confirm our initial observation that leaves and grains of colored-grain, mold-resistant cultivars without testa (CRT^{+-}) have much higher flavan-4-ols content than mold-susceptible cultivars.

Breeding for resistance. In our breeding program, we successfully transferred resistance from colored-grain lines with high levels of grain mold resistance into white-grain breeding lines (ICRI-

SAT Annual Reports 1985, p.37; and 1986 p.31). The white-grain, mold-resistant advanced breeding lines that we identified, are tall with low yield potential. We crossed these mold-resistant advanced breeding lines with the white-grain, mold-susceptible improved cultivars to transfer grain mold resistance into short and early genotypes with good yield potential and other desirable agronomic traits. We screened each of the resulting 518 segregating F_2 progenies and selected F_2 progenies that combine grain mold resistance with desired agronomic traits. The environmental conditions after flowering were ideal for grain mold development and as a result, our segregating material was exposed to very high levels of grain mold infection. We selected 132 white-grain F_2 progenies with a threshed grain mold rating (TGMR) of 3 or less on a 1-5 rating scale, where 1 = no mold, and 5 = more than 50% grain surface area molded. In addition, the selected F_2 progenies have desirable plant and grain characteristics and a few are intermediate in plant height with semicompact panicles. All the selected F_2 progenies are being advanced to F_3 during the 1987/88 postrainy season and their F_4s will be screened again for grain mold resistance during the 1988 rainy season.

We started developing and compositing a grain-mold resistant population. We incorporated into the population, white-grain, mold-resistant breeding lines; colored-grain, mold-resistant lines; and high-yielding improved lines. We will incorporate additional sources of mold resistance into the population in 1988 and random-mate it for at least two generations before improving the population using recurrent selection methods.

Multilocational testing. The International Sorghum Grain Mold Nurseries (ISGMN) of 1985 and 1986 were composed of 33 identical entries—25 mold-resistant, colored-grain lines with testae, 6 mold-resistant, colored-grain lines without testae and with negligible tannin, and 2 susceptible controls. The ISGMN was tested at Farako-Bâ (Burkina Faso), Bhavanisagar and ICRISAT Center (India) in 1985 and 1986, Laguna (Philippines) in 1985, and Ferkessedougou (Côte d'Ivoire), and Dharwad (India) in 1986. Sufficient mold developed on susceptible controls to enable effective evaluation at all these locations. At all the locations, 27 test entries including the six lines without testae (IS 13885, IS 14375, IS 14380, IS 14384, IS 14390, and IS 25070) were resistant. This suggests that mold resistance is stable in these lines.

Ergot (*Sphacelia sorghi*)

The development of ergot, an ovary replacement disease, is closely linked to the flowering of sorghum. A good knowledge of flowering is an essential prerequisite to the study of the disease. Therefore, our studies focused on the flowering behavior of sorghum.

We chose four ICSH 1 panicles and recorded the day when each spikelet flowered to study the pattern of flowering within each panicle. The first spikelet flowered on 1 December 1986 and the time required to complete flowering in the four panicles ranged from 8 to 12 days. Flowering frequency followed a near-normal curve with peak flowering (20-29%) occurring 4-5 days after the onset of flowering. During peak flowering, as many as 27-33 primary branches in 8-11 nodes had flowering spikelets. Primary branches containing more than 20 spikelets required 3-6 days (mode 4 days) to complete flowering. All spikelets in the top third of the panicles required 4-5 days to complete flowering, and a similar duration was required to complete flowering in all spikelets borne on primary branches in two consecutive nodes in the mid-third section of a panicle.

We also recorded the time of flowering of hermaphrodite spikelets in the four ICSH 1 panicles from 3 to 5 December, 1986, to determine the time of the day when sorghum flowers. We observed five primary branches arising from the same node in each panicle. A spikelet was considered to have flowered when the glume began to open, exposing the stigma and anthers. Flowering began at 0750 and stopped at 1030. Out of the 424 spikelets observed, 327 (77%, range 71-83%) flowered before 0900 and 95 (22%, range 18-27%)

after 0900; two spikelets did not open even after the 3-day observation period. Usually spikelets close on the day of flowering, but 10 spikelets remained open throughout the day and closed the following morning. During the time of flower opening, the temperature was 16–24°C and relative humidity was 32–70%.

Observations from these studies will be used to develop resistance screening techniques and to study host-pathogen interaction.

West Africa

Grain Mold

For the second consecutive year, we assessed the usefulness, in the Northern Guinean zone, of the overhead sprinkler irrigation method developed at ICRISAT Center for grain-mold screening. We compared the effect of sprinkler irrigation and no irrigation in the same experiment in three replications at Farako-Bâ. The irrigated and rainfed plots were the main plots separated by a distance of 14 m. We sowed a tall local cultivar between the main plots. We tested 10 genotypes including two resistant controls in two-row subplots. We started irrigation when the earliest genotype flowered and continued each day for 54 days between 1600 and 1800. During this period the rainfed plots received 225.5 mm of rain and the irrigated plots received an additional 279 mm of water. We randomly selected 10 panicles from each genotype and evaluated them on the basis of TGMR using a scale of 1–5, where 1 = no mold, and 5 = more than 50% grain surface area molded.

Except for one of the control entries, IS 14375, sprinkler irrigation increased TGMR from 11% to 44%. For example, with irrigation, TGMR was 4.1 for ICSV 16-2 BF, 4.7 for 84 S 123, and 4.8 for ICSV 2 IN (SPV 386); the TGMRs for these genotypes without irrigation were 2.3 for ICSV 16-2 BF, 2.9 for 84 S 123, and 2.8 for ICSV 2 IN (SPV 386). We believe that the sprinkler irrigation method assures adequate grain mold development for screening sorghum genotypes in the Northern Guinean zone and may be useful in drier years when rainfall between flowering and maturity is low.

Anthracnose (*Colletotrichum graminicola*)

Inheritance of resistance. Our study on leaf anthracnose at Farako-Bâ consisted of 17 parents known to have a range of disease reactions, 17 F_1 crosses involving these parents (including 3 reciprocals), and 2 F_2 crosses.

The severity of the natural disease incidence was high enough to make evaluations meaningful. There was a dominant resistant reaction; the F_1 plants were resistant if one of their parents was resistant. Disease scores taken over the last 2 years at Farako-Bâ on 400 hybrids produced using cytoplasmic-genetic male-steriles and restorers with known disease reactions supported a similar conclusion.

Grey Leaf Spot (*Cercospora sorghi*)

Disease incidence. Previous observations on several improved and local genotypes indicated that grey leaf spot symptoms first appear during anthesis or shortly thereafter. Infection in the top four leaves progresses slowly until just before physiological maturity. Severe infection occurs when grains are mature. To confirm these observations, we closely studied the progress of grey leaf spot in three susceptible genotypes, ICSV 1001 BF (Framida), ICSV 16-3 BF, and IS 18696 under natural infection conditions at Niangoloko. We monitored the severity of the disease in each of the top four leaves separately on 20 tagged plants from the three central rows of seven-row plots in three replications. We assessed disease severity each week starting at 77 DAS by using a 1–6 scale, where 1 = no symptoms, and 6 = more than 75% leaf area infected. Since infection in each of the top four leaves did not differ much, we combined their mean disease scores and plotted them against DAS.

In the three genotypes studied, grey leaf spot symptoms did not appear on the top four leaves until several DAF. The disease progressed slowly until 30 DAF for ICSV 16-3 BF and IS 18696, and 36 DAF for ICSV 1001 BF (Framida). The development of the disease was more uniform and rapid in IS 18696. At 30 DAF, the severity scores were relatively low, between 2.1 and 3.8 for all three genotypes. The disease became severe only towards physiological maturity (Fig. 6). This pattern of disease development implies that grey leaf spot may not cause serious yield losses. We intend to study this disease in more genotypes and assess the effect of the disease on grain yield.

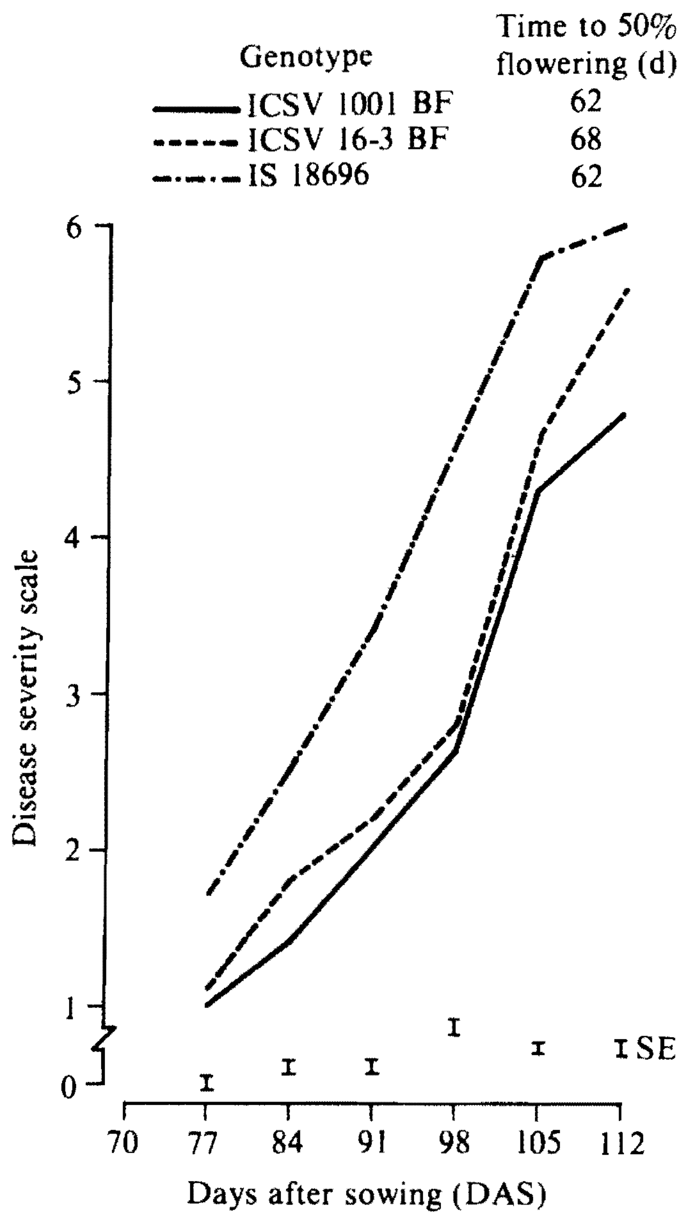


Figure 6. Progress of grey leaf spot disease in the top four leaves from natural inoculum for three genotypes, based on a 1-6 scale, where 1 = no symptoms and 6 = more than 75% leaf area infected, Niangoloko, Burkina Faso, rainy season 1987.

Inheritance of resistance. At Farako-Bâ, we evaluated 15 parents known to exhibit a range of disease reactions to grey leaf spot, 18 F_1 crosses (including 4 reciprocals) involving these parents, and 3 F_2 crosses.

The severity of the natural disease incidence was high enough to make evaluation meaningful. Mean disease scores on the F_1 relative to those of their parents indicated that in general, the susceptible reaction was dominant and that unless both parents were resistant, the F_1 was susceptible.

Southern Africa

Downy Mildew (*Peronosclerospora sorghi*)

Resistance screening. Downy mildew incidence was high enough for screening at three locations in Zimbabwe (Matopos, Henderson, and Panmure) and one in Zambia (Golden Valley). We screened for resistance, 2900 entries at Matopos under artificial conditions, 1200 entries at Henderson, 200 entries at Panmure, and 1000 entries at Golden Valley. Several local commercial varieties were resistant (incidence <5% infected plants) at all locations, as well as Tegemeo (2 LC × 17/B/1), Sandala from Tanzania, ICSV 2 (ZSV 1, SPV 386) from Zambia, SV 1 (M 39335) and SV 2 (A 6460) from Zimbabwe (all white-grained). The commercial hybrids PNR 8311 (red-grained) and PNR 8544 (white-grained) were also resistant in Zambia and Zimbabwe. Serena (Dobbs × P 127) and the commercial hybrid DC 75 (both red-grained) were susceptible (incidence <30% infected plants). All commercial varieties from Botswana and Lesotho, and Red Swazi from Zimbabwe were susceptible at all locations. Twenty-seven out of 28 entries of the International Sorghum Downy Mildew Nursery (ISDMN) were completely free of the disease (3 replications), while the susceptible control had more than 70% infected plants.

Host range. In cooperation with the Department of Research and Specialist Services and Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) in Zimbabwe, eight of the most commonly grown maize cultivars in Zimbabwe were tested as potential hosts of the downy mildew pathogen. All of them became infected after artificial inoculation, both at Matopos and Henderson stations, but spore production was low. The spores from these infected maize plants infected sorghum seedlings.

Leaf Blight (*Exserohilum turciucum*)

Resistance screening. We successfully screened 1200 entries including 640 entries for the second time, at Henderson station under natural infection conditions. The control cultivar ICSV 109 had 80% of the leaf area affected at the mid-dough stage of grain development. Eighty-seven entries were resistant to both leaf blight and downy mildew. Examples of white-grained entries with resistance to leaf blight in the 1986 and 1987 seasons, and downy mildew in 1987 are: (555 × 168)-1-1-1-5 KAD [ICSV 145 (SAR 1) local selection], (555 × 168)-23-1-1-1AK-1KAD, [148 × ICSV 1001 BF (Framida)]-8-1-2-2-2-2-2AK-3KAD, KU 417-19- 4KAD, KU 302- 4KAD, (IS 12611 × SC 108-3)-1-1-3-1KAD), SC 108-3 × CS 3541)-19-1-1-1KAD. Red-grained entries with resistance to leaf blight were 65D and Town from Botswana.

Ergot (*Sphacelia sorghi*)

Infection with macrospore-type conidia and sclerotial germination. With assistance from the Imperial College (UK), we confirmed literature statements that one-year old conidia can cause infection. Infected spikelets produced honeydew 7–15 days after panicle inoculation. Throughout the honeydew phase, macrospore-type conidia were produced.

We found ergot sclerotia at most locations in Malawi, Tanzania, Zambia, and Zimbabwe. In cooperation with Imperial College and the University of Zimbabwe, we stimulated mature ergot sclerotia to germinate over a wide range of temperatures (4–37°C) in the dark. However, the germination percentages were below 10%.

Virus

Virus-like symptoms were observed on sorghum lines grown in Lesotho, Malawi, Swaziland, Tanzania, and Zimbabwe. Symptoms appear primarily on late-sown material in both cool and hot conditions. There were no symptoms on QL 11, in the International Virus Differential Nursery, under uniform severe virus pressure at Golden Valley, Zambia, in 1986 and 1987; but from serological tests it too was found to be infected, indicating that it will be necessary to use serological tests to identify virus-free hosts.

Regional Disease Nurseries

For the first time, a regional disease observation nursery and resistance screening nurseries for downy mildew, leaf blight, rust, and grain mold were grown in the region. Due to the severe drought in most of the region, regional testing for resistance was not very effective. The cooperating national programs incorporated the locally adapted entries in their collections for further screening. Based primarily on results obtained in Zimbabwe, entries were identified for the 1988 regional nurseries.

Eastern Africa

Long Smut (*Tolyposporium ehrenbergii*)

Biology. In a collaborative project with the Kenya Agricultural Research Institute (KARI) on long smut, we began studies on the biology of the causal fungus *Tolyposporium ehrenbergii*, development of resistance screening techniques, and the identification of 'hot spots' for field screening for resistance.

Table 2. Germination of *Tolyposporium ehrenbergii* chlamydospores into sporidia after 60 h on potato dextrose agar medium at different pH levels, laboratory test, Muguga, Kenya, 1987.

pH of medium	Germination (%) At a constant temperature of 30°C
4.0	97.9 (± 2.1)[1]
4.5	100.0 (± 0.0)
5.0	79.1 (± 6.2)
5.5	82.7 (± 5.2)
6.0	94.9 (± 2.9)
6.5	80.0 (± 6.3)
7.0	95.7 (± 3.0)
7.5	81.1 (± 6.4)
8.0	72.6 (± 6.2)

1. Numbers in parentheses are standard errors (SEs).

We investigated the germination of chlamydospores in artificial media under various pH conditions at 30°C (Table 2). We found that chlamydospores germinated better in acid media (optimum pH 4.5) than in alkaline media. We continued our studies on developing a reliable method of inoculating sorghum with long smut and compared the efficiency of sporidia and chlamydospores in causing infection. Eleven sorghum genotypes supplied by the Katumani Research Station, Kenya, were used for these studies. We found that sporidia were a more effective source of inoculum than chlamydospores, with 10 out of the 11 genotypes inoculated with sporidia showing infection. Only 4 of the 11 genotypes inoculated with chlamydospores were infected.

Resistance screening. At Marimanti Research Station, Eastern Province, Kenya, we evaluated a diverse collection of sorghum genotypes introduced from different sources for long smut incidence under natural infection conditions. The following genotypes from ICRISAT Center were highly resistant: IS 18757 (QL3) ICSV 221 (E 35-1 × IS 5604)-4-1-1-2-1, ICSV 212 (FLR 274 × CSV 4)-6-2-1. These will be retested to confirm their resistance. ICSH 153 (CSH 11), a high-yielding hybrid, was highly susceptible.

Ergot

Resistance screening. The collection of sorghum germplasm from Rwanda was received from the Genetic Resources Unit (GRU), ICRISAT Center, and screened at Rubona and Karama Research Stations in collaboration with the Rwandan national program. None of the sorghum genotypes showed high levels of resistance, with the best 10 showing 10-20% infection.

In Ethiopia in collaboration with the national program, 248 genotypes with intermediate and highland adaptation were inoculated with ergot at Arsi Negele Research Station. Forty-eight had less than 10% infected florets, and 27 of these had less than 5% infected florets. ETS 2454, ETS 3135, ETS 3147, ETS 3148, ETS 3286, ETS 3753, ETS 4485, and ETS 4762 were highly resistant with only 1-2% infected florets.

Striga

ICRISAT Center

Striga Seed Germination

Effects of nutrients. Sorghum roots exude stimulants that trigger *Striga asiatica* seed germination. We assessed the effects of N, P, and K on stimulant production by sorghum. We grew plants of the host cultivar Swarna in sterile sand with nutrient solutions for one week and collected the root leachates. The experiment was a 2×2×2 factorial design consisting of 0 and 50 mg N L^{-1}, 0 and 50 mg K L^{-1} and 0 and 25 mg P L^{-1}. We treated *Striga* seeds preconditioned by keeping them moist at 28-30°C for 10 days with the leachates and determined percentage germination to assess stimulant production (Table 3). A N×K interaction affected stimulant production. The presence of N considerably reduced stimulant production whereas K promoted stimulant

Table 3. *Striga asiatica* seed germination (%) in different N,P, and K treatments, laboratory test, ICRISAT Center, 1987.

Treatment	K_0[1]			K_{50}			Overall mean
	P_0	P_{25}	Mean	P_0	P_{25}	Mean	
N_0	41.2(±1.7)[2]	44.1(±2.3)	42.6	60.1(±2.4)	55.7(±2.2)	57.9	50.2
N_{50}	8.5(±1.0)	9.7(±1.3)	9.1	10.5(±0.9)	11.2(±1.2)	10.8	9.9
Mean	24.8	26.9	25.8	35.3	33.4	34.3	30.0

1. Subscripts indicate concentration of N, P, or K in mg L^{-1}.
2. Numbers in parantheses are standard errors (SEs).

production in the absence of N. Phosphorus levels, however, had little effect on stimulant production.

Effects of soil moisture. We buried *Striga* seeds sandwiched between glass fibre filter paper discs in two concentric circles, around pregerminated sorghum seed in an Alfisol. Mean *Striga* seed germination was 0 at 7% soil moisture, it was 43% at 10% soil moisture, and 34% at 16% soil moisture. *Striga* seed germination was higher in the inner circle (33%) than in the outer circle (19%). Stimulant production and its diffusion through soil may be retarded by low soil moisture, resulting in low *Striga* germination.

Manipulation of field operations and practices to promote *Striga* infestation and uniformity. We have observed *S. asiatica* infestations at ICRISAT Center to be highly variable from season to season and even from area to area within the same field, which makes it difficult to effectively and reliably screen sorghum germplasm and breeding lines for resistance. We manipulated several field operations and management practices reported to promote *Striga* emergence and establishment in a 1-ha low fertility, Vertisol field previously observed to have low and variable *S. asiatica* infestation. We rototilled the field to a depth of 3 inches at the beginning of the summer season in the last week of January 1987, and artificially infested the top soil of 75% of the field with one-year-old *S. asiatica* seeds. We sprinkle-irrigated the field at the beginning of May and kept it continually wet until mid-May when the whole field was sown in alternate strips with CSH 1, a *S. asiatica*-susceptible hybrid and ICSV 145 (SAR 1), a *S. asiatica*-resistant variety. We did not apply any fertilizer to the field. After 4 weeks of crop growth, we observed high levels of *Striga* infestation on CSH 1, the susceptible genotype that was wilted and stunted. We did not observe *Striga* plants on CSH 1 in the portion of the field that was not infested with *S. asiatica* seeds. We counted an average of 297 emerged and established *S. asiatica* plants per 2.1 m^2 on *Striga*-infested CSH 1. *Striga* infestation delayed time to 50% flowering of CSH 1 by 19%, reduced plant height by 32%, and decreased grain yield by 49%. We observed no *Striga* on ICSV 145 (SAR 1), the *Striga*-resistant variety anywhere in the field and its growth was normal. Preliminary indications are that manipulation of field operations and practices significantly increased *Striga* infestation and uniformity in the field. In 2.1 m^2 plots, *Striga* emergence in 1985 averaged 16 and in 1986, 54 plants $plot^{-1}$. These field operations and practices will be repeated in 1988 for confirmation.

Breeding for Resistance to *Striga asiatica*

We yield-tested 10 advanced breeding lines in an advance *Striga* trial, 25 in a preliminary *Striga* trial and 208 in a *Striga* observation nursery during the rainy season 1987 in *Striga*-sick fields at ICRISAT Center and Akola in India. *Striga* *asiatica* infestation was uniform and high at Akola but not at ICRISAT Center. Based on data from Akola, we selected three lines (ICSV 697, ICSV 760, and ICSV 761) from the advanced *Striga* trial and three lines (ICSV 840, ICSV 841, and ICSV 842) from the preliminary *Striga* trial, with less than 2 emerged *Striga* plants per 2.1 m^2 compared with 47 for CSH 1. The selected varieties gave yields of 2.1–2.3 t ha^{-1} in the advanced trial and 2.2–3.2 t ha^{-1} in the preliminary trial compared to ICSV 145, which gave 1.9 t ha^{-1}, in the advanced trial and 2.2 t ha^{-1} in the preliminary trial. From the *Striga* observation nursery, we selected 78 lines with less than 6 emerged *Striga* plants per 2.1 m^2 compared to 63 emerged *Striga* plants per 2.1 m^2 for CSH 1. We screened 965 F_2-F_6 progenies and selected 344 individual plant or bulk selections for further testing; we also screened 335 low-stimulant producers and selected 22 low-stimulant genotypes for further testing.

We formed a sorghum population involving improved lines with high yield potential and sources of resistance to *Striga asiatica* into it, and completed the first cycle of random mating. The population will be improved by recurrent selection.

West Africa

Striga hermonthica

Resistance screening. The pot experiments we conducted in 1985 and 1986 (ICRISAT Annual Reports 1985, p. 41–42 and 1986, p. 33), enabled us to select eight cultivars for further testing in 1987. We tested them in pots at Kamboinsé and in *Striga*-infested farmers' fields near Farako-Bâ. They were also evaluated for grain yield in the absence of *Striga* at Farako-Bâ station. One resistant control, ICSV 1001 BF (Framida), and two susceptible controls, S 29 in field and CK 60B in pots were used. Five of the test entries, IS 7777, IS 6961, IS 7739, IS 14825, and IS 14928 were superior to ICSV 1001 BF (Framida) in resistance and IS 8140 and IS 16184 were comparable to ICSV 1001 BF (Framida) (Table 4). IS 7777 and IS 7739 were highly photoperiod-sensitive and did not flower. Over the three trials, ICSV 1001 BF (Framida) produced the highest average yield (1.84 t ha^{-1}). Other resistant varieties with high grain yields were IS 14928 (1.32 t ha^{-1}) and IS 14825 (1.31 t ha^{-1}). The susceptible cultivar, S 29 produced 1.09 t ha^{-1}.

Control. In 1986, we used the spreading-type groundnut cultivar 59–426 to study the effect of soil shading on *Striga* infection. This year, we confirmed our earlier observations that groundnut, when used as a soil cover, suppresses *Striga*. We grew two sorghum genotypes, ISCV 1 BF (E 35-1) and ICSV 1001 BF (Framida) with and without groundnut at three sites in farmers' fields near Farako-Bâ in a 4 × 4 latin-square design.

At every location, the *Striga* infestation on sorghum was less in plots with groundnuts than in plots without. The reduction in the number of *Striga* plants was more than 50% in several cases. In most cases, the soil temperature was lower in plots with groundnuts but the differences rarely exceeded 1° C. Differences in soil moisture were also small with no obvious pattern between treatments. These results suggest that groundnut as a cover crop in association with sorghum suppresses *Striga*. Soil temperature and moisture do not adequately explain this suppression phenomenon.

Southern Africa

We recognize that both *S. asiatica* and *S. forbesii* are economic pests of sorghum in the SADCC area. We observed *S. forbesii* around KweKwe (Zimbabwe) and around Ilonga (Tanzania). We carried out screening and biosystematic studies and found that *S. forbesii* is self-pollinating. Using a modified checkerboard design with one year of testing, we found that SAR 19, SAR 22, and SAR 23 are resistant to *S. forbesii*, while SAR 34, SAR 26, PMC, Red Swazi, Radar, and ICSV 1001 BF (Framida) are not.

In cooperative studies with the National Program at Sebele, Botswana, we screened for

Table 4. Agronomic performance of *Striga* resistance of a few selected low-stimulant sorghum cultivars in Farako-Bâ (FB) and Kamboinsé (KB); Burkina Faso, rainy season 1987.[1]

	Grain yield (t ha^{-1})						Number of *Striga* plants	
Cultivar	FB (Station)	FB 1 (*Striga*)	FB 2 (*Striga*)	Mean	Time to 50% flowering (d)	Plant height (m)	FB 1 (*Striga*)	KB (Pots)
IS 7777[2]							1(0.18)[3]	0
IS 6961	0.91	0.53	0.49	0.65	79	3.34	1(0.27)	2(0.42)
IS 7739[2]							2(0.40)	5(0.55)
IS 14825	2.04	1.11	0.78	1.31	74	3.46	6(0.73)	3(0.44)
IS 14928	2.26	0.86	0.84	1.32	73	3.50	7(0.70)	6(0.71)
IS 8140	2.32	0.99	0.96	1.42	64	1.99	20(1.28)	11(1.00)
IS 16184	2.62	0.91	0.81	1.45	67	1.83	34(1.33)	6(0.68)
Controls								
ICSV 1001 BF (Framida) (Resistant)	3.03	1.56	0.93	1.84	71	2.23	31(1.41)	21(1.14)
S 29 (Susceptible)[4]	1.61	0.97	0.70	1.09	70	3.88	212(2.31)	
CK60B (Susceptible)[5]								44(1.58)
SE	±0.25	±0.23	±0.14		±0.7	±(0.18)	±(0.11)	
Mean (12 entries)	1.67	1.11	0.86		73	3.11	(1.00)	(0.82)
CV %	30	41	40	2	5	36	(42)	

1. Randomized complete block design with 4 replications for FB (Station) and FB 1 (*Striga*), and 6 replications for FB 2, plot size 8 m^2. Ten replications in pots for test of *Striga* resistance.
2. Did not flower (highly photosensitive).
3. Values in parentheses are log (x + 1.1) transformations.
4. S 29 used in fields at Farako Bâ.
5. CK 60B used in pots at Kamboinsé.

resistance to *S. asiatica* in field and pot experiments. By using a split-plot design with 8 sorghum lines as subplots and 3 *Striga* accessions as main plots, SAR 16, SAR 19, and SAR 35 were found to have resistance to *S. asiatica*. There appeared to be a significant difference in the virulence among the three *Striga* samples.

Insect Pests

ICRISAT Center

Shoot Fly (*Atherigona soccata*)

Bioecology. In the initial studies on insect-host-plant environment interaction, we found that newly hatched shoot fly larvae survived for less than 30 min on dry petri dishes or filter paper but lived for over 24 h on slightly wet surfaces. In further tests, we found that moisture exclusion in the whorl and leaves of sorghum (measured on a 1–5 scale at 0600 as leaf surface wetness and water droplet accumulation in the spindle leaf) varied between resistant (IS 2146) and susceptible (CSH 1) cultivars and with crop age (Fig. 7).

We then monitored larval movement towards the growing point after egg hatch. Larvae moved faster towards the growing point and produced deadhearts much earlier at all crop ages (5, 10, and 14 days) in suceptible CSH 1 than in resistant IS 2146. Larvae also moved faster in 10-day old plants, with higher leaf surface wetness (Fig.

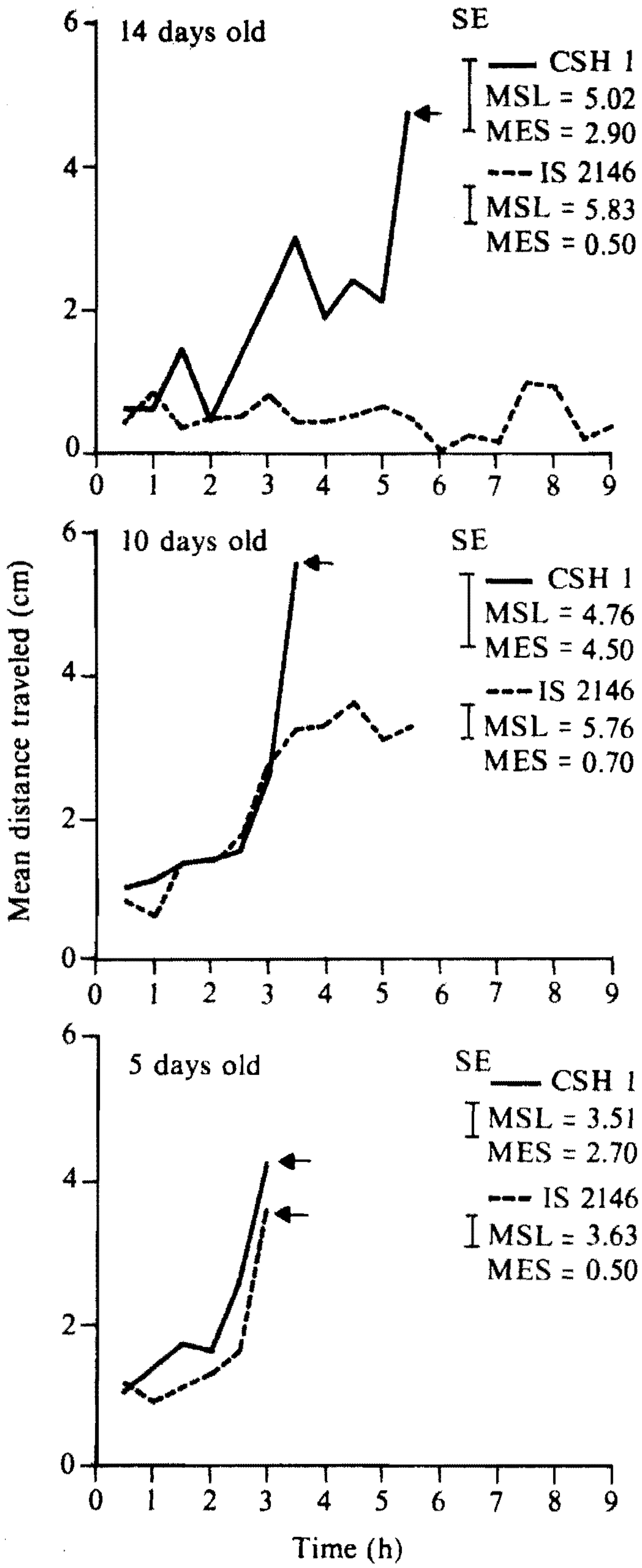


Figure 7. Shoot fly larval movement in the stem of a sorghum seedling in relation to cultivar and crop age. (Arrows indicate larval arrival at growing apex; MSL = Mean stem length (cm), MES = Moisture exclusion score).

7) but moved the slowest in 14-day old plants. They, however, arrived much earlier at the growing point (<3 h) and produced deadhearts much sooner in 5-day old plants than in 10-or 14-day old plants due to shorter stem length.

These studies indicate that moisture exclusion in relation to crop age and cultivars is reflected in shoot fly larval behavior and subsequent deadheart formation.

Screening for resistance. In preliminary screening, we evaluated 275 B and R lines and retained 3 lines for further testing. In an advanced screening of 180 lines (ICRISAT Annual Report 1986, p.34), 22 lines were selected for confirmation of shoot fly resistance.

In a large-plot (180 m^2), demonstration of resistance to shoot fly in cultivated sorghum, we recorded 25–30% deadhearts in resistant genotype IS 18551 compared with 95–100% in susceptible CSH 1. We also compared the shoot fly resistance screening technique under no-choice conditions using field cages (ICRISAT Annual Report 1984, p.30) and plastic tray cages. While both techniques gave similar results, plastic tray cages have the advantage of easy handling and low labor input.

Introgression of useful genes from wild sorghum relatives. The F_2 and BC_1F_1 seed arising from crosses between parasorghums [IS 14262, IS 14275, IS 18938, and IS 18945 that were found to have high levels of resistance to shoot fly (ICRISAT Annual Report 1986, p.34)] and adapted sorghum (IS 2146) were sown in the rainy season and studied for fertility. A major proportion of the segregating plants resembled the cultivated parent. A few plants of the wild parental type were recovered (Fig. 8). The intermediates showed a wide variation ranging from cultivated to wild parental types. The plants also showed varying degrees of sterility. The intermediates will be evaluated for shoot fly resistance during the next rainy season.

Breeding for resistance. We completed 6 cycles of mass selection for shoot fly resistance in our shoot-pest resistant population, ICSP 118 (ICRI-

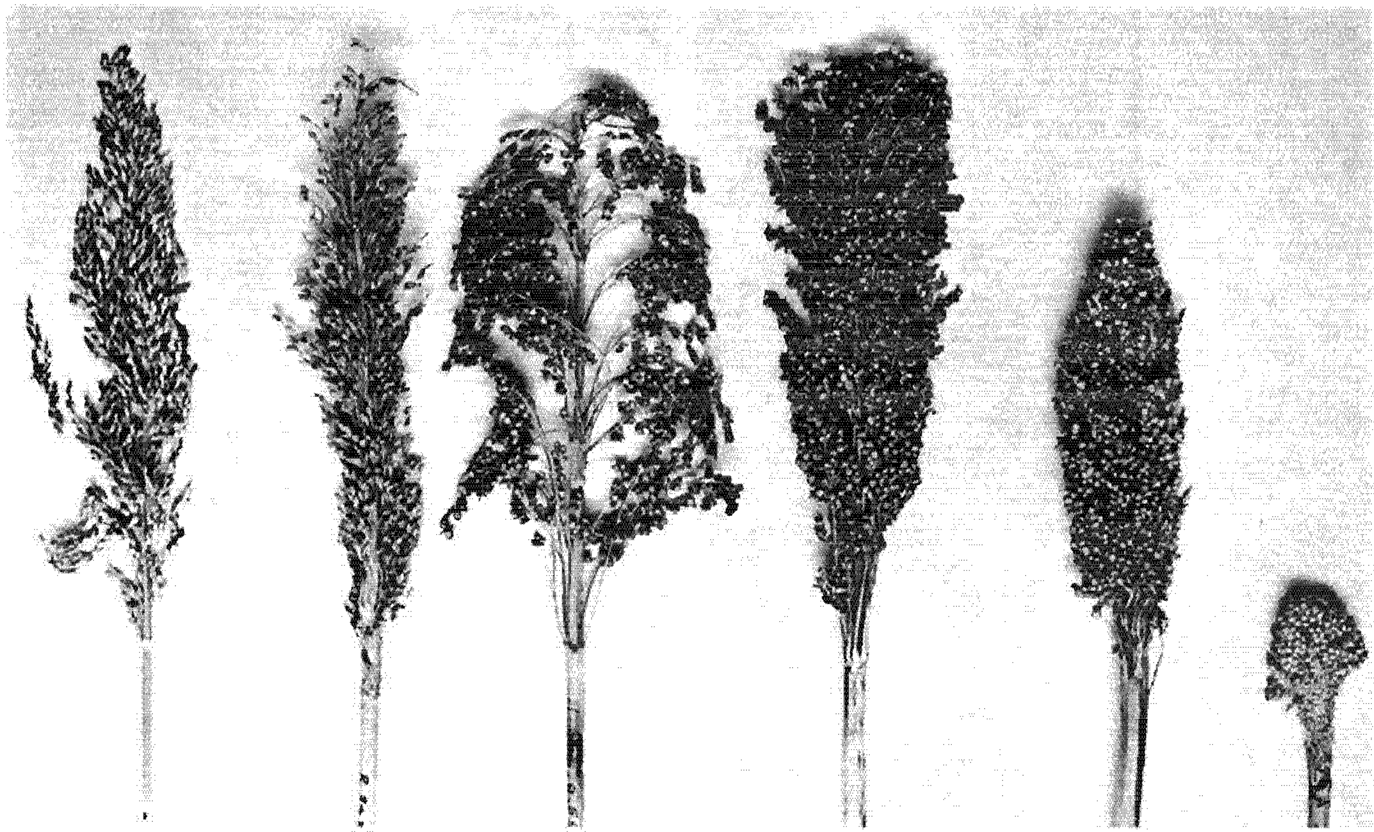


Figure 8. Variation in the F_2 segregants of a cross between wild parasorghum *Sorghum dimidiatum*, IS 18945, and adapted cultivar IS 2146. This cross was made to transfer shoot fly resistance genes from wild to cultivated sorghums.

SAT Annual Report 1986, p.36). We evaluated the 6 cycles of ICSP 1 18 for resistance to shoot fly during the 1987/88 postrainy season at ICRISAT Center to estimate progress made under mass selection. We observed a decrease in the percentage of shoot fly deadhearts from Cycle 1 (71.2) to Cycle 6 (58.5), i.e., a reduction of 18%. The percentage of shoot fly deadhearts were 49.1% in the resistant control (IS 18551) and 81.4% in the susceptible control (CSH 1).

We screened 314 F_3 and 118 F_4 progenies for shoot fly resistance during the postrainy season 1987/88. Of these, we selected 51 F_3 and 58 F_4 progenies for further testing. We evaluated 61 advanced shoot fly resistant breeding lines for yield and agronomic eliteness during the rainy season and for shoot fly resistance during the postrainy season at ICRISAT Center and selected 3 lines, ICSV 702, ICSV 705, and ICSV 708 with good yield and resistance to shoot fly.

Stem Borer (*Chilo partellus*)

Yield loss assessment. In a yield loss assessment trial at Hisar, India, under natural infestation, no grain yield was obtained in zero protection treatment as against about 4 t ha^{-1} under intensive protection for stem borer control (carbofuran granules in leaf whorls at 15, 25, 35, and 45 DAE at a rate of 0.75 kg a.i. ha^{-1} each time). There was a linear relationship (with negative slope) between stem borer damage (deadhearts) and grain yield.

We obtained differential stem tunneling using stem cages (Fig. 9) by releasing different numbers of 10-day old stem borer larvae into the cages. Infestation with 1 larva $plant^{-1}$, either 35 or 45 DAE gave the lowest success in infestation (70%) while at 4 larvae $plant^{-1}$, we obtained 100% infestation (Table 5). The length of stem tunnels increased with increase in larval number and

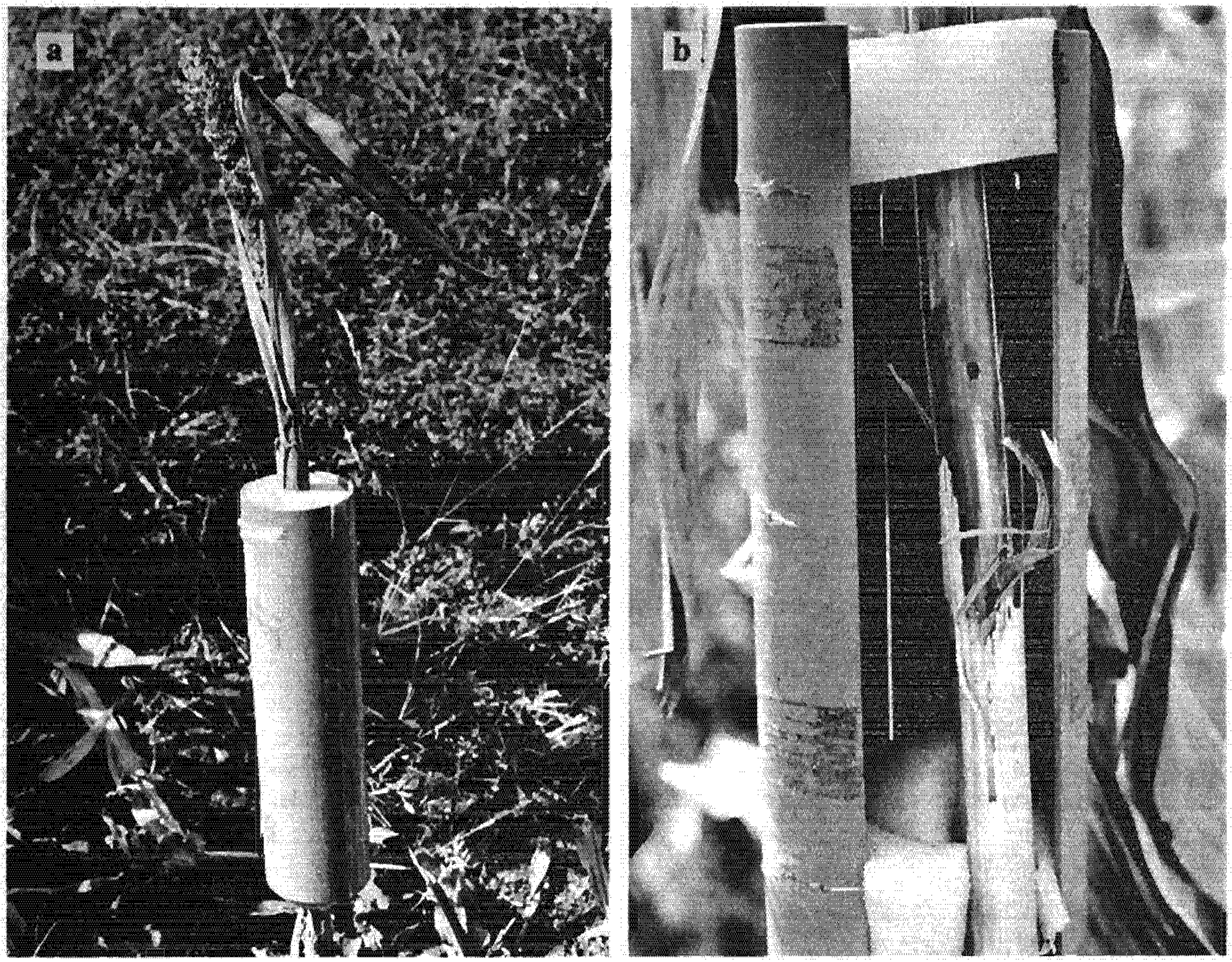


Figure 9a. Stem-cage made from PVC pipe used at ICRISAT Center to obtain differential stem tunneling in borer infestation. b. Stem damage inside cage.

number of infestations. First instar larvae were unable to establish in the stem.

Resistance screening. In preliminary screening for stem borer resistance, 234 breeding and 3400 germplasm lines were evaluated at Hisar and 50 lines were selected for further testing. Two hundred and fifty-three genotypes were evaluated under artificial infestation at ICRISAT Center, and under natural infestation at Hisar, and 100 of these were retained for confirmation.

We observed ovipositional nonpreference as a mechanism of stem borer resistance under natural infestation at Hisar, where minimum egg laying was recorded on resistant genotypes IS 8811 (14 egg masses per 50 plants) compared to susceptible CSH 1 (110 egg masses per 50 plants).

Breeding for resistance. The shoot-pest resistant population, ICSP 118 was also evaluated for resistance to stem borers under natural infestation at Hisar, and under artificial infestation at ICRISAT Center during the 1987 rainy season. There was no significant decrease in the percentage of stem borer deadhearts from Cycle 1 to 3 and a slight decrease from Cycle 4 to 6 under natural infestation but there was an increase in the percentage from Cycle 1 to 6 under artificial

Table 5. Effect of releasing 10-day old stem borer larvae in stem cages on infestation, tunneling, and grain yield of sorghum, ICRISAT Center, rainy season 1987.

Infestation stage (DAE)[1]	No. of larvae plant^{-1} 1	2	4	8	Mean
Infestation (%)					
35	70	75	100	100	86.3
45	70	95	90	90	86.3
55	80	80	100	100	90.0
35 and 45	95	100	100	100	98.8
45 and 55	75	95	100	90	90.0
35,45, and 55	100	100	100	100	100.0
SE				±2.3	
Mean	81.7	90.0	98.3	96.7	
CV (%)				10	
Total stem tunnel length (cm plant^{-1})					
35	11.1	9.3	11.5	16.9	12.2
45	4.7	9.0	20.1	17.8	12.9
55	14.3	16.1	20.7	25.8	19.2
35 and 45	15.9	15.5	18.7	25.9	19.0
45 and 55	15.3	19.2	24.6	35.7	23.7
35, 45, and 55	16.5	23.2	39.1	37.8	29.2
SE				±1.3	
Mean	13.0	15.4	22.5	26.7	
CV (%)				28	

1. DAE = Days after crop emergence.

infestation. The percentage of stem borer deadhearts of ICSP 118 in Cycle 6 was 63.3% under natural infestation compared to 16.6% for IS 2205 and 96.1% for CSH 1. We believe that mass selection for stem borer resistance is not effective and will therefore use the S_2 recurrent selection method in an attempt to improve stem borer resistance in ICSP 118.

We also screened 11 F_4 progenies for stem borer resistance under natural infestation at Hisar and artificial infestation at ICRISAT Center during the 1987 rainy season and selected 9 progenies with resistance to stem borer under both natural and artificial infestation.

Sorghum Midge (*Contarinia sorghicola*)

Biology. We studied the life cycle of sorghum midge on 14 resistant and one susceptible genotypes under field conditions. We caged five panicles of each genotype with 40 midges panicle^{-1} for 2 consecutive days and recorded midge emergence pattern, days to complete postembryonic development, and the number of midges emerging panicle^{-1}. The developmental period was prolonged by 5–8 days on IS 10712, IS 19474, IS 19512, ICSV 830, ICSV 831, ICSV 197 (PM 11344), and TAM 2566. Midge emergence was lower (<100 midges panicle^{-1}) on IS 9807, IS 19474, ICSV 830, ICSV 831, ICSV 832, ICSV 197 (PM 11344), and DJ 6514 compared to 640 midges panicle^{-1} recorded on susceptible control CSH 1 (Table 6).

Resistance screening. We screened 2004 germplasm and breeding lines for resistance at Dharwad, India, and selected 28 germplasm accessions, 28 breeding lines, and 111 population breeding lines. In multilocational testing of 83 germplasm and breeding lines under natural and head-cage conditions at ICRISAT Center and Dharwad, we selected 72 lines with high levels of resistance (damage rating <3).

Breeding for resistance. We completed 6 cycles of mass selection for midge resistance in the head-pest resistant sorghum population ICSP 117 (ICRISAT Annual Report 1986, p.38). We evaluated the 6 cycles of ICSP 117 for resistance to midge under natural infestation during the rainy season 1987 at Dharwad, to estimate progress made under mass selection. We observed a significant decrease in the percentage of chaffy florets from 72.1% in Cycle 1 to 27.4% in Cycle 3, but a slight increase after Cycle 4. The percentage of chaffy florets in ICSP 117 Cycle 6 was 31.5% compared to 6.6% for the resistant control, ICSV 197 (PM 11344), and 56.5% for the susceptible control CSH 1.

We produced 210 hybrids between midge-susceptible female parents and midge-resistant male parents and evaluated them for yield at ICRISAT Center and for midge resistance at

Table 6. Biology and adult emergence pattern of sorghum midge (*Contarinia sorghicola*) on 15 sorghum cultivars ICRISAT Center, postrainy season 1986/87.

Cultivar	No. of midges emerged panicle^{-1} d^{-1} (days after infestation)																		No. of midges emerged panicle^{-1}	Postembryonic development period (d)
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
IS 3461									85	25	7	5	4	2					128	25.6 (±1.12)[1]
IS 7005									82	75	20	6	7	5	3				198	26.0 (±1.31)
IS 8571									43	66	29	7	5	4	4	4			160	26.4 (±1.60)
IS 8721					75	50	61	99	40	44	33	27	21						450	24.0 (±2.30)
IS 9807									25	21	2	5	3	4					60	26.0 (±1.50)
IS 10712									23	19	32	33	1	1	3	2	2	2	118	27.0 (±1.88)
IS 19474										20	31	16	12	2	2	3	3	6	98	27.0 (±2.26)
IS 19512											82	32	10	4	5	1	1		135	27.0 (±1.16)
ICSV 830										5	9	3	2	2	3	3			27	27.3 (±2.03)
ICSV 831					1							1	4	9	1	1	1	3	20	30.0 (±2.51)
ICSV 832	10	4	7	2	11	6	4												44	18.0 (±2.03)
ICSV 197 (PM 11344)												5	9	1	2	1	3	5	26	30.5 (±2.27)
DJ 6514				3	1	3	5	3	2	6									23	23.0 (±2.01)
TAM 2566								22	19	4	4	29	26	22	22				148	28.0 (±2.39)
Control CSH 1				139		86	98	64	100		46	47	25	27	6	1	1		640	22.0 (±2.43)

1. Numbers in parentheses are standard errors (SEs).

Dharwad. We selected 2 hybrids (ICSH 889 and ICSH 890) that yielded well and were resistant to midge (less than 25% chaffy florets compared to 80% for CSH 1). We identified two midge-resistant male parents (ICSV 833 and ICSV 834) to be nonrestorers and these will be converted to male-steriles. We also evaluated 130 advanced midge-resistant breeding lines for yield at ICRISAT Center and midge resistance at Dharwad, during the 1987 rainy season. We selected 34 midge-resistant lines with high yield potential. ICSV 745 and ICSV 758 were the most productive (> 4.0 ha^{-1}) midge-resistant lines.

Stability of resistance. We studied the stability of resistance to sorghum midge under no-choice conditions for four seasons. Five panicles were infested in each replication with 40 midges for 2 consecutive days under head cages. Data were collected on the percentage of florets damaged by midge. Cultivars IS 3461, IS 7005, IS 8571, IS 9807, IS 10712, IS 19474, ICSV 830, ICSV 831, ICSV 832, ICSV 197 (PM 11344), and DJ 6514 suffered <25% midge damage over four seasons compared to 87.7% in the susceptible control CSH 1. DJ 6514 with 9.8% and ICSV 197 (PM 11344) with 11.5% midge damage were found to be the most stable cultivars.

Head Bug (*Calocoris angustatus*)

Yield loss assessment. We evaluated the effect of different levels of head-bug infestation on grain yield in the susceptible sorghum hybrid CSH 5 at four stages of panicle development (half anthesis, postanthesis, milk, and dough). Plots were sprayed with carbaryl (1 kg a.i. ha^{-1}) in eight different combinations of protection at the four stages of panicle development. Head bug numbers were recorded in 10 randomly-selected panicles in each plot 24 h before, and 24 h after spraying.

Plots protected at all four stages of panicle development yielded 2.63 t ha^{-1} compared to 1.08 t ha^{-1} in the unprotected plots. Head bugs inflicted 59% avoidable losses in grain yield. Plots protected at half-anthesis and/or postanthesis and milk stages suffered a loss of 19% in grain yield. However, plots that were not protected at these stages suffered 34–56% loss in grain yield.

Regression of head bug numbers at half-anthesis (x_1), postanthesis (x_2), milk (x_3), and dough (x_4) stages on grain yield (y) explained 93.7% of the variation ($y=3652-156.5x_1-83.4x_2+9.4x_3-55.7x_4$). An infestation of one head bug $panicle^{-1}$ at all stages of panicle development would result in a loss of 286 kg ha^{-1}. Based on cost of control and the present market value of the grain, head bug numbers of 0.5–1 $panicle^{-1}$ would constitute the economic injury level for this insect and warrant control measures.

West Africa

Head Bug (*Eurystylus* spp)

Resistance screening. We evaluated 30 sorghum cultivars, including controls, selected as less susceptible to head bugs (*Eurystylus* spp) from the breeding trials in 1985 (in Mali) and 1986 (in Burkina Faso) at two sowing dates and in two locations, Kamboinsé and Farako-Bâ. In each plot, two adjacent panicles were individually caged after complete anthesis. Twenty pairs of adult bugs were released into one cage while the second cage had no insects and served as a control. Twenty days after the release of bugs into the cages, we opened the cages to count the total number of bugs including nymphs. After harvest, 100 grains were weighed from panicles with and without head bugs. Seven entries were found to be later flowering than the rest and were therefore excluded from the analysis. At Farako-Bâ, head bug population pressure was too low, so we did not consider that location.

The head bug population counts in cages and 100-grain masses, e.g., with and without head bugs, on some selected sorghum cultivars are shown in (Table 7). The head bug counts in cages were least in the resistant control, Malisor 84-7. The reduction in 100-grain mass due to head bug attack was least in ICSV 2 BF (SPV 35). ICSV 16-5 BF was moderately resistant when both criteria were considered and had the highest yield (2.10 t ha^{-1}). ICSV 1147 BF supported the highest population buildup and suffered the maximum loss in 100-grain mass.

Southern Africa

Pest Surveys

We assessed the relative importance of the different insect pests of sorghum in Malawi, Tanzania, Zambia, and Zimbabwe. *Chilo partellus*, *Atherigona soccata*, and aphids (*Melanaphis sacchari*, *Rhopalosiphum maidis*) were found to be the predominant species. *Sitotroga cerealella*, *Sitophilus zeamais*, and *Sitophilus oryzae* were the most important storage insects. Studies on their distribution and damage severity are in progress.

Shoot fly (*Atherigona soccata*)

Biology. Shoot fly in the SADCC region is a problem only in late-sown sorghum. We monitored shoot fly populations at Matopos using fishmeal traps developed at ICRISAT Center (ICRISAT Annual Report 1982, p.20). Trap catches were high in March (up to 80 d^{-1}) but the population declined rapidly in April and was zero in May.

International Sorghum Shoot Fly Nursery (ISSFN)

We sowed the ISSFN in Tanzania (Gairo), Zambia (Golden Valley), and Zimbabwe (Aisleby and Panmure). The best entries across locations were PS 28062, PS 31388-2, and PS 31405-5.

Table 7. Build up of head bugs (*Eurystylus* spp) within cages, and their effect on 100-grain mass of selected sorghum cultivars, Kamboinsé, Burkina Faso, rainy season 1987[1].

	No. of head bugs in cages[2]			100-grain mass (g) HB(+)[3]			HB(-)[3]		
Cultivar	KB 1	KB 2	Mean	KB 1	KB 2	Mean	KB 1	KB 2	Mean
ICSV 1063 BF	54 (7.2)	67 (8.1)	61 (7.7)	1.63	1.57	1.60	1.88	1.79	1.84
ICSV 7-1 BF	52 (7.2)	77 (8.5)	65 (7.8)	1.41	1.23	1.32	1.68	1.53	1.61
ICSV 1122 BF	63 (7.9)	64 (7.9)	64 (7.9)	1.26	1.21	1.24	1.75	1.79	1.77
ICSV 2 BF (SPV 35)	89 (9.2)	47 (6.9)	68 (8.1)	1.41	1.27	1.34	1.65	1.48	1.57
ICSV 1001 BF (Framida)	91 (9.2)	57 (7.5)	74 (8.4)	1.75	1.26	1.51	2.83	2.05	2.27
ICSV 16-5 BF	110 (9.3)	119(10.4)	115 (9.8)	2.14	1.63	1.89	2.48	2.05	2.27
ICSV 1147 BF	155(12.4)	147(11.8)	151(12.1)	1.41	1.17	1.29	2.41	1.60	2.01
Controls									
Malisor 84-7 (Resistant)	51 (7.1)	52 (7.2)	52 (7.2)	1.07	1.44	1.26	1.61	1.53	1.57
Local variety[4]	-	46 (6.8)		1.34	-	1.70			
SE	(±1.8)	(±1.3)		±0.19	±0.18		±0.31	±0.25	
Mean (22 for KB 1) (23 for KB 2)	(10.7)	(9.2)		1.59	1.42	1.51	2.12	1.79	1.96
CV (%)	(28)	(23)		21	21	26	24		

1. Randomized complete block design with 3 replications, plot size 7.5 m^2.
2. KB 1 was sown on 25 June and KB 2 on 8 July 1987. Values in parentheses are square root transformations.
3. HB(+) = with head bugs; HB(-) = without head bugs.
4. Did not establish in KB 1.

Stem Borer (*Chilo partellus*)

Yield loss assessment. We evaluated grain yield loss due to *Chilo partellus* using the methodology developed at ICRISAT Center (ICRISAT Annual Report 1985, p. 43). Two varieties, Red Swazi and Segaolane were used in this study. Results obtained from trials sown during rainy and dry (with irrigation) seasons indicated that stem borer attack occurring 25-35 DAE was the most severe. Yield losses of 43% on Segaolane and 30% on Red Swazi were recorded during the rainy season.

Insect rearing. We successfully transferred to SADCC/ICRISAT and the Department of Research and Specialist Services in Zimbabwe, the mass rearing technique developed at ICRISAT Center for *C. partellus* (ICRISAT Annual Report 1982, p. 23 ; 1983, p. 30) and modified it to suit local conditions. Three generations were successfully reared with a larvae-to-adults output of about 65% and male to female ratio of 1:1.

Screening for resistance. We evaluated the SADCC/ICRISAT disease nursery containing 1200 entries from the SADCC region at Aisleby in Zimbabwe for stem borer resistance under heavy stem borer pressure. Forty entries were selected for further testing.

International Sorghum Stem Borer Nursery (ISSBN)

Of the five locations, Ilonga in Tanzania, Golden Valley in Zambia, and Aisleby, Panmure, and Mzarabani in Zimbabwe, where the ISSBN was sown, acceptable results were obtained only from Aisleby and Mzarabani. Out of 25 entries, we selected 4 (IS 4776, IS 12308, IS 22039, and PB 10306) with less than 50% stem-borer infestation.

Central America, Mexico, and the Caribbean

Sugarcane Borer (*Diatraea saccharalis*)

We artificially infested the ISSBN sent by ICRISAT Center with 16-19 larvae of *Diatraea saccharalis* per plant at 25 DAS. On a scale of 1-10 where 1 is resistant and 10 is most susceptible, we scored line IS-23411 as 3.6 and lines IS 4757, ICSV 1 (CSV 11), IS 5619, IS 5585, IS 18579, IS 18580, and IS 13100 with an average score of 4.3. We scored the local control, ISIAP Dorado, which is noted for good stem borer tolerance as 5.0. The average score of all 25 entries in the trial was 4.7.

Plant Improvement

ICRISAT Center

Photoperiod-sensitive Landrace Conversion

We continued the conversion of Kaura, Guineense, and Farafara landraces from Nigeria (ICRISAT Annual Report 1986, p.40-41). We evaluated 24 first backcross (BC_1F_2) segregating progenies involving 4 Kaura and 2 Guineense landraces, and 27 F_2 segregating progenies involving 1 Guineense and 8 Farafara landraces during the 1987 rainy season at ICRISAT Center. We identified desirable dwarf and early day-neutral F_2 progenies that we backcrossed to their respective landraces during the 1987/88 postrainy season to complete the second and first backcrosses.

We also initiated conversion of five landraces (3 Durra-Caudatums: IS 29017, IS 29018, IS 29027; IS 29054, and 2 Durras: IS 29054, IS 29102) from the Yemen Arab Republic. These landraces, which are tall and photoperiod-sensitive, have desirable large panicles with bold white or yellow grains, good food quality, and a fair degree of tolerance to drought. We crossed the five landraces to three dwarf and early, day-neutral genotypes (IS 10513, IS 18729, and IS 10927) during the 1986/87 postrainy season and raised their F_1s during the 1987 summer season. Because these F_1s were photoperiod-sensitive, we covered the F_1 seedlings with black polythene bags when they were 15-days old from 1630 to 0830 continuously for a period of 3 weeks to induce flowering. We evaluated their F_2 progenies during the 1987 rainy season and identified desirable dwarf, early, day-neutral F_2 progenies that we backcrossed to their respective landraces during the 1987/88 postrainy season to complete the first backcross.

Multifactor-resistant Populations (MFR)

We merged R/MFR and B/MFR population-base materials to form a broadbased BR population from which we will derive two populations; ICSP 1 BR/MFR and ICSP 2 BR/MFR that we will improve for rainy-season adaptation. This was done because we did not have sufficient diverse, improved, nonrestorer lines with stable resistances to grain molds, shoot fly, stem borer, midge, and *Striga* to be able to form broadbased nonrestorer (B) populations. The BR/MFR population-base material (ICRISAT Annual Report 1986, p.41) remains unchanged and will henceforth become ICSP 3 BR/MFR and will be improved for postrainy-season adaptation. Because of these changes, we will only composite three broadbased populations and not five as reported in ICRISAT Annual Report 1984 (p.40).

Merging R/MFR and B/MFR population-base material. We separately intermated R/MFR and B/MFR population-base materials during the 1986/87 postrainy season and introduced additional sources of resistance to shoot fly, stem borer, midge, and *Striga asistica*, ability to emerge through a soil crust, and lines with high-

Table 8. Number of sorghum lines with desirable traits that have been introduced into R/MFR and B/MFR (rainy-season adaptation) and ICSP 3 BR/MFR (postrainy-season adaptation) populations.

	Number of resistant lines	
Factors/adaptation aspects	R/MFR and B/MFR (Rainy-season adaptation)	ICSP 3 BR/MFR (Postrainy-season adaptation)
Shoot fly	9	15
Stem borer	10	5
Midge	11	0
Grain molds	3	0
Striga	5	3
Stand establishment	7	3
Nonsenescence	4	6
Leaf diseases and downy mildew	6	0
Photosensitive and temperature-insensitive	0	29
Bold grain	0	30
Terminal drought	0	17
ms_3-postrainy-season adapted lines	0	9
Dwarf and early	3	3

yield potential during the 1986/87 postrainy season. Table 8 gives the number of improved lines with resistances or desirable agronomic traits that we have so far incorporated in R/MFR and B/MFR population-base materials. We merged R/MFR and B/MFR population-base materials during the 1987 rainy season and formed a broadbased BR/MFR rainy-season population-base material that we random mated during the 1987/88 postrainy season.

ICSP 3 BR/MFR (BR/MFR postrainy season population-base material). We random mated this population-base material during the 1987 rainy season, and the second and third cycles of random mating will be carried out during the 1988 postrainy and summer seasons. The number of improved lines with resistance sources that have been incorporated into this population to date are given in Table 8.

Evaluating Advanced Elite Varieties

We evaluated 75 elite postrainy-season varieties in two separate trials during the 1987 postrainy season at ICRISAT Center. From the advanced trial of 32 entries, we selected three varieties (ICSV 86 603, ICSV 86 586, and ICSV 86 590), that yielded 4.5 t ha^{-1} or more compared to 4.1 t ha^{-1} for the control variety M 35-1. From the preliminary trial of 43 entries, we selected three more varieties (ICSV 86 612, ICSV 86 616, and ICSV 86 646) which yielded 4.6 t ha^{-1} or more compared to 3.9 t ha^{-1} for the control variety M 35-1. These selected varieties are being evaluated for grain yield during the 1987/88 postrainy season to further confirm their superiority over the control.

We yield tested 36 elite varieties in the advanced variety trial (AVT) and 125 elite varieties in two separate preliminary variety trials (PVT) during the rainy season at ICRISAT Center, Bhavanisagar, and Dharwad, India. Yield data of selected high-yielding entries from the AVT are given in Table 9 and those from the PVTs in Table 10. ICSV 221 produced the highest grain yields (4.35 t ha^{-1}) across locations in the AVT while ICSV 681 and ICSV 745 produced the highest grain yields (ICSV 681—4.41 t ha^{-1} and ICSV 745—4.68 t ha^{-1}) in the PVT. The selected varieties in

Table 9. Mean grain yield (t ha⁻¹) of top-yielding sorghum entries evaluated in advanced variety trials (AVTs)[1] at five Indian locations[2], rainy season 1987.

	Location					
Entry	1	2	3	4	5	Mean
ICSV 221	2.80	6.32	2.51	3.32	6.78	4.35
ICSV 430	3.03	5.15	3.33	4.56	5.41	4.29
ICSV 361	2.72	4.83	2.43	4.45	6.53	4.19
ICSV 233	2.14	5.16	2.17	4.62	5.93	4.00
ICSV 273	1.89	6.01	1.90	3.92	6.23	3.99
ICSV 331	2.67	4.74	1.92	4.23	6.39	3.99
ICSV 543	2.61	5.11	2.12	3.42	6.45	3.94
Control						
ICSV 112 (SPV 475)	1.17	4.90	2.04	4.13	7.24	3.90
SE	±0.35	±0.33	±0.28	±0.59	±0.33	±0.17
Trial mean (36 entries)	1.59	4.94	1.77	3.43	5.88	3.52
CV (%)	38	12	28	30	10	
Efficiency (%)	101	103	126	101	94	

1. 6 × 6 triple lattice design.
2. Locations:
   1 = ICRISAT Center, Andhra Pradesh, plot size 9.6 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   2 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, high fertility (N 86:P 40:K 0).
   4 = Bhavanisagar, Tamil Nadu, plot size 8 m^2, Alfisol, high fertility (N 80:P 30:K 30).
   5 = Dharwad, Karnataka, plot size 7.2 m^2, Vertisol, high fertility (N 100:P 60:K 60).

AVTs varied in plant height (1.6–2.3 m) and time to 50% flowering (66–74 d). Four selected varieties, ICSV 1 (CSV 11), ICSV 743, ICSV 745, and ICSV 758 were found to be resistant to midge in the preliminary midge resistance nurseries at Dharwad. ICSV 543 was also found to be resistant to anthracnose, grey leaf spot, and zonate leaf spot in preliminary disease screening nurseries at Pantnagar, India. Two other varieties, ICSV 705 and ICSV 712 that yielded slightly less than the selected varieties, were found to be resistant in preliminary shoot fly screening nurseries at ICRISAT Center.

Female Parents (Male-steriles) for Hybrids

Milo cytoplasm. We evaluated the general combining ability (GCA) of our 14 most promising new male-steriles during the 1987 rainy season at ICRISAT Center and Bhavanisagar. We selected 3 male-sterile lines (ICSA 11, ICSA 18, and ICSA 65) that gave high and positive GCA effects across locations. These male-steriles will be evaluated again at more locations to confirm their superior GCA. We also evaluated the GCA of our 12 most promising postrainy season male-sterile lines during the 1986/87 postrainy season at ICRISAT Center. We selected 5 male-steriles (ICSA 70, ICSA 72, ICSA 73, ICSA 74, and ICSA 79) with high and positive GCA. These selected male-steriles will be used to produce postrainy-season hybrids for preliminary yield tests in 1988.

We evaluated the performance of B-lines of our most promising A-lines during the 1987 rainy season at ICRISAT Center, Bhavanisagar, and Dharwad. Three B-lines, ICSB 3, ICSB 11,

Table 10. Mean grain yield (t ha^{-1}) of top-yielding sorghum entries evaluated in preliminary variety trials[1] (PVTs) at six Indian locations[2], rainy season 1987.

	Location						
Trial/Entry	1	2	3	4	5	6	Mean
PVT 1							
ICSV 681	5.62	5.91	2.45	3.21	2.45	6.83	4.41
ICSV 682	4.88	5.78	2.46	2.25	3.39	7.66	4.40
ICSV 694	4.98	5.95	1.96	2.11	4.98	5.96	4.32
ICSV 688	5.40	5.53	1.74	2.69	3.23	7.21	4.30
ICSV 689	3.41	6.43	1.95	2.88	3.07	7.03	4.18
ICSV 687	4.47	6.39	2.09	2.26	2.42	7.13	4.13
ICSV 683	3.76	5.82	1.64	2.54	3.43	7.02	4.03
Control							
ICSV 112 (SPV 475)	3.74	4.74	2.45	1.06	2.67	7.40	3.68
SE	±0.47	±0.42	±0.40	±0.34	±0.49	±0.47	±0.18
Trial mean (25 entries)	3.93	4.77	1.84	1.70	2.56	5.98	3.46
CV (%)	21	15	38	35	33	14	
Efficiency (%)	114	103	104	91	101	108	
PVT 2							
ICSV 745	4.39	4.62	4.01	2.32	5.51	7.25	4.68
ICSV 758	4.69	4.00	3.77	3.05	5.44	6.83	4.63
ICSV 743	4.44	3.31	2.89	2.18	6.20	7.42	4.41
ICSV 725	4.75	3.88	3.03	2.56	4.77	7.15	4.36
ICSV 739	3.58	4.69	3.37	1.80	5.58	6.87	4.32
ICSV 727	3.66	4.28	4.25	2.67	3.06	7.96	4.31
ICSV 723	3.70	3.50	3.15	2.55	4.92	7.81	4.27
ICSV 747	2.60	4.27	2.42	2.04	5.36	7.52	4.04
Control							
ICSV 112 (SPV 475)	4.32	3.78	2.65	1.56	3.93	6.10	3.73
SE	±0.57	±0.40	±0.41	±0.40	±0.62	±0.57	±0.20
Trial mean (100 entries)	2.36	2.85	1.80	1.25	2.98	5.14	2.73
CV (%)	42	24	39	55	36	19	
Efficiency (%)	98	104	120	108	106	105	

1. PVT 1, 5 × 5 triple lattice design.
   PVT 2, 10 × 10 triple lattice design.
2. Locations:
   1 = ICRISAT Center, Andhra Pradesh, plot size 9.6 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   2 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, high fertility (N 86:P 40:K 0).
   4 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, low fertility (N 43:P 20:K 0).
   5 = Bhavanisagar, Tamil Nadu, plot size 8 m^2, Alfisol, high fertility (N 80:P 30:K 30).
   6 = Dharwad, Karnataka, plot size 7.2 m^2, Vertisol, high fertility (N 100:P 60:K 60).

and ICSB 18 produced high and stable grain yields (> 4.3 t ha^{-1}) significantly higher than the grain yield of the control 296B (3.4 t ha^{-1}). The selected B-lines varied in plant height (1.2–1.6 m) and time to 50% flowering (59–67 d). ICSB 11 showed resistance to anthracnose, zonate leaf spot, and grey leaf spot in preliminary disease screening nurseries at Pantnagar.

We continued the conversion of 39 nonrestorers into new female parents. We completed third and fourth backcrosses for 24 of these during the 1986/87 postrainy season and second and third backcrosses for the remaining 15 nonrestorers during the 1987 rainy season.

We also evaluated 920 F_4 progenies derived from B × B × R crosses and selected progenies with desirable agronomic characteristics. These will be evaluated in 1988 and nonrestorers will be identified for conversion to new female parents. We also evaluated 180 F_2 progenies derived from (B × B)B × R × B, and made 694 individual plant selections for further testing.

Nonmilo cytoplasm. We made crosses between milo (A_1) and nonmilo cytoplasm male-steriles (A_2, A_3, and Maldandi) and 250 germplasm lines that were observed to restore fertility on A_2 (130), A_3 (95), and Maldandi (25) in 1986 (ICRISAT Annual Report 1986, p.46). We grew the resulting hybrids during the 1987 rainy season at ICRISAT Center and confirmed 69 germplasm lines to specifically restore fertility on A_2 only, 26 on A_3, and 17 on Maldandi. We also found that some germplasm lines restore fertility on milo (A_1) as well as on one or more of the nonmilo cytoplasmic male-steriles (Table 11). We did not find any germplasm line that restores fertility on milo as well as on all the three types of nonmilo cytoplasm male-steriles.

Table 11. Sorghum germplasm lines that restored fertility when crossed onto milo (A_1) and nonmilo (A_2, A_3, and Maldandi) cytoplasmic male-steriles, ICRISAT Center, rainy season 1987.

Type of cytoplasm	Number of lines
A_1, A_2, A_3, Maldandi	0
A_1, A_2, A_3	23
A_1, A_2, Maldandi	3
A_1, A_3, Maldandi	1
A_2, A_3, Maldandi	1
A_1, A_2	49
A_1, A_3	21
A_2, A_3	18
A_1, Maldandi	3
A_2, Maldandi	2
A_3, Maldandi	2
A_1	0
A_2	69
A_3	26
Maldandi	17
Total	235

Male Parents (Restorers)

We evaluated 64 restorers during the 1987 rainy season at ICRISAT Center, Bhavanisagar, and Dharwad. We identified eight (ICSR 30, ICSR 103, ICSR 105, ICSR 107, ICSR 117, ICSR 122, ICSR 144, and ICSR 154) restorers that gave high and stable yields across locations (> 4.5 t ha^{-1}), significantly higher than the control restorer, CSV 4 (4.0 t ha^{-1}). These restorers are tall (1.6–2.3 m) and flower late (67–75 d). We will use them to produce tall hybrids with high fodder yields.

Hybrid Evaluation

We evaluated 96 hybrids during the 1986/87 postrainy season at ICRISAT Center and selected five hybrids (ICSH 86 646, ICSH 86 758, ICSH 86 694, ICSH 86 693, and ICSH 86 675) that yielded 4.9–5.2 t ha^{-1} compared to 3.8 t ha^{-1} for the commercial control hybrid CSH 12R. The selected hybrids were tall (2–3 m), with the desirable stay-green plant character and did not lodge.

We evaluated 36 agronomically elite hybrids in the advanced hybrid trial (AHT) and 89 hybrids in two separate preliminary hybrid trials (PHT) during the 1987 rainy season at ICRISAT Center, Bhavanisagar, and Dharwad. Yield data of the selected high-yielding hybrids in the PHT are given in Table 12 and those in the AHT in Table 13. The selected hybrids varied in plant height (1.8–2.4 m) and time to 50% flowering (60–70 d). Some of the selected hybrids (ICSH 479, ICSH 245, ICSH 527, ICSH 799, and ICSH 801) were found to have resistance to anthracnose, zonate leaf spot, and grey leaf spot in preliminary disease screening nurseries at Pantnagar.

Table 12. Mean grain yield (t ha^{-1}) of top-yielding sorghum entries evaluated in preliminary hybrid trials (PHT)[1] at six Indian locations[2], rainy season 1987.

	Location						
Trial/Entry	1	2	3	4	5	6	Mean
PHT 1							
ICSH 793	7.19	6.98	3.73	1.77	6.03	9.00	5.78
ICSH 815	5.94	5.82	3.40	2.93	6.57	8.97	5.61
ICSH 801	6.77	6.55	2.28	2.54	5.88	8.83	5.47
ICSH 799	6.25	7.15	2.83	2.85	4.71	8.42	5.37
Control							
ICSH 153 (CSH 11)	6.35	6.37	3.12	2.00	4.82	8.72	5.23
SE	±0.91	±0.56	±0.58	±0.59	±0.88	±0.61	±0.29
Trial mean (64 entries)	5.38	5.84	2.32	2.18	3.83	8.28	4.64
CV (%)	24	14	35	38	32	10	
Efficiency (%)	90	101	112	97	159	96	
PHT 2							
ICSH 856	5.42	5.97	2.67	3.44	6.25	8.75	5.44
ICSH 842	5.94	5.93	1.25	3.70	7.78	7.06	5.28
ICSH 841	5.83	5.00	2.25	2.99	5.56	9.86	5.25
ICSH 839	6.15	6.70	1.08	2.56	5.24	8.20	5.00
ICSH 859	6.25	5.15	2.14	2.47	4.61	8.56	4.91
Control							
CSH 6	6.15	3.38	1.67	2.36	4.23	4.86	4.93
SE	±0.86	±0.79	±0.49	±0.30	±0.71	±0.69	±0.29
Trial mean (25 entries)	5.49	4.80	1.45	2.24	5.49	7.71	4.53
CV (%)	22	23	48	19	23	13	
Efficiency (%)	88	81	86	107	79	86	

1. PHT 1, 8 × 8 triple lattice design.
   PHT 2, 5 × 5 triple lattice design.
2. Locations:
   1 = ICRISAT Center, Andhra Pradesh, plot size 9.6 m², Vertisol, high fertility (N 86:P 40:K 0).
   2 = ICRISAT Center, Andhra Pradesh, plot size 12 m², Vertisol, high fertility (N 86:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m², Alfisol, high fertility (N 86:P 40:K 0).
   4 = ICRISAT Center, Andhra Pradesh, plot size 12 m², Alfisol, low fertility (N 43:P 20:K 0).
   5 = Bhavanisagar, Tamil Nadu, plot size 8 m², Alfisol, high fertility (N 80:P 30:K 30).
   6 = Dharwad, Karnataka, plot size 7.2 m², Vertisol, high fertility (N 100:P 60:K 60).

Table 13. Mean grain yield (t ha^{-1}) of top-yielding sorghum entries evaluated in advanced hybrid trials (AHT)[1] at five Indian locations[2], rainy season 1987.

	Location					
Entry	1	2	3	4	5	Mean
ICSH 527	5.43	6.54	4.08	8.11	5.97	6.23
ICSH 479	5.12	5.68	3.14	8.83	7.21	6.00
ICSH 566	5.45	5.75	4.01	7.07	7.50	5.96
ICSH 245	6.22	6.32	3.37	6.30	7.57	5.96
ICSH 444	6.24	6.75	4.24	4.90	7.30	5.89
ICSH 228	4.30	6.19	4.60	6.69	6.88	5.73
Control						
ICSH 153 (CSH 11)	5.86	5.86	2.71	6.94	7.87	5.85
SE	±0.56	±0.39	±0.30	±0.73	±0.36	±0.22
Trial mean (36 entries)	5.15	5.65	3.19	6.31	7.12	5.48
CV (%)	19	12	17	20	9	
Efficiency (%)	102	117	104	104	108	

1. 6 × 6 triple lattice design.
2. Locations:
   1 = ICRISAT Center, Andhra Pradesh, plot size 9.6 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   2 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Vertisol, high fertility (N 86:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, high fertility (N 86:P 40:K 0).
   4 = Bhavanisagar, Tamil Nadu, plot size 8 m^2, Alfisol, high fertility (N 80:P 30:K 30).
   5 = Dharwad, Karnataka, plot size 7.2 m^2, Vertisol, high fertility (N 100:P 60:K 60).

We also evaluated 25 hybrids during the 1987 rainy season at ICRISAT Center, and selected five (ICSH 882, ICSH 879, ICSH 862, ICSH 878, and ICSH 873) that yielded 4.89–5.39 t ha^{-1} compared to the control commercial hybrid ICSH 153 (CSH 11) that yielded 4.26 t ha^{-1}. The hybrids varied slightly in plant height (2.1–2.5 m) and time to 50% flowering (65–68 d).

West Africa

Burkina Faso

We continued our efforts to identify cultivars and hybrids with high and stable grain yields and with resistances to multiple stresses for the bioclimatic zone where they are likely to be grown. Acceptable cooking quality was also an important criterion in selection (see Grain and Food Quality).

Advanced Variety Yield Trial

In pursuit of our objective to identify relatively late-maturing cultivars (> 80 DAF) suitable for June sowing and early-maturing cultivars (< 70 DAF) suitable for July sowing in the 900–1200 mm a^{-1} rainfall zone, we conducted two AVTs each at two locations, Farako-Bâ, which received 860 mm rainfall during 1987, and Saria, which received 691 mm rainfall during 1987. In the late-maturity trial (15 entries), germplasm accession IS 18495 gave a grain yield of 3.20 t ha^{-1}, IS 6928 gave 2.89 t ha^{-1}, and IS 12611 gave 2.75 t ha^{-1}, while the control cultivar ICSV 1 BF (E

35-1) gave 2.56 t ha^{-1} and the control cultivar Gnofing gave 1.11 t ha^{-1}. IS 22380, IS 23141, and IS 23526 were the other promising accessions in this trial.

In the early maturity trial, the hybrid control SPH 225 gave the highest yield (3.54 t ha^{-1}) followed by brown-grain cultivars IS 7286 (3.33 t ha^{-1}) and Naga White (3.18 t ha^{-1}). Among the white-grain cultivars, ICSV 111 IN gave the highest yield (3.10 t ha^{-1}), followed by M 24581 (2.87 t ha^{-1}). Drought-susceptibility scores of the same trial sown very late in the season at Kamboinsé showed that SPH 225, ICSV 111 IN, ICSV 23O IN, and M 24581 had relatively better drought tolerance.

In our effort to identify superior cultivars for the 600–900 mm a^{-1} rainfall zone, we conducted two advanced trials at Kamboinsé, Pabré, Saria, and Farako-Bâ and two others in Farako-Bâ, Saria, and Kamboinsé. The results from Kamboinsé were excluded from consideration because of poor stands in the trials. All the four trials were evaluated for seedling establishment in a field that was disc-harrowed before the rains, without ridges and without fertilizers; they were also evaluated for *Striga*, midge attack, and foliar-disease infection. This year we added a test for germination quality of harvested grains to obtain an indication of the deterioration of grain harvested in the rainy season. It has been a common observation that improved cultivars, which generally mature early, suffer from grain deterioration due to grain molds and head-bug attack. This is reflected in poor food quality and poor plant stand when they are sown in the next season.

Data on some high-yielding entries are presented in Tables 14 and 15. The entries ICSV

Table 14. Performance of selected advanced sorghum cultivars at Farako-Bâ (FB), Pabré (PB), and Saria (SA), Burkina Faso, rainy season 1987.[1]

Cultivar	Grain yield (t ha^{-1})				Time to 50% flowering (d)	Mean seedling establishment (%)[2]	*Striga* plants pot^{-1}	Seed germination (%)[4]
	FB	PB	SA	Mean				
Trial 1								
ICSV 1078 BF	2.42	1.61	1.81	1.95	67	76	4(0.55)[3]	35(36)
ICSV 1105 BF	2.73	0.89	1.89	1.84	72	79	11(1.05)	5(12)
ICSV 1084 BF	2.37	1.26	1.75	1.79	78	72	13(1.11)	24(28)
ICSV 1055 BF	2.00	1.28	2.06	1.78	71	93	7(0.72)	31(32)
ICSV 1079 BF	1.86	1.29	1.81	1.65	70	91	3(0.52)	39(38)
ICSV 1083 BF	2.14	1.06	1.70	1.63	77	75	10(0.90)	45(42)
ICSV 1103 BF	2.82	0.55	1.47	1.61	70	75	16(1.17)	40(39)
Controls								
IRAT 204	2.58	1.11	0.99	1.56	62	50	9(0.96)	11(18)
CK60B (mean over 20 pots)							15±8	
SE	±0.30	±0.14	±0.28		±2	±10	(±0.09)	(±3.9)
Trial mean (20 entries)	2.22	0.98	1.56		73	55	(0.91)	(31)
CV (%)	27	29	36		5	36	(31)	(25)

1. Randomized block design with 4 replications; plot size 8 m^2.
2. Determined 14 DAS in a field disc-harrowed before rains, without ridges and fertilizers.
3. Values in parentheses are log (x + 1.1) transformations.
4. Grains for the germination test were harvested at Pabré where there was severe incidence of head bugs. Values in parentheses are arc sine transformations.

Table 15. Performance of selected advanced sorghum cultivars at Farako-Bâ (FB), and Saria (SA), Burkina Faso, rainy season 1987.[1]

Cultivar	Grain yield (t ha^{-1})				Time to 50% flowering (d)	Mean seedling establishment (%)[2]	*Striga* plants pot^{-1}	Seed germination (%)[4]
	FB 1	FB 2	SA	Mean				
Trial 3								
ICSV 1125 BF	2.79		2.16	2.48	69	81	5(0.73)[3]	74(60)
ICSV 1115 BF	1.57		2.06	1.82	71	71	6(0.66)	66(54)
ICSV 1135 BF	1.28		2.31	1.80	67	60	14(1.15)	60(51)
ICSV 1127 BF	2.13		1.36	1.75	68	60	14(1.13)	43(41)
ICSV 1141 BF	1.61		1.75	1.68	65	78	11(1.06)	80(64)
ICSV 1112 BF	1.67		1.68	1.68	67	77	1(1.18)	86(68)
ICSV 1128 BF	0.98		2.00	1.49	80	88	11(1.01)	89(71)
ICSV 1123 BF	0.80		1.28	1.04	79	67	8(0.88)	83(66)
Controls								
IRAT 204	0.93		0.97	0.95	65	70	8(0.90)	16(23)
CK 60B (mean over 20 pots)							15±8	
S 29 (Local)								95(78)
SE	±0.30		±0.27		±2	±14	(±0.08)	(±4)
Trial mean (36 entries)	1.25		1.46		72	68	(0.92)	(59)
CV (%)	43		32		5	36	(27)	(10)
Trial 4								
ICSV 1049 BF	2.30	3.4	2.78	2.84	70	88	8(0.78)	70(59)
ICSV 1163 BF	2.79	3.22	2.44	2.80	71	90	6(0.77)	86(69)
ICSV 1157 BF	2.90	2.92	2.53	2.78	69	95	8(0.93)	78(63)
ICSV 1092 BF	2.91	3.43	2.01	2.78	70	58	11(1.02)	85(67)
ICSV 1156 BF	2.95	3.30	2.05	2.77	71	88	2(0.43)	84(67)
Controls								
ICSV 1002 BF	2.56	2.89	2.61	2.69	73	87	5(0.61)	85(68)
CK 60B (mean over 20 pots)							15±8	
S 29 (Local)								95(78)
SE	±0.37	±0.36	±0.37		±1	±12	(±0.09)	(±6)
Trial mean (36 entries)	2.45	2.86	1.79		71	75	(0.89)	(65)
CV (%)	27	22	36		2	28	(32)	(11)

1. Randomized-block design with 4 replications; plot size 8 m^2.
2. Determined 14 DAS in a field disc-harrowed before rains, without ridges and fertilizers.
3. Values in parentheses are log (x + 1.1) transformations.
4. Values in parentheses are arc sine transformations. S 29 was a control, giving 37 entries for analysis.

1055 BF, ICSV 1079 BF, ICSV 1125 BF, and ICSV 1049 BF had excellent seedling establishment and *Striga* resistance; however, the germinability of harvested grains needs to be improved. The other promising entries possessing good seedling establishment, *Striga* resistance, and germinability are ICSV 1163 BF and ICSV 1156 BF. This system of evaluation will be intensified to identify cultivars with multiple desirable traits.

Female Parents

During 1985, we observed 45 female parents obtained from ICRISAT Center for hybrid production in Burkina Faso and at other locations in West Africa (ICRISAT Annual Report 1985, p. 58). Female parents selected from these nurseries were reevaluated at Farako-Bâ and Kamboinsé during the crop seasons of 1986 and 1987. Based on their general performance, stable male sterility, off-season behavior, and disease resistance, eight lines were selected for intensive use for hybrid production in West Africa (Table 16).

Hybrid Evaluation

We evaluated 62 experimental hybrids produced by using elite male and female parents and selected 17 of them. Several hybrids yielded more than 3 t grain ha^{-1} and exhibited superiority over variety controls at both locations (Table 17) Hybrid combinations with male-sterile parents ICSA 11, ICSA 37-1, ICSA 38, ICSA 39, and ICSA 41 were found to be the best.

On-farm Testing

We evaluated eight sorghum cultivars (including a local control, Gnofing) in a multilocational adaptation trial, conducted at 11 villages in the 900–1200 mm rainfall zone of Burkina Faso. At each of these 11 villages, a replicated trial was

Table 16. Some important characteristics of selected female parents of sorghum, Burkina Faso, rainy seasons 1985, 1986, and 1987[1].

Female parent	Time to 50% flowering (d)	Plant height (m)	Disease score[2]			
			ZLS[3]	GLS[3]	SS[3]	LAN[3]
ICSA 2	73	1.26	3	2	2	1.5
ICSA 11	70	1.21	3	2	2	2.0
ICSA 37	75	1.20	2	2	3	2
ICSA 38	75	1.23	2	2	3	2
ICSA 39	74	1.19	2	2	3	2
ICSA 41	75	1.26	2	2	3	2
ICSA 26	71	1.19	3	2	1.5	2.5
ICSA 1	78	1.02	2	2	2	2.5
Control						
ATx 623	74	1.21	3	3	3	4

1. Time to flowering and plant height observations were averaged over two locations (Farako-Bâ and Saria) in each of the three crop seasons, 1985, 1986, and 1987. Disease scores were averaged over the observations made at Farako-Bâ during the three crop seasons.
2. Disease scores on a 1–5 scale, where 1 = highly resistant and 5 = highly susceptible.
3. ZLS = Zonate leaf spot, GLS = Grey leaf spot, SS = Sooty stripe, and LAN = Leaf anthracnose.

Table 17. Mean performance of selected experimental sorghum hybrids at two locations, Burkina Faso, rainy season 1987[1].

Hybrids	Time to 50% flowering (d)	Plant height (m)	Grain yield (t ha^{-1})		
			Farako-Bâ	Saria	Mean
ICSA 11 × MR 908	65	1.9	3.47	2.69	3.08
ICSA 37-1 × MR 864	67	2.0	3.41	2.71	3.06
ICSA 37-2 × MR 908	71	2.0	3.12	3.00	3.06
ICSA 11 × MR 844	70	1.9	3.71	2.27	2.99
ICSA 26-2 × MR 908	67	1.9	3.11	2.68	2.90
Controls					
ICSV 1001 BF (Framida)	77	2.3	2.44	1.70	2.07
SE			±0.44	±0.34	
Trial mean (36 entries)			2.95	2.17	
CV (%)			22	22	
ICSA 38 × MR 844	68	1.9	4.82	3.33	4.08
ICSA 39 × MR 844	70	1.9	3.75	3.86	3.80
ICSA 41 × MR 841	69	2.0	3.96	3.56	3.76
ICSA 38 × MR 877	73	1.9	3.39	3.84	3.62
ICSA 38 × MR 908	71	2.0	3.28	3.96	3.62
ICSA 39 × MR 908	71	2.0	3.62	3.61	3.62
ICSA 41 × MR 880	69	2.0	3.36	3.55	3.45
Controls					
ICSV 1001 BF (Framida)	77	2.3	2.58	2.85	2.72
SE			±0.54	±0.37	
Trial mean (36 entries)			2.91	3.13	
CV (%)			26	17	

1. 6 × 6 lattice design, 2 replications, net plot size 8 m^2 at Farako-Bâ and 7.5 m^2 at Saria.
2. Mean over the two locations.

conducted in cooperation with a farmer, who followed improved management practices (plowing and application of N43: P40: K30 fertilizer) under our technical supervision. The overall mean grain yield of the trial across 10 locations was 2.11 t ha^{-1} (Table 18). All the test cultivars gave significantly superior yields to the local control variety, Gnofing (1.17 t ha^{-1}). The cultivars S 34 and ICSV 111 IN gave the highest mean yield (2.43 t ha^{-1}) and ranked first at most of the locations. Regression analyses of cultivar yields on their respective environmental mean yields indicated that S 34 was the most stable cultivar (Fig. 10). The control Gnofing had the highest incidences of foliar diseases and *Striga*.

Mali

Breeding and introduction of high-yielding, stable varieties with acceptable food quality for the diverse regions of Mali, continue to be the objec-

Table 18. Grain yield (t ha⁻¹) performance of el'te sorghum cultivars in a multilocational adaptation trial conducted at 11 locations[1], Burkina Faso, rainy season 1987[2].

	Location[3]										
Cultivar	1	2	3	4	5	6	7	8	9	10	Mean[3]
S 34	2.67	2.40	2.26	2.17	2.78	1.96	1.84	3.32	2.83	2.09	2.43
ICSV 111 IN[4]	1.71	2.79	2.69	2.08	3.30	1.53	-[5]	3.07	-	2.28	2.43
ICSV 2 IN	2.04	2.74	2.33	2.00	2.73	2.13	1.30	3.44	2.56	2.08	2.34
ICSV 247 IN	2.07	2.60	2.41	2.01	3.02	2.00	1.54	3.59	2.33	1.77	2.33
ICSV 1049 BF	2.24	2.68	2.08	2.08	3.07	1.73	1.44	3.40	2.36	2.14	2.32
ICSV 126 IN	1.92	2.48	2.50	1.98	2.99	1.73	1.51	2.62	2.55	1.58	2.19
IS 6928	1.79	1.52	1.61	1.22	1.94	1.35	1.06	2.66	2.10	1.43	1.67
Control											
Gnofing	1.22	1.03	1.12	0.78	1.25	1.26	1.25	1.55	1.11	1.12	1.17
SE	±0.15	±0.16	±0.15	±0.14	±0.16	±0.13	±0.13	±0.21	±0.09	±0.18	
Mean	1.96	2.28	2.12	1.79	2.63	1.71	1.42	2.96	2.26	1.81	2.11
CV (%)	19	18	17	20	15	19	22	17	9	20	

1. Mean group yield was calculated over 10 locations, excluding Dankare.
2. RBD experiment with 6 replications, plot size was either 24 m² or 16 m².
3. Locations:
   1 = Tondogosso, 2 = Koumbia, 3 = Kare, 4 = Pa, 5 = Boro, 6 = Koho, 7 = Assio, 8 = Souroukoudougou, 9 = Tiara, and 10 = Bana.
4. Heavy bird attack on ICSV 111 IN at locations 7 and 9 precluded it from being considered in the analysis.
5. - = Data not available.

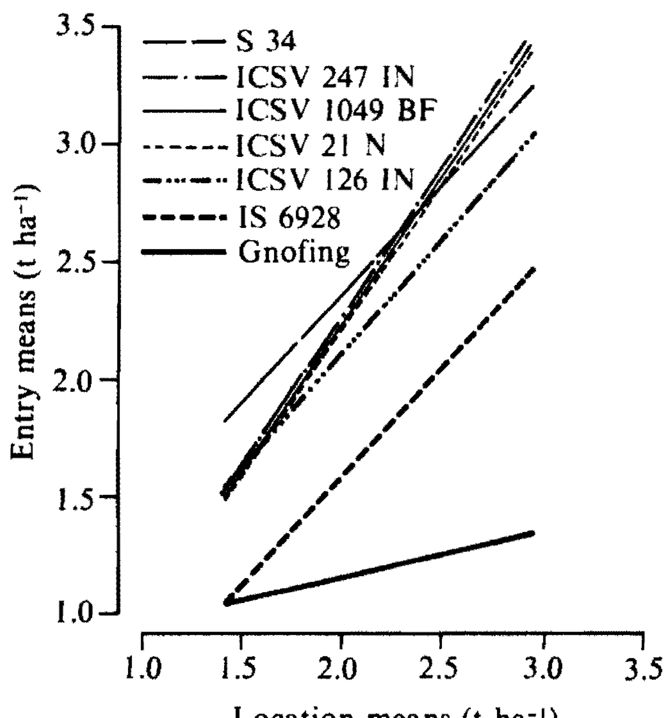


Figure 10. Linear relationships between entries and location means in a multilocational trial at 11 locations in Burkina Faso, rainy season 1987.

tives of our program. Our breeding populations and crossing programs are directed toward the generation of late-maturing sorghums targeted for the high rainfall southern zone, and medium-to early maturing sorghums that may be adapted to low rainfall areas of Mali. During the 1987 rainy season, we conducted AYTs for each of these maturity groups.

Preliminary and Advanced Yield Trials

Two hundred and thirty four F_6 lines from our breeding program were divided into maturity groups and sown in PYTs at seven locations throughout Mali. From these trials, data on yield, resistance to foliar diseases, and agronomic characteristics were used to select 9 early and 14 medium-maturing lines for promotion to AYTs in 1988.

Our intermediate-maturity AYT, consisting of 25 entries sown in a balanced lattice design at four locations compared 15 advanced lines from the West African program of ICRISAT with five recent introductions from West Africa, and 5 controls. The variety S 34 from Nigeria, with a mean grain yield of 2.45 t ha^{-1} (Table 19), was ranked first at Koula and Sotuba, second at Kita, and third at Katibougou. Last year, this line was shown to be high yielding in our agronomy trials (ICRISAT Annual Report 1986, pp.300-301) and had acceptable grain quality characteristics for use in Malian *tô* preparation. Other entries with mean yields over 2.0 t ha^{-1} include 7613-039 from Senegal and 85-F_4-218 from our program at ICRISAT. 85-F_4-164, which had the highest mean yield in our 1986 PYT, was ranked fourth at Koula and fifth at Sotuba, with a yield over 3 t at Sotuba in 1987. 85-F_4-77, which had the highest mean yield in the 1986 intermediate PYT, and was the best line in our seedling-stage drought tests, only performed well at Kita in 1987.

International Trials and Nurseries

Replicated nurseries, containing 179 sorghum cultivars and hybrids from ICRISAT Center, ICRISAT Burkina Faso program, and Texas A&M University, were sown at Bema, Cinzana, Longorola, Samanko, and Sotuba. Thirty-eight lines were retained for further observation and potential inclusion in our crossing program as sources of resistance to the two most severe foliar diseases in Mali: sooty stripe (*Ramulispora sorghi*) and leaf anthracnose (*Colletotrichum graminicola*).

Table 19. Performance of selected lines in the intermediate-maturity advanced yield trial (AYT) at four locations, Mali, 1987.

	Grain yield (t ha^{-1})[1]							
Entry	Kita	Sotuba	Katibougou	Koula	Mean	Mean yield rank	Mean time to 50% flowering (d)	Mean plant height (m)
S 34	2.21	3.50	2.13	1.95	2.45	1	75	1.86
7613-039	1.94	3.11	2.18	1.05	2.07	3	72	1.90
85 F_4 218	1.69	2.88	2.12	1.51	2.05	4	75	1.98
85 F_4 164	1.44	3.03	1.45	1.72	1.91	8	75	1.83
85 F_4 77	1.95	1.58	1.95	1.07	1.64	15	72	2.13
Controls								
ICSV 1002 BF	1.88	3.49	1.89	1.93	2.30	2	77	1.89
L 30	2.09	2.52	1.76	1.75	2.03	5	75	2.11
Malisor 84-1	2.25	2.14	2.43	0.87	1.92	7	71	2.17
Malisor 84-7	1.47	2.56	1.64	1.26	1.73	13	74	1.34
CSM 388	1.58	1.21	2.09	1.59	1.62	16	84	3.59
SE	±0.19	±0.20	±0.25	±0.22			±0.5	±0.05
Trial mean (25 entries)	1.60	2.70	1.77	1.33			74	2.06
CV (%)	30	19	41	41				
Efficiency[2]	160	103	116	103				

1. 5 × 5 balanced lattice, harvested plot size 7.9 m^2 at Kita, Katibougou, Koula, and 9.2 m^2 at Sotuba.
2. Compared with randomized blocks.

The ICRISAT International Sorghum Trials and Nurseries, consisting of 25 test entries and 11 local controls, were sown at Sotuba and Bema in a 6 × 6 lattice design with three replications. ICSV 401 had the highest mean yield (2.54 t ha^{-1}) among the inbred lines, and showed excellent drought tolerance at Bema where it ranked first in grain yield, producing 2.74 t ha^{-1}, in spite of severe midseason drought stress and a total seasonal rainfall of only 377 mm.

Southern Africa

Breeding Nursery

Based on earlier regional selections for drought resistance, yield, disease resistance (downy mildew, virus, and leaf blight), earliness, and grain color, we made 2556 crosses and advanced the F_1s to F_2s in the winter season. In the following generations a number of selections were made at regional locations. We selected 48 F_4 families with hard pearly white grain and resistance to downy mildew.

Variety Trials

The Regional Sorghum Line Evaluation Trial (RSLE) was sown at four locations and the Regional Sorghum Preliminary Variety Trial (RSPVT) was sown at eight locations in the region.

In the RSLE, 212 selections from the 1984/85 and 1985/86 introductions and nurseries were sown at four locations. Mean yield in the trial at Matopos (with a rainfall of 350 mm) was 1.9 t ha^{-1} compared to 3.17 t ha^{-1} at Golden Valley where rainfall was higher. The highest yielder at Matopos was SDS 10164 (4.0 t ha^{-1}) followed by MP 532 (2.6 t ha^{-1}), LARSVYT 58 85 (2.6 t ha^{-1}), SDS 355 (2.5 t ha^{-1}), and SDS 9341 (2.5 t ha^{-1}). Control yields were 1.47 t ha^{-1} for hybrids and 1.17 t ha^{-1} for varieties. At Golden Valley, SAR 37 (5.75 t ha^{-1}), BYU 250 (5.35 t ha^{-1}), MP 623 (4.55 t ha^{-1}), MP 615 (4.15 t ha^{-1}), and SDS 2337 (4.3 t ha^{-1}) yielded most compared to the trial mean of 3.17 t ha^{-1} and control yields of 3.45 t ha^{-1} for hybrids and 3.67 t ha^{-1} for varieties.

In the RSPVT, 17 lines advanced from the 1985/86 New Line Trial were evaluated with 12 Zambian lines, 4 populations, 4 hybrid controls, and 15 released varieties from Botswana, Malawi, Tanzania, and Zimbabwe at eight locations across the region.

ICSV 1001 BF (Framida) (2.39 t ha^{-1}) and Red Nyoni (2.02 t ha^{-1}) yielded highest across the region, followed by a random-mating population SDBP 45 (1.81 t ha^{-1}) and the introduction SDS 2298 (1.8 t ha^{-1}). Hybrid control yields across were 2.26 t ha^{-1}. At Matopos, Red Swazi had the highest yield (3.07 t ha^{-1}) and control hybrids yielded 2.4 t ha^{-1}. At Mzarabani, SDBP 45 topped the trial (2.73 t ha^{-1}) and the control hybrid yielded 1.0 t ha^{-1}. At Maseru the overall best variety was SDS 2293-1 (2.89 t ha^{-1}) while the control hybrids yielded 3.65 t ha^{-1}. At Mafeteng, SDS 2293-6 (1.41 t ha^{-1}) had a fair yield and good plant aspect compared to the yield of 1.97 t ha^{-1} of the control hybrid which had a fair plant aspect.

The Regional Sorghum Advanced Variety Trial (RSAVT) was grown at Gwebi and Matopos in Zimbabwe and Sebele in Botswana. Fifteen advanced varieties were evaluated and SDS 2690-2 had the highest yield across locations (3.18 t ha^{-1}) with the control yields were 1.83 t ha^{-1} for hybrids and 2.04 t ha^{-1} for varieties. SDS 2690-2 ranked first in the trial at Matopos (3.48 t ha^{-1}) and Gwebi (5.06 t ha^{-1}), while Segaolane was first at Sebele (1.44 t ha^{-1}), a very dry location, where SDS 2690-2 yielded 1.0 t ha^{-1} compared to the control hybrid yield of 0.8 t ha^{-1}.

Hybrids

At Matopos, with 350 mm of rain, we evaluated 149 new test crosses. The four with the highest yield were M 70079A × SDS 3423 (2.45 t ha^{-1}), ATx 623 × SDS 238 (2.65 t ha^{-1}), SPL 23A × 8/74 (2.45 t ha^{-1}), and SPL 199A × SDS 10160 (2.8 t ha^{-1}). These yields are higher than the yields of the three hybrid controls (average 1.85 t ha^{-1}). In a second testcross with 35 crosses, the 4 best hybrids were ICSA 12 × LARSVYT 13 (2.95 t ha^{-1}), ICSA 19 × LARSVYT 19 (3.45 t ha^{-1}), ICSA 37 × LARSVYT 61 (2.85 t ha^{-1}), and ICSA 19 × LARSVYT 30 (2.95 t ha^{-1}). These yields were all statistically better than the hybrid controls.

In preliminary trials at Matopos, we evaluated 549 experimental hybrids under rainfed conditions and selected 32 for further testing. The hybrids SDSH 1 (2.75 t ha^{-1}), SDSH 5 (3 t ha^{-1}), SDSH S (3.05 t ha^{-1}), and SDSH 12 (2.88 t ha^{-1}) yielded significantly more ($P = 0.01$) than the mean yield (1.31 t ha^{-1}) of the hybrid controls. The test hybrids had good plant aspect score and did not lodge under dry conditions.

Population Development

The Sorghum Population Adaptation Trial (SPAT) containing 27 random-mating populations and four controls (2 hybrids and 2 varieties) looked very impressive under extreme drought at Matopos and Lucydale. Foliar diseases were a problem at Golden Valley and Ilonga where rainfall was high. The purpose of the trial is to synthesize three populations; one for cool dry, one for hot dry, and one for hot wet environments.

The lowest yields were realized in the hot dry climates of Makoholi and Sebele. SABP 35 yielded 0.77 t ha^{-1} at Makoholi and 0.83 t ha^{-1} at Sebele; SDBP 42 yielded 0.56 t ha^{-1} at Makoholi and 0.74 t ha^{-1} at Sebele; and SDBP 39 yielded 0.89 t ha^{-1} at Makoholi and 0.38 t ha^{-1} at Sebele. In the cool dry climate, represented by Matopos and Lucydale, SDBP 35 yielded 2.96 t ha^{-1} at Matopos and 1.33 t ha^{-1} at Lucydale; and SDBP 49 yielded 3.17 t ha^{-1} at Matopos and 1.29 t ha^{-1} at Lucydale. SDBP 37, SDBP 29, SDBP 44, and SDBP 57 also performed well at these stations. The hot wet condition is represented by Mzarabani and Golden Valley. Here SDBP 2 yielded 2.41 t ha^{-1} at Mzarabani and 4.08 t ha^{-1} at Golden Valley; SDBP 49 yielded 2.49 t ha^{-1} at Mzarabani and 9.23 t ha^{-1} at Golden Valley. SDBP 50 yielded 3 t ha^{-1} at Golden Valley. SDBP 35, SDBP 39, SDBP 42, and 49 are most widely adapted; and SDBP 42, SDBP 46, and SDBP 47 are fairly resistant to downy mildew.

We synthesized two new populations, ICSP-SD 88001 (early maturing) and ICSP-SD 88002 from selected cold and drought-resistant F_2 plants. We also made three new blended varieties, ICSV-SD 8800, ICSV-SD 88002, and ICSV-SD 88003, bringing together good yield, earliness, and excellent white, large, hard grains. We selected 40 from 200 S_2s to form the SADCC ICCSPIRMFR Population.

This is a joint evaluation with ICRISAT Center towards developing a genetically broadbased multifactor-resistant R-population.

Eastern Africa

At the Kiboko Research Station, Eastern Province, Kenya, we screened for drought resistance from a nursery consisting of 160 elite genotypes from the East African Regional Sorghum and Millet (EARSAM) region, 450 F_4 families from Poza Rica in Mexico, 55 advanced materials from Texas, 20 elite varieties from ICRISAT Center, 24 elite hybrids from Katumani national performance yield trial, and advanced material. Seventy-four genotypes were selected for GS_2 and GS_3 drought resistance.

In the Asian Regional Sorghum Hybrid Adaptation Trial (ARSHAT) 1987 at Alupe research station, Western Province, Kenya, 12 entries were selected. Average yield ranged from 0.67 to 2.24 t ha^{-1}.

At the Nazreth Research Station, Ethiopia, individual plant selections were made from 324 F_4 lines, 193 F_3 lines, and 230 F_2 segregating generations. From their advanced material, 26 superior varieties with diversity in seed color, testa, maturity, and height were selected for inclusion in the EARSAM lowland yield trial in 1988. These genotypes are now being increased at Kiboko in Kenya.

ICRISAT variety (SC 108-3 × CS 3541)-19-1 from SEPON 80 was selected and purified by the Ethiopian Sorghum Improvement Program.

After several years of testing it has now been released as Dinkmash.

Central America, Mexico, and the Caribbean

We carried out a trial to assess pollen dispersal in five varieties released in Central America and Mexico with the objective of aiding seed production by national programs. The donor pollen was placed 80 cm around each test variety. The variety M 62641 had a contamination level of 8.5%, the Sepon 77 bulk variety had a contamination level of 6.1%, ISIAP Dorado 5.9%, Centa S-2, and M 1057 0%.

We evaluated our best advanced materials in a trial called the Mesoamerican Sorghum Variety Yield Trial (MASVYT) during 1987 at our Poza Rica station located 60 m above sea level. The average yield of 3.5 t ha^{-1} was considered good under dryland farming conditions (Table 20).

We evaluated 30 improved genotypes of the local creole photosensitive sorghums in three maize/sorghum cropping systems. In the 'aporque' system (ridges), genotypes 84-CM-161 and ES 727 demonstrated flower competition with the associated maize hybrid H 3 compared to the local control because of their shorter nature and reduced foliage, thereby permitting increased net grain to the farmer. In a system, where maize and sorghum were sown at the same time, ES 790 and ES 733 allowed the maize to yield well while giving good yields themselves.

Table 20. Performance of the best sorghum genotypes in the Mesoamerican Sorghum Variety Yield Trial (MASVYT), Poza Rica, Mexico, rainy season 1987.

Genotype	Grain yield (t ha^{-1})	General aspect[1]	Time to 50% flowering (d)	Plant height (cm)	Time to physiological maturity (d)
M 90322 × M 90812	5.48	2.5	70	155	96
M 90306	5.05	2.0	70	161	96
SAR 24	4.91	2.5	63	154	91
M 90322	4.84	3.0	68	185	95
PP 290	4.49	2.0	62	165	88
M 81981-1	4.47	3.0	69	195	95
M 90411 × (NSA 935 × 77CS1)	4.33	2.5	70	160	97
ISIAP Dorado	4.38	3.0	72	143	97
M 82011-3	4.36	2.0	68	191	93
D 71246	4.36	3.0	84	157	115
ICSV 112 (SPV 475)	4.28	3.0	83	-	111
DIAL 475-746-4-2-1-5	4.24	3.5	70	168	97
M 90362	4.21	3.0	86	164	115
M 0378	4.17	3.0	67	170	93
SE	±0.59				
Trial mean	3.50				
CV (%)	17				

1. Based on a 1-5 scale, where 1 = excellent and 5 = poor.

Grain and Food Quality

ICRISAT Center

Chemical Composition

A total of 13 000 germplasm lines grown during the 1985 postrainy season at ICRISAT Center were screened for protein and lysine contents between 1985 and 1987. We identified 77 promising lines based on their grain protein and lysine contents. Seven elite ICRISAT cultivars were analyzed for chemical composition. The protein content of ICSV 145 (SAR 1) and ICSV 197 (PM 11344) was comparatively higher than ICSV 1 (CSV 11), SPV 386, ICSV 112 (SPV 475), SPH 221, and Hageen Durra 1. Starch content was higher in Hageen Durra 1 and ICSV 112 (SPV 475) than in the other cultivars.

Chemical Factors Related to Thin Fermented Porridges

In several countries of Africa, opaque beer (thin fermented porridge) is a common food. The diastatic power of malt is an important criterion in opaque beer production. Malting of grains is generally done at a low relative humidity (RH; about 40%). We modified the malting conditions by germinating grains at a high relative humidity (above 90%) to examine the potential to increase diastatic activity in 10 cultivars (Table 21). Sorghum Diastatic Units (SDU) can be improved by increasing the RH, but this may result in a higher malting loss. ICSV 1001 BF (Framida), Dobbs, and IS 7055 recorded high SDU values (Table 21), while ICSV 145 (SAR 1) and M 35-1 (the control), had much lower values, indicating a wide cultivar variation for SDU. Protein digestibility using the in vitro technique showed that malting also improved the in vitro protein digestibility (IVPD). As a result of malting, the cultivars showed wide variation in decrease of starch and protein content with concomitant increase in soluble sugar content.

West Africa

Traditional Dehulling and *Tô* Qualities

We evaluated, traditional processing and *tô* qualities of grain samples from some of the promising cultivars harvested during the 1987 crop season at Saria, Burkina Faso. The percentage of endosperm recovery from traditional mortar and pestle dehulling was lowest for brown-grain types such as ICSV 1001 BF (Framida) and highest for hard, white-grain types such as Gnofing and ICSV 1 BF (E 35-1) (Table 22). However, the extent of pericarp removal was most effective for Gnofing and only of acceptable standard for some of the improved types. We obtained flour from dehulled endosperm by using a Moto® electrical grinding machine. Soft-grain types such as IS 22380 had a higher percentage of flour that passed through US standard 60 mesh sieve, than hard grain types such as ICSV 1 BF (E 35-1). *Tô* was prepared according to traditional methods in a medium acidified by adding lemon juice. The *tô* quality of cultivars ICSV 111 IN, ICSV 126 IN, ICSV 1 BF (E 35-1), IS 956, and Gnofing was acceptable. As is the case in some parts of Africa, *tô* prepared from the brown-grain types was acceptable to the panelists. However, when provided with *tô* from a brown-grain type and a white-grain type, the panelists preferred the latter.

Table 21. Diastatic activity, starch, soluble sugars, and in vitro protein digestibility (IVPD) in germinated sorghum grains[1], ICRISAT Center 1986.

Cultivar	Origin	Sorghum diastatic units (SDU)	Starch (%)	Soluble sugars (%)	Protein (%)	IVFD (%)
CO 4	India	148.9	64.3	13.1	11.1	90.0
		(0.3)[2]	(69.4)	(1.8)	(12.4)	(83.0)
Dobbs	Uganda	178.9	59.9	11.4	5.3	71.0
		(0.3)	(65.3)	(1.8)	(9.0)	(49.0)
ET 3491	Ethiopia	159.0	64.3	11.1	11.1	91.0
		(0.2)	(67.5)	(1.4)	(12.4)	(79.0)
Lulu dwarf	Tanzania	147.0	65.4	6.6	7.2	
		(0.3)	(72.3)	(1.4)	(9.7)	(82.0)
IS 7055	Sudan	228.0	63.6	11.8	7.3	73.0
		(0.5)	(65.9)	(1.7)	(11.1)	(59.0)
ICSV 1001 BF (Framida)	Burkina Faso	174.0	59.8	10.5	11.2	70.0
		(0.2)	(62.0)	(2.5)	(14.3)	(63.0)
ICSV 145 (SAR 1)	ICRISAT Center, India	40.0	56.4	6.7	6.3	91.0
		(0.4)	(67.1)	(1.2)	(7.2)	(81.0)
ICSV 1 (CSV 11)	ICRISAT Center, India	122.3	64.9	10.9	8.7	90.0
		(0.4)	(67.3)	(1.1)	(10.7)	(82.0)
SPV 472	ICRISAT Center, India	74.3	68.8	9.0	7.6	90.0
		(0.2)	(70.1)	(1.2)	(9.5)	(85.0)
Control						
M 35-1	India	52.5	67.7	7.8	8.7	86.0
		(0.5)	(70.9)	(1.4)	(9.9)	(81.0)
SE		±19.1	±1.1	±0.71	±0.67	±3.1
		(±0.04)	(±1.2)	(±0.13)	(±0.64)	(±4.0)

1. Germination at 30°C at 90–95% RH for 96 h.
2. Figures in parentheses show the values of nongerminated grains.

Table 22. Traditional grain processing and *tô* qualities of 16 sorghum cultivars, Burkina Faso, 1987[1].

Cultivar	100-grain mass (g)	Floaters[2]	Endosperm recovery (%)[3]	Pericarp removal score[4]	Flour[5]	*Tô* quality	
						Acceptance[6]	Color[7]
ICSV 2 IN	1.75	86	54	3	64	2.2	5Y8/2
ICSV 111 IN	2.40	60	64	2	62	1.4	5Y8/1
ICSV 126 IN	2.17	58	63	2	66	1.1	5Y8/2
ICSV 247 IN	1.97	78	61	3	55	2.3	5Y8/3
S 34	2.52	68	60	2	62	2.0	5Y8/3
ICSV 1049 BF	2.32	60	61	2	61	2.2	5Y8/3
M 24581	2.45	74	66	2	60	1.4	5Y8/2
ICSV 1 BF (E 35-1)	2.88	22	69	2	59	1.2	5Y8/1
IS 956	2.42	85	62	2	65	1.1	5Y8/2
IS 6928	2.13	55	54	3	61	1.9	2.5Y8/2
IS 22380	2.18	100	54	3	70	2.0	5Y7/2
IS 23526	2.95	51	55	2	60	2.3	5Y8/2
Gnofing	2.30	45	75	1	53	1.3	10R6/2
IS 7286	2.02	100	43	3	70	1.9	10R5/3
Naga White	1.75	100	49	4	66	2.2	10R4/3
ICSV 1001 BF (Framida)	2.52	100	43	4	71	1.7	10R5/3
SE	±0.04	±3	±3	±1	±2		
Mean	2.29	71	58	3	63		
CV (%)	4	9	10	16	6		

1. Averaged over 6 replications for grain mass and floaters and 3 replications for all other characteristics.
2. Number of grains floating in a sample of 100 grains when placed in a solution of sodium nitrate.
3. Three kilograms of grain were traditionally dehulled and the mass of endosperm recovered was expressed as percentage of recovery.
4. The cleanliness of endosperm and pericarp removal were scored on a scale of 1-5, where 1 = very good and 5 = very poor.
5. Mass of flour sifted through a USA standard sieve no.60 when a sample of 100 g flour was sifted, until no more flour passed through the sieve.
6. *Tô* was evaluated independently by seven farm workers on a scale of 1-3, where 1 = good, 2 = acceptable, and 3 = poor.
7. Color of *tô* was compared with Munsells' soil color charts.

Cooperation with National Programs

Multilocational Trials and Nurseries

Asian Regional Sorghum Variety Adaptation Trial (ARSVAT 86)

ARSVAT 86 consisted of 25 entries including a local control and two ICRISAT-bred controls ICSV 1 (SPV 351) and ICSH 153 (CSH 11). We distributed seeds of ARSVAT 86 sets to our cooperators in Asia. These were evaluated at 10 locations in India, 5 in Pakistan, 1 in Thailand, 1 in the Philippines, 1 in the People's Republic of China, and 1 in Burma. Mean grain yields of selected high-yielding entries from 14 locations are presented in Table 23.

The ICRISAT-bred hybrid control ICSH 153 (CSH 11) in the trial gave the highest mean grain

Table 23. Mean grain yield (t ha^{-1}) of top-yielding sorghum entries in the Asian Regional Sorghum Variety Adaptation Trial (ARSVAT 86), 1986.[1]

	Indian location[2]									Pakistani location[3]					
Entry	1	2	3	4	5	6	7	8	9	10	11	12	Philip-pines	Thai-land	Mean
ICSV 219	4.78	5.77	5.01	6.60	10.90	2.27	3.62	5.42	1.78	3.23	3.33	2.17	1.88	2.36	4.22
ICSV 112 (SPV 475)	5.72	4.45	6.65	6.38	8.24	3.02	3.22	4.21	1.14	3.69	2.96	2.64	2.05	3.01	4.10
ICSV 102	4.97	4.71	4.96	5.73	10.69	2.58	3.41	5.22	2.25	2.86	2.35	3.09	2.12	2.29	4.09
ICSV 225	4.39	5.22	5.58	5.69	8.76	2.81	3.56	5.22	2.58	3.50	2.93	2.02	2.09	2.38	4.05
ICSV 210	4.38	4.73	5.46	7.10	9.34	2.14	3.61	4.50	3.46	2.73	2.69	1.78	2.01	1.67	3.97
ICSV 200	5.16	3.41	4.61	5.47	9.78	1.84	3.94	6.08	2.87	2.87	2.59	2.07	1.42	2.10	3.87
ICSV 197 (PM 11344)	3.09	5.17	6.05	7.06	12.99	1.91	3.31	4.11	1.90	2.33	2.22	0.91	0.73	2.36	3.87
ICSV 202	4.27	3.89	7.18	5.23	7.80	2.29	3.76	5.89	1.99	1.63	3.05	2.53	2.12	2.36	3.86
ICSV 166	3.92	4.82	5.20	5.48	10.11	2.34	3.18	5.06	1.85	3.22	2.65	1.25	1.50	2.39	3.78
ICSV 162	4.83	2.50	4.71	6.30	12.07	1.55	3.59	3.95	2.26	2.80	2.29	1.74	2.52	1.73	3.77
ICSV 110	4.23	2.93	4.33	6.03	11.11	1.57	3.44	5.21	1.19	3.81	3.06	1.16	2.63	2.14	3.77
ICSV 221	4.13	3.74	4.84	6.49	8.99	1.87	3.36	3.78	1.69	3.27	3.00	2.56	2.12	1.64	3.68
ICSV 224	4.58	4.18	5.14	6.26	8.68	2.20	3.56	3.49	2.20	3.32	2.58	0.91	1.58	2.24	3.64
Controls															
ICSV 1 (CSV 11)	3.31	5.74	5.44	5.78	8.42	3.14	4.17	4.78	1.73	2.22	1.65	1.78	2.44	2.17	3.77
ICSH 153 (CSH 11)	6.77	4.81	7.51	7.16	11.97	1.84	3.02	5.44	3.00	4.70	3.78	4.27	1.74	4.04	5.00
Local	2.91	5.51	5.81	4.94	6.93	2.61	3.81	5.22	2.68	2.36	2.89	2.76	0.29	2.58	3.66
SE	±0.36	±0.77	±0.38	±0.38	±1.14	±0.31	±0.24	±0.28	±0.27	±0.29	±0.15	±0.48	±0.18	±0.22	±0.12
Trial mean (25 entries)	4.21	4.12	5.59	5.73	9.53	2.12	3.43	4.59	2.18	2.73	2.74	2.03	1.78	2.35	3.79
CV (%)	15	32	12	12	21	25	12	11	22	18	10	41	17	16	-
Efficiency (%)	101	108	170	105	91	96	101	99	101	99	105	122	114	100	-

1. 5 × 5 Lattice, plot sizes range from 3.50 to 11.25 m^2.
2. Locations:
   1 = ICRISAT Center, and 2 = Adoni, Andhra Pradesh; 3 = Bhavanisagar, Tamil Nadu; 4 = Dharwad, Karnataka; 5 = Jalna, Maharashtra; 6 = Kanpur, and 7 = Pantnagar, Uttar Pradesh; 8 = Surat, Gujarat; and 9 = Kovilpatti, Tamil Nadu.
3. 10 = Yousufwala; 11 = Dadu; and 12 = Islamabad.

yield across locations. Among the varieties, ICSV 219 gave the highest mean grain yields across locations (4.2 t ha^{-1}) compared to ICSV 1 (SPV 351) (3.8 t ha^{-1}). Variety ICSV 112 (SPV 475) gave the highest yield (3.09 t ha^{-1}) across locations in Pakistan compared to 2.68 t ha^{-1} for the local variety.

Asian Regional Sorghum Hybrid Adaptation Trial (ARSHAT 86)

ARSHAT 86 consisted of 25 entries including a local control, Hageen Durra, an ICRISAT-bred hybrid released in the Sudan and ICSH 153 (CSH 11), an ICRISAT-bred hybrid released in India. We distributed sets of ARSHAT 86 seed to our cooperators in Asia. These were evaluated at 10 locations in India, 5 in Pakistan, and 1 in Thailand. Mean grain yields of the selected high-yielding entries from 12 locations are presented in Table 24.

ICSH 110 (SPH 296) gave the highest mean grain yields (4.96 t ha^{-1}) across locations whereas the control hybrid ICSH 153 (CSH 11) yielded 4.79 t ha^{-1}. ICSH 110 (SPH 296) gave the highest yields (4.96 t^{-1}) across locations in Pakistan whereas ICSH 153 (CSH 11) yielded 4.14 t ha^{-1}. Hageen Durra produced low grain yields (3.42 t ha^{-1}) across Asian locations.

Table 24. Mean grain yield (t ha^{-1}) of top-yielding sorghum entries in the Asian Regional Sorghum Hybrid Adaptation Trial (ARSHAT 86), 1986[1].

	Indian location[2]								Thai location[3]				
Entry	1	2	3	4	5	6	7	8	9	10	11	12	Mean
ICSH 120	6.03	5.98	14.48	5.12	3.78	3.26	2.85	1.76	2.70	6.93	2.57	4.03	4.96
ICSH 281	7.43	7.03	8.69	4.52	3.85	2.91	3.79	2.33	4.42	6.83	1.81	4.76	4.86
ICSH 110	6.44	6.90	8.47	3.73	4.88	2.96	4.95	1.63	3.32	7.53	3.05	4.29	4.85
ICSH 106	7.39	6.89	8.21	3.75	3.76	3.05	4.90	1.57	4.32	6.59	2.91	4.50	4.82
ICSH 205	6.06	7.37	9.23	4.37	4.38	3.00	5.01	1.72	3.54	6.92	2.49	3.65	4.81
ICSH 138	7.41	6.14	11.45	4.11	3.69	2.67	4.02	2.24	4.08	7.67	1.38	2.73	4.80
ICSH 109	6.33	5.57	10.19	3.45	4.11	2.14	5.18	2.30	2.87	7.32	3.49	3.23	4.68
ICSH 116	6.77	6.61	10.54	3.16	3.07	3.33	4.81	2.24	2.91	6.18	1.64	3.36	4.55
ICSH 203	7.61	7.00	8.92	3.56	4.04	2.92	3.30	1.72	4.40	5.32	2.59	0.83	4.41
ICSH 204	6.71	6.97	10.20	3.55	3.90	2.76	4.20	1.57	2.63	5.90	1.91	1.91	3.54
Controls													
ICSH 153 (CSH 11)	6.29	6.33	10.05	4.22	4.23	2.98	3.95	3.09	3.90	6.33	2.79	3.32	4.79
Hageen Durra	5.60	4.96	9.12	2.67	1.92	2.52	3.33	0.72	1.85	3.91	1.56	2.81	3.42
Local	6.01	5.44	15.03	4.21	1.99	2.39	5.39	2.41	1.69	3.45	3.66	0.87	4.38
SE	±0.63	±0.39	±1.05	±0.41	±0.40	±0.33	±0.24	±0.18	±0.23	±0.36	±0.11	±0.67	±0.14
Trial mean (32 entries)	6.28	6.25	9.61	3.56	3.33	2.78	4.32	1.72	2.91	5.63	2.14	3.04	-
CV (%)	17	11	19	20	21	20	10	19	14	11	9	38	-

1. 1. Randomized block design, plot sizes range from 3.06 to 11.25 m^2.
2. Locations:
India: 1 = Bhavanisagar, Tamil Nadu; 2 = Dharwad, Karnataka; 3 = Jalna, Maharashtra, 4 = Kanpur, Uttar Pradesh; 5 = ICRISAT Center, Andhra Pradesh; 6 = Pantnagar, Uttar Pradesh; 7 = Surat, Gujarat; and 8 = Kovilpatti, Tamil Nadu.
3. Thailand: 9 = Khon Kaen. Pakistan: 10 = Yousufwala, 11 = Dadu, and 12 = Islamabad.

West African Sorghum Adaptation Trials and Nursery

We organized three regional sorghum adaptation trials during 1987: West African Sorghum Variety Adaptation Trial—Early maturity (WASVAT—Early), West African Sorghum Variety Adaptation Trial—Medium maturity (WASVAT—Medium), and West African Sorghum Hybrid Adaptation Trial (WASHAT). WASVAT—Early had 20 entries including controls and the entries were contributed by ICRISAT and the national programs of Cameroon, Ghana, Mali, Niger, and Senegal. Seeds were distributed to cooperators located in 10 countries of the region. WASVAT—Medium had 20 entries including controls and the entries were contributed by ICRISAT and the national programs of Burkina Faso, Cameroon, Mali, and Niger. Seeds were distributed to cooperators located in 14 countries of the region. WASHAT had 25 entries including controls, the entries of which were supplied to cooperators located in 7 countries of the region.

Seeds of a regional nursery, West African Sorghum Disease Resistance Nursery (WASDRN) were also supplied to the national programs of Côte d'Ivoire, Mali, and Niger. The results of regional trials and nurseries from several locations are awaited.

West African Sorghum Hybrid Adaptation Trial (WASHAT)

We received complete data on WASHAT 87 from all the cooperators who conducted the trial at 15 experimental stations located in seven countries of West Africa. Grain yield data from 10 of the test locations is presented in Table 25. Mean grain yield of the trial was higher than 3 t ha^{-1} at 4 of the 10 locations. ICSH 336 was ranked first for mean grain yield (2.8 t ha^{-1}). Other promising hybrids with relatively higher grain yields and top ranks at various locations were: ICSH 643, ICSH 642, ICSH 479, ICSH 229, ICSH 507, ICSH 230, and ICSH 647. Test hybrids ICSH 229 and ICSH 230 also obtained top ranks for grain yields in WASHAT 86 (ICRISAT West Africa programs Annual Report 1986, p.120).

In general, the controls gave lower yields than the test hybrids at most of the locations. Overall mean time to 50% flowering of the trial across locations was 68 days and mean plant height was 1.85 m.

Central America and Mexico Multilocational Hybrid and Variety Trial

We carried out multilocational testing of our best hybrids and varieties in Central America and Mexico under dryland conditions. Sepon 77 bulk variety was superior ($P < 0.05$) to the others, with an average yield of 7.2 t ha^{-1}, while the hybrid 1399A × VG 28 gave the best yield of 4.2 t ha^{-1} among hybrids.

Seed Distribution

ICRISAT Center

In response to seed requests, we provided improved varieties, hybrids, parents of hybrids, and resistant sources to our cooperators. By the end of December 1987, we had supplied 9365 samples of sorghum seeds. In Asia, India received the maximum number (1908), followed by Pakistan (1012), the Philippines (587), the People's Republic of China (456), Burma (321), and Thailand (294). In Africa, 1526 samples were supplied to Burkina Faso, 587 to Zimbabwe, 438 to Zaire, 345 to Kenya, and 177 to Cameroon. The Central American-Mexican-Caribbean network supplied 438 samples to Mexico, and 103 to countries in the Caribbean.

West Africa

In Burkina Faso, several organizations involved in on-farm research and testing received large quantities of seeds of ICSV 16-5 BF, ICSV 1002 BF, and ICSV 1001 BF (Framida). The national agricultural research institute, Institut national d'études et de recherches agricoles (INERA), used a number of promising entries (S 34, ICSV 111 IN, ICSV 2 IN, ICSV 126 IN, ICSV 247 IN, ICSV 1 BF (E 35-1), ICSV 1001 BF (Framida), and ICSV 1002 BF on highway demonstrations for public information on advances made in sorghum research.

We sent a number of *Striga*-resistant varieties to East African countries and the UK for testing

Table 25. Mean grain yield (t ha^{-1}) of test sorghum hybrids in the West African Sorghum Hybrid Adaptation Trial (WASHAT 87), conducted at ten locations in West Africa, rainy season 1987[1].

	Locations[2]										
Hybrid	1	2	3	4	5	6	7	8	9	10	Mean
ICSH 336	3.90	3.26	1.81	3.15	3.11	4.33	2.61	1.05	3.72	1.04	2.80
ICSH 232	3.28	3.51	2.07	3.42	2.56	4.72	1.64	1.01	4.29	0.98	2.75
ICSH 643	3.92	3.81	1.53	1.89	2.49	3.73	2.38	0.98	5.58	0.89	2.72
ICSH 642	3.39	3.34	1.92	1.70	2.75	2.87	3.16	1.44	4.90	0.98	2.64
ICSH 479	3.08	3.17	1.54	1.80	2.51	3.72	1.98	0.98	6.31	1.11	2.62
ICSH 229	3.12	3.23	1.52	3.15	2.73	3.55	2.27	1.17	3.92	1.44	2.61
ICSH 230	3.33	3.14	1.63	2.94	2.79	3.38	1.92	1.07	4.06	1.32	2.56
ICSH 647	3.30	3.55	0.93	2.24	2.85	4.33	1.35	0.83	5.35	0.80	2.55
ICSH 507	4.24	3.63	1.34	1.71	2.62	3.21	2.10	1.03	4.41	1.17	2.55
ICSH 231	3.38	3.27	1.69	2.16	2.78	3.28	2.23	1.25	4.04	1.17	2.52
ICSH 401	3.02	3.23	1.68	3.02	2.59	3.45	1.95	1.22	4.01	1.46	2.46
ICSH 644	3.66	3.77	0.97	2.10	2.42	4.09	0.97	1.03	4.76	0.74	2.45
ICSH 569	3.43	3.33	1.48	1.49	2.73	3.73	1.74	1.22	3.97	1.21	2.43
ICSH 233	2.45	2.86	1.81	2.39	2.74	3.93	1.76	1.10	4.37	0.49	2.39
ICSH 645	3.67	3.40	1.01	1.55	2.46	3.08	0.84	1.24	5.32	0.99	2.36
ICSH 648	2.96	3.00	0.81	3.04	2.74	3.57	1.71	0.92	3.91	0.90	2.36
ICSH 646	3.63	3.32	1.03	1.53	2.62	3.88	1.60	0.88	3.74	0.69	2.29
ICSH 526	3.14	3.22	1.06	0.93	2.79	4.37	0.59	1.10	4.54	0.78	2.25
ICSH 331	3.55	3.03	1.33	1.38	2.80	2.99	1.48	1.10	3.64	1.06	2.24
ICSH 461	2.97	3.28	0.71	1.52	1.60	3.19	1.00	1.12	3.81	0.65	1.98
Controls											
ICSH 109	2.26	3.65	1.50	1.24	2.23	3.24	0.98	1.16	4.03	0.94	2.12
Hageen Durra	0.93	2.21	1.23	2.01	2.45	3.09	0.71	1.12	2.91	0.70	1.74
ICSV 1001 BF (Framida)	2.80	2.31	0.69	1.31	0.49	3.07	2.49	1.05	2.59	0.93	1.77
Naga White	3.24	3.50	1.10	1.23	2.20	3.97	1.86	0.91	3.09	1.19	2.23
Local	1.35	2.40	0.92	0.72	1.95	2.54	1.98	1.12	5.58	0.60	-
SE	±0.27	±0.25	±0.21	±0.39	±0.29	±0.39	±0.31	±0.06	±0.65	±0.13	
Mean	3.12	3.22	1.33	1.94	2.48	3.57	1.73	1.08	4.82	0.97	
CV (%)	15	14	30	35	20	19	31	10	26	35	

1. 5 × 5 lattice experiment with 3 replications, net plot size was either 7.5 or 8 m^2.
2. Locations:
 1 = Farako-Bâ, 2 = Saria, 3 = Fada, 4 = Gampela, 5 = Kolo, 6 = Sotuba, 7 = Ferke, 8 = Dapaong, 9 = Maroua, and 10 = Bouake.

against a wide range of *Striga* samples. The Food and Agricultural Organization of the United Nations (FAO) in Rome and the United States Agency for International Development (USAID) in Haiti received seeds of promising varieties for evaluation.

Eastern Africa

We supplied two sets of sorghum varieties, one for lowland (from the ICRISAT/Mexico program) and the other for highland conditions (from the EARSAM and ICRISAT Center material) to Burundi, Kenya, Mexico, Rwanda, and Uganda. We supplied sorghum varieties to the Institute for Agricultural Research (IAR), Ethiopia, to be evaluated for resistance to *Striga hermonthica* at three different sites in *Striga*-sick plots. SAR 24, ICSV 1001 BF (Framida), Tetron, and ICSV 1006 recorded high levels of resistance to *Striga hermonthica*. N 13, Seredo, and SR 16 DCHN were moderately resistant. Sorghum drought-tolerant selections made at the Kiboko research station were also sent to Zimbabwe and Somalia. We also supplied one set of experimental and elite sorghum hybrids each to Kenya and Somalia.

Central America, Mexico, and the Caribbean

During 1987, we fulfilled 160 requests for seed from collaborators in Africa, the Caribbean, Europe, Latin America, and the USA. These requests represented 967 individual lines and a total of 1.642 t of seed.

ICRISAT Cultivars Released or in Prerelease Stage

The ICRISAT-bred variety ICSV 112 (SPV 475) was recommended for release by the AICSIP workshop for general cultivation in India. Our other variety ICSV 145 (SAR 1), which is resistant to *Striga asiatica*, was also recommended for release by the AICSIP workshop for cultivation in *Striga*-endemic areas in India.

In Mexico, the variety ICSV 112 (SPV 475) was released as UANL-I-187 by the University of Nuevo Leon, Mexico. ICSV 112 (SPV 475) and ICSV 1 (SPV 351) have also been proposed for release in Malawi where a 2-year yield average of 3.1 t ha^{-1} of ICSV 112 (SPV 475) and 2.8 t ha^{-1} of ICSV 1 (SPV 351) exceeded the yield of the local PN 3 of 1.7 t ha^{-1}. Other ICRISAT materials released in 1987 in Mexico are Blanco 86 (ISIAP Dorado) by Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP) and M 90362 released as UANL-I-287 by the University of Nuevo Leon. We gave technical help and R-line seed (M 90362) to Agroconsa private seed company which enabled them to identify and release the hybrid ATx 625 × M 90362 as Agroconsa 1.

In Ethiopia, a selection from an ICRISAT-bred sorghum variety ICSV 1 (SPV 351), (SC 108-3 × CS 3541)-19-1 was released as Dinkmash by the Institute of Agricultural Research. In Zambia, a sorghum hybrid based on an ICRISAT-bred female parent ICSA 104 (SPL 177A) was released. In Swaziland, five entries from ISVAT 85 (ICSV 110, ICSV 132, ICSV 2, ICSV 112, and ICSV 162) have been selected for seed multiplication at the Big Bend Station where the two highest-yielding varieties will be selected for prerelease. From 2 years of testing in Mozambique, seven introductions were found promising, of which IS 857 and Mz 84 WI 58 (SDS 3220) are now in the national seed multiplication program.

In other parts of Africa, ICSV 1002 BF is in prerelease stage in the Gambia. ICSV 1001 BF (Framida) was tested by the Global 2000 project in northern Ghana in an attempt to popularize this variety, that has been extensively tested in that country. In Sudan, ICSV 1007 BF and IS 9830, the two *Striga*-resistant varieties, were in on-farm testing in irrigated projects with financial assistance from the International Development Research Centre (IDRC). ICSV 16-5 BF entered pre-extension trials in Burkina Faso.

Workshops, Conferences, and Seminars

ICRISAT Center

International Workshop on Sorghum Stem Borers

Over 35 scientists from 12 nations gathered at ICRISAT Center from 17 to 20 November to confer with about 20 ICRISAT scientists on insect pest management strategies relating to sorghum stem borers. The Workshop brought together entomologists and breeders from Burkina Faso, Cameroon, El Salvador, France, India, Kenya, Nigeria, Somalia, Sudan, UK, USA, and Zimbabwe, to discuss the latest advances in research on stem borers of sorghum, and related crops such as maize, rice, and pearl millet. The Workshop also provided regional reports from developing countries. Given the importance of host-plant resistance to stem borers in pest-management strategies, emphasis was placed on identifying and utilizing genetic sources to develop resistance to these pests, in preference to the use of pesticides.

At the plenary session, the Workshop recognized that as resources were meager, the various international organizations working on stem borers should collaborate in their research to avoid duplication of efforts.

West Africa

Meetings of the Steering Committee of the West and Central African Sorghum Research Network (WCASRN)

Two Steering Committee meetings were held in Ouagadougou, 11-12 March and 15-17 December. The Committee is comprised of four elected national scientists, one each from Côte d'Ivoire, Mali, Niger, and Nigeria, and the Coordinator from Semi-Arid Food Grain Research and Development (SAFGRAD)/ICRISAT. SAFGRAD, Institut du Sahel (INSAH), and Institut de recherches agronomiques tropicales et des cultures vivrières (IRAT) are represented on the Committee as observers. A number of issues affecting the national programs on sorghum research were reviewed.

Monitoring Tour

The third monitoring tour under the aegis of WCASRN was conducted in Burkina Faso, 30 September–3 October. Representatives from the national programs in Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, the Gambia, Ghana, Niger, Nigeria, Senegal, and Togo participated in the tour; four scientists from Mali also joined the group for part of the tour. The participants monitored current sorghum research activities in the national program, and the ongoing research work in the ICRISAT West African Regional Program. Three research stations were visited: Farako-Bâ, Saria, and Kamboinsé. The participants found the tour useful and they selected many promising cultivars and asked for seeds.

Training Workshop on *Striga* Control and Screening

This workshop, the first of its kind, was organized under the aegis of the WCASRN, and was held in Ouagadougou, 5-10 October. There were 12 participants from 11 countries: Burkina Faso, Cameroon, the Gambia, Ghana, Kenya, Mali, Niger, Nigeria, Sudan, Togo, and Uganda. In addition to ICRISAT scientists, specialists from IRAT, Sudan, and Old Dominion University, USA, assisted in the training.

Southern Africa

Sorghum Monitoring Tour/Workshop

This monitoring tour/workshop was conducted from 20–31 March. Thirteen participants from Malawi, Mozambique, Swaziland, Tanzania, and Zimbabwe, and five scientists from the Regional Program and one from the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL) participated. Sorghum nurseries and trials in nine locations in Zambia and Zimbabwe were monitored for varietal performance and adaptation.

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

This workshop was held at Matopos, Bulawayo, Zimbabwe, 21-24 September. There were 47 participants representing all the national programs of the region and various agricultural research divisions. The main objective of the workshop was to exchange ideas and updates on current research results from national and regional trials and to plan activities for 1987/88. Issues on present and future training of national program staff were also discussed.

The meeting recognized that interaction between national programs of the SADCC countries and the SADCC/ICRISAT program had steadily improved.

Eastern Africa

Short Course on Seed Production

A short course was organized jointly by EARSAM and SADCC from 13-18 September in Nairobi, Kenya, for national program scientists primarily concerned with seed production and crop improvement. The main objective was to help participants become better acquainted with current seed production and technology research in eastern and southern Africa.

Over 50 participants from 13 countries (Botswana, Burundi, Ethiopia, Kenya, Lesotho, Malawi, Rwanda, Somalia, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe) were present. Experts from INTSORMIL, FAO, the International Centre of Insect Physiology and Ecology (ICIPE), Centro Internacional de Mejoramiento de Maîz y Trigo (CIMMYT), the Uganda Seed Scheme, and private sector seed companies also attended and presented relevant papers on seed production.

The group recognized several issues of particular importance including seed quality, training, and the regional movement of seed.

Participants from national programs gained a better understanding of the range of activities in seed-program development to be able to respond more effectively to seed problems in their respective countries. Participants also visited the Kenya Seed Company in Kitale. A second joint short course is planned for 1989.

Central America, Mexico, and the Caribbean

Seventy scientists attended the joint Comision Latinoamericano de Investigadores en Sorgo (CLAIS)/INTSORMIL meeting on local photosensitive sorghums held in Honduras in December. This meeting allowed interaction with regional scientists, and fostered excellent working relationships between INTSORMIL, ICRISAT, and CLAIS.

The ICRISAT regional staff attended the 33rd Annual Meeting of the Cooperative Program for the Improvement of Crops and Animals (PCCMCA) held in Guatemala in April and presented 10 papers based on ICRISAT/National Programs collaborative research.

Publications

Institute Publications

Plant Material Description

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Midge-resistant sorghum variety ICSV 197. Plant Material Description no. 11. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-128-3. (PME 011)

Book

House, L.R. 1987. Manuel pour la sélection du sorgho. 2ème éd. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 240 pp. 45 ref. ISBN 92-9066-085-6. (BOF 002)

Journal Articles

Agrawal, B.L., Sharma, H.C., and **Leuschner, K.** 1987. Registration of 'ICSV 197' midge resistant sorghum cultivar. Crop Science 27(6):1312-1313. (JA 659)

Bandyopadhyay, R., Mughogho, L.K., and **Satyanarayana, M.V.** 1987. Systemic infection of sorghum by *Acremonium strictum* and its transmission through seed. Plant Disease 71(7):647-650. (JA 622)

House, L.R. 1987. Sorghum–present status and future potential. Outlook on Agriculture 16(1):21-27. (JA 711)

Murty, D.S., and **Nicodemus, K.D.** 1987. Interallelic relations among endosperm variants in sorghum. Journal of Heredity 78:391-394. (JA 594)

Nambiar, P.T.C., Rego, T.J., and **Srinivas Rao, B.** 1987. Comparison of the requirements and utilization of nitrogen by genotypes of sorghum (*Sorghum bicolor* (L.) Moench), and nodulating and non-nodulating groundnut (*Arachis hypogaea* L.). Field Crops Research 15(2):165-179. (JA 535)

Reddy, Belum V.S., Seetharama, N., and **House, L.R.** 1987. Sorghums in the post-rainy season. 1. Effect of irrigation and date of sowing on the grain and stover yields of diverse cultivars. Experimental Agriculture 24:31-36. (JA 412)

Sharma, H.C., and **Leuschner, K.** 1987. Chemical control of sorghum head bugs (Hemiptera: Miridae). Crop Protection 6(5):334-340. (JA 662)

Subramanian, V., Prasada Rao, K.E., Mengesha, M.H., and **Jambunathan, R.** 1987. Total sugar content in sorghum stalks and grains of selected cultivars from the world germplasm collection. Journal of the Science of Food and Agriculture 39(4):289-295. (JA 279)

Woodhead, S., and **Taneja, S.L.** 1987. The importance of the behavior of young larvae in sorghum resistance to *Chilo partellus*. Entomologia Experimentalis et Applicata 45:47-54. (JA 636)

Conference Papers

Krishna, K.R., and **Lee, K.K.** 1987. Management of vesicular arbuscular mycorrhiza in tropical cereals. Pages 43-45 *in* Mycorrhiza in the next decade: practical applications and research priorities: proceedings of the Seventh North American Conference on Mycorrhiza, 3-8 May 1987, Gainesville, FL, USA (Sylvia, D.M., Hung, L.L., and Graham, J.H., eds.). Gainesville, FL, USA: Institute of Food and Agricultural Sciences, University of Florida. (CP 364)

Peacock, J.M. 1987. ICRISAT's sorghum research in the semi-arid tropics. Pages 15-33 *in* Sorghum for acid soils: proceedings of a Workshop on Evaluating Sorghum for Tolerance to Al-toxic Tropical Soils in Latin America, 28 May-2 Jun 1984, Cali, Colombia. Cali, Colombia: Centro Internacional de Agricultura Tropical. (CP 194)

Ramaiah, K.V. 1984. Physiological specialization of *Striga hermonthica* and crop specificity. Pages 58-65 *in* Proceedings of the Third International Symposium on Parasitic Weeds, ICARDA/International Parasitic Seed Plant Research Group, 7-9 May 1984, Aleppo, Syria (Parker, C., Musselman, L.J., Polhill, R.M., and Wilson, A.K., eds.). Aleppo, Syria: International Center for Agricultural Research in the Dry Areas. (CP 171).

Seetharama, N., Krishna, K.R., Rego, T.J., and **Burford, J.R.** 1987. Prospects for sorghum improvement for phosphorus efficiency. Pages 229-249 *in* Sorghum for acid soils: proceedings of a Workshop on Evaluating Sorghum for Tolerance to Al-toxic Tropical Soils in Latin America, 28 May-2 Jun 1984, Cali, Colombia. Cali, Colombia: Centro Internacional de Agricultura Tropical. (CP 196)

Seetharama, N., Prasada Rao, K.E., Subramanian, V., and **Murty, D.S.** 1987. Screening for sweet stalk sorghums, and environmental effect on stalk sugar concentrations. Pages 169-179 *in* Technology and applications for alternate uses of sorghum: proceedings of the National Seminar, 2-3 Feb 1987, Parbhani, India. Parbhani, Maharashtra 431 402, India: Marathwada Agricultural University. (CP 308)

Sharma, H.C. 1987. Insect pests of sorghum and their management. Pages 121-134 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 263)

Subramanian, V., Jambunathan, R., and **Prasada Rao, K.E.** 1987. Dry milling characteristics of sorghum grains and their relationship to product quality. Pages 45-54 *in* Technology and applications for alternative uses of sorghum: proceedings of the national seminar, 2-3 Feb 1987, Marathwada Agricultural University, Parbhani, India. Parbhani, Maharashtra 431 402, India: Marathwada Agricultural University. (CP 346)

Thesis

Mao, Mohamed Ahemed. 1987. The effect of planting dates and irrigation on the yield of two rainy season sorghum cultivars. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 110 pp.

CEREALS
PEARL MILLET

Contents

Cover photo: Breeder's seed of pearl millet ICMA 1 (81A) under multiplication at ICRISAT Center, dry season 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

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

PEARL MILLET

ICRISAT's research efforts on pearl millet have attained a degree of maturity, as is evident by the significant acreage of ICRISAT varieties now grown in India, and the number of our varieties presently under test or in seed production by National Programs in India and several African countries. Despite this, and in order to continue to make an impact on pearl millet research and production, we regularly assess our research projects and make changes whenever necessary. Willingness to try new ideas and methods and to shift resources away from ineffective projects are characteristics we value in our program. A significant part of our annual report for 1987 reflects this process of change and innovation.

In 1986 we decided to focus our entomological research in West Africa on the millet stem borer [*Coniesta (Acigona) ignefusalis*], as it appears that the opportunities for finding resistance to this pest are greater than they are for the other pests that affect pearl millet. This has already helped us to better understand the biology of this insect and significantly improve methods of field screening and evaluation of pest infestation.

We moved the main location of our pathology research in West Africa to a more favorable site and installed a sprinkler irrigation system to ensure conditions conducive to disease development. As a consequence, we are now able to reliably screen our West African breeding material for downy mildew resistance, an absolute prerequisite when breeding for resistance. In India, we developed a method of screening pearl millet seedlings for downy mildew resistance in the greenhouse. This procedure will not entirely replace field screening, but it provides a very efficient method of discarding early-generation breeding material susceptible to the disease before it is even sown in the field. One greenhouse bay of 55 m^2 substitutes for several hectares of field plots and saves a season in the breeding processes.

Research in physiology initially concentrated on empirical, field-level screening methods for assessing genotype response to drought and temperature stresses. With such screening now in operation, we are able to better understand why certain genotypes are more tolerant of stress than others in these field evaluations. Research projects are now looking directly at differences in critical maximum temperatures for seed germination (above the optimal range), at differences in seedling root-growth characteristics, and at reasons for differences in grain filling under drought stress.

We concluded our research on nonsymbiotic nitrogen fixation in pearl millet as our data indicate that this phenomenon does not contribute sufficient nitrogen to crop growth to make a major impact on production. Staff and resources in this project were transferred to work on more general problems of plant nutrition within the Resource Management Program (RMP).

We reviewed our progress in breeding open-pollinated varieties at ICRISAT Center. Data indicate that varieties produced by the recombination of inbred lines (synthetic varieties) are not yielding so well as varieties produced from progenies of the composites. We therefore greatly reduced our synthetic variety project, and put more resources into expanding the genetic diversification project, through the creation of populations with such desirable plant characters as high tillering.

We also improved the way in which we select and evaluate new genetic variability for the hybrid breeding program. This involves the creation of a series of potential pollinator and male-sterile (ms) line nurseries, where we systematically evaluate material for all the characteristics that are required in successful hybrid parents. This assures that any test cross we make is a potential new hybrid.

Our breeding program at the ICRISAT Sahelian Center (ISC) now concentrates almost exclusively on exploiting crosses among superior germplasm lines from across the whole West African region, whose recombination has yet to be exploited. The effort is being assisted by a collaborative research project on the genetic structure of pearl millet in West Africa, and the degree of genetic distance between populations of both wild and cultivated *Pennisetum* across Africa.

In the West African regional breeding program, there is now more emphasis evaluating genetic material for response to a range of biotic and physical stresses, to ensure that breeding material does possess the required adaptation to Sahelian conditions. We are also assisting national programs develop the same capacity to assess their breeding materials for response to stress.

We believe that this willingness to change research direction, and redeploy resources will ensure that we continue to maintain an effective research program, and that our collaborators will continue to receive a flow of adapted genetic material and research methods in the years to come.

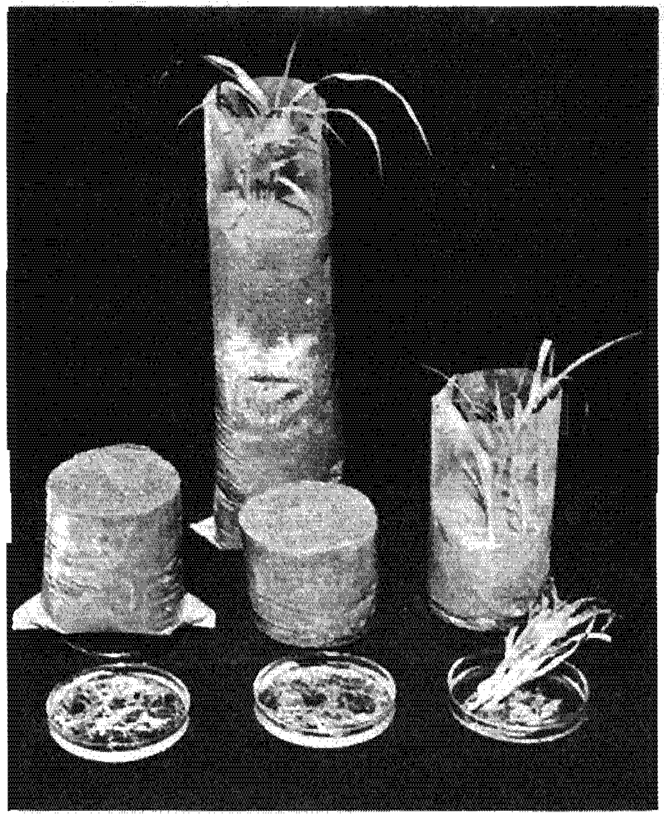


Figure 1. Seedling root growth-rate study methodology (background), an intact plastic tube containing pearl millet seedlings (center), a tube divided into three layers, and (foreground), root samples from each layer, ICRISAT Center, 1987.

Physical Stresses

Crop Establishment

Moisture Deficit Tolerance during Emergence

Poor seedling emergence frequently results from lack of sufficient seedbed moisture at the time of sowing, but there is genotypic variation in pearl millet for emergence ability under conditions where moisture is scarce.

We compared seedling growth rates in three genotypes (IP 3288, IP 11217, and IP 9365) that emerged in deficit moisture conditions in the field and three genotypes (IP 3349, IP 3275, and IP 5300) that failed to emerge under these conditions. They were sown in 30-cm long columns of Alfisol in 10-cm diameter polythene tubes with two levels of water applied at sowing: 30 mm (control) and 20 mm (stress). We used sequential samplings of the seedlings from 2 days after sowing (DAS) to 13 DAS to estimate the growth rates of roots and shoots. At each sampling, the soil column was divided into three equal vertical zones, the roots were washed from each zone, and their lengths and dry masses measured (Fig. 1).

Both root and shoot growth rates and final (13 DAS) root lengths were significantly greater in the control than in the stress treatment. In the top (0–8 cm) soil zone, final root length in the stress treatment was 141 mm seedling^{-1} compared to 180 mm seedling^{-1} in the control treatment, a reduction of 22%. Reductions were also evident in the 9–16 cm zone (9%) and the 17–24 cm zone (6%).

There were no significant (P=0.05) differences between the tolerant and susceptible groups of genotypes in mean root growth rate in the control treatment. In contrast, the mean root growth rate of the tolerant group in the stress treatment was 26 mm d^{-1} compared to a growth rate of 19 mm d^{-1} in the susceptible group (Table 1). The differences between the two groups were greater in the drier upper soil layers. For example, in the 0–8 cm zone, the decrease in root growth rate in the stress treatment in the tolerant genotypes was only 11% of the rate in the control treatment, compared to a 50% reduction in growth rate in the susceptible genotypes. Similarly, in the 9–16 cm zone, the tolerant genotypes had the same root growth rate in both treatments compared to a decrease of 27% in the stress treatment in the susceptible group (Table 1).

These observations suggest that maintenance of root growth rates in a drying seedbed soil may be an important factor in tolerance of such conditions.

Table 1. Mean root growth rates of pearl millet genotypes tolerant and susceptible to low seedbed moisture conditions. ICRISAT Center, dry season 1987.

Soil zone	Mean soil moisture (%)	Mean root growth rate ($mm\ d^{-1}$) Tolerant	Susceptible
0–8 cm zone			
Control	6.3	10.6	10.2
Stress	4.7	9.4	5.1
SE		±1.09	
9–16 cm zone			
Control	11.2	12.0	13.6
Stress	8.8	12.0	9.9
SE		±0.66	
17–24 cm zone			
Control	14.5	6.7	4.2
Sress	9.7	6.4	4.5
SE		±0.56	
0–24 cm (mean)			
Control	10.7	28.0	27.7
Stress	7.7	26.0	18.9
SE		±1.84	

Seed Source Effects on Establishment

We compared the effect of the methods and environment, of seed multiplication on the survival of seedlings in the seedling drought screen (ICRISAT Annual Report, 1986, p. 71). Seed lots of four genotypes, multiplied in various environments, or multiplied at the same time under the same conditions, were tested in a number of seedling screens. The survival of each genotype was plotted against the mean survival of all four genotypes for each test environment. Apparent 'genotypic' differences observed in seed lots from different multiplication environments (Fig. 2a) were markedly reduced when the seed lots were multiplied in the same environment (Fig. 2b). Furthermore, differences between genotypes when multiplied under the same conditions, were more apparent when the stress treatment resulted in 20–50% survival at the time of observation rather than in lower levels of survival (Fig. 2).

In a second experiment with 10 genotypes, we compared seed lots produced (a) at two contrasting times of the year (hot season, May 1986, mean daily temperature = 33.4°C; and cold season, December 1986, mean daily temperature = 22.9°C), and (b) by either sibbing or selfing. Mean final seedling survival was greater with the sibbed seed (47.6%) than for the selfed seed (39.8%) for the December seed production season, and greater for the cool season (39.8% for selfed seed) than for the hot season (32.3% for selfed seed).

As these results indicate the importance of seed quality and mode of reproduction on seedling survival under drought stress, we will continue investigations on the comparative importance of seed quality in genotype performance during seedling establishment.

Germination at Supraoptimal Temperatures

We initiated research to develop a laboratory test that would provide an indicator of field performance in the seedling drought screen. We

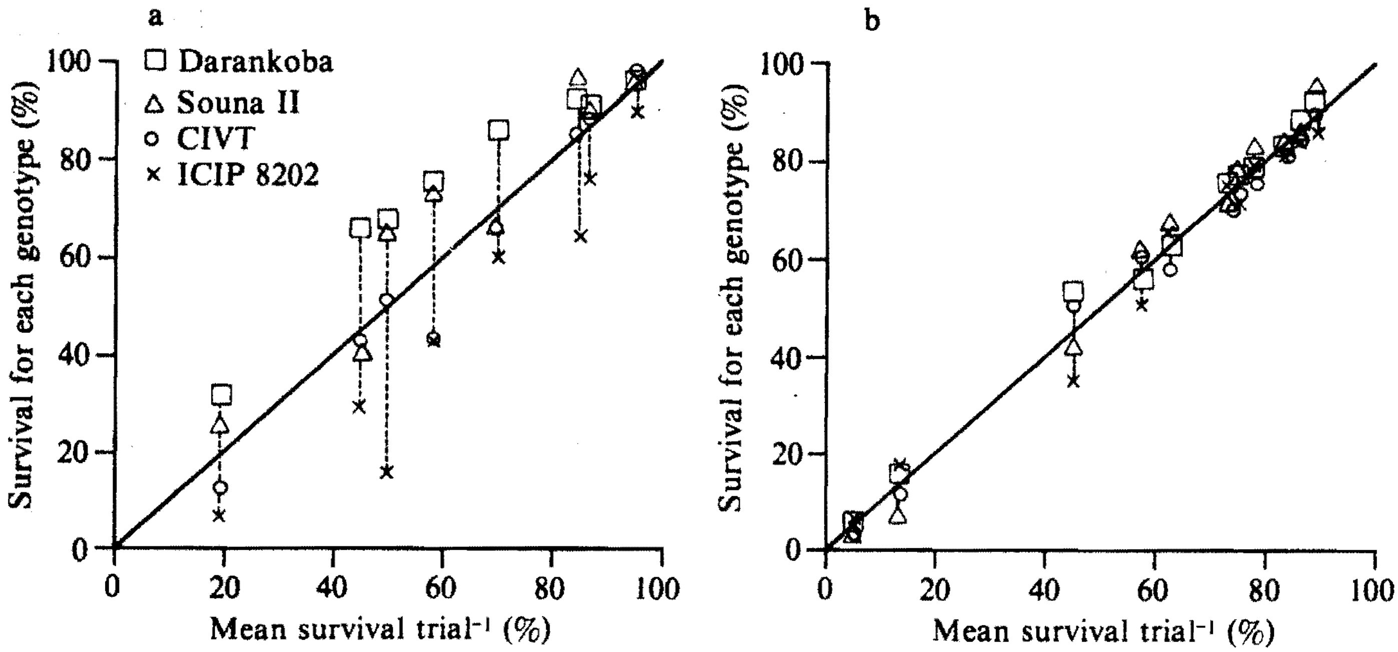


Figure 2. Comparison of spread in survival of four pearl millet genotypes with seed originating (a) from different multiplication environments (1986) and (b) after reproduction under the same environment (1987). ISC, Sadoré, Niger, 1987.

chose to examine the effects of supraoptimal temperatures on the progression of germination in time because high soil temperature occurs concurrently with seedling drought, and temperature controls most aspects of growth. Initially, we measured the progression of germination at supraoptimal temperatures of four genotypes on a temperature-gradient plate at the University of Reading, UK. The progression of germination was first described by the established model:

$$1/t(G)=[T_c(G)-T]/\theta_2(G) \qquad (1)$$

where t(G) is the time taken for cumulative germination to reach percentile G at temperature T, T_c is the maximum temperature or ceiling temperature of germination, and θ_2 is the thermal time at supraoptimal temperatures. The assumption inherent in the development of the equation is a negative linear relationship between 1/t(G) and T at supraoptimal temperatures. We found little difference between the slopes of germination rate on temperature between the 10th and 70th percentiles for the four genotypes, indicating that θ_2 is constant at supraoptimal temperatures for a given seed lot. Where the thermal time within the supraoptimal temperature range does not vary within the seed population, variation in T_c (G) alone accounts for differences in the rate of germination. Assuming thermal time does not vary within a seed population and fitting equation (1) to the different percentiles of G and corresponding T values, we obtained estimates of θ_2 and T_c (50%) (Table 2). Researchers at the University of Reading have found that thermal time also does not vary within a seed lot at supraoptimal temperatures in such crops as chickpea, pigeonpea, soybean, and cowpea, while the variation of T_c (G) within each seed population can be described by the equation:

$$T_c(G)=[K_s-\text{probit}(G)]\sigma \qquad (2)$$

where K_s is an intercept constant at 0° C and σ is the standard deviation of T_c(G) within each population.

The raw data from supraoptimal temperatures was then analyzed by probit analysis of percentage germination in terms of the equation:

$$\text{probit}(G)=K_s+(T+\theta_2/t(G))/\sigma \qquad (3)$$

where dose ($T+\theta_2/t(G)$) or T_C is the maximum temperature for progress to germination. The best estimates (those giving minimum deviation) of θ_2, K_S, and σ were obtained (Table 2) by an iterative routine with probit analysis using different values of θ_2 and the derived T_C values plotted against cumulative germination percentage (Fig.3a-d). The distribution of the estimates of T_C and values of θ_2 differed slightly for the two methods of estimating the data (Table 2). This can be accounted for since all data were used in the second method of analysis, with only a subset in the first method. We found there was a considerable difference between seed lots for the value of thermal time for germination, and ceiling temperatures to 50% germination. This variation between seed lots was confirmed in two larger sets of seed lots (Table 2), as well as the standard susceptible control MBH 110, used in the seedling screen. Furthermore, the value of θ_2 also varied inversely with seed size, i.e., small seeds had larger values.

Whether the difference in seed lots for θ_2 and T_C (50%) is due to genotypic differences or seed quality differences is yet to be determined, although all seed lots from India and Niger were reproduced under the same conditions at those locations.

Table 2. Range in thermal time (θ_2), constant (K_s), standard deviations (σ), and ceiling temperature [T_C(G=50%)] derived from two equations for a range of pearl millet genotypes, multiplication environments, and seed sizes, University of Reading, 1987.

Genotype(s)	Ks	σ	θ_2 (°C d)	T_c (G=50%) (°C)
Equation 1				
Iniadi	-[1]	-	9.9	41.7
Sadoré Local	-	-	6.7	40.0
3/4HK-B78	-	-	7.7	41.7
Darankoba	-	-	6.8	40.0
Equation 3				
Iniadi	7.7	5.4	11.4	41.9
Sadoré Local	11.1	3.6	7.6	40.3
3/4HK-B78	12.3	3.4	7.6	41.8
Darankoba	11.9	3.4	6.6	40.4
Eleven genotypes multiplied in Niger	6.7-15.4	2.8-6.1	3.4-8.0	40.3-43.4
Seven genotypes multiplied in India	3.7-12.2	3.4-13.5	4.0-15.0	49.6-39.6
3/4HK-B78 $1.4<\theta<1.7$[2]	9.1	4.6	5.8	42.0
3/4HK-B78 $1.7<\theta<2.0$	12.2	3.5	4.9	43.0
3/4HK-B78 $2.0<\theta<2.36$	11.1	3.8	4.2	42.3
3/4HK-B78 $2.36<\theta$	11.9	3.5	4.3	42.0
MBH 110	3.7	12.7	15.4	45.5

1. - = Data not available.
2. θ = Diameter in mm, of the sieve used to grade the seedlot.

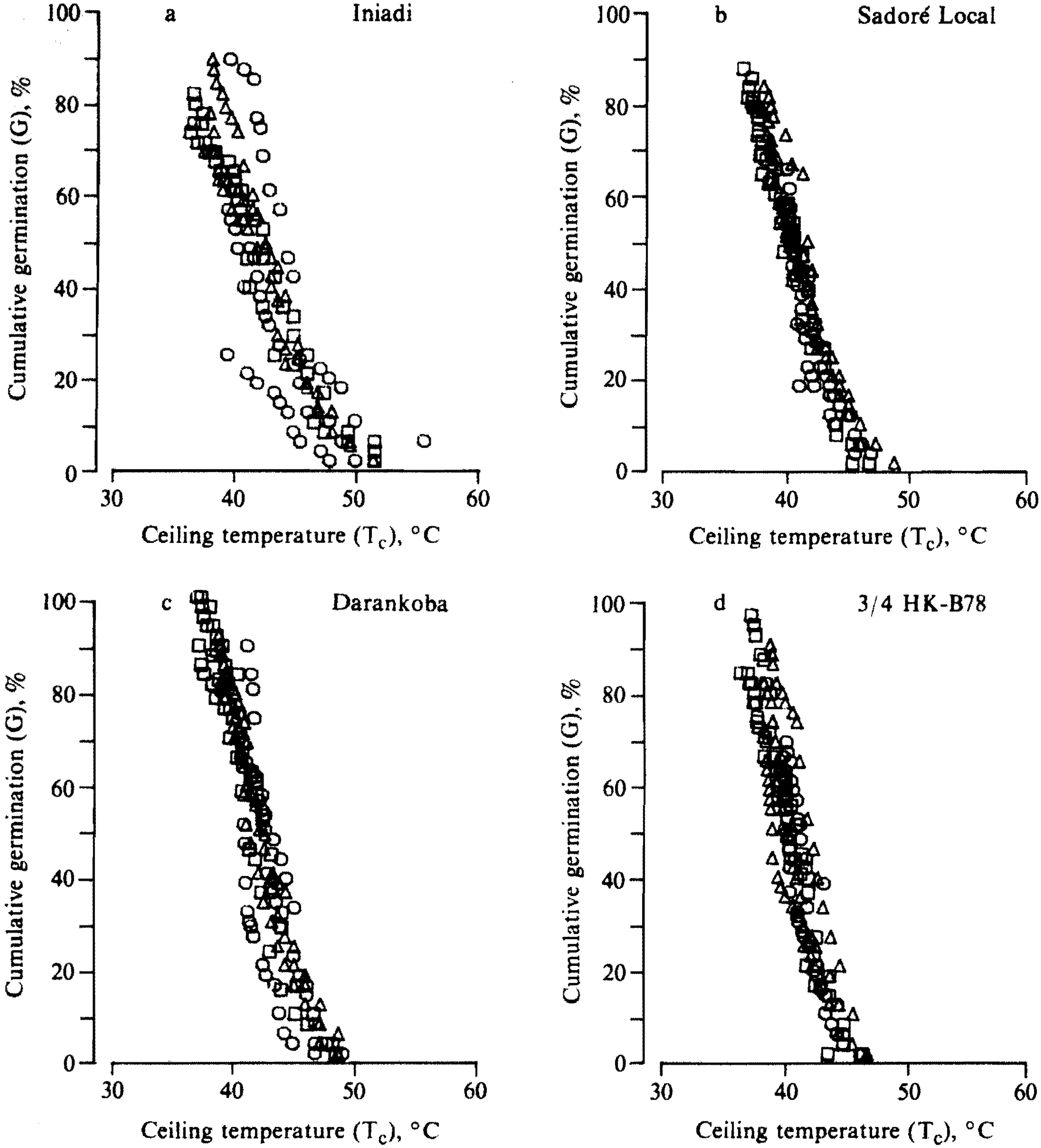


Figure 3. Variation in ceiling temperature [T_c, ° C, where $T_c(G) = T + \theta_2/t(G)$] with cumulative germination (G,%) for four pearl millet genotypes, as derived from equation (3) using probit analysis of the row data, at 36° C (□), 37.8 °C (Δ), and 39.5 °C (o), in which θ_2, K_s and σ are given in Table 1. University of Reading, England, 1987.

Drought Stress

Mechanisms of Tolerance of Terminal Stress

We reported earlier (ICRISAT Annual Report, 1986, pp. 71-75) that maintenance of grain yield per panicle is an important determinant of tolerance of drought stress during the grain-filling stage (terminal stress). Since grain yield per panicle is the product of grain setting and grain filling, we initiated exploratory investigations of both setting and filling under stress, designed to understand the effects of stress on the processes of grain setting-pollination and fertilization, and of grain filling-supply of assimilates to grain and grain growth.

Grain setting. We tested pollen viability by acetocarmine staining and pollen germinability in sucrose solution and found no evidence of differences between pollen from nonstressed and stressed plants. Hand pollination of stigmas of stressed plants with pollen from both nonstressed and stressed plants, and the reciprocal pollination of stigmas of nonstressed plants with pollen from both nonstressed and stressed plants, indicated no differences in grain setting between the two sources of pollen grains. However, grain setting was poorer in the stressed plants compared to the nonstressed plants, regardless of the source of pollen. These results suggest that stress does not affect either the viability or germinability of pollen, but that the stigmas of stressed plants are either less receptive to pollen tube growth, or that embryo growth following fertilization is in some way inhibited by the stress, resulting in fewer grains being set. Histological studies of pollination, fertilization, and embryo development are required to differentiate between these two possibilities.

Assimilate supply. We varied the supply of assimilates (carbohydrates) for grain growth by different degrees of defoliation in both stressed and nonstressed plants. There was a reduction in grain set in response to defoliation at anthesis in both nonstressed and stressed plants, indicating that grain set is sensitive to a reduction in assimilate supply and that the grain does not necessarily have priority for assimilates at this time. The latter was confirmed by $^{14}CO_2$ labeling studies that indicated that about 75% of the carbon fixed at anthesis appeared as structural components of the upper internodes, which are still growing at flowering.

Defoliation later than 10 days after flowering (DAF) only affected seed size. At this time $^{14}CO_2$ labeling indicated that up to 90% of the assimilate was translocated to the grain in both stressed and nonstressed plants. While these experiments are only preliminary, the results suggest that there are no surplus assimilates in pearl millet during flowering and grain filling. Reductions in both grain setting and grain filling can therefore be expected from a reduction in crop photosynthesis in stressed conditions.

Grain growth rates. Cultivars with a large grains do not usually yield more than cultivars with smaller grains, because they have fewer grains. Under terminal drought stress however, possession of large grains may have advantages that are not apparent under nonstressed conditions. This occurs because the common negative correlation of grain size and grain number often disappears under terminal stress. For example, the average coefficient for this correlation in the 1981-1987 drought nursery trials was -0.62 in the absence of stress but only -0.23 in terminal stress. The advantage of large grains may therefore not be offset by a small grain number to the same degree in stress.

Large grains appear to be more commonly associated with a high grain growth rate rather than a long grain growth duration (Fig.4). We have found considerable variation in grain growth rate in pearl millet in the absence of stress. Genotypes that performed well in terminal stress conditions, such as ICTP 8203, do have both high grain growth rates and a high yield per panicle. In an experiment where this variety was compared to HHB 60 under terminal stress, it maintained both larger grains and more grains per panicle than HHB 60. Both differences could be due to a better assimilate supply to the panicle in ICTP 8203. We are now in the

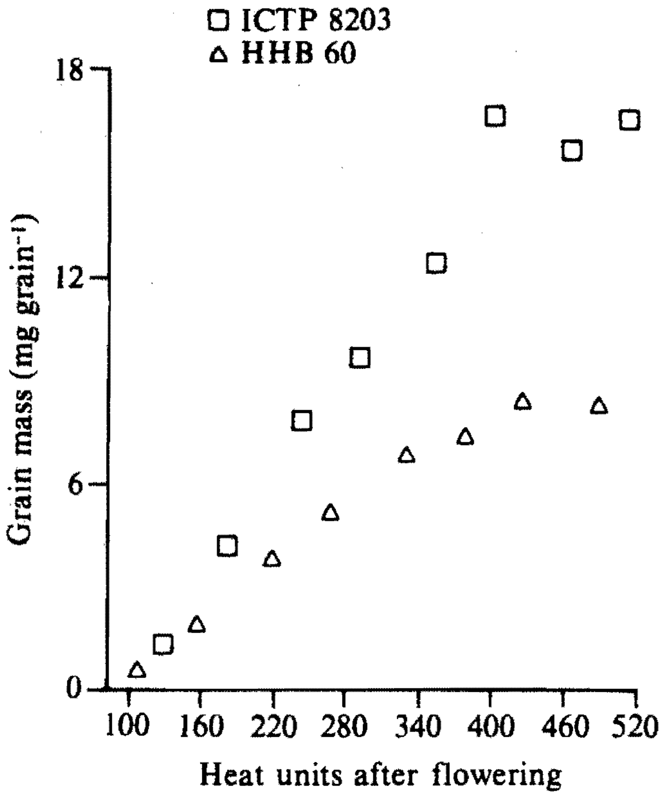


Figure 4. Grain growth rates for pearl millet cultivars ICTP 8203 and HHB 60, as a function of thermal time (base 10°C after flowering). ICRISAT Center, rainy season 1987.

process of comparing grain growth rate and maintenance of grain number per panicle under stress across a range of genotypes to evaluate the importance of both mechanisms of drought tolerance.

Drought Tolerance of Dwarf Hybrids

As a part of a larger study of the consequences of the dwarfing (d_2) gene in pearl millet (see 'Yield Physiology' under 'Plant Improvement, ICRISAT Center' of this Annual Report), in 1987 we evaluated the response of eight pairs of isogenic tall and dwarf hybrids to drought stress during grain filling in two experiments. One experiment was done during the dry season and the other under the rainout shelter during the rainy season. We made these comparisons because there is some concern that dwarf material may be less tolerant to drought than tall material and that poor grain filling in the dwarfs (ICRISAT Annual Report, 1985, pp. 117–119) makes them particularly vulnerable to stress during grain filling.

On average, across both experiments, there was no difference in the yields of tall and dwarf hybrids (3.6 vs. 3.5 t ha^{-1}) in the absence of stress (Table 3). Yields under terminal stress were reduced slightly more in the dwarf hybrids than in the tall hybrids (31.2% vs. 26.1%), but the difference in actual yields was not statistically significant, suggesting no greater vulnerability to this type of stress in the dwarfs.

Seed size was smaller (seed mass was lower) in the dwarf hybrids than in the tall hybrids in both the stressed and the nonstressed treatments, but the reduction in seed mass under stress was similar for both types (Table 3). There is therefore, no evidence that the tendency towards a smaller seed size in the dwarf hybrids gives them any differential susceptibility to stress.

Table 3. Mean yields and yield components, and mean reduction in stress (%) for tall and dwarf pearl millet hybrids. ICRISAT Center drought nursery, dry season 1987, and rainout shelter, rainy season 1987.

Yield/component	Treatment means: Non-stressed	Treatment means: Stressed	Reduction in stress (%)
Grain yield ($g m^{-2}$)			
Tall	362	270	26.1
Dwarf	353	243	31.2
SE	±7.6		
Grain no. m^{-2} (10^{-3})			
Tall	44.0	37.5	15.2
Dwarf	47.6	37.9	20.5
SE	±1.02		
Grain mass (mg $grain^{-1}$)			
Tall	8.27	7.21	13.4
Dwarf	7.50	6.44	14.2
SE	±0.107		

Biotic Stresses

Foliar Diseases

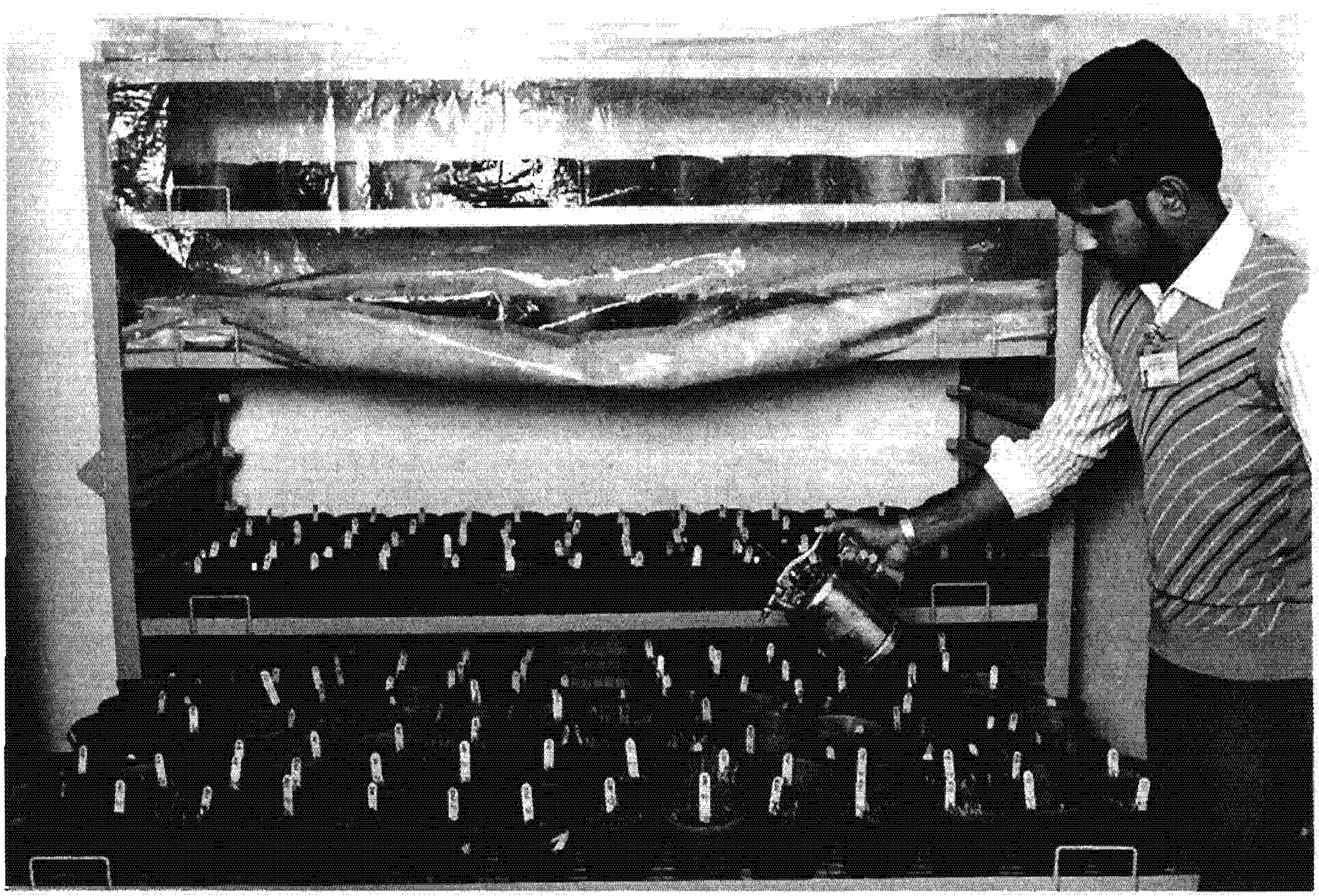
Downy Mildew (*Sclerospora graminicola*)

Recovery resistance. In continuation of our research on recovery resistance (ICRISAT Annual Report 1986, p.75), we selected and evaluated 584 single-plant progenies of downy-mildew recovered plants of inbred lines ICML 13 (SDN 503), P 1449, ICMB 1 (81 B), and 841 B. About 30% of the entries showed 80–100% recovery. In addition, a high frequency of recovery resistance was also found in several selections of a rust-resistant entry, 700481-27-5. Seven F_1 hybrids made from parents with recovery resistance showed 86–100% recovery in a preliminary trial.

Greenhouse screening for resistance. We developed, and are extensively using, a greenhouse technique for mass screening pearl millet seedlings for resistance to downy mildew. Seedlings are spray-inoculated at the coleoptile to 1-leaf stage with a suspension of sporangia and incubated for 12–16 h at 20°C and >95% relative humidity (Fig. 5). Plants are then returned to greenhouse benches where the frequency of plants showing systemic downy mildew is assessed after 10–15 days. Tests so far indicate that there is a good correlation between greenhouse and downy mildew nursery data.

We find that this screening technique has several advantages over field testing, although we recommend that materials at advanced stages of breeding also be screened in a field downy mildew nursery. Greenhouse screening provides more flexibility in that the reaction of breeding materials to downy mildew can be obtained in

Figure 5. Spray-inoculation of young pearl millet seedlings with a sporangial suspension under controlled environmental conditions for mass screening of breeding materials for downy mildew resistance.



less than 3 weeks, and therefore can be determined after harvest of one generation and before sowing, or at least before selfing or crossing operations, in the next generation. It also reduces the resources needed for field screening since land is not required and fewer man days of labor are needed. The results obtained by this technique are also more repeatable than those from the field-screening techniques, because inoculation is done at the most susceptible stage and the environment is favorable for inoculation and infection.

Field screening for resistance. At ICRISAT Center we evaluated about 2000 breeding materials including potential A and B lines, pollinators, and population derivatives in the downy mildew nursery. About 60% of the entries did not develop disease. In a program to improve downy mildew resistance in 12 varieties derived from four composites (SRC, NELC, IVC, and MC), we evaluated 250 S_4 progenies in the downy mildew nursery. Although 100 progenies showed high degrees of downy mildew resistance, only 32 were agronomically acceptable.

Using sprinkler irrigation for the first time at the Institut national de recherches agronomiques du Niger (INRAN) station at Bengou, we screened 232 entries (varieties and breeding lines) of 13 trials for downy mildew resistance. Entries in trials of West African material such as ICRISAT Pearl Millet African Zone A Trial (IMZAT), INRAN/ICRISAT Cooperative Trial South Zone (COTRISUD), and INRAN/ICRISAT Cooperative Trial North Zone (COTRINOR), had a mean downy mildew incidence of <10%, and none of the test entries had more than 20% incidence (Table 4). In contrast,

Table 4. Downy mildew incidence in pearl millet at Bengou, Niger, rainy season 1987.

Trial name[1]	Number of entries screened	Percentage of the entries in the DM incidence (%) class						Mean incidence of trial (%)	DM incidence of susceptible control (%)
		<1	1-5	6-10	11-20	21-30	>30		
IMZAT	15	13	20	40	27	0	0	9	44[2]
COTRINOR	10	10	40	50	0	0	0	9	23[2]
COTRISUD	12	0	8	67	25	0	0	9	13[2]
PMAEVT	15	0	33	27	33	7	0	10	NI[3]
PMPVT	10	0	30	30	30	0	10	11	NI
PMIEVT	16	0	6	44	44	6	0	11	NI
IRT	12	25	42	8	0	0	25	14	NI
WADMVN	10	20	30	10	10	20	10	15	21[2]
WADMON	24	8	42	0	13	13	25	18	33[2]
IPMDMN	27	19	11	4	7	11	48	28	30[2]
PMIHT	17	0	6	29	18	12	35	34	NI
ABPAIR	38	11	5	5	11	11	58	39	22[2]
IPMSN	26	0	12	4	12	31	42	40	45[4]

1. IMZAT=ICRISAT Millet Zone A Trial, COTRINOR = INRAN-ICRISAT Cooperative Trial, Zone North, COTRISUD = INRAN-ICRISAT Cooperative Trial, Zone South, PMAEVT = Pearl Millet Advanced Early Varieties Trial, PMPVT = Pearl Millet Preliminary Varieties Trial, PMIEVT = Pearl Millet Initial Early Varieties Trial, IRT = Initial Restorers Trial, WADMVN = West African Downy Mildew Variability Nursery, WADMON = West African Downy Mildew Observation Nursery, IPMDMN = International Pearl Millet Downy Mildew Nursery, PMIHT = Pearl Millet Initial Hybrids Trial, ABPAIR = DM Screening of A/B Pairs, IPMSN = International Pearl Millet Smut Nursery.
2. Susceptible control= NHB 3.
3. NI = DM-susceptible control not included in trial.
4. Susceptible control= BJ 104.

trials in which the majority of the entries came from India, such as the International Pearl Millet Smut Nursery (IPMSN), International Pearl Millet Downy Mildew Nursery (IPMDMN), Pearl Millet Initial Hybrid Trial (PMIHT), and A/B pairs (ABPAIR) had much higher levels of downy mildew susceptibility. Twelve accessions of the wild species, *Pennisetum violaceum* from Mali and Burkina Faso, were tested in pots for downy mildew reaction and none showed resistance, with incidence ranging from 17 to 100%.

We evaluated local germplasm accessions for downy mildew in Malawi, Tanzania, Zambia, and Zimbabwe, and a set of seven differentials was tested at two locations in Zambia and in Malawi as a part of the Southern African Development Coordination Conference (SADCC)/ICRISAT program. Local germplasm was mildly susceptible in some cases, and very susceptible in others while the entries in the differentials test had low levels of infection compared to the severely infected controls 7042 DMS and Impala. We found accessions and advanced breeding material from India and West Africa to be less susceptible to downy mildew than local varieties in the SADCC region.

Rust (*Puccinia penniseti*)

Components of resistance. We evaluated 155 rust-resistant germplasm accessions at ICRISAT Center for uredinial shape, size, and rupturing, and for production of telia. One hundred-and-eight entries produced very small uredinia that covered about 5% of the leaf area. Uredinia did not rupture in eight of these entries, and only 44 of them produced telia. The remaining entries produced small to large uredinia that covered 10–65% of the leaf area. Uredinia did not rupture in 7 of these entries, and 22 of them did not produce telia. Entries that produced nonrupturing uredinia will reduce disease development in a given season and those that do not produce telia may reduce inoculum build-up for the next season through the alternate host.

Field screening for resistance. We evaluated 1100 entries including germplasm accessions, breeding material, and international disease nursery entries for rust reaction at Bhavanisagar in India. The majority of the 181 germplasm accessions selected from an earlier screening remained rust-free, and none developed more than 10% rust on the upper four leaves. Other material showed moderate-to-high rust severity. At ICRISAT Center, we evaluated 428 entries including breeding material, ergot- and smut-resistant lines, and accessions, and found that 40% of the entries developed 5% or less rust. Sixty-five of the 158 entries that were evaluated at both locations remained rust free.

False Mildew (*Beniowskia sphaeroidea*)

In Zimbabwe, we found resistance to false mildew under natural disease pressure in both local germplasm collections and in introductions. As in 1986 (ICRISAT Annual Report 1986, p.78), 7042 DMR had a high level of resistance (<5% severity), 7042 RR, ICMPES 29, and ICMPS 1500-7-3-2 were moderately resistant (5–10% severities), and RMP 1 and GAS, both bred in Zimbabwe, were susceptible.

Leaf Spot (*Bipolaris urochloae*)

We investigated a disease previously unreported in Zimbabwe, whose symptoms are characterized by leaf spots that are extremely variable in shape and size. The spots may be small and oval shaped to large, rectangular or spindle-shaped measuring 2-15 mm × 2-25 mm. The spots have brown margins with grey to tan centers. Under humid conditions, the lesions may coalesce to cover large areas of the leaf blade and sheath, and severely affected leaves may die prematurely, sometimes resulting in plants that fail to produce panicles. The pathogen was identified as *Bipolaris urochloe* (Putterill) Shoem by the Commonwealth Agricultural Bureaux International Mycological Institute (CABIMI), UK.

Virus Diseases

We confirmed by serological tests that pearl millet, including ICMV 1 (WC-C75), recently released as WC-C75 in Zambia, can be infected by viruses in Zambia, although the extent of damage was not assessed. Several viruses, including both maize dwarf mosaic virus and sugarcane mosaic virus, may be involved.

In India, we observed a high incidence of streaking generally accompanied by stunting and increased tillering in a postrainy-season seed production sowing of pearl millet near Bangalore. Several plants with similar symptoms were also observed in our summer sowing at ICRISAT Center. With the help of the virology unit at ICRISAT Center, we found rhabdovirus particles in crude sap extractions of affected plants.

Panicle Diseases

Ergot (*Claviceps fusiformis*)

Flowering events in relation to resistance. At ICRISAT Center, we recorded the protogyny period (time interval between initiation of stigma emergence and anthesis on the same panicle), the time interval between ergot inoculation and anthesis, and ergot severity and seed set in four ergot-resistant inbred lines (ICMPES numbers), two ergot- resistant male-sterile lines and their corresponding B lines, and four ergot-susceptible genotypes, including 841 A/B pair and two hybrids, BJ 104 and BK 560. Both the protogyny period and the time interval between inoculation and anthesis were significantly shorter in the resistant than in the susceptible geno-

Table 5. Variation in flowering events in pearl millet lines, resistant and susceptible to ergot, and its relation to ergot severity and seed-set. ICRISAT Center, rainy season 1987.

Entry[1]	Protogyny period (h)	Time from inoculation to anthesis (h)	Ergot severity (%)	Seed-set (%)
ICMPES 1	22[2]	10	<1[3]	72 (±11.2)[4]
ICMPES 2	52	25	<1	54 (±11.2)
ICMPES 29	43	19	<1	35 (± 7.9)
ICMPES 34	37	20	4±3.1	84 (±11.2)
ER MS 1A	72	40	1	<1
ER 1B	56	25	<1	51 (± 7.9)
ER MS 2A	72	43	<1	<1
ER 2B	55	27	<1	46 (±11.2)
ES 841 A	82	54	53	2 (± 2.2)
ES 841 B	68	40	18	27 (± 7.9)
BJ 104	94	71	52	5 (± 2.2)
BK 560	91	64	53	3 (± 2.2)
SE	±3.1	±3.2	±11.8[5]	

1. ICMPES and ER entries are ergot resistant; ES entries are ergot susceptible.
2. All data based on 42-90 panicles from 3 replicates.
3. SE not computed for values <1.
4. Values in parentheses are standard errors (SEs).
5. SE for comparison of 4 susceptible entries only.

types (Table 5). Ergot severity showed significant positive correlation with protogyny period and the inoculation-anthesis time interval, and significant negative correlation with seed set. Differences in the length of the protogyny period and in inoculation-anthesis time were, however, quite large among different panicles within an entry. These results agree with our earlier finding that rapid self-pollination in inoculated, bagged panicles reduces ergot severity.

Field screening for resistance. We screened 2470 entries from the pathology and breeding research units for ergot resistance at ICRISAT Center during the postrainy and rainy seasons, and at Aurangabad (rainy season) under artificial inoculation. These included F_6 and F_7 progenies from Togo × ER (ergot resistant) lines from which we are attempting to breed new sources of ergot resistance. A large proportion (95%) of F_7 entries showed very high levels of resistance (<5% severity); we selected resistant panicles of 114 entries that have both resistance and desirable agronomic traits for further testing.

We evaluated 1722 breeding lines including progenies from crosses involving 843B × ER lines, S_1 and half-sib progenies of the Ergot-Resistant Composite (ERC), and pollinators. Of 200 F_4 and F_5 progenies of 843B × ER lines screened, 74% had <5% ergot severity; we harvested seed from resistant panicles of 159 lines for further evaluation. A large proportion (81%) of ERC progeny lines had <5% ergot severity; we selected 37 lines for utilization in the next cycle. Of 371 pollinators screened, about 80% were highly susceptible to ergot, only 5% showed resistance (<5% severity).

Many local germplasm accessions were found to be susceptible to ergot under natural disease pressure at SADCC/ICRISAT locations in Malawi, Tanzania, and Zimbabwe. In a multilocational, regional nursery, ICMP 3 (ICMPES 28) and ICMPES 29 had ergot severities below 5% at four locations, both in 1986 and 1987. In 1987, ergot sclerotia formed at all locations where the disease was observed.

In a test of ergot resistance using artificial inoculation at Henderson, Zimbabwe, five ergot-resistant lines from ICRISAT Center (ICMPES 34, 49, 63, 70, and 95) had <10% ergot. Other ICMPES lines had slightly higher levels of infection.

Smut (*Tolyposporium penicillariae*)

Studies on smut infection. At Bengou, Niger, we studied the influence of the date of sowing and the effect of bagging on smut severity in the smut-susceptible hybrid BJ 104. Smut severity was very low (1–3%) on panicles that were not bagged and much higher (20–67%) on bagged panicles (Table 6). Smut severity was highest (67%) on the third (last) date of sowing (6 July) and lowest (20%) on the first date of sowing (15 June). The higher smut severity on the third sowing was possibly due to lower temperatures and better distribution of rainfall (consistently higher humidity) from boot-leaf to anthesis stages of the crop.

Field screening for smut resistance. We screened more than 2800 Breeding and Pathology entries for smut resistance by artificial inoculation at ICRISAT Center. These included F_3 progenies from crosses involving smut-resistant dwarf lines, F_5 progenies from selfed smut-

Table 6. Influence of sowing date and bagging at the boot stage on smut severity on pearl millet BJ 104. Bengou, Niger, rainy season 1987.

Date of sowing	Date of boot leaf stage	Smut severity (%)[1] Bagged heads	Unbagged heads
15 Jun	21 Jul	20 (99)[2]	3 (140)
24 Jun	3 Aug	40 (89)	2 (97)
6 Jul	18 Aug	67 (46)	1 (72)
18 Jul	29 Aug	40 (50)	2 (57)

1. Based on a 0–100% scale, where 0 = no symptoms and 100 = panicle completely covered with smut.
2. Figures in parentheses indicate number of panicles scored.

resistant germplasm accessions, and F_7 progenies from Togo × ER lines. More than 80% of the entries had high levels of smut resistance (<1% severity). We selected 31 entries based on resistance and desirable agronomic traits for further testing. Breeding entries included S_1 progenies from the Bold Seeded Early Composite, Medium Composite, and New Elite Composite (which are being improved for smut resistance by saving seed harvested from selfed smut-resistant panicles for use in the next cycle of random mating), pollinators, and smut-resistant B and R lines. Seeds from resistant (<5% severity) panicles were harvested by breeders for further evaluation and utilization.

We screened three West African/International trials for smut resistance at Bengou, Niger. Panicles were not artificially inoculated, but were bagged to enhance infection. Mean smut severity of the IMZAT entries was 9%, with 9 out of 16 entries having <5% severity and only 2 entries having >10% severity, compared with the susceptible control (BJ 104) with 47% severity. The mean smut severity for the West African Downy Mildew Observation Nursery (WADMON), which includes local and improved varieties from across West Africa, was 10%. Nineteen entries had < 10% smut and the remaining 9 entries had 11 to 35% smut severity. In the IPMSN, 8 of 28 entries had no smut, 11 others recorded <10%, and only 5 had >20% smut.

Genotypes developed at ICRISAT Center appeared to have resistance to smut under natural disease pressure in Malawi and Zimbabwe both in 1986 and 1987. Lines that performed especially well were ICMPS 100-5-1, ICMPS 900-9-3, P 24, ICMP 3 (ICMPES 28), and ICMPES 29.

Striga hermonthica

Screening for resistance. At ICRISAT Sahelian Center (ISC), we tested IMZAT entries for *Striga hermonthica* reaction in both the *Striga*-sick plot and in pots artificially infested with approximately 10000 *Striga* seeds pot^{-1}. All entries were heavily infected, the lowest mean *Striga* count pot^{-1} (30 plants) was found on ICMV IS 85333, and the highest (78 plants) on SE 361. The control, Sadoré Local, had 52 *Striga* plants pot^{-1}. In the *Striga*-sick plot, SE 361 (3.5 plants $plot^{-1}$) and ICMV IS 85333 (3 plants $plot^{-1}$) had the fewest number of *Striga* plants, and ICMV IS 85327 had the highest number (14.5 plants $plot^{-1}$). The differences in relative numbers of *Striga* plants in pot and field testing with ICMV 85333 and SE 361 suggests that there may not be a high correlation between evaluation done in pots and that done in the field. Although Sadoré Local had high *Striga* infection in the field (55.3 plants $plot^{-1}$) it recorded the highest grain yield, indicating a high level of tolerance to *Striga*.

Six pearl millet lines identified as possessing some *Striga* resistance have been tested in pots and in a farmer's field at Bengou, Niger. In the pot trial, 85W 287 was less susceptible to *Striga* than the three local cultivars used as controls, but there were no differences in *Striga* reaction between the other lines tested and the control. In a farmer's field trial, there was less *Striga* on these six lines than on the controls. However, the agronomic performance of five of the lines, (except 85W 288), was poor, and they yielded less than the local variety.

Screening *Pennisetum violaceum* for *Striga* resistance. Forty accessions of the wild millet species, *Pennisetum violaceum*, collected by Institut français de recherche scientifique pour le développement en coopération (ORSTOM) in Mali, Burkina Faso, and Niger in 1985 and 1986, were tested for *Striga* reaction in pots at ISC. The pots were artificially infested with approximately 10 000 *Striga* seeds pot^{-1} and replicated eight times; seven varieties (local and improved) were used as controls. All accessions were found to be heavily infected with *Striga*. The mean infection level 73 DAS was 41 plants pot^{-1} with the highest mean count of 79 for an accession from Mali, and the lowest of 12 for an accession from Tin Akof, Burkina Faso. The mean rate of infection for the seven controls was 32 *Striga* plants pot^{-1}. The mean survival of the wild millet species at 81 DAS was 78%, compared to 89% in

Figure 6. Screening the wild species *Pennisetum violaceum*, for reaction to *Striga hermonthica*. Plots left and center show severe infection by *Striga*, right is a *Striga*-free control. Pot test, ISC Sadoré, 1987.

the control varieties, but 7 days later it decreased to 53% in the wild species and 81% in the control (Fig. 6).

Insect Pests

Stem Borer [*Coniesta (Acigona) ignefusalis*]

Biology. Previous investigators had reported an abnormal male/female ratio based on stem borer adults collected from light traps. We sexed 1087 pupae and found the sex ratio to be essentially 1:1. The differences noted in light trap catches are probably due to differential responses of males and females to light. Our studies on the longevity of adults on different foods indicated that adult food does not seem to be a requirement as adults fed sugar or honey solutions did not live longer than those fed only water. In limited field-trapping studies, presence of pheromone production by virgin females was also demonstrated. The Wing-pheromone trap was more efficient than the Delta trap.

Laboratory studies on larvae show that termination of diapause is under photoperiodic control with contact moisture being a secondary factor. This agrees with field observations where pupation does not occur until both optimum photoperiod and contact moisture are present. This dual mechanism ensures the survival of the insect in areas where rainfall patterns are erratic.

In addition to diapause, the pearl millet stem borer also undergoes "aseasonal quiescence". This is a state of arrested development and is a direct response to adverse environmental conditions. This differs from diapause in that the triggering mechanism for diapause must occur before the onset of diapause and in that diapause is a regularly occurring phenomenon. Aseasonal quiescence was evident during the growing season, which was marked by prolonged dry spells. The interrupted development of the stem borer essentially eliminated a second generation.

Field survival of diapausing larvae. During the postrainy season, 11 fields at ISC were sampled at monthly intervals to study larval survival and time of pupation. Approximately 1000 standing stalks were examined each month. There was a progressive decrease in the number of live larvae as the season progressed. The larval population decreased by more than 80% by the time rains normally commence, and over 96% by July when pearl millet was actually sown. This high mortality during the nongrowing season is probably the most important regulatory factor in the entire life cycle of this insect.

Relationship between larval populations and exit holes. Direct country stem borer larvae is a time-consuming and labor-intensive operation. Utilizing this method of sampling would preclude screening large numbers of pearl millet lines to find resistant sources.

During the 1987 growing season, we found a high correlation between the number of exit holes and larval population. In six separate tests, the linear correlation coefficient (r) ranged from 0.71 to 0.95 (significant at 0.01 level in five tests and at 0.05 level in one test) indicating that recording exit holes would give the necessary precision if used in a screening program. Another advantage in using this method of evaluation is that the stems need not be examined during the growing season as the exit holes on the dry stems can be counted at any time. Since both diapause and nondiapause larvae make an exit hole in the stem, this method would reflect total larval populations.

Crop loss assessment. To investigate crop losses from pearl millet stem borer infestations, we sowed six pearl millet varieties in a replicated split-plot design. One of the split-plots was treated with carbofuran 2 kg a.i. ha^{-1} at sowing time—and side-dressed with 7 kg a.i. ha^{-1} 60 DAS. We examined plots six times during the growing season. The seasonal mean infestation level was 105 stem borer larvae $plot^{-1}$ of 22.5 m^2, while in the treated plots there were 34 larvae $plot^{-1}$ (SE ±25.3). The treated plots gave a mean yield of 1.05 t ha^{-1}, while the control plots gave 0.72 t ha^{-1} (SE ± 0.06). Thus, yield losses resulting from this level of infestation were around 30%.

Influence of carbofuran on plant growth, yield, and stem-borer population. We applied carbofuran at four rates: 3, 6, 9, and 12 kg a.i. ha^{-1} to the variety CIVT as an in-furrow preplant treatment.

Plant height increased by 30% and total dry matter by 50% on each of the samplings made 20, 30, and 42 DAS. Grain yield was more than doubled on the 9 and 12 kg treatments. The increase in yield could not all be attributed to the insect control; although, stem borer populations were drastically reduced. The response to carbofuran should be investigated as it may provide clues to the production constraints of pearl millet in the region.

Evaluation of sources of resistance. Work carried out in the past in West Africa indicated that numerous lines and landraces of pearl millet possess varying degrees of resistance to stem borer. During the 1987 growing season, two replicated tests were conducted in which 14 pearl millet varieties were evaluated for resistance to stem borer. One variety, P3 Kolo (INRAN) supported a lower larval population than the control, CIVT. In addition to having antibiosis, this variety was observed to have a good level of tolerance to stem borer attack. There was no evidence of resistance in the two different Zongo accessions that were reported to possess a mucilage-like substance that traps developing larvae. There was also no evidence of this type of material in these two accessions.

In the evaluation of these varieties, the natural population was augmented by placing stems containing diapausing larvae in each of the plots. This method of infestation resulted in a uniform larval population and suggests that, with minor modifications, it can be used in a screening program to ensure uniform levels of infestation.

Headworm [*Heliocheilus (Raghuva) albipunctella*]

During the 1987 growing season, there was a localized infestation of pearl millet headworm at ISC. A field of 3.4 ha sown with CIVT was found to be uniformly infested. One thousand panicles were collected at random and stored in paper bags. Later, these panicles were weighed, threshed, and the number of larvae that had completed their development in each panicle was recorded.

While only a few panicles had more than 5 larvae, infestation of 3–4 larvae resulted in a 20% yield loss, 5 larvae caused a 34.5% yield loss, and more than 5 caused a 44.8% yield loss. These data parallel those reported in 1986 (ICRISAT Annual Report 1986, p.84). Furthermore, the data also showed that infestation by one larva resulted in reduced grain yield by 2 g or 6.6% panicle^{-1}. By extrapolation, this would indicate that the maximum number of larvae that CIVT could support was 15 panicles^{-1}. This information will be useful in estimating losses in farmers' fields that occur as a result of headworm attack.

Plant Nutrition

Biological Nitrogen Fixation

Assessment of Nitrogen Fixation

We previously reported that nitrogenase activity (C_2H_4 reduction) of pearl millet BJ 104 is small and that the contribution of N_2-fixation to the nitrogen nutrition of pearl millet is negligible (ICRISAT Annual Report 1986, pp. 89–91).

In 1987, we further assessed the agronomic significance of N_2-fixation by pearl millet and sorghum using the natural abundance of ^{15}N by the $\delta^{15}N$ technique, which makes use of the difference between ^{15}N in the atmosphere and that in the soil. The ^{15}N in the soil is universally larger than that in the atmosphere; an N_2-fixing plant has a lower $\delta^{15}N$ than a non-N_2-fixing plant.

We grew pearl millet BJ 104 and sorghum CSH 5, both noninoculated, and inoculated with *Azospirillum lipoferum*, groundnut Kadiri 3 (Robut 33-1) and a nonnodulating and non-N_2-fixing groundnut line in the field without applying nitrogen fertilizer. Plant samples were analyzed for ^{15}N using a Finnigam MAT 250 spectrometer at the National Agricultural Research Center (NARC), Japan. In other experiments, we measured the mean ^{15}N in the legume, Kadiri 3 (Robut 33-1) grown in a medium free of combined nitrogen to use in calculating plant nitrogen derived from N_2-fixation. From these values (Table 7), it can be calculated that Kadiri 3 (Robut 33-1) derived 71% of its plant nitrogen from N_2-fixation. BJ 104 and CSH 5, whether noninoculated or inoculated, had higher $\delta^{15}N$ than the nonnodulating and non-N_2-fixing groundnut line, suggesting that (a) N_2-fixation by BJ 104 and CSH 5 is too low to detect by the $\delta^{15}N$ technique; (b) BJ 104 and CSH 5 stimulated denitrification to a greater degree than N_2-fixation; and (c) inoculation of BJ 104 and CSH 5 resulted in such low levels of N_2-fixation as to be agronomically insignificant in nitrogen accumulation in the plant and the soil.

Response to Inoculation with N_2-fixing Bacteria

We reported the results of a series of inoculation trials with N_2-fixing bacteria (ICRISAT Annual Report 1982, pp. 88). In 1985/86, we conducted another series of 27 inoculation trials with pearl millet and sorghum in the greenhouse and in the field. There were 9 test-tube, 9 pot, and 9 field trials, with two different N_2-fixing bacteria,

Table 7. $\delta^{15}N$ values in pearl millet BJ 104, sorghum CSH 5, groundnut Kadiri 3 (Robut 33-1), and a nonnodulating groundnut line, ICRISAT Center, postrainy season 1987.

Crop	$\delta^{15}N$ (⁰/₀₀)
Pearl millet BJ 104	
Noninoculated	9.78
Inoculated	10.17
Sorghum CSH 5	
Noninoculated	10.86
Inoculated	10.70
Groundnut Kadiri 3 (Robut 33-1)	1.78 (71%)[1]
Nonnodulating groundnut	7.87
SE	±0.44
CV (%)	13

1. Proportion (P) of plant nitrogen derived from N_2-fixation, which was calculated from the following equation.

$$P = \left(\frac{\delta^{15}N \text{ nonnodulating plant} - \delta^{15}N \text{ nitrogen fixing plant}}{\delta^{15} N \text{ nonnodulating plant} - B} \right) \times 1000$$

where B is the mean $\delta^{15}N$ value (-0.70) of a legume grown in medium free of combined nitrogen.

Azotobacter lipoferum and *A. chroococcum*, various inoculum levels, different N-fertilizer levels, and partial or complete sterilization of the soil. The results of each trial were expressed as the probability level of significance of the difference between the treatment inoculated with N_2-fixing bacteria and the noninoculated control across the bacteria, inoculum levels, and N-fertilizer levels (Fig. 7).

In only two trials with BJ 104 grown in completely sterilized soil, were there significant ($P < 0.05$) increases in total dry matter (TDM) due to inoculation. One test-tube trial with CSH 5 showed significant decrease in TDM with inoculation. In none of the field inoculation trials were there significant increases in the TDM yield of pearl millet or sorghum. These results suggest that even improved inoculation management has not been able to enhance the benefit from inoculation with N_2-fixing bacteria. We will therefore discontinue efforts to obtain increased cereal production by inoculation with N_2-fixing bacteria.

Vesicular-Arbuscular Mycorrhizae (VAM)

Utilization of Rock Phosphate

The ability to mobilize phosphorus from different rock phosphate sources varies with VAM fungal species (ICRISAT Annual Report 1984, p.103). We further tested the ability of *Glomus monosporum* to utilize both partially acidulated and unprocessed rock phosphate in pots containing an Alfisol. Compared to the control (without P), the unprocessed rock phosphate sources did not increase TDM production and P uptake with or without VAM inoculation (Table 8). VAM significantly increased TDM production and P uptake from acidulated rock phosphates especially those from Togo.

In a second experiment, we examined the growth and P uptake of pearl millet in sand culture with three unprocessed rock phosphate sources (Table 9). Plants did not grow very well in the sand containing any of three rock phosphate sources with or without VAM inoculation. However, VAM inoculation resulted in a significant increase in TDM production and P uptake over the noninoculated control with all three sources of rock phosphate.

These results suggest that most of the P taken up and translocated by VAM is derived from soluble P sources i.e., the acidulated portion in rock phosphate, but that VAM or mycorrhizal roots can also take up a small quantity of P from unprocessed rock phosphates.

Growth, Yield, and N Uptake

During the rainy season we studied TDM, and N accumulation, grain yield, and Nitrate Reductase Activity (NRA) (a measure of potential of

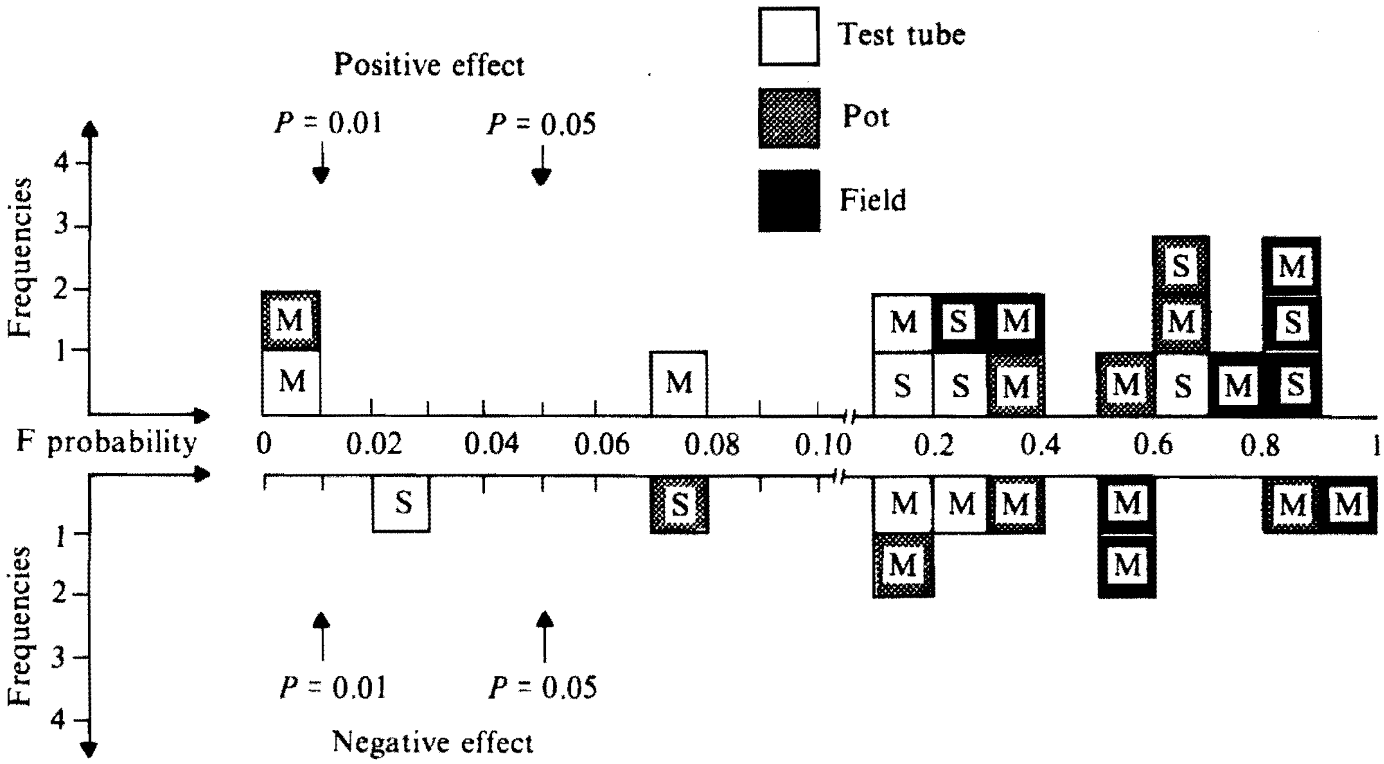


Figure 7. Distribution of probability levels of significance of the difference between two treatments, inoculation with N_2-fixing bacteria and noninoculated control. Data are from 9 test tube, 9 pot, and 9 field experiments with pearl millet (M) and sorghum (S), ICRISAT Center, 1985/86.

Table 8. Effect of VAM (*Glomus monosporum*) inoculation on biomass and P uptake of pearl millet ICMV 1 (WC-C75) grown with different rock phosphate sources in soil culture in pots, ICRISAT Center, 1987.

	Biomass[1] (g plant^{-1})		P uptake[1] (mg plant^{-1})	
P source	Control	Inoculated	Control	Inoculated
Unprocessed rock phosphate				
Kodjari	11.3	11.9	13.9	14.3
Togo	12.4	15.0	13.9	16.0
Mussuri	8.7	14.1	9.3	13.9
Acidulated (50%) rock phosphate				
Kodjari	21.7	25.2	26.6	26.0
Togo	20.8	30.5	18.5	29.9
Superphosphate	23.8	31.8	23.5	44.8
Control (without P)	14.7	13.5	17.2	17.4
SE	±1.8		±2.8	
Mean	16.2	20.3	17.6	23.2
CV (%)	9		13	

1. 82 days after sowing.

Table 9. Influence of VAM (*Glomus monosporum*) on growth and P uptake of pearl millet ICMV 1 (WC-C75) grown with different unprocessed rock phosphate sources in sand culture in pots, ICRISAT Center, 1987.

Unprocessed rock phosphate source	Biomass[1] (g $plant^{-1}$)		P uptake[1] (mg $plant^{-1}$)	
	Control	Inoculated	Control	Inoculated
Kodjari	0.20	4.02	0.09	3.45
Togo	0.30	4.92	0.14	3.31
Mussuri	0.16	5.13	0.21	3.58
SE	±0.018	±0.210	±0.015	±0.141
CV (%)	12		14	

1. 82 days after sowing.

plant N uptake) in leaves and stems at different growth stages of 17 pearl millet cultivars (Table 10). The experiment was designed to examine the relationships between N assimilation and yield in pearl millet grown on Alfisols with low (20 kg N ha^{-1}) and high (80 kg N ha^{-1}) N-fertilizer levels.

The mean TDM and the grain yield across the cultivars did not differ between low and high N-fertilizer levels. Only in MBH 110 (3.94 t ha^{-1}) and ICMV 1 (WC-C75) (3.47 t ha^{-1}), was there a significant increase in grain yield with 80 kg N ha^{-1}. Only in MBH 110 was there a significant increase in TDM—8 t ha^{-1} with 80 kg N ha^{-1}, compared to 5.70 t ha^{-1} with 20 kg N ha^{-1}.

Mean NRA in leaves (60.0μ moles NO_2 g^{-1} h^{-1}) and in stems (62.8 μ moles NO_2 g^{-1} h^{-1}) was maximum at 20 DAS and then declined at 40 DAS, and again increased significantly at 50 DAS to 34.0 μ moles NO_2 g^{-1} h^{-1} in leaves and 8.8 μ moles NO_2 g^{-1} h^{-1} in stems. The mean specific NRA was not significantly affected by the N level but that in stems was less at 80 kg N ha^{-1} than at 20 kg N ha^{-1}. Total plant N uptake differed significantly among the cultivars, ranging from 69 kg N ha^{-1} in Mainpuri Local to 107 kg N ha^{-1} in ICMH 451 (Table 10) and showed significant (r=0.70) correlation with grain yield. Neither specific NRA nor total NRA correlated with total N uptake.

Grain yield and TDM differed significantly ($P<0.01$) among cultivars (Table 10). In general, the improved cultivars yielded better than the local cultivars, partly due to a higher harvest index in the improved cultivars. Although total NRA did not differ among the cultivars, specific NRA in leaves and stems did. However, the specific NRA was not correlated with grain yield or TDM.

Grain and Food Quality

Dehulling Quality

Ease and completeness of dehulling are important aspects of grain quality for pearl millet used in food products which require dehulling (removal of the seedcoat) prior to food preparation. A number of factors may influence dehulling quality, including grain shape (Annual Report 1986, pp. 92-94) and grain hardness (Annual Report 1985, pp. 105-106). We carried out additional studies of dehulling quality in three cultivars, Fakiaybad (soft grain), SAD 448 (hard grain), and ICMV 1 (WC-C75) (hard grain), comparing dehulling quality and the relative abundance of five endosperm protein solubility fractions. We dehulled grains of each cultivar by the traditional, hand-pounding method, and with barley pearling and tangential abrasive dehulling devi-

Table 10. Mean grain yield, total plant biomass, total plant N uptake, harvest index, mean specific nitrate reductase activity (NRA) in leaves and stem tissues, and total NRA per plant of pearl millet cultivars, ICRISAT Center, rainy season 1987[1].

Cultivar	Grain yield (t ha^{-1})	Total plant biomass (t ha^{-1})	Total plant N uptake (kg ha^{-1})	Harvest index (%)	Specific NRA[2] (μ mol NO_2 g^{-1}) dry mass h^{-1} Leaf	Stem	Total NRA[2] (μ mol NO_2 plant h^{-1})
ICMH 451	4.0	9.1	107	44	36	19	346
Ex-Bornu	3.4	9.0	103	38	28	16	342
MC-C8	3.4	8.5	95	40	42	22	384
IVC-C7	3.3	8.6	103	39	34	22	362
MBH 110	3.3	6.8	85	48	40	26	370
ICH 107	3.1	7.6	86	41	36	31	332
ICMV 1 (WC-C75)	3.1	7.3	96	42	36	24	288
EC-C6	3.1	7.5	86	41	40	20	372
D2-C6	3.0	7.4	85	41	34	25	378
ERC-Co	2.9	7.8	85	38	42	29	370
BJ 104	2.9	6.8	80	43	44	24	336
Durgapura local	2.7	7.5	88	36	40	22	372
Jodhpur local	2.6	6.7	82	39	38	22	354
GAM 73	2.6	7.0	86	37	27	26	252
Mainpuri local	2.5	8.5	69	30	37	22	372
RCB 2	2.5	7.1	89	35	33	22	298
PSB 8	2.4	5.9	74	41	34	24	298
SE	±0.13	±0.28	±4.6	±0.8	±1.7	±1.4	±23
Mean	3.0	7.6	88	40	36	23	342
CV (%)	12	11	15	6	34	40	38

1. Data are means of four replications grown with 20 and 80 kg N ha^{-1}. Net plot area harvested 21 m^2.
2. Values are means of four plants sampled from each plot at 20, 30, 40, and 50 DAS. Average of both nitrogen treatments.

ces (TADD), and measured N distribution in the following endosperm protein fractions: albumen±globulin (fraction I), prolamins (fraction II), cross-linked prolamins (fraction III), glutelins (fraction IV), and glutelin-like (fraction V), in both whole and dehulled grain.

Recovery of dehulled grain was higher in SAD 448 and ICMV 1 (WC- C75) than in Fakiaybad by all three dehulling procedures (Table 11). There were differences among the cultivars for contents of both fraction I and fraction II proteins. Fakiayabad had a higher fraction I in the whole grain (but not in the dehulled grain) and a significantly lower fraction II content in both the whole grain and the dehulled grain, regardless of the method of dehulling (Table 11). There were only minor differences among cultivars for the other three endosperm protein fractions. This study suggests that the prolamin content may be a factor in the hardness of grains and thus in their ability to withstand loss in the dehulling process. However, studies with more cultivars varying in dehulling qualities are required to confirm these observations.

Table 11. Nitrogen distribution in whole and dehulled grains of three pearl millet cultivars, ICRISAT Center 1986.

Cultivar	Method of dehulling	Dehulled grain recovery (%)	Protein (%)	Soluble nitrogen fractions (%)[1]				
				I	II	III	IV	V
Fakiayabad	WG[2]	–[3]	12.2	29.6	39.7	2.1	6.7	13.8
	TM[4]	68.8	12.0	14.2	29.6	1.8	2.8	11.7
	BP[5]	76.5	10.4	17.1	34.8	2.5	2.9	13.1
	TADD[6]	77.1	12.1	18.7	32.4	1.5	4.1	11.2
SAD 448	WG	–	13.6	23.1	46.6	1.8	5.5	11.4
	TM	71.7	13.6	13.6	34.5	2.1	2.7	11.8
	BP	89.5	12.8	17.0	44.4	3.0	2.9	13.1
	TADD	88.3	12.7	18.8	44.6	1.4	5.3	11.1
ICMV 1 (WC-C75)	WG	–	14.6	25.1	45.9	1.8	5.6	15.5
	TM	75.3	14.0	13.4	36.6	1.7	3.1	12.7
	BP	86.8	13.7	15.0	43.1	2.3	3.0	13.2
	TADD	86.2	13.0	17.8	43.9	1.6	5.6	12.4
SE (analysis)	±0.31	±1.40	±1.60	±0.18	±0.40	±0.35		

1. Fractions: I = albumin + globulin; II = prolamins; III = cross-linked prolamins; IV = glutelins; V = glutelin-like.
2. WG = Whole grain.
3. – = Not applicable.
4. TM = Traditional.
5. BP = Barley pearler.
6. TADD = Tangential Abrasive Dehulling Device.

Milling Quality

The particle size distribution pattern of pearl millet flours used for making different food products is considered important in determining the texture of these products. In order to obtain information on the differences in flour textural requirement for various food products, we studied particle size distribution in flour samples collected from Niger and Senegal used in making several food products.

Flour from dehulled grains used for *fura* (thin porridge) contained the following distribution of particle size: 26.7% of the sample retained on a 45-mesh sieve; 54.7% passed through a 100-mesh sieve (Table 12). Flour from dehulled grains used for *hourou* (thick porridge) had a nearly similar distribution. In flour used for *cous cous,* a steam-cooked product that is granulated prior to cooking, 35.9% of particles were retained on a 45-mesh sieve and only 29.7% passed through a 100-mesh sieve. Nearly 100% of a sample of coarse grits of pearl millet (*brisé*) used for making *tiakri* (a porridge-like product) or *dougoub djenn* (a rice-like product) collected from l'Institut de technologie alimentaire, Senegal, was retained on a 20-mesh sieve. For fine grits (*sanxal*) used for making *lakh, cous cous,* etc., 68.7% was retained on a 20-mesh sieve and 30% on a 40-mesh sieve. Particle size distribution will thus be useful in evaluating the suitability of cultivars and experimental milling methods for various food uses in West Africa.

Food Quality

We prepared several traditional foods that are common in Niger and Mali, with the help of

Table 12. Particle size distribution of pearl millet flours and grits collected in Niger and Senegal, 1986.

	Retention (%) on different-sized sieves (mesh size)					
Flour/grits	20	45	60	80	100	>100
Flour for *fura*[1]	0.13 (±0.01)[2]	26.7 (±0.61)	8.1 (±0.23)	7.0 (±0.26)	1.9 (±0.11)	54.7 (±0.72)
Flour for *cous cous*[1] (granulated)	15.4 (±0.93)	35.1 (±1.66)	8.4 (±0.33)	7.1 (±0.44)	2.4 (±0.06)	29.4 (±0.39)
Brise (coarse grits)[3]	99.2 (±0.15)	–[4]	-	–	–	–
Sanxal (fine grits)[3]	68.7 (±0.90)	30.0 (±0.70)	1.3 (±0.20)	–	–	–

1. Sample collected in Niger.
2. Figures in parentheses are standard errors (SEs).
3. Sample collected in Senegal.
4. – = Entire grits sample retained on the larger mesh sieves.

scientists from these countries. The food samples were processed and analyzed for chemical composition, amino acid composition, and in vitro protein digestibility (IVPD) (Table 13). Protein content (on a percentage sample basis) was slightly higher in several of the foods compared to the flour, as was the content of several amino acids. Protein digestibility (IVPD) was reduced considerably in *cous cous,* and *tô* from Niger (alkaline preparation) as endosperm proteins may have been modified due to the preparation or cooking method.

In contrast, there was no loss of IVPD in either *tô* from Mali (acidic preparation) or in *roti* from India, compared to the IVPD of the flour and whole grain. Thus the method of preparation (particularly the method of cooking) may have important effects on the ultimate nutritional quality of the grains as used by the consumer.

Table 13. Composition and in vitro protein digestibility (IVPD) of pearl millet BJ 104 grain, flour, and foods prepared from them, ICRISAT Center, 1986.

Flour/food	Protein (%)	Fat (%)	Ash (%)	Starch (%)	Sugars (%)	Amylose (%)	Fiber (%)	IVPD (%)
Whole grain flour	10.3	6.5	1.8	67.3	1.9	31.2	1.4	85
Dehulled grain flour	9.1	5.2	1.4	72.7	1.1	35.2	0.8	84
Fura (uncooked)[1]	9.9	4.6	1.1	70.9	2.1	29.0	0.9	58
Fura (cooked)[1]	9.5	5.4	1.1	71.1	1.3	31.2	0.9	51
Tô (Niger)[1]	9.8	3.5	1.4	67.5	0.5	32.9	0.8	74
Tô (Mali)[1]	9.5	3.7	1.5	67.1	1.0	32.9	0.8	92
Cous cous[1]	10.0	5.6	1.5	70.4	1.2	34.5	0.7	67
Roti[2]	10.7	5.4	–	70.3	1.9	–	1.3	84
SE (analysis)	±0.20	±0.36	±0.53	±0.55	±0.19	±0.80	±0.09	±5.1

1. Prepared from dehulled grain flour.
2. Prepared from whole grain flour.

Plant Improvement: ICRISAT Center

Genetic Diversification

We initiated research in three main areas: improvement of populations with specific traits; selection and improvement of landraces; and major gene evaluation. This more strategic research has been made possible by reducing the emphasis on breeding open- pollinated synthetic varieties.

Creation of New Populations

We are creating broad-based populations, with particular traits or combinations of traits, which do not exist at present in the composites in our population improvement project. By using population improvement methods, we can utilize a wide range of parental materials including landraces, inbred lines, and elite open-pollinated varieties. We will feed progenies from these populations into composites in our population improvement project (which improves agronomically elite composites rather than these broad-based populations). To a lesser extent, we will use the population progenies in our pollinator and male-sterile breeding projects. We are beginning by creating six populations:

- **High Tillering Population 88 (HiTiP 88).** We selected for intermating 15 inbred lines with outstanding tillering capacity and good agronomic performance from our pollinator collection and the 1984 breeder/physiologist nursery. We will select in this population for high tillering, earliness, and high yield. Our objective is to produce a population that combines high yield with a tillering capacity that is higher than that presently found in elite material.

- **Large Grain Population 87 (LaGraP 87).** We made this population by random mating 100 half-sib families from panicles selected from the third random mating of the Large-Seeded Gene Pool (LSGP). This gene pool has many African landraces as parents. We will use progenies with good grain size and resistance to downy mildew from this population to feed into the later-flowering composites.

- **Large Grain Population 88 (LaGraP 88).** We will intermate selected half-sib families from the LSGP, large-seeded S_1lines from both the open-pollinated variety ICTP 8203 and the Bold Seeded Early Composite (BSEC), and other lines with very high grain mass. We are aiming to further improve seed size whilst selecting for yield, to obtain high-yielding material with an individual grain mass that is higher than that currently found in large-grained pearl millet.

- **White Grain Population 88 (WhiGraP 88).** We are introducing several sources of white grain into high-yielding, early, large-seeded material. We will use this population as a source of white-grained lines, and determine if it is possible to obtain a high-yielding, uniformly white-grained population.

- **African Population 88 (AfPop 88).** We are combining previously selected West African introductions into a single population, which will be improved for adaptation to Indian conditions. It should serve as a source of late-flowering material, with high levels of resistance to downy mildew.

- **Late Backup Composite (LBC).** This composite has been made in our population improvement project using late-maturing Indian material and varieties from West Africa as parents. We will compare the yield and agronomic characteristics of AfPop 88 and LBC, and then merge them in a proportion relating to their performance.

- **High Growth Rate Population 88 (HiGroP 88).** We are initiating this population by crossing very early landraces and accessions of wild pearl millet with an early F_2 population that has high biomass production and disease resistance. Our objective is to select for high growth rate in early-maturing material, as a strategy for combining high yield and earliness.

Landrace Evaluation

In view of the specific adaptation required for pearl millet in northern India to frequent drought, high soil temperatures, and long day-length, we started a program to select and improve landraces from this region. We have begun a systematic evaluation of 300 population samples (landraces) from northern India, obtained from the ICRISAT Genetic Resources Unit (GRU), for their response to terminal drought stress (Fig. 8).

We plan to:

- identify landraces for improvement using population breeding methods;
- gain some understanding of the structure of variation within and among landrace populations and to try to relate this to environmental conditions in the places of origin of the landraces; and
- evaluate presently used selection procedures to improve adaptation to drought stress in relation to adaptation to northern Indian pearl millet-growing conditions.

Figure 8. ICRISAT Plant Breeder recording evaluations on the Rajasthan landrace pearl millet collection. ICRISAT Center, dry season 1987.

Major Gene Evaluation

We initiated studies to evaluate different sources of several traits controlled by major genes:

- Dwarfing genes. We will cross and then backcross different dwarfing sources identified by GRU (Fig. 9) to an inbred line, ICMP 85231, selected for its earliness and disease resistance. When near isogenic lines are obtained we will be able to assess the usefulness of the genes from these sources, and compare their inheritance in a common, agronomically desirable background.
- Genes for light grain color. We will also backcross different sources of white-grained material identified in different breeding projects to ICMP 85231 to study the inheritance of this trait.
- Trichomeless gene. We have completed the first crosses to introduce this gene into a synthetic variety and two R-lines by backcrossing. We intend to assess its potential as a marker gene in seed multiplication, and its effects on fertility, smut and ergot resistance, and shootfly susceptibility.
- Early (e_1) gene. We have completed the first cross, in a backcross breeding program, to introduce the e_1 gene into three R-lines, ICMP 85410, ICMP 85409, and ICMP 451. Currently, the e_1 gene is not available in an agronomically elite, downy mildew resistant

Figure 9. Dwarfing sources being used in the pearl millet backcrossing program to produce near-isogenic lines for comparison of the usefulness of various sources. ICRISAT Center, dry season 1987.

background, and this backcross breeding program should therefore provide excellent parental sources of the e_1 gene. This gene can be used in hybrid breeding to make late lines earlier without changing the genetic background of the line. We can thus improve the nicking of parental lines that have very different flowering times.

As part of a continuous effort to utilize landrace material collected by the GRU, we selected 254 individual plants in the first evaluation of material from Cameroon and Uganda. We subsequently tested their photoperiod sensitivity in the extended daylength nursery. The earlier, less photoperiod-sensitive material is being evaluated for introduction into AfPop 88 or WhiGrap 88.

Plant Introductions

Material received from overseas in 1987 included 135 breeding lines and bulk populations from the SADCC/ICRISAT millet program at Bulawayo, Zimbabwe; and 4 pairs of A/B lines, and 36 half-sib families from two dwarf composites from Kansas State University, USA. We have evaluated and selfed these entries during the 1987 rainy season.

Breeding Varieties

Pedigree Breeding

Both pedigree breeding to make synthetic varieties, and population improvement methods to make varieties (termed composite varieties in this discussion) have been used since the beginning of pearl millet breeding at ICRISAT Center. We use the term synthetic variety (which is loosely defined in the literature) to refer to varieties that have been made by random mating inbred lines (F_4 and beyond) derived from crosses, rather than progenies (usually S_1 or S_2) derived from composites. In order to better compare the effectiveness these two methods, synthetic varieties and composite varieties were jointly tested in a single trial, the Pearl Millet Advanced Variety Trial (PMAVT), beginning in 1985. Over 3 years in this trial the composite varieties yielded about 300 kg ha^{-1} more than the synthetic varieties when either the best entry or the means of the composite and synthetic varieties were compared. The highest-ranking synthetic variety in this 49-entry trial was 8th over 4 locations in 1986, 13th over 9 locations in 1986, and 26th over 5 locations in 1987. The superiority of composite varieties has also been obvious in the International Pearl Millet Adaptation Trial (IPMAT) from 1976 to 1986 (Table 14). In 9 of the 10 years, the highest-yielding open-pollinated variety was a composite variety. The exception in 1978 was ICMS 7703 which was later released for general cultivation in India. In 6 out of the 10 years the mean of the composite varieties was higher than that of the synthetic varieties.

In All India Coordinated Pearl Millet Improvement Project (AICPMIP) trials, some of the older synthetics (those which were first entered in the initial trials in 1980) have ranked well, but they have not outyielded ICMV 1 (WC-C75) by any appreciable margin.

We conclude from these results that synthetic variety breeding is less effective than population improvement in producing high-yielding, open-pollinated varieties. From a theoretical viewpoint this is perhaps to be expected, since it takes more generations to breed a synthetic variety than a composite variety. The extra generations are required for further inbreeding, where selection, which may well be effective in improving the inbred line, is less likely to be effective in improving an open-pollinated product derived from it. In population improvement, a further cycle of selection can be done instead of the generations of inbreeding.

Table 14. Comparative performance of composite (C) and synthetic (S) varieties in the International Pearl Millet Adaptation Trial (IPMAT), 1976–1987.

Year of IPMAT[1]	No. of locations	No. of entries C	No. of entries S	Mean yield (t ha^{-1}) C	Mean yield (t ha^{-1}) S	Best entry Rank C	Best entry Rank S	Best entry Yield (t ha^{-1}) C	Best entry Yield (t ha^{-1}) S
1976	26	5	3	2.02	1.72	7	9	2.17	2.12
1977	29	5	1	1.72	1.59	3	14	1.83	1.59
1978	36	7	1	1.98	2.09	7	5	2.04	2.09
1979	29	6	4	1.79	1.85	3	6	1.95	1.88
1980	31	5	4	1.78	1.81	5	7	1.90	1.86
1981	25	6	4	1.97	1.89	8	13	2.09	1.96
1983	19	5	6	1.92	1.96	1	5	2.11	2.03
1984	17	5	5	1.73	1.67	8	15	1.80	1.69
1985	21	5	5	2.17	2.15	8	9	2.24	2.24
1986	14	5	2	2.27	2.18	7	14	2.37	2.18
Mean	24.7	5.4	3.5	1.93	1.89	5.7	9.7	2.05	1.96

1. IPMAT not conducted in 1982.

A synthetics breeding project which does not produce high-yielding, open-pollinated varieties could still be justified, as the inbred lines can also be directly used in hybrid breeding. However, we can also assist the hybrid breeding effort by improving composites or populations and by creating high-yielding varieties from them, as all of these can be used as parental sources of inbred lines.

Because of these results, we have now discontinued synthetics breeding as such, and are using the resources saved to create more diverse parental material in the genetic diversification project. However, we are still making synthetics, on a much reduced scale, using tested inbred lines already available from the male-sterile and pollinator projects. We select inbreds, from B-line nurseries or the pollinator collection that, on the basis of pedigree and phenotype, are likely to give phenotypically distinctive synthetic varieties. In 1987, we made nine synthetics from inbreds from our male-sterile breeding project and tested them in the Pearl Millet Initial Variety Trial-4 (PMIVT-4), and the best three were ranked 5th, 8th, and 9th in this 49-entry trial. Thus, this technique may be reasonably promising as a breeding strategy, although these synthetics have yet to compete in the same trial as composite varieties. We will continue with this activity on a limited scale, as it uses few resources, and review its utility when we have more results.

To properly conclude the synthetics breeding project we will retest many of the best past synthetics, which will include some that were dropped because of unacceptable variablity, in a single trial in the 1988 rainy season, to evaluate their yield potential and their value as parents for introgression into our elite composites.

We will computerize the pedigrees of the many existing inbred lines in the synthetic project, screen them for downy mildew in the greenhouse, and after further evaluation and testcrossing to an A-line to see if they are restorers, we will contribute the best R-lines to the Potential R-Lines Nursery-1 (PRLN-1). In 1987, we evaluated 946 inbreds beyond F_7 and selected 522 of them for inclusion in PRLN-1 of 1988.

Population Improvement

Advancement of existing composites. Since the 1986 rainy season we have completed a further cycle of S_1 progeny testing in the Medium Composite (MC), the New Elite Composite (NELC), the Ergot Resistant Composite (ERC), and the BSEC.

We random mated the following:

- sixth cycle bulk of the Dwarf Composite (D2C);
- first cycle bulk of the Early Composite II (EC II);
- C_0 bulk (first random mating) of the Smut-Resistant Composite II (SRC II); and
- C_0 bulk (third random mating) of the Elite Composite II (ELC II).

Performance of varieties. In the 1987 rainy season, we evaluated 31 composite varieties, 12 synthetic varieties, and a range of controls in PMAVT. Of the 31 composite varieties, 12 came from the MC, 13 from the NELC, 3 from the EC II, 2 from the Smut Resistant Composite (SRC), and 1 from the Inter Varietal Composite (IVC). Over five locations the 10 highest-yielding varieties were either from the MC (seven varieties yielding 122-126% of ICMV 1 (WC-C75)), or the NELC (three varieties yielding 123-126% of ICMV 1). The best synthetic variety was ranked 26th and yielded 114% of ICMV 1.

Formation of new composites. We made up to 24 varieties from a cycle of a composite to test different strategies for making composite varieties. Results from these recent experiments indicate that if we have 10-25 progenies as parents, or mass select the composite bulk, we can more reliably expect that the variety will yield well than if we use a smaller number. We have therefore, decided to change our usual method of making varieties. Instead of selecting as parents small sets of about 5-10 progenies on the basis of yield at or across the different locations where the progenies were tested, we will use greater numbers of progenies or mass select the bulk, and thus greatly reduce the number of varieties we make. We will, therefore, be able to increase our activities on creating and improving composites, and we will start by forming three new composites:

- **Bristled Early Composite 88 (BEC 88).** We will recommence work on a bristled composite, the parental material of which is mainly the bristled Super Serere Composite (SSC). Bristled hybrids are preferred in some parts of India, so BEC 88 will be used as a source to breed bristled pollinators.

- **Early Composite 87 (EC 87).** Two of the most promising early composites, which differ in maturity, seed size, and tillering (EC II and BSEC) are being merged to form this new composite (Fig. 10). We hope to obtain a composite that is: earlier than EC II, has a higher individual grain size than EC II, and is higher-yielding than BSEC.

- **Mixed Dwarf Early Composite 88 (MDEC 88).** We will intermate the elite dwarf material that we selected from the male-sterile project (where most of the breeding effort is on dwarf lines) with early tall material. In later generations, dwarf material will be derived from MDEC 88 to feed into the dwarf composite, and tall and dwarf material from it will be used in the male-sterile project. Thus, both MDEC and D2C can be used as composites to support the male-sterile breeding effort, and the genetic base of the D2C will be broadened.

We will, by introducing these new composites, increase the emphasis on early-maturing material (i.e., on composites which should flower in about 50 days or less). The composites in this early group will be EC II, EC 87, BSEC, and BEC 88. In addition, selected early progenies from MBEC 88 will be introgressed into these early composites.

Depending on the subsequent performance of these composites, we will either maintain all of them, keeping them phenotypically diverse by selection, or we will drop or merge the less promising ones.

Figure 10. Typical panicles of the new pearl millet Early Composite 87, formed by merging the Early Composite II and the Bold Seeded Early Composite.

Breeding Hybrids

Breeding Male-Sterile Lines (A-Lines)

New male-sterile lines. We contributed three male-sterile lines (ICMA 87001, ICMA 87002, and ICMA 87003) to the 1987 AICPMIP male-sterile lines trial. All three are based on the A_1 male-sterility inducing cytoplasm and all possess high levels of resistance to downy mildew (<5% incidence). Male-sterile line ICMA 87001 is a late-maturing (72 days to 50% flowering) d_2 dwarf. Male-sterile lines ICMA 87002 and ICMA 87003 are of normal height and have large seeds (10-11 g 1000^{-1}). ICMA 87002 is of mid-early maturity (56 days to 50% flowering), and ICMA 87003 is early maturing (50 days to 50% flowering). All three of these male-sterile lines are moderately sensitive to increases in daylength, flowering 10-11 days later in the artificially extended 15.5-h days than in the normal 13.5-h days during the rainy season at ICRISAT Center (ICRISAT Annual Report 1986, p. 100).

Of the male-sterile lines we have contributed to AICPMIP in the past 2 years, 863A appears to be most promising as a parent of hybrids for the Indian subcontinent that are agronomically acceptable, appropriate in maturity, broadly adapted, and high-yielding. This conclusion is based on multilocational evaluation of testcross nurseries, and initial and advanced hybrid trials in the rainy seasons of 1986 and 1987.

Evaluating new maintainer (B-lines). Systematic evaluation of our B-lines is now a routine part of our male-sterile breeding. Backcrossing to convert B-lines to A-lines is now generally only started after the B-line has been successfully screened in a progressive series of three Potential B-line Nurseries (PBLN). The first nursery, PBLN-1, is a single location, observational nursery used to identify the best agronomically elite advanced generation inbreds in a wide (F_6–F_9) array of phenotypes. PBLN-2 is a multilocational trial of selections from PBLN-1, used to identify broadly adapted, productive inbreds and evaluate their disease resistance. PBLN-3 is a further multilocational evaluation of PBLN-2 selections which also tests topcrosses of the B-lines to open-pollinated testers. Every year, we start a PBLN-1 in the dry season and grow the PBLN-2 and PBLN-3 derived from it in the subsequent two rainy seasons. We, therefore, evaluated in 1987, both PBLN-2 (selected from PBLN-1 in 1986), and PBLN-3 (initiated with PBLN-1 in 1985).

PBLN-2 was a multilocational trial of 220 potential B-lines grown at Bhavanisagar, ICRISAT Center, and Hisar. We also grew these 220 lines as a nonreplicated nursery in cooperators' fields at Aurangabad, Gwalior, and Mysore, primarily to evaluate their resistance to downy mildew. We selected 70 for promotion to PBLN-3 in the 1988 rainy season, based on:

- visual scores for yield, uniformity, and agronomic eliteness across four locations (Bhavanisagar, Gwalior, ICRISAT Center, and Hisar);
- mean grain yield across two locations (Bhavanisagar and ICRISAT Center);
- photoperiod response in the extended daylength nursery at ICRISAT Center; and
- downy mildew incidence across all six locations.

We used delayed flowering in the extended daylength nursery at ICRISAT Center as an important selection criterion as our data on time to flowering in the north were unreliable due to the effects of drought. We expect that the extended daylength nursery has allowed us to retain a number of lines whose flowering was delayed at Hisar or Gwalior because of the unfavorable microenvironment (saline patches or insufficient moisture), while eliminating those lines that were late under northern Indian conditions because of excessive photoperiod sensitivity.

In PBLN-3, we tested 63 B-lines and their topcrosses to two composites [the ICRISAT Restorer Composite II (ICRC II), and EC II] at Bhavanisagar, Hisar, and ICRISAT Center. These 63 potential B-lines, which are of diverse origin and phenotype, were also grown as a nonreplicated nursery in cooperators' fields at Gwalior and Mysore, mainly to evaluate their resistance to downy mildew. We retained 35 for further evaluation of their general combining ability and productivity per se and have started backcrossing 21 of them to convert them to A-lines. We used as selection criteria:

- visual scores for yield, uniformity, and agronomic appearance across four locations (Bhavanisagar, Gwalior, Hisar, and ICRISAT Center);
- average measured grain yield of the B-line and its topcross hybrids across two locations (Bhavanisagar and ICRISAT Center);
- photoperiod response in the extended daylength nursery at ICRISAT Center; and
- downy mildew incidence across all five locations.

Of the selection criteria, delayed flowering of the line per se in the extended daylength nursery at ICRISAT Center, poor topcross grain yields, and excessive height of topcross hybrids were the most useful criteria for rejection within this group of B-lines.

New male-sterile cytoplasm sources. We have completed the transfer of nuclear genes from maintainer line ICMB 1 (81B) into the male-sterility inducing cytoplasm derived from *Pennisetum violaceum*, which was identified by scientists from ORSTOM. The resulting male-sterile line, ICMA 88001, will be released to AICPMIP in 1988 to allow our cooperators to assess their breeding materials for the ability to restore fertility in this cytoplasm in an adapted, agronomically elite genetic background. In the coming year we will conduct a study of fertility restoration in near-isogenic hybrids made on the near-isogenic male-sterile lines ICMA 1 (81A) and ICMA 88001 to test if the cytoplasmic male-sterility systems of these two male-sterile lines are indeed different.

We continued work on other possible alternatives to the A_1 CMS system, including male-sterility inducing cytoplasms from the following groups of materials:

- accessions collected from Ghana and Botswana identified by the ICRISAT Genetic Resources Unit;
- progenies of variety crosses involving ICMV 3 (IBV 8004) and Ex-Bornu as female parents; and
- progenies and bulks of the Early Composite II (EC II).

Our preliminary studies suggest that there are only two major groups of cytoplasmic male-sterility systems in pearl millet. This is far less than the seven cytoplasms identified so far in the literature. The first of these includes the A_1 cytoplasm and the V *P. violaceum* cytoplasm of ICMA 88001, plus several others. In this group of cytoplasms, sterility is maintained by ICMB 1 (81B) and MS 5054B, and fertility is restored by ICMP 501, and J 104. In the second major group of cytoplasms, which includes A_2, A_3, and the cytoplasm of PT 732A, among others, sterility is maintained by ICMP 501 and J 104, but fertility is restored by MS 5054B and ICMB 4 (834B). ICMB 87003 maintains sterility in both groups of cytoplasms, while ICMP 451 and IPC 000715 restores fertility in both. The reason why we have identified fewer cytoplasms is that the erroneous effects caused by differences in nuclear genes (rather than cytoplasm) have been reduced. We have done this by studying inbreds where nuclear differences have been reduced by backcrossing. We conclude that even though the number of cytoplasms is almost certainly lower than previously thought, it is still possible to diversify the cytoplasmic base of pearl millet hybrids. We now have a set of inbreds that will enable us to distinguish between the two different cytoplasmic groups.

Breeding for reduced photoperiod sensitivity. Many genetic materials of African origin flower too late under the longer days at northern Indian locations. Lack of a reliable test site to select for early flowering in northern India has hampered our efforts to introgress materials of African origin into male-sterile lines for this region. In an attempt to overcome this problem we have initiated screening of selected F_2 populations and F_3 progenies under artificially extended daylength (15-h day) in the rainy season at ICRISAT Center. In an increased area of artificially extended daylength we selected early-flowering plants and progenies in breeding materials having the highly photoperiod-sensitive maintainer line 852B in their parentage. This procedure should allow us to eliminate materials that are excessively delayed in flowering under northern Indian conditions before attempting to select for less highly heritable traits.

We will also be using this technique to transfer the e_1 gene for photoperiod-insensitivity (for daylengths up to 16 h) into the genetic backgrounds of late-maturing, downy mildew-resistant maintainer lines such as 861B, 862B, and ICMB 87001. Male-sterile lines based on less photoperiod-sensitive derivatives of these three B-lines should have advantages for both hybrid breeding and hybrid seed production. Such male-sterile lines could be crossed with a broader array of pollinators that flower earlier, nick well, and have an improved probability of producing medium-maturing hybrids compared to the three existing late lines. In terms of hybrid seed production, the difference in flowering time of the male-sterile line and the pollinator should be much less sensitive to the season and latitude in which seed production is attempted and therefore much easier to predict. This could reduce the risks associated with multiplication of new hybrids for hybrid seed producers, and reduce the probability of productive new hybrids failing to reach farmers' fields because of difficulties in their seed production.

Breeding Pollinators (R-Lines)

In the 1987 dry and rainy seasons, we evaluated the 797 active entries in the pollinator collection. Out of these, we retained 696 as active entries mainly on the basis of downy mildew resistance, and satisfactory seed set of bagged panicles. The approximate distribution for time to 50% flowering at ICRISAT Center under high-fertility conditions in the dry season was 1% <45 days, 65% between 46-55 days, and 16% >55 days. The remaining 18% have not yet been classified. We will, therefore, intensify our efforts to breed early pollinators. With regard to the proportion of dwarfs, 18% of the pollinators are dwarf (presumed homozygous for the d_2 dwarfing gene) and 82% are nondwarf, which reflects the lower priority accorded to the breeding of dwarf hybrids.

In the dry season, we evaluated 700 inbred lines (F_6 or equivalent) with diverse pedigrees derived from R×R and R×B crosses, ICRISAT composites NELC, MC, New Early Composite (NEC), D1C, IVC and SRC, and crosses of Indian and African lines, in the Potential R-lines Nursery-1 (PRLN-1). They were grown in both normal and artificially extended daylengths (15-h day).

We rejected lines with poor seedling emergence, poor uniformity, or with more than 10% downy mildew in a greenhouse seedling screen test. After these rejections 261 lines remained for promotion to PRLN- 2 which also had 29 control entries (including the downy mildew susceptible control NHB 3). We grew PRLN-2 in the rainy season of 1987 at ICRISAT Center (in both normal and extended daylength), Hisar, and Bhavanisagar, and in the Mysore, Aurangabad, and ICRISAT Center downy mildew nurseries, and in the ICRISAT Center smut nursery. We rejected lines taller than 2 m at either Hisar or in the extended daylength nursery, and lines which differed in time to 50% flowering by more than 10 days between ICRISAT Center and Hisar. Lines that had downy mildew at any location, a smut rating of more than 20% in the ICRISAT Center smut nursery, or a poor agronomic score at Hisar or ICRISAT Center were also eliminated. We promoted 27 lines to PRLN-3, where they and their topcrosses to a B-line composite will be evaluated. We retained 36 lines for further testing in PRLN-2 of 1988.

Hybrid Testing

We evaluated 36-entries in the Pearl Millet Advanced Hybrid Trial (PMAHT) in the 1987 rainy season. Of the test entries seven were both fertile and had more than 105% of the trial mean yield across ICRISAT Center (high and low fertility), Bhavanisagar, and Hisar. Of these seven hybrids (ICMH 85118, ICMH 87030, ICMH 87023, ICMH 87021, ICMH 87031, ICMH 87029, and ICMH 87018) the male-sterile lines are 843A (1 hybrid), 852A (1 hybrid), 833A (2 hybrids) and 863A (3 hybrids). The highest-yielding entry, ICMH 85118 (male-sterile line 843A), yielded 17% more grain than the highest-yielding control hybrid, MBH 110.

We conducted a trial of nine elite hybrids (Table 15) at two locations to test if current hybrids outyield those that were released in the 1960's or 1970's. The three recently released hybrids, MBH 110, ICMH 451, and ICMH 423, outyielded the three previously released hybrids, BJ 104, BK 560, and HB 3, in the high-yielding environment at Hisar. However, at ICRISAT Center where the yield was lower, these hybrids had on average about the same grain yield as the previously released hybrids. We also had three new unreleased hybrids in the trial (ICMH

Table 15. Summary of performance of three groups of pearl millet hybrids; recently released, new, and earlier-released hybrids, at ICRISAT Center (IC) and Hisar (HSR), rainy season 1987.

	Grain yield (t ha^{-1})			Time to 50% flowering (d)		Height (m)		Time to maturity (d)	
Group	IC	HSR	Mean	IC	HSR	IC	HSR	IC	HSR
Recently released hybrids[1]	3.25	4.10	3.68	47	49	1.83	2.56	76	72
New hybrids[2]	3.17	4.01	3.59	49	54	1.59	2.02	83	78
Earlier-released hybrids[3]	3.32	3.40	3.30	45	48	1.63	2.32	77	70
SE	±0.10	±0.28	±0.15	±0.3	±0.7	±0.02	±0.05	±0.3	±0.9
Mean	3.25	3.79	3.52	47	50	1.68	2.30	81	73
CV(%)	8	19	1	3	3	6	1	2	

1. ICMH 451, ICMH 423, and MBH 110.
2. ICMH 85410, ICMH 84122, and PH 5002.
3. BJ 104, BK 560, and HB 3.

85410, ICMH 84122, and PH 5002), but they failed to outyield the recently released hybrids.

We assessed fertility restoration in the 1987 rainy season, based on pollen shed and selfed seed set of hybrids of 27 pollinators crossed to three male-sterile lines ICMA 87001, ICMA 87002 (A_1 cytoplasm), and ICMA 88001 (*violaceum* (V) cytoplasm). The fertility restoration requirements of the V cytoplasm were found to be similar to those of the A_1 cytoplasm. Thus, if the V cytoplasm is used in breeding male-sterile lines, ICRISAT pollinators will, in general, restore fertility.

Yield Physiology Studies

Dwarfing Gene Effects

We continued our study of the effects of the dwarfing (d_2) gene in pearl millet (ICRISAT Annual Report 1985, pp. 117-119) by making and testing 16 pairs of isogenic tall/dwarf F_1 hybrids. To do this, we used four pairs of isogenic tall/dwarf inbred lines as pollinators on four dwarf male-sterile lines. As the dwarfing gene is recessive, the dwarf line of each pair produced a dwarf (d_2 d_2) hybrid, while the tall line produce the tall (D_2 d_2) counterpart.

We yield tested these 16 pairs of hybrids in the rainy seasons of 1985, 1986, and 1987 at ICRISAT Center. We partitioned the genotypic variation into the variation due to the effects of height, pollinator, and male-sterile line and the various interactions between these effects (Table 16). This allowed a comparison of the importance of the dwarfing gene, relative to the importance of the parents, in determining grain yield, its components, biomass, and harvest index.

The dwarfing gene had a significant effect on grain yield, representing 20% of the genotypic variation for yield (Table 16). The dwarfs yielded 9% less than the talls which was due entirely to a significantly smaller grain size in the dwarfs (7.51 vs. 8.40 mg grain^{-1}). As expected, the dwarfing gene accounted for the majority of the variation in height, and nearly half of the variation in biomass, although its effect on harvest index was much smaller (38.7% for the dwarfs vs. 36.8% for the talls).

Table 16. Contribution of the dwarfing gene to total genotype variation (% genotype sums of squares) for grain yield, yield components, and growth. Data are from a set of 16 pairs of isogenic tall/dwarf pearl millet hybrids. ICRISAT Center, rainy seasons 1985, 1986, and 1987.

		Percentage of total genotype variation for:					
Source of variation	df[1]	Grain yield	Grain no. m^{-2}	Grain mass	Height	Biomass	Harvest index
Height	1	20***	1	9***	83***	43***	12***
Male-sterile	3	6**	64***	36***	5***	20***	33***
Pollinator	3	35**	27***	47***	10***	26***	23***
All interactions	24	38*	7**	8***	1***	10**	32*

1. df = degrees of freedom
*$P<0.05$; ** $P<0.01$; *** $P<0.001$.

With the exception of height and biomass, parental effects in terms of the fraction of the total genotypic variation for which they accounted were much greater than those of the dwarfing gene. Thus, there seems to be an adequate opportunity to breed dwarf hybrids with yields equal to those of tall hybrids. In fact, the interaction of height and pollinator accounted for a fraction of the genotypic sums of squares for grain yield nearly equal to that of the dwarfing gene itself (17% vs. 20%), suggesting that selection among dwarf pollinators would be effective in overcoming the problem of small seed. Subsequent work on the selection of dwarf pollinators for improved seed filling (seed size in relation to seed number) in their hybrids has produced hybrids with a yield potential in excess of 4 t ha^{-1}. This work demonstrated considerable genetic variation among dwarf pollinators for seed filling in hybrids made from them and has shown that this variation is closely related to mean hybrid grain yield ($r^2 = 0.81$, $P<0.001$).

Plant Improvement: ICRISAT Sahelian Center

Our main objective is to breed adapted varieties and develop improved genetic material combining high and stable yield potential for use by the National Research Programs (NRPs). We emphasize regional adaptation (which includes good emergence and seedling survival, early maturity and resistances to diseases and insect pests), increased and stable yield potential.

The breeding program has three units, one located at ISC is responsible for breeding pearl millet suitable for the southern Sahelian Zone (300-700 mm annual rainfall), another located at Kamboinsé (Ouagadougou) for the Transition Zone (TZ, 700-900 mm annual rainfall).

A third unit located at the ISC is responsible for coordinating our regional cooperative activities in addition to input into breeding for the southern Sahelian Zone. The breeding program relies on the cooperation and support extended by scientists in the NRPs, ORSTOM, and the International Board for Plant Genetic Resources (IBPGR).

Genetic Diversification

At ISC, evaluation and utilization of genetic diversity present in pearl millet and *Pennisetum violaceum*, in the form of accessions, segregating progenies derived from crosses, and elite breeding material received from programs within the region and from ICRISAT Center is a major activity.

Morphological and Enzyme Diversity in *P. violaceum*

The ORSTOM team evaluated over 100 accessions of *P. violaceum* collected in 1986 in Burkina Faso, Mali, and Niger in the rainy season at ISC. Observations were recorded on time to heading, and reaction to diseases and insects in addition to 14 morphological characters. Observations indicate that late-maturing types were absent, and that generally all accessions showed poor seedling vigor and were susceptible to downy mildew (DM). Accessions from Aïr (Niger) and Adrar des Iforas (Mali) were extremely susceptible to DM. There were no intermediate forms among accessions from the pastoral zones, whereas accessions from the areas where pearl millet is cultivated have not always segregated for these intermediate forms. The absence of these intermediate forms and late-maturing accessions will be confirmed in evaluations that will be continued next year targeted with collections made in Mauritania and Chad.

The ORSTOM team has also analyzed polymorphism in 12 genes coding for eight enzymes in 43 accessions of the wild millet, *P. violaceum* (39 collected in 1985 and 1986 from Mali and Niger, two from Sudan, and one each from Cameroon and Senegal). Results of these analyses were combined with those obtained in 1986 on 10 accessions of *P. violaceum* and 74 of pearl millet. Principal component analysis and discriminant analysis confirmed the separation of wild and cultivated forms of pearl millet (Fig. 1). The wild millet accessions from Adrar des Iforas and the Aïr mountains constitute two isolates that are genetically narrow and most distant from cultivated millets, whereas other wild millet accessions from Mali and Niger are very similar to each other. Wild millets collected in the agricultural zones of Niger are slightly closer to cultivated millets than wild millets collected in the pastrol zones of Niger. Within West Africa cultivated early-maturing millets from Mali are closest to wild millets but cultivated late-maturing millets are, as a whole, the furthest from wild species. Results indicate that the enzyme diversity in the wild millets of Mali and Niger is lower than the diversity that exists in the cultivated early-maturing millets of these two countries. Analysis for the two enzyme systems is in progress on recent collections made in Chad, Mauritania, and Senegal.

Generation and Evaluation of Segregating Progenies

In the southern Sahelian Zone program, we evaluated a range of breeding material at different levels of inbreeding. We evaluated 7 F_1s derived from crosses involving ICTP 8202 (early and bold grain) and improved local varieties and have selected six for advancing as F_2 populations. Ten F_2 populations involving crosses between 3/4 HK-B78 and improved local varieties were evaluated to derive improved dwarf phenotypes. We selected 44 dwarf plants (< 1.2 m height) and 22 medium-tall plants (between 1.2 to 1.5 m) for further inbreeding. We evaluated 2589 F_3 progenies derived from 197 crosses involving regionally adapted material. We selected 553 progenies for use in the development of 17 preliminary open-pollinated varieties, as parents in hybrid breeding, as entries for a dwarf source nursery, and for possible use in populations. A preliminary analysis indicated that 13 parents contributed 38% of the 553 DM-free progenies selected. These parents in order of their contribution are CIVT (12% of the progenies selected), HKP (8.3%), 3/4 HK-B78 (6%), IKMV 8201, IBMV 8302, Ex-Bornu, ITMV 8301, Souna III, and INMV 8212 (4.7% each), DG P1, P3 Kolo, Zanfarwa, and IKMV 8101 (3.5% each). In addition we have evaluated 862 F_4 to F_7 progenies and made selections as individual plants or as progeny bulks in 295 progenies for use as parents in variety development and generation of inbreds. We have selected 5 backcross F_3 bulks derived from the cross Souna 62 × Togo $4_2(3)$ to develop a variety combining bold seed and early maturity. We have constituted a dwarf nursery (d_2) of 253 entries derived from crosses involving 3/4 HK-B78 and ICMB 1 (81B). As the DM pressure was high we could select only 80 individual plants in 57 progenies. Seed of these along with the 89 dwarf phenotypes selected in the segregating progeny nurseries will be increased in the postrainy season and evaluated for DM reaction before their characterization and utilization in the development of dwarf phenotypes. To increase the diversity in dwarf backgrounds crosses were made in the postrainy season with five dwarf sources characterized by the Genetic Resources Unit at ICRISAT Center with two tall local landraces Zongo Kolo and Haini-Kirei de Bengou. These dwarf sources included IP 8008 (India), IP 8112 (Senegal), IP 8228 (ICRISAT), IP 8058 (Niger) carrying the recessive d_2 gene, and IP 8056 (Niger), that carries more than one dwarfing gene non-allelic to d_2. All these five accessions recorded less than 10% DM. We could not use d_3 (IP 10401) and d_4 (IP 10402) sources as these were extremely susceptible to DM (> 95%).

In our TZ breeding program, crosses between full-season photoperiod-sensitive and early-maturing (photoperiod low-sensitive or day-neutral) genotypes are important for introgression of genes from otherwise isolated types because of their photoperiod sensitivity. Identification of superior parents, crossing, and selection continued. We aim to select progenies that combine desirable characters such as local adaptation, disease resistance, desirable food quality, yield components, and stability. In the past, we have evaluated and utilized full-season cultivars of Burkina Faso. This year we continued preliminary evaluation of a new set of full-season accessions supplied by GRU. Over 550 accessions originating from 5 West African countries were evaluated (273 in 1986 and 299 in 1987) at Farako-Bâ. These accessions were generally tall (>3 m), with thin and short (<30 cm) panicles. They flowered from early September to late October. We selected 38 accessions that flowered from 15 September to 10 October, were DM-free, and had desirable agronomic and panicle characteristics to use as parents in crossing and inclusion in preliminary yield trials.

In our regional breeding program, to create new diversity combining adaptation to Sahelian conditions with good levels of DM resistance, 41 crosses were generated involving five improved varieties from Nigeria and seven from other West African countries. The varieties from Nigeria were good sources for DM resistance while the others provided general adaptation to the Sahel. All the 12 parents were selected on their performance in regional trials in West Africa. Additionally, 63 crosses were generated using Iniari (a West African, early-maturing, short, large-seeded cultivar with a high harvest index) and improved cultivars from Nigeria.

Breeding Varieties

Pedigree Breeding

In the 1987 postrainy season we recombined groups of progenies we selected in the 1986 rainy season evaluations to form 18 preliminary varieties. We yield tested these in a Pearl Millet Initial Varieties Trial (PMIVT) at Bengou, Cinzana, and Sadoré and a Pearl Millet Preliminary Varieties Trial (PMPVT) at Sadoré. Based on visual evaluations, DM incidence, and grain yield (ranged from 1.31 t ha^{-1} to 1.57 t ha^{-1} with a trial mean of 1.40±0.114 t ha^{-1}) we selected five entries for evaluation in the 1988 PMAVT. Mean yield of the 10-entry PMPVT was 1.07±0.109 t ha^{-1} with four entries, selected to be evaluated in the Pearl Millet Advanced Varieties Trial(PMAVT) of 1988, yielding in the range of 1.08 to 1.51 t ha^{-1}.

We conducted a PMAVT during this year with contributions from the southern Sahelian and TZ breeding programs. This 16-entry trial was sent to seven locations and results are available from four locations (Table 17). Based on grain yield performance at individual locations, DM incidence, and visual assessments we have selected entries ICMV IS 86313, ICMV IS 85321, and ICMV IS 86101 for inclusion in IMZAT and cooperative trials of 1988.

In our TZ breeding program, 113 F_1s between full season and early-maturing parents were evaluated, of which 31 were retained. Of 35 F_2 populations evaluated, 133 plants were selected from 22 crosses. We have observed over the

Table 17. Performance of selected entries of Pearl Millet Advanced Varieties Trial (PMAVT) at four West African locations, and downy mildew (DM) incidence at Bengou, Niger, rainy season 1987.

Entry	Location and grain yield (t ha^{-1})[1]				Time to 50% flowering (d)[2]	DM incidence (%)[3]
	Bengou	Kamboinsé	Ouahigouya	Sadoré		
ICMV-IS 86313	2.06	1.80	0.34	1.06	50	2
ICMV-IS 85321	1.91	1.83	0.53	0.80	50	5
ICMV-IS 86101	2.07	1.92	0.52	0.43	53	11
Controls						
Improved variety[4]	1.80	1.22	0.46	0.93	54	9
Local[5]	1.74	-	0.36	1.24	59	-
SE	±0.11	±0.10	±0.05	±0.11	±1	
Mean (16 entries)	1.79	1.51	0.45	0.75	53	10
CV (%)	13	13	24	30	2	

1. Randomized block design, plot size 19 m² Bengou, 6 m² Kamboinsé and Ouahigouya, and 18 m² Sadoré.
2. Recorded at Bengou.
3. Recorded in DM nursery, Bengou.
4. CIVT at Bengou and Sadoré; IKMV 8201 at Kamboinsé and Ouahigouya.
5. Kapelga was sown at Kamboinsé but failed to yield due to drought stress and attack by cantharid beetles.

years, that photoperiod-sensitive, late-flowering genotypes grow slowly whereas early-flowering genotypes grow rapidly. Last year we attempted to increase the frequency of late-flowering plants by selection for slow growth up to 6 weeks after sowing. In a nursery bed at high density, we sowed an F_2 population bulk of 5 crosses (with one common parent) which were known to yield late segregates. About 3 500 2-week old seedlings were transplanted in the 1986 crop season at 8.8 plants m^{-2}. Seedlings of Kapelga (photoperiod-sensitive) and GT 79 (early-maturing) were transplanted as repetitive controls. The nursery was irrigated as and when required. Plants with early vigorous growth could be easily identified and were uprooted from the nursery beginning 2 weeks after transplanting. Over 200 slow-growing plants that flowered in September were selected and harvested for F_3 evaluation. Selfed seed was harvested from 35 selected lines based on panicle characters, disease reaction, and agronomic score.

Population Improvement

We have completed the third random mating of ISC Composite 851, assembled from 193 F_1s involving 40 varieties and adapted landraces from West Africa. Half-sibs will be derived from the C_0 bulk in the 1988 rainy season.

We carried out cooperative testing of S_1 progenies of two Malian composites, Souna × Sanio and Pool-4 at Cinzana and Sadore. Based on results from Sadoré we selected 30 Souna × Sanio and 17 Pool-4 progenies to develop varieties and reconstitute the next cycle bulk. We applied a selection differential of about 50% to select parents of varieties, and a selection differential of 32% to select progenies for recombination. Over 600 S_1s were derived from the ICRISAT Center large-seeded gene pool and were grouped into two classes based on panicle length (between 30 and 40 cm and > 40 cm) for evaluation in 1988.

In our TZ breeding program four yield trials were constituted with entries of different maturity groups. These included the Full Season (130-160 d) Varieties Preliminary Trial (FSVPT) with 25 entries conducted at four locations in the 700-1100 mm rainfall zone, Full-Season (130-150 d) Varieties Advanced Trial (FSVAT 1) with 10 entries conducted at four locations in 700-1100 mm rainfall zone, Full Season (110-130 d) Varieties Advanced Trial (FSVAT 2) with 12 entries conducted at four locations in 600-900 mm rainfall zone, and Early-Maturing (80-100 days) Varieties Trial (EMVT) with 16 entries conducted at 4 locations in 600-900 mm rainfall zone.

Recombined populations from selections made from local cultivars entered the 3rd to 5th year of evaluation. Two recombined populations and 10 new varieties were tested for the first time. Three entries 7/8 SRMP 4, P8 and SRM Dori, contributed by Institut national d'études et de recherches agricoles (Burkina Faso) (INERA) were also included. INERA collaborated in the trials; all entries in the yield trials were screened in the DM nursery in collaboration with the INERA pathologist. Compared to base populations, the two newly recombined populations had improved for DM resistance but yields were similar or, in one case, lower.

The FSVPT included 21 selections from a set of accessions observed in the previous year. Four entries (Table 18) were selected for continued evaluation. FSVPT failed at Kamboinsé due to severe drought and yields were much reduced at Saria and Bengou due to drought during flowering and the grain-filling stage. Results of FSVAT 1 and FSVAT 2 confirmed the stable yield per-

Table 18. Performance of selected full-season pearl millet varieties for grain yield and downy mildew at five locations in Burkina Faso and Niger, rainy season 1987.

	Grain yield (t ha^{-1})[1] in different locations and rank						DM infection index[2] (%)	
Entry	Farako-Bâ	Rank	Saria	Rank	Bengou	Rank	Kamboinsé	Fada
IKM 86/87/22	1.80	3	0.55	15	1.44	2	3	-[3]
IKM 86/87/25	1.77	4	0.77	10	0.43	19	9	3
IKM 86/87/29	1.94	1	0.88	8	0.68	6	7	6
IKM 86/87/38	1.31	12	0.53	16	0.48	16	4	0
Controls								
IKMP 3	1.87	2	0.98	4	0.60	12	17	12
IKMP 1	1.52	8	1.07	3	0.67	8	21	13
Kapelga	1.64	6	1.36	1	0.28	23	52	24
Local[4]	1.57	7	1.08	2	2.05	1		
SE	±0.16		±0.16		±0.10			
Trial mean (25 entries)	1.27		0.73		0.62			
CV (%)	32		52		40			
Efficiency(%)	101		109		104			

1. 5 × 5 balanced lattice, plot size varied from 6 to 9.6 m^2.
2. INERA/ICRISAT collaborative screening in DM nursery.
3. Failed to germinate.
4. Farako-Bâ Local at Farako-Bâ, Saria Local at Saria and Bengou Local at Bengou.

formance of varieties IKMP 2, IKMP 3, IKMP 5, IKMP 1, and IKMP 4. The first three varieties were proposed for on-farm trials in 1986 (ICRISAT Annual Report 1986, p. 120). In the EMVT average grain yields (two locations) of new varieties ranged from 0.34 to 1.45 t ha^{-1} compared to 1.22 t ha^{-1} for the control IKMV 8201 (mean of the trial 0.99±0.127 t ha^{-1}). Of the seven varieties contributed to the PMAVT from the TZ program, ICMV IS 86101 performed well (Table 17).

Population progeny evaluation led to selection of 59 progenies for recombination of IKMP 5 out of 250 S_1s evaluated at Kamboinsé and Ouahigouya. Over 400 individual-plant selections for S_1 progeny tests were made from the population IKM 85/86/RP1 from 6 000 plants screened in the DM nursery. In addition to freedom from DM, selections were based on flowering date (7-15 September), and panicle and agronomic characteristics. A total of 126 lines from IKMC 1 were selected following evaluation of 820 half-sibs. Selfed seed was harvested from the selected lines for recombination.

In our regional breeding program 1380 early-maturing (75-90 d) half-sib progenies from single-plant selections derived from 22 bulk northern Nigerian accessions were evaluated. Nearly 350 progenies were retained to construct a population for recurrent selection. Of the 131 S_1 selections previously selected for high grain mass (> 15g 1000^{-1}), 71 were retained. Over 900 single-plant selections were made following evaluation of 37 medium-maturing (91-110 days) accessions from northern Nigeria. These will be evaluated as S_1 progenies and selected progenies will be used in the development of a medium-maturing composite.

Breeding Hybrids

At Bengou in the DM nursery we again evaluated 13 A and B pairs (from 4th to 6th backcross), selected on their reaction to DM in the 1986 rainy season. We observed that all pairs except two of ICMA 1(81A) × Souna $Mali_5$ were susceptible to DM. A similar reaction was observed in October sowings of these 13 pairs. We made plant × plant crosses on these two pairs and will advance them through this method in the DM nursery. In the postrainy season we sowed 21 A and B pairs received from ICRISAT Center and ORSTOM for seed increase. The DM incidence was very severe and we found that all pairs were highly susceptible (Table 19) indicating that we have to breed seed parents in situ. Similarly we observed that the DM incidence

Table 19. Reaction to downy mildew (DM) of A and B pairs of pearl millet, ISC, Niger, postrainy season 1987[1].

	DM incidence (% hills)	
A and B pairs	A-line	B-line
ICMA/B 1 (81 A/B)	95	100
833 A/B	13	27
ICMA/B 4 (834 A/B)	36	36
841 A/B	50	18
861 A/B	100	100
862 A/B	94	88
863 A/B	81	72
ICMA/B 87001	100	100
ICMA/B 87002	100	100
ICMA/B 87003	95	81
Pb 111 A/B	100	100
5054 A/B	100	100
5141 A/B	65	54
DSA 105 A/B	100	100
DSA 118 A/B	100	100
DSA 134 A/B	27	63
DSA 144-1 A/B	40	18
DSA 501 A/B	100	100
PMC 23 A/B	9	0
PMC 30 A/B	50	90
N 86-287/288 A/B[2]	86	95

1. Hill population (2 plants $hill^{-1}$) ranged from 10 to 54 for each entry, DM as natural incidence.
2. Incorporates *Pennisetum violaceum* cytoplasm in the A-line, seed provided by the Institut français de recherche scientifique pour le développement en coopération (ORSTOM).

was severe on 146 progenies derived from B × B line crosses from ICRISAT Center and on 9 progenies selected for conversion at ISC into seed parents. We selected 50 individual DM-free plants from 26 progenies for further screening and utilization. In addition, following evaluation of segregating progenies in the rainy season, 48 lines were selected for possible conversion into seed parents following screening for DM reaction.

We evaluated 133 testcrosses, a high proportion of which were made on 833 A, Pb 111 A, and 29-3-2, with CIVT as a systematic control. The testcrosses were early (mean time to 50% flowering 53±0.3 d) and suffered infestation by *Rhinyptia infuscata* that resulted in empty panicles. Testcrosses of comparable time to 50% flowering as the control CIVT (58±0.5 d) did not produce yields superior to the control. The DM incidence was also high on the testcrosses (mean DM 29%). Based on the observations made over the last 4 years, we will concentrate on the male-sterile Souna Mali, and on inbred × variety cross hybrids.

To initiate a collection of pollinators which combine earliness, medium plant stature, long panicles (>30 cm), and resistance to DM we tested 11 pollinators (based on performance in testcross combinations in previous years) for their yield potential in a trial at two locations and for DM reaction in the DM nursery at Bengou. Based on the results we have retained four pollinators, which yielded from 53 to 90% of the control CIVT (mean over two locations 1.79 t ha^{-1}) and will use these in the development of inbred × variety cross hybrids.

The ORSTOM team has carried out research on identification of male-sterility maintainers of *P. violaceum* (V) cytoplasm, geographic distribution of fertility restorers of V cytoplasm, and comparision of A_1 and V cytoplasms.

Several partially inbred maintainers of V-cytoplasm are available, they have been derived from crosses among Tiotande, $23D_2B$, ICMB 1 (81B), Hombori, Massue, and an accession each from India and Tanzania. However maintainers derived from crosses involving these parents were found to lack the required seedling vigor and resistance to DM. Eight early-maturing accessions from six countries in Africa were identified as maintainers. In addition, 13 late-maturing sources (originating from eight countries in Africa) segregating for maintenance ability were identified. These will be further inbred to isolate maintainers.

Ninety-seven new crosses between V male-sterile cytoplasm and late accessions were studied for fertlity reaction. In each cross, around 10 plants were scored for dehiscence of anthers on entire panicles. The scoring scale used was from 0 (anthers do not exsert or exsert and fail to dehisce) to 100 (all anthers exsert and dehisce). The observations indicated a strong correlation between the scoring scale for fertility and the fertility observed by staining pollen grains with carmine or Alexander's stain. The accessions were grouped into early (<100 days) and late (>100 days) based on time to maturity. Results indicate that the groups constituted based on the degree of restoration of fertility on V cytoplasm and the diversity of these groups corroborate earlier observations on enzymatic diversity. In West Africa the distinction between late- and early-maturing cultivars is very marked in comparison to other regions. Pearl millets from southern Africa are distinct from Central African millets and are close to the late-maturing millets of West Africa. Central African millets are close to early West African millets and are similar in their genetic diversity. In these two groups we can easily find sterility maintainers or fertility restorers, whereas in accessions from southern Africa restorer frequency is very low. It is relatively easy to identify maintainers among the late-maturing millets of Burkina Faso, Mali, and Senegal; and late-maturing restorers in accessions from Benin and Niger.

Research on comparision of A_1 and V cytoplasm did not make the anticipated progress as there is a need for an A_1 maintainer that has better seedling establishment capability than $23D_2B_1$ and a range of sterility maintainers of V-cytoplasm. About 30 V male-sterile cytoplasm maintainers were crossed to A_1 cytoplasm sources and their restoration capability will be observed in 1988.

Cooperation with National Programs

ICRISAT Center

Supply of Breeding Materials

This year we sent 9009 seed samples to 26 countries (Table 20). As usual, the majority of these lines were entries in our trials and nurseries. We sent the Uniform Progeny Nursery (UPN 87) to 20 cooperators in two countries, and the Pearl Millet Inbred Nursery (PMIN 87) to 17 cooperators in India. We had two Elite Products Nursery (ELPN-1 and ELPN-2). ELPN-1 consists of nine ICRISAT hybrids that are released or in AICPMIP trials, and we sent nine sets to eight countries. ELPN-2 consists of open-pollinated varieties that are released or in AICPMIP trials. We sent 11 sets of ELPN-2 to nine countries (Fig. 11).

Varieties for National Trials

Eight open-pollinated varieties and eight hybrids

Table 20. Pearl millet seed samples dispatched from ICRISAT Center, 1987.

Country	No. of trials	Trial entries	Breeding lines	Breeder seed	Total samples
Argentina	0	0	2	0	2
Australia	1	21	20	0	41
Botswana	0	0	2	0	2
Burkina Faso	1	27	0	0	27
Burma	1	21	0	0	21
Chad	8	104	0	0	104
Egypt	0	0	10	0	10
Gambia	4	52	4	0	56
India	118	5935	818	289	7042
Italy	0	0	5	0	5
Korea	1	21	0	0	21
Mexico	3	38	10	0	48
Niger	3	75	274	0	349
Pakistan	17	228	56	0	284
Peoples Republic of China	1	17	0	0	17
Republic of Benin	2	24	0	0	24
Senegal	1	27	0	0	27
Sudan	0	0	0	3	3
Swaziland	0	0	6	0	6
The Philippines	0	0	2	0	2
UK	0	0	18	0	18
USA	0	0	157	0	157
Vietnam	1	17	1	0	18
Yemen Arab Republic	0	0	4	0	4
Zambia	0	0	343	0	343
Zimbabwe	2	42	336	0	378
Total	164	6649	2068	292	9009

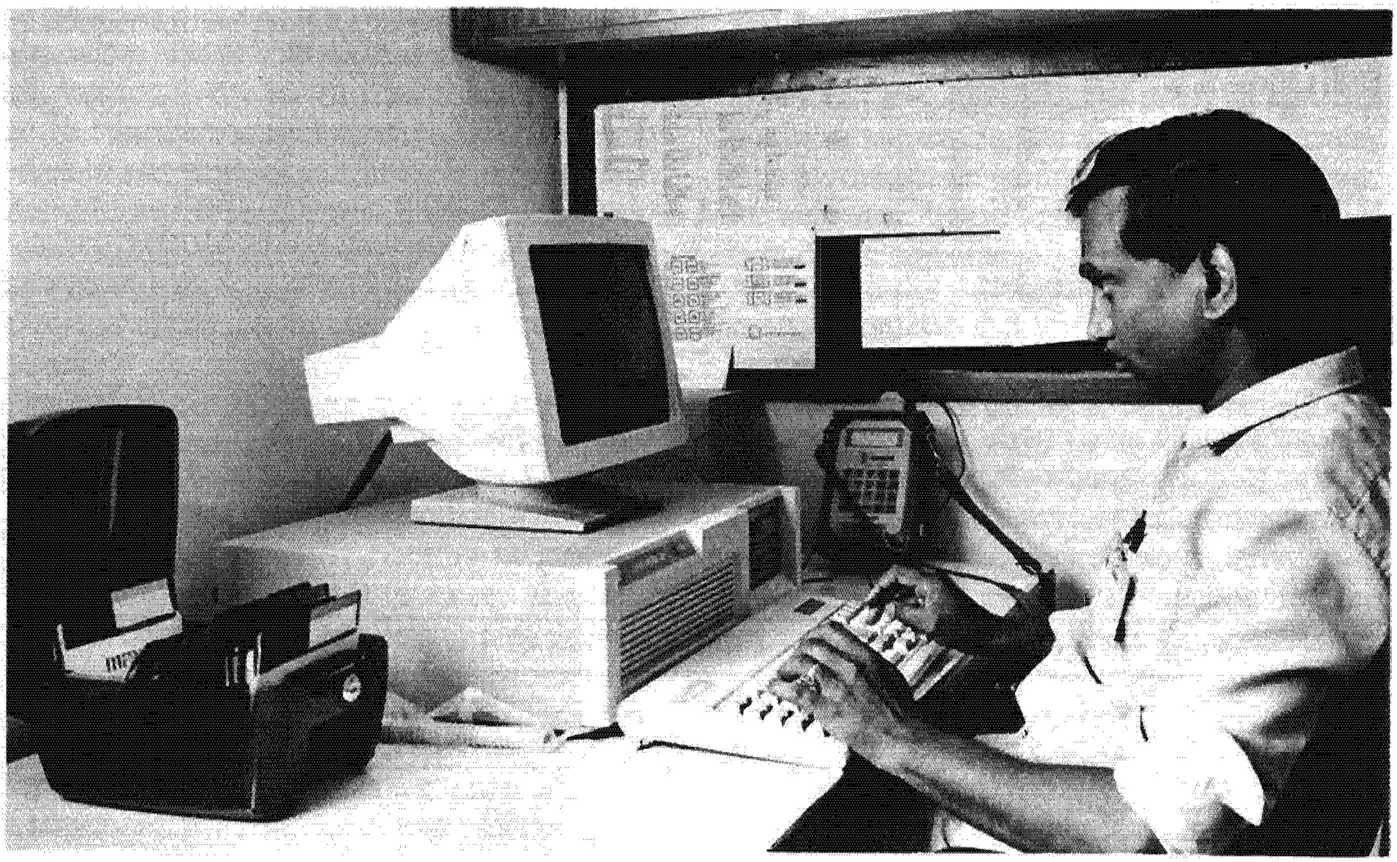


Figure 11. Seed supply record keeping and correspondence for pearl millet is now done entirely on microcomputers allowing easy maintenance of statistics such as those in Table 21.

from ICRISAT were tested in the AICPMIP trials of 1987. In addition, three open-pollinated varieties were jointly entered by cooperators and ICRISAT. We contributed six restorer lines and 12 A/B pairs to trials of parental lines. We also provided several entries as standard controls including ICMV 1 (WC-C75) and ICMH 451. ICRISAT entries continued to yield well relative to the trial means (Tables 21 and 22).

Evaluation of Disease Resistance in National Trials

We screened 11 AICPMIP trials and nurseries for their combined reaction to DM, ergot, and smut during the 1987 rainy season at ICRISAT Center.

Among the AICPMIP population trials, a large number of entries showed resistance to DM, but very few to smut, and none to ergot. All 19 entries in the early trial showed resistance to DM and smut, but none to ergot. Of 48 A/B lines and 22 R lines, all showed resistance to DM, 3 A/B pairs and 2 R lines showed resistance to smut, and again none to ergot.

We also evaluated the six-entry Pearl Millet Pathology Trial (PMPT III D) from AICPMIP for rust resistance at Bhavanisagar. Entry 700481-27-5-2, supplied by ICRISAT, remained rust free; all other entries except PMCDR 1, developed moderate to severe rust infection.

Organization of International Trials

The twelfth IPMAT 12 (1987), had 24 entries including one local control (13 hybrids, 9 composite varieties, and 1 synthetic variety). It was sent to 27 locations in India, and Pakistan. This

Table 21. Grain yield of ICRISAT pearl millet entries presently in All India Coordinated Pearl Millet Improvement Project (AICPMIP) trials, as of the rainy season 1986.

Entry	Male-sterile or parental composite	Years in trials	Grain yield		
			t ha^{-1}	% trial mean	% controls mean[1]
Hybrids					
ICMH 423	841A	4	2.06	106	109
ICMH 451	ICMA 1 (81A)	3	2.26	114	117
ICMH 501	ICMA 4 (834A)	3	2.13	106	109
ICMH 83202	ICMA 1 (81A)	2	2.02	100	103
ICMH 83506	ICMA 1 (81A)	2	2.11	104	108
ICMH 83401	ICMA 1 (81A)	2	2.18	107	111
ICMH 83720	ICMA 1 (81A)	1	2.32	101	102
ICMH 84122	ICMA 1 (81A)	1	2.66	115	117
ICMH 84913	ICMA 1 (81A)	1	2.33	101	102
Open-pollinated varieties					
ICMS 8021		4	1.64	109	98
ICMS 8010		3	1.71	110	100
ICMV 81111	IVC	3	1.75	112	102
ICTP 8203		3	1.61	103	94
ICMV 82132	SRC	2	1.76	108	97
ICMV 83118	MC	2	1.71	105	94
ICMS 8283		2	1.69	104	93
ICMS 8253		1	2.01	117	107
ICMV 83104	NELC	1	1.85	108	98
ICMV-84400	NELC	1	2.01	118	107

1. Percentages of controls are calculated over mean of the two comparable controls [MBH 110 and ICMV 1 (WC-C75)] over the years in the trial.

year 5 of the 23 entries were from five of our cooperators.

Across 19 locations in India and Pakistan the highest-yielding fertile hybrids with good DM resistance were on male-sterile lines 863A and 861A. However, some of these have been rejected because they mature late. Only ICMH 87003 will be promoted to AICPMIP trials (Table 23). The best open-pollinated varieties were ICMV 85208 from the IVC, and ICMV 84421 from the MC.

There were two early entries in the trial, hybrid ICMH 85410 and variety ICMV 87902. They were lower-yielding, but within 150 kg ha^{-1} of the control variety ICMV 1 (WC-C75) which flowered 5 days later.

Organization of International Disease Nurseries

Downy mildew nursery. With the help of numerous cooperators, we evaluated the 27-entry International Pearl Millet Downy Mildew Nursery (IPMDMN) at 10 locations in India and West Africa. Nine entries including P 24-2, P 310-17, P 1449-3, 862 B, ICMP 501, and ICMP 85410 had <5% DM severity at all the locations.

Table 22. Fodder yield, time to 50% flowering, and plant height relative to the controls, downy mildew reaction and status of ICRISAT pearl millet entries presently in All India Coordinated Pearl Millet Improvement Project (AICPMIP) trials, as of the rainy season 1986.

Entry	Male-sterile or parental composite	Years in trials	Percentage of controls mean[1]			DM (%)		Status[4]
			Fodder yield	Time to 50% flowering	Plant height	T[2]	C[3]	
Hybrids								
ICMH 423	841A	4	110	104	96	3.5	1.6	Rel
ICMH 451	ICMA 1 (81A)	3	116	108	105	1.9	3.0	Rel
ICMH 501	ICMA 4 (834A)	3	112	105	109	1.6	3.0	Rel
ICMH 83202	ICMA 1 (81A)	2	106	109	99	3.6	3.6	Dro
ICMH 83506	ICMA 1 (81A)	2	109	107	98	2.8	3.6	Dro
ICMH 83401	ICMA 1 (81A)	2	107	109	96	2.4	3.6	Ret
ICMH 83720	ICMA 1 (81A)	1	104	103	93	5.9	6.4	Pro
ICMH 84122	ICMA 1 (81A)	1	119	109	104	2.7	6.4	Pro
ICMH 84913	ICMA 1 (81A)	1	108	109	97	2.1	6.4	Pro
Open-pollinated varieties								
ICMS 8021		4	117	105	102	2.4	2.8	Dro
ICMS 8010		3	105	104	101	2.7	3.0	Ret
ICMV 81111	IVC	3	127	106	105	5.5	3.0	Dro
ICTP 8203		3	96	96	98	5.6	3.0	Dro
ICMV 82132	SRC	2	121	107	103	4.0	3.6	Dro
ICMV 83118	MC	2	106	107	105	5.6	3.6	Dro
ICMS 8283		2	95	102	104	3.4	3.6	Ret
ICMS 8253		1	115	108	108	4.8	6.4	Ret
ICMV 83104	NELC	1	125	108	110	1.8	6.4	Ret
ICMV-F84400	NELC	1	122	106	107	3.3	6.4	Ret

1. Percentages of controls are calculated over mean of the two comparable controls [MBH 110 and ICMV 1 (WC-C75)] over the years in the trial.
2. T = Test entry.
3. C = Controls [mean of ICMV 1 (WC-C75) and MBH 110].
4. Rel = Released for cultivation in India, Dro = Dropped from trial, Ret = Retained in trial, Pro = Promoted to advanced trials.

In a Pearl Millet Disease Monitoring Nursery (PMDMN) operated collaboratively with AICPMIP scientists, we tested six cultivars, BJ 104, BK 560, MBH 110, ICMH 451, ICMV 1 (WC-C75), and ICMS 7703, at 15 locations across India. MBH 110 was the most resistant entry with <4% DM severity at all the locations. Except BJ 104 and BK 560 the other entries were generally resistant.

Ergot nursery. We organized the 30-entry, 1987 IPMEN, which was grown at four Indian locations, Aurangabad, ICRISAT Center, Ludhiana, and Mysore. Twenty-four of the entries had also been tested in the 1986 IPMEN. Ergot severities of these entries were almost always <5% in the seven tests over the 2 years, compared with 56 to 91% in the susceptible control, BJ 104. All entries were tested for smut at ICRI-

Table 23. Performance of selected entries in International Pearl Millet Adaptation Trial (IPMAT 12), across 19 locations in India and Pakistan, rainy season 1987.

Entry	Male-sterile or parental composite	Grain yield		Time to 50% flowering (d)	Plant height (m)
		t ha^{-1}	Rank		
ICMH 86204	863A	2.94	2	58	2.29
ICMH 86145	861A	2.93	3	57	2.22
ICMH 87003	863A	2.91	5	50	1.86
ICMH 86245	863A	2.80	8	55	2.29
ICMV 85208	IVC	2.73	12	55	2.25
ICMV 84421	MC	2.63	15	52	2.10
ICMH 85410	ICMA 2 (843A)	2.47	21	48	1.39
ICMV 87902	BSEC	2.46	22	48	1.97
MBH 110		2.92	4	49	1.92
ICMV 1(WC-C75)		2.60	17	53	2.17
ICMS 7704		2.36	23	56	2.33
SE		±0.60		±0.3	±0.021
Trial mean (22 entries)		2.69		53	2.07

SAT Center and were highly resistant; several entries were also resistant to downy mildew at all locations.

Smut nursery. We also organized the 22-entry 1987 IPMSN, which was grown successfully at three locations, Bengou (Niger), Samaru (Nigeria), and ICRISAT Center. Most entries were resistant (<10%) across locations, compared with the susceptible control, BJ 104, which had 58% severity. Eight entries (ICMPS 100-5-1, 200-5-5, 601-6-1-4, 601-6-3-1, 601-6-6-3, 900-9-3, 1600-2-4, and ICMV 82132) that were common for 2-3 years (1985, 1986, and 1987) showed resistance (1-6% severity) across all (3-6) locations over years.

Rust nursery. We evaluated the 40-entry International Pearl Millet Rust Nursery (IPMRN) at Bhavanisagar and Aurangabad in India. No entry was rust-free at both the locations, although four entries, P 24-1, P 548, 700481-21-8, and 852 B, developed <10% rust at both locations.

Release and Adoption of ICRISAT Materials

The following materials have recently been released or are now under cultivation:

- After 4 years of testing in the AICPMIP trials, hybrid ICMH 423 was released by the Government of India on 1 January 1988 for general cultivation in the millet-growing areas of India. This hybrid has yielded 101% of the widely grown hybrid MBH 110 but with 20% more fodder yield. The seed parent, 841A, and the pollinator, ICMP 423, were bred at ICRISAT. In 1987 we distributed breeder seed of the parents of this hybrid to 26 institutions in India (Table 24).
- A second hybrid, Pusa 23, was also released for general cultivation in India. The hybrid was bred at the Indian Agricultural Research Institute (IARI), using ICRISAT seed parent 841A.
- A third hybrid, HHB 50, which was bred at Haryana Agricultural University (HAU), and is under cultivation in that State, was released

Table 24. Breeder seed of released pearl millet hybrids and released and prerelease varieties supplied in India from ICRISAT Center, 1987.

Hybrid/Variety	Seed dispatched (kg)	Recipient organizations
ICMH 451		
ICMA 1 (81A)	122	36
ICMB 1 (81B)	95	
ICMP 451	69	
ICMH 501		
ICMA 4 (834A)	15	12
ICMB 4 (834B)	8	
ICMP 501	13	
ICMH 423		
841A	51	26
841B	31	
ICMP 423	60	
ICMV 1 (WC-C75)	472	31
ICMV 4 (ICMS 7703)	104	20
ICMS 7704	26	6

for general cultivation in India. The seed parent of this hybrid is ICRISAT's 81A.

- The recently released ICRISAT hybrid, ICMH 451, reached farmers' fields in 1987 after a rapid seed multiplication program undertaken by the Indian public and private sectors. Studies on the acceptability of this hybrid to the farmer are yet to be undertaken. However, in the AICPMIP trials of 1986 ICMH 451 was the highest-yielding hybrid. Over 3 years in AICPMIP trials it is the joint highest-yielding hybrid for grain and the highest-yielding hybrid for fodder.
- ICRISAT variety, ICTP 8203 has been cultivated in Maharashtra in 1987 on a fairly wide scale. The variety is early, large-seeded, and yields about the same as hybrid MBH 110. ICTP 8203 is well adapted to Maharashtra, Andhra Pradesh, and Karnataka. A proposal for its release in these three states has been prepared for consideration by the State Release Committees.
- Two open-pollinated varieties have been released or pre-released in Zambia. A mass-selected version of ICMV 1 (WC-C75) has been released, and a mass-selected ICMV 82132 pre-released. ICMV 82132 is resistant to smut, as it was derived from the Smut Resistant Composite, and it outyields ICMV 1 by a considerable margin in Zambia, where it is particularly well adapted to the Western Province.

Supply of Breeder Seed

We now have three hybrids and two open-pollinated varieties released in India. In addition ICTP 8203 is proposed for release in Maharashtra, and ICMS 7704, although it has not been released, has been so extensively tested in AICPMIP and minikit trials that we have limited demand for breeder seed.

In 1987, we distributed a large quantity of breeder seed of the parents of the hybrids, and of the open-pollinated varieties themselves (Table 24). This breeder seed is the original source of all seed multiplication, and is being used in India by many public and private sector organizations.

ICRISAT Sahelian Center

Supply of Breeding Materials

We supply improved breeding material and varieties to national and regional programs in the form of breeder seed, elite breeding lines, progenies at various levels of inbreeding, source nurseries, and to meet specific seed requests. During the year, over 700 seed samples were supplied to 11 countries in West Africa. Mali was supplied with the largest number of samples of genetic material during the year. These figures do not take into account regional, cooperative, advanced and initial trial entries, and the seed supplied for large-scale evaluations.

Regional and International Trials

Results of IMZAT-86 are reported this year. This trial, containing 14 test entries and two control varieties, was conducted at 10 locations in seven countries of West Africa, and results are reported here for eight locations (Table 25). Six of the test entries were contributed by two of our cooperating national programs—three each by INRAN, and IAR. Averaged over eight locations, the five top-ranking test entries were, C12L, INMV 8271, ITMV 8001, CT2, and SE 360. C12L was contributed by INRAN and SE 360 by IAR. Location-specific performance responses of the entries were very high. Hence, candidate entries for further testing in 1987 were made on the basis of performance at individual locations.

In 1987, we continued to conduct IMZAT. Of the 15 test entries in this trial, INRAN and IAR contributed three each. This regional trial was distributed for sowing at 13 locations in eight countries in West Africa. Additionally, we conducted two multilocational cooperative yield trials with INRAN and one with IAR with contributions from the respective institutes and ICRISAT. The cooperative trial with IAR was also supplied to Ghana. Results of these multilocational trials will be reported next year.

We have planned to evaluate varieties developed at ICRISAT Center in a ICRISAT Center Sahelian Center Seedling Screen (ICSCSS) for

Table 25. Mean grain yield of entries of ICRISAT Millet Zone A Trial (IMZAT 1986) at seven West African locations, rainy season 1986[1].

	Locations and grain yield (t ha^{-1})								
Entries	Sadoré	Bengou	Maradi	Kamboinsé	Koporo	Cinzana	Bambey	Sapu	Mean
C 12 L	0.97(5)	2.07	1.22(1)	1.55	1.09	2.04(2)	2.06	1.00(5)	1.50
INMV 8271	1.00(4)	1.93	0.76	1.69	1.76(1)	1.24	2.41(5)	1.15(1)	1.49
ICMV 5 (ITMV 8001)	0.89	2.17(2)	0.93(4)	1.73	0.80	1.56	2.59(2)	1.10(2)	1.47
CT 2	0.89	1.64	1.15(2)	1.30	1.06	1.75	2.56(4)	1.05(3)	1.43
SE 360	0.65	1.76	0.81	2.02(4)	1.36(3)	1.77(5)	2.25	0.78	1.42
IKMV 8201	0.61	2.26(1)	0.77	2.46(1)	1.02	1.43	1.90	0.87	1.42
ICMV 7 (ITMV 8304)	1.05(2)	1.95	0.56	2.33(2)	0.60	1.62	2.29	0.91	1.41
SE 2124	0.85	2.15(5)	0.40	2.22(3)	0.78	1.90(4)	1.94	0.95	1.40
T 18 L	0.67	1.83	0.88(5)	1.78	0.36	2.01(3)	2.57(3)	1.02(4)	1.39
SE 13	0.84	1.84	0.54	1.47	1.24(4)	2.07(1)	1.82	0.84	1.34
INMV 8206	0.65	2.16(3)	0.80	1.58	1.42(2)	1.36	1.85	0.76	1.32
INMV 8212	0.88	1.83	0.86	1.72	0.97	1.40	1.86	0.78	1.29
IKMC 1	0.97(5)	1.80	0.77	1.94(5)	0.68	1.45	1.73	0.97	1.28
IKMV 8501	0.32	1.79	0.57	1.55	0.92	1.04	1.59	0.67	1.06
Controls									
Improved	1.79(1)	2.00	0.87	1.88	1.16(5)	1.71	2.29	0.78	
Local	1.04(3)	2.15(4)	1.09(3)	0.78	1.01	1.33	2.83(1)	0.83	
SE	±0.19	±0.15	±0.21	±0.16	±0.25	±0.12	±0.18	±0.14	
Mean	0.88	1.96	0.81	1.75	1.01	1.61	2.16	0.90	1.38
CV (%)	43	16	52	18	49	15	16	30	

1. Rankings of top 5 entries are shown in parentheses, randomized block design, plot size varied from 6 m^2 to 18 m^2.

stand establishment before including them in the yield trials. A stand establishment screen of 144 entries run in March 1987, was unfortunately interrupted by 18 mm rain received on March 17. We sowed 35 of these entries at Bengou in an observation nursey with plot sizes varying between 4.8 to 28.8 m^2. Downy Mildew incidence ranged from 0-100% with a mean of 48%. Two entries, ICMV-D 85307 and ICMV-E 8313, were early (46 days to 50% flowering vs control CIVT 58 days), recorded less DM (14%, vs control CIVT 20%), and yielded similar to the control (2.27 t ha^{-1}, mean of the nursery 1.71±0.109 t ha^{-1}). These entries will be evaluated in a seedling screen in 1988 before being included in preliminary yield trials. We hope this procedure of screening for DM reaction and stand establishment prior to inclusion in the yield trials is a more practical approach to using genotypes bred at ICRISAT Center.

Regional Disease Nurseries

The West Africa Downy Mildew Observation Nursery (WADMON) was conducted by five national programs in 1987 and included 24 entries contributed by national programs and

Table 26. Downy mildew (DM) incidence and severity at dough stage of selected entries in the West African Downy Mildew Observation Nursery (WADMON), at four West African locations, rainy season 1987.

		DM incidence (I)[1] (%) and severity (S)[2] (%)									
		Mean		Bambey[3]		Bengou[4]		Kamboinsé[5]		Samaru[6]	
Entry	Origin	I	S	I	S	I	S	I	S	I	S
Composite Précoce (COMPRE S3R)	IER, Mali	1	1	0	0	1	1	1	1	3	1
SE 2124	IAR, Nigeria	2	1	0	0	2	1	1	1	6	4
INMV 8514	IAR/ICRISAT, Nigeria	3	2	0	0	5	3	0	0	6	4
SE 361	IAR, Nigeria	5	3	0	0	4	1	1	1	12	10
GR P1	INRAN, Niger	5	4	0	0	5	3	1	1	15	13
ICMV-IS 87345	ISC, Niger	6	4	0	0	12	8	0	0	11	9
3/4 HK	INRAN, Niger	13	10	8	7	23	15	9	9	13	9
H 80-10-GR	INRAN, Niger	18	11	0	0	53	28	10	8	11	8
ICMV-IS 86305	ISC, Niger	19	15	0	0	34	24	7	6	36	29
SE 360	IAR, Nigeria	19	9	0	0	53	19	0	0	24	18
Controls											
Improved		8	6	3	1	12	11	5	4	12	7
Local		34	31	99	99	17	10	4	4	17	12
NHB 3		41	28	0	0	33	24	70	54	60	33
Trial mean (24 entries)		12	9	5	5	18	11	11	9	13	9

1. Based on number of plants infected as a proportion of total plants in a plot.
2. Based on a 1-5 scale, where 1 = no symptoms and 5 = symptoms on main stems and all tillers so that there are no productive panicles. Based on a mean of 74–83 plants from two replications.
3. Institut sénégalais de recherches agricoles, Senegal.
4. ICRISAT Sahelian Center, Niger.
5. Institut national d'études et de recherches agricoles, Burkina Faso.
6. Institute for Agricultural Research, Nigeria.

ICRISAT for evaluation of DM resistance. The highest mean DM incidence was 18% at Bengou, followed by 13% at Samaru, 11% at Kamboinsé, and 5% at Bambey. Composite Précoce (COMPRE S3R) a test entry from Mali, had the lowest DM incidence (1%) across all locations. Five varieties had less than 5% DM incidence over all locations, four had 10 to 20%, and the susceptible control, NHB 3, had 41% (Table 26).

We received data from four countries for the West African Downy Mildew Variability Nursery (WADMVN), which was sent to seven countries to evaluate possible virulence differences in *S. graminicola* populations among locations. The breeding line 700651 had consistent DM resistance over all four locations; 81B was the most susceptible entry over all locations (Table 27). There were interesting interactions between some pearl millet entries and the DM pathogen population at some locations. There was no DM on MBH 110 at Bambey and Samaru, but there was 30% incidence at Bengou and 74% incidence at Kamboinse. The susceptible hybrid, NHB-3, had only 1% DM incidence at Bambey but at the other three locations it had between 21% and 58%. Similarly, 81B had less than 5% incidence at Bambey, was DM-free at Kamboinsé, but had 69% incidence at Bengou, and 100% incidence at Samaru. These findings indicate the possible existence of different pathotypes of *S. graminicola* in different parts of West Africa. The same set of entries will be reevaluated in 1988 to confirm these conclusions.

Varieties for National Testing

In 1986 we proposed for wide scale tests in farmers fields varieties IKMP 3 for normal sowing in 700-900 mm rainfall zone, IKMP 2 and IKMP 5 for normal sowing in the 500-650 mm zone, and variety IKMV 8201 for late sowing in both rainfall zones. In 1987, we proposed variety IKMP 1 for normal sowing dates, and IKMC 1 for delayed sowings in the 700-900 mm zone. Now, in Burkina Faso, at least two varieties each

Table 27. Downy mildew (DM) incidence at dough stage of selected entries in the West African Downy Mildew Variability Nursery (WADMVN), at five West African locations, rainy season 1987.

		DM incidence (%)[1]					
Entry	Origin	Mean[1]	Bambey[2]	Manga[3]	Bengou[4]	Kamboinsé[5]	Samaru[6]
700651	Nigeria	2	0	0	1	0	4
INMV 8220	IAR/ICRISAT, Nigeria	5	5	5	4	3	0
IKM/CVP 39/83/84/351	INERA/ICRISAT, Burkina Faso	10	28	4	1	4	6
ICMV 1 (WC-C75)	ICRISAT, India	17	6	30	14	8	23
ICMB 1 (81B)	ICRISAT, India	35	4	1	69	0	100
MBH 110	MAHYCO, India	37	4	77	30	74	0
NHB 3	AIOMIP, India	41	1	89	21	58	38
Trial mean (10 entries)		16	5	22	15	15	20

1. Based on a mean of 69–90 plants per entry in two replications and two rows per replication.
2. Institut sénégalais de recherches agricoles, Senegal.
3. Crops Research Institute/Gesellschaft für Technische Zusammenarbeit, Ghana.
4. ICRISAT Sahelian Center, Niger.
5. Institut national d'études et de recherches agricoles, Burkina Faso.
6. Institute for Agricultural Research, Nigeria.

are available for large-scale tests and extension for the two major rainfall zones and sowing dates. Seed of these two proposed varieties was supplied to Organisme régional de développement (ORD)/Food and Agriculture Organization of the United Nations (FAO) collaborative programs in Burkina Faso for seed multiplication and extensive on-farm tests. Variety IKMV 8201 has been extended for general cultivation in Yetenga region by ORD, Ouahigouya. We have supplied 5 kg of breeder seed of variety IKMV 8201 to ORD, Yetanga for multiplication. Breeder and foundation seed of this variety was also supplied to the millet breeder of INERA for multiplication at the request of Comité permanent interetats de lutte contre la sécheresse dans le Sahel(CILSS)/Institut du Sahel (INSAH). Seed of ICMV 5 (ITMV 8001) supplied to the Chadian National Program/FAO in 1986 was multiplied on about 8 ha in 1987 for on-farm tests and distribution to farmers. We supplied 60 kg of ICMV 5 (ITMV 8001), 30 kg of ICMV 7 (ITMV 8304), and 1.5 kg each of ICMV 1 (WC-C75), MBH 110, and ICTP 8203 to Projet productivité de Niamey for on-farm tests. We supplied seed of variety IKMV 8201 to the National Cereals Research and Extension Program of the Institut de la recherche agronomique (IRA) of Cameroon for Semi-Arid Food Grain Research and Development (SAFGRAD)-coordinated on-farm tests. Seed of 3/4 HK-B78 (15 kg) was supplied to the INRAN agronomist for intercropping studies. To Projet développement rural de Maradi we supplied 10 kg seed of variety ITMV 8304 and to Vision mondiale internationale, Mali, seed of varieties ITMV 8001, ITMV 8304, and IKMV 8201 for on-farm tests.

SADCC/ICRISAT Regional Program

Generation of Breeding Material for Regional Testing

Plant introductions. We introduced a range of material from ICRISAT Center and from Uganda. We selected MDS 29, a synthetic; four hybrids, ICMH 851018, ICMH 851017, ICMH 851014, and ICMH 852031; and four varieties ICMV 84421, ICMV 85208, Serere 42, and Serere 10L for retesting.

Seven improved composite bulks from ICRISAT Center were evaluated and ICMP 87408 (MC-C8), and ICMP 87300 (IVC-C6), were selected for inclusion in the 1987/88 regional trial.

Pedigree breeding. We advanced for further evaluation 141 F_4 and 459 S_2 progenies derived primarily from introductions from Senegal, Uganda, and Niger. We have generated five synthetic varieties (ICMV-SD 87001, 87002, 87003, 87004, and 87005) from inbred lines within the breeding program. Three varieties (ICMV-SD 87006, ICMV-SD 87007, and ICMV-SD 87008) have been selected from IBMV 8413 (Senegal), and are being random mated for mass selection.

Population improvement. Earlier we formed four composites; Early, Medium, Dwarf, and Bristled. Based on their performance at three locations in initial trials, the Early and Medium Composites have been bulked to form Early Composite (SDEC). We reconstituted the Dwarf Composite (SDDC) and the Bristled Composite (SDBC) to broaden their genetic bases. From these three composites, we selected progenies to form 12 varieties, ICMV-SD 87009-87020. These will be further mass selected and also included in the 1987/88 yield trials.

We have selected parents to constitute three new composites: Bold Grain (SDBGC), Intermediate Zone (SDIZC), and White Grain (SDWGC), and are random mating them.

Hybrid breeding. Forty inbreds were selected from 361 introductions from ICRISAT Center, Sudan, and Burkina Faso, and crossed to three male-sterile testers. We selected 213 additional pollinators from 1095 introducted from ICRISAT Center. We evaluated 800 testcrosses involving four male-sterile testers and 471 pollinators and retained 51 of them for further testing. We crossed 208 new pollinators on from 3 to 7 testers for evaluation in the 1987/88 season.

Organization of Regional Trials

We organized three pearl millet regional trials, the Tall Varieties Trial, Dwarf Varieties Trial and Introduced Varieties Trial. Each trial was grown at 9–10 locations. Results were received from six locations for the Tall and the Dwarf Varieties Trials and from five locations for the Introduced Varieties Trial. In the Tall Varieties Trial, ICMH 83506 gave the highest grain yield (1.9 t ha^{-1}) followed by ICMH 83401, ICMH 83507, IVS-P78, ICMS 8414, ICMS 8359, and ICMS 8330. The best hybrid, (ICMH 83506), was only 13% better than the best variety (IVS-P78) in terms of grain yield. In the Dwarf Varieties Trial, ICMP 87005 (D2-C5) from ICRISAT Center produced the highest grain yield (1.7 t ha^{-1}) followed by NC(d_2) and ExB(d_2). Hybrid ICMH-SD 87001 (861 A × IBMI 8207) produced the highest yield (2.0 t ha^{-1}) in the Introduced Varieties Trial, followed by ICMH-SD 87002 (Pb111 A × IBMI 8207), ICNMV 85, ICMPES 8, and ICNMV 49. We also selected ICNMV 75 and IPA 7910439 for further testing on the basis of their performance in this and the previous year.

We selected 107 finger millet, *Eleusine coracana,* entries from an evaluation of 729 accessions, and will test them in three regional trials: Early-Maturing (FMEVT), Medium-Maturing (FMMVT), and Late-Maturing (FMLVT) in 1987/88.

We conducted a cereal forage trial of 81 entries which included Sudan grass *Sorghum Sudananse*, pearl millet, finger millet, and lines derived from crosses of pearl millet × *Pennisetum monodii.* Our cooperators were very interested in the latter lines and we expect to rapidly become more involved with forage testing.

Varieties for National Testing

ICMV 1 (WC-C75) has been released as WC-C75 in Zambia, and two other varieties, ICMV 82132 and Ugandi, are in the pre-release stage. Five varieties [ICMV 1 (WC-C75), Ugandi, ICMV 82132, ICTP 8203, and NC(d_2)] have been identified in Botswana, and four varieties [NC(d_2), IVC(d_2), ICMV-SD 87003, and ICMV 82132] in Malawi, for on-farm testing in 1987/88. Five varieties [NC (d_2), ICMV-SD 87001, 87002, 87007, and ICNMV 179] have been included in advanced trials in Tanzania; and five varieties [ICMV-SD 87001, ICMV 82132, ICMV-SD 87002, ICTP 8203, and NC(d_2)] have been promoted to advanced trials in Zimbabwe for 1987/88. In addition to entries for national and regional trials, we have supplied 263 breeding lines, including bold grain lines and SDPC, to Zambia, and 135 entries to ICRISAT Center. We also supplied 729 accessions of finger millet to Lesotho, Zimbabwe, Zambia, Malawi, and Tanzania.

Regional Disease Nursery

As in 1986, we grew a 20-entry nursery of diverse genotypes at 10 locations in five SADCC countries, to monitor the occurrence of diseases and to determine whether resistance previously identified elsewhere is effective in the SADCC region. Disease levels were high enough for reliable screening in two or more countries for ergot, smut, and leaf spots and several entries showed good resistance.

Workshops, Conferences, and Seminars

West African Regional Pearl Millet Improvement Workshop

The annual regional pearl millet improvement workshop was held in cooperation with ISRA, from 21-24 September, 1987, at Bambey, Senegal. This workshop brought together pearl millet scientists from the West African region and provided an opportunity to visit and discuss ISRA's approach to millet improvement and ICRISAT's cooperative activities.

Nearly 40 scientists from the national programs of Benin, Burkina Faso, Côte d'Ivore, the Gambia, Ghana, Mali, Niger, Nigeria, and Senegal participated in the workshop. Representatives of CILSS/INSAH, ICRISAT Center, and ISC also attended. The program included formal presentations of ISRA's millet research, and visits to experimental fields and laboratories at Bambey, and on-farm trials outside the station. Suggestions were invited on the reoriented research objectives of ISC's entomology program. The thrust on the two major pests, *Coniesta (Acigona) ignefusalis* and *Heliocheilus (Raghuva) albipuntella*, was found to be appropriate as they cause major yield reductions in farmers' fields. In the near future relevant cooperative entomology research with scientists in the national programs will be established. Some of the important recommendations included: the necessity of widening the genetic base for utilization in different agroclimatic zones of West Africa; intensification of research on millet production systems; emphasis on integrated pest management research, and increased regional cooperation to incorporate stable and durable resistances to *Striga* and downy mildew. More details were sought by the participants for the constitution of an advisory committee to assist ICRISAT in the conduct of cooperative research activities. Responses of participants indicated that the workshop was extremely useful, particularly in the opportunity it offered for interaction between scientists from national programs, CILSS, and ICRISAT.

International Pearl Millet Scientists' Day

An International Pearl Millet Scientists' Day was held at ICRISAT Center on 8-9 September. Participants included 30 scientists from the Indian National Program, nine researchers/producers from private seed companies in India, six scientists from other countries (Botswana, Malawi, Mali, and Pakistan), and 10 in-service trainees from seven countries. Emphasis was on breeding and pathology, with most of the time spent observing and discussing field nurseries and experiments. Scientists were given time to identify entries in our field nurseries for which they would like seed.

A discussion session included short presentations by ICRISAT millet scientists on three specific topics of current interest: "Influence of day-length on flowering of pearl millet", "Re-evaluation of associative N_2 fixation in pearl millet and sorghum at ICRISAT", and "Computerization of the ICRISAT Center pearl millet breeding program". Scientists' responses indicated particular interest in the use of computerization in breeding programs and the need in India for DM resistance (including better understanding of recovery resistance), photoperiod-insensitive R-lines, new male-sterile lines that flower in <50 days, male-sterile lines using cytoplasm other than the A_1 cytoplasm, and research on forage millets. Malian scientists expressed concern about the DM susceptibility of Indian materials in Mali and showed interest in computerization and in more collaboration with ICRISAT on drought research.

Publications

Institute Publications

Plant Material Descriptions

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Pearl millet variety ICMV 1. Plant Material Description no. 1. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-095-3. (PME 001)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Pearl millet variety ICMV 2. Plant Material Description no. 2. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-096-1. (PME 002)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Pearl millet variety ICMV 3. Plant Material Description no. 3. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-097-X. (PME 003)

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 366 pp. ISBN 92-9066-134-8. (CPE 044)

Journal Articles

Alagarswamy, G., and **Bidinger, F.R.** 1987. Genotypic variation in biomass production and nitrogen use efficiency in pearl millet [*Pennisetum americanum* (L.) Leeke]. Pages 281-286 *in* Genetic aspects of plant mineral nutrition (Gabelman, H.W., and Loughman, B.C., eds.). Dordrecht, Netherlands: Martinus Nijhoff. (JA 555)

Bidinger, F.R., **Mahalakshmi, V.**, and **Rao, G.D.P.** 1987. Assessment of drought resistance in pearl millet [*Pennisetum americanum* (L.) Leeke]. I. Factors affecting yields under stress. Australian Journal of Agricultural Research 38(1):37-48. (JA 566)

Bidinger, F.R., **Mahalakshmi, V.**, and **Rao, G.D.P.** 1987. Assessment of drought resistance in pearl millet [*Pennisetum americanum* (L.) Leeke]. II. Estimation of genotype response to stress. Australian Journal of Agricultural Research 38(1):49-59. (JA 572)

Mahalakshmi, V., **Bidinger, F.R.**, and **Raju, D.S.** 1987. Effect of timing of water deficit on pearl millet (*Pennisetum americanum*). Field Crops Research 15(3,4):327-339. (JA 547)

Rai, K.N., **Appa Rao, S.**, and **Rao, A.S.** 1987. Inheritance of a spikeletless character in pearl millet. Current Science 56(18):953-954. (JA 667)

Singh, S.D., **Andrews, D.J.**, and **Rai, K.N.** 1987. Registration of ICML 11 rust-resistant pearl millet germplasm. Crop Science 27(2):367-368. (JA 559)

Singh, S.D., **Gopinath, R.**, and **Pawar, M.N.** 1987. Effects of environmental factors on asexual sporulation of *Sclerspora graminicola*. Indian Phytopathology 40(2):186-193. (JA 523).

Singh, S.D., and **Singh, Govind.** 1987. Resistance to downy mildew in pearl millet hybrid NHB-3. Indian Phytopathology 40(2):178-180. (JA 324)

Soman, P., **Jayachandran, R.**, and **Bidinger, F.R.** 1987. Uneven variation in plant-to-plant spacing in pearl millet. Agronomy Journal 79:891-895. (JA 632)

Conference Papers

Anand Kumar, K., and **Appa Rao, S.** 1987. Diversity and utilization of pearl millet germplasm. Pages 69-82 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 379)

Bidinger, F.R., **Mahalakshmi, V.**, **Soman, P.**, and **Talukdar, B.S.** 1987. Breeding for adaptation to environmental stress? Pages 269-278 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 372)

Fussell, L.K., **Serafini, P.G.**, **Bationo, A.**, and **Klaij, M.C.** 1987. Management practices to increase yield and yield stability of pearl millet in Africa. Pages 255-268 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 373)

Krishna, K.R., and **Lee, K.K.** 1987. Management of vesicular arbuscular mycorrhiza in tropical cereals. Pages 43-45 *in* Mycorrhiza in the next decade: practical applications and research priorities: proceedings of the Seventh North American Conference on Mycorrhiza, 3-8 May 1987, Gainesville, FL, USA (Sylvia, D.M., Hung, L.L., and Graham, J.H., eds.). Gainesville, FL, USA: Institute of Food and Agricultural Sciences, University of Florida. (CP 364)

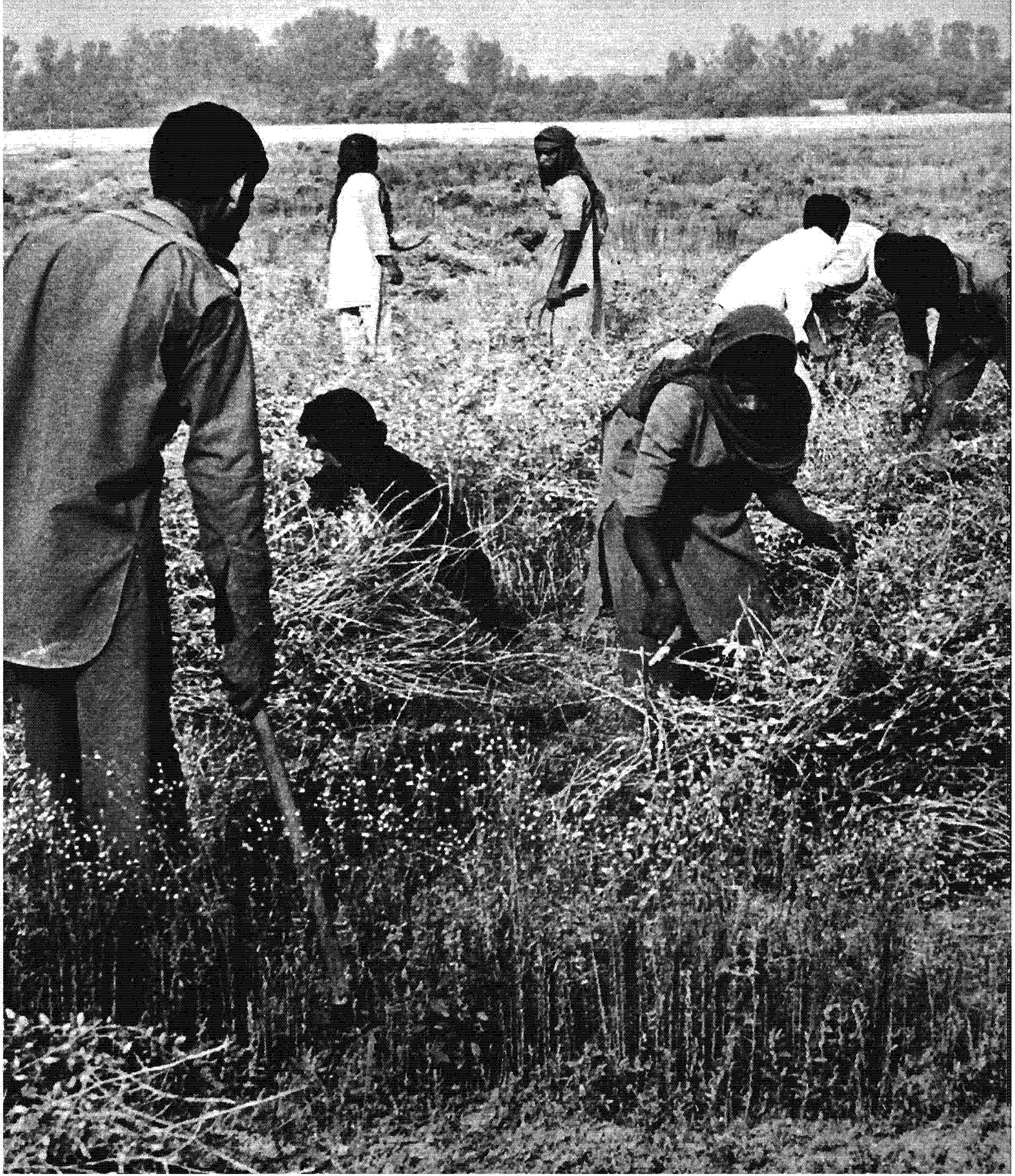
Rai, K.N., and **Singh, N.B.** 1987. Breeding pearl millet male-sterile lines. Pages 127-137 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 378)

Singh, S.D., **Ball, S.**, and **Thakur, D.P.** 1987. Problems and strategies in the control of downy mildew. Pages 161-172 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 377)

Thakur, R.P. 1987. Diseases of pearl millet and their management. Pages 147-158 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 239)

Thakur, R.P., and **Chahal, S.S.** 1987. Problems and strategies in the control of ergot and smut in pearl millet. Pages 173-182 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 376)

LEGUMES
CHICKPEA



Contents

Cover photo: Harvesting chickpea plots at the ICRISAT Cooperative Research Station, Hisar, India, postrainy season 1986.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India.

CHICKPEA

Chickpea forms an important component of the daily menu in countries where it is a major crop. It is very versatile in the ways it can be used. Traveling from South Asia to the Mediterranean countries to Ethiopia, and observing the variety of chickpea products on the market makes one realize the importance of this crop.

This report not only covers research at ICRISAT Center, but gives an account of our collaborative work with the International Center for Agricultural Research in Dry Areas (ICARDA), Syria, the National Agricultural Research Centre (NARC), Pakistan, and our extensive cooperation with the All India Coordinated Pulses Improvement Project (AICPIP).

Drought stress almost always reduces chickpea yields in the semi-arid tropics (SAT), and the agronomic research that recorded differential varietal responses this year to varied water regimes, is of great direct practical significance. So is the observation that tolerance exists against low temperatures in some genotypes, resulting in a remarkable reduction in flower drop during the cold winter months at higher latitudes.

Heliothis armigera is the major pest in most of the chickpea-producing areas, and for a better understanding of the flight patterns and fluctuations in populations of this insect, a wide network of pheromone traps was established over the past 6 years. Weekly *Heliothis* catches show interesting variations related to latitude, cropping pattern, and temperature differences. Diseases form a main threat to successful chickpea cultivation and the identification of sources of resistance against, for instance, fusarium wilt and dry root-rot, and their use in resistance breeding has been very important to increase the yield stability of the crop. Also, this year's work on botrytis gray mold, stunt disease, and various combinations of disease resistances shows encouraging progress. Interesting screening work was done on wild *Cicer* species.

Chickpeas can be prepared for human and animal consumption in a wide variety of ways and our Biochemistry group found interesting quality differences between types and varieties. The genetic improvement program continued to lay emphasis on combining resistance to stress factors with high yield potential. For instance, the combination of wilt and *Heliothis* resistance in lines like ICCL 86111 and ICCL 86102 resulted in their good yield performance in wilt infested, unsprayed areas. Earliness in maturity is advantageous under conditions where the crop duration is limited. This was the reason why the wilt-resistant, short-duration variety ICCV 2 gained popularity.

The chickpea improvement programs in Syria and Pakistan were successful in identifying and using sources of resistance to ascochyta blight, while the joint ICARDA/ICRISAT efforts resulted in a gratifying increase in varietal releases. Promising results were also obtained in breeding for resistance to such stress factors as cold and nematode incidence. While reading the report it will be realised how much of the progress is achieved only because of the collaboration of National programs and the International institutes.

When describing work completed during the year, it is appropriate to look ahead and appraise the situation to see, whether, and where, or how, changes in approach or methodology are required. More detailed data on the agronomic demands and agronomic sensitiveness of the chickpea will be sought. We shall aim to expand disease and pest screening and to refine and increase the efficiency of the techniques used. Product processing and quality research will receive due attention, and in the integrated improvement program breeders will assemble and apply the latest results from different disciplines to make available improved products of early or more advanced generations to any interested program.

Figure 1. Long rows of chickpea cultivars passing through heterogenous saline patches on a Vertisol, ICRISAT Center, postrainy season 1984/85.

Physical Stresses

Most of our effort is directed towards water-limited environments, to identify drought-tolerant genotypes. In subtropical climates where cold stress during winter can be a problem, we are trying to better understand environmental and physiological reasons for unstable yields and low harvest index.

Screening for Drought Tolerance Using Line-Source Sprinklers

Last year we reported our initial attempts to use the line-source sprinkler technique when comparing chickpea genotypes for their response to water (ICRISAT Annual Report 1986, p. 131). We then screened 20 genotypes and found the same order of genotypic differences as we obtained in previous studies, that compared yield with and without irrigation. In the 1986/87 postrainy season, we again compared 46 genotypes, including some used in the previous season, using the line-source sprinkler system. The non-irrigated soil was at a lower moisture status than in the previous year and so a wide range of moisture levels was achieved.

Comparative responses were similar to those previously obtained. Genotypes showing good yields at the dry end of the moisture gradient but responding well to increasing moisture were Annigeri, ICCV 10, ICCL 84223, and ICCL

85225. Those with drought tolerance but low yield potential under well-watered conditions were ICC 4958, ICC 10448, ICCV 8, and ICCL 84303. Those having reasonable yield potential under well-watered conditions but high susceptibility to drought included ICCV 4 (ICCL 83004), ICCV 5 (ICCL 83009), ICCL 83149, and ICCL 85311.

As measured in the previous season, biomass and seed yield of all genotypes that were not affected by disease, increased linearly with moisture application up to the highest moisture level. This linearity over a wide range of soil-moisture levels validates the use of two moisture levels only, as in the case of treatments with and without irrigation, when comparing chickpea genotypes for drought response. It therefore does not seem necessary to continue genotypic comparisons using line-source sprinklers.

Screening for Salinity Tolerance in Naturally Saline Fields

Chickpea is particularly sensitive to salinity, even when compared with other salt-sensitive legumes, and the increasing salinization of many traditional chickpea-growing areas poses a major threat to the crop. The identification of salt-tolerant genotypes offers a possible solution to this problem. Screening for salinity tolerance in naturally saline fields is difficult because of the heterogenous occurrence of salinity in both magnitude and distribution. Nevertheless, we attempted to compare genotypes for their response to salinity by exploiting natural salinity gradients on a Vertisol at ICRISAT Center, where salinity, measured as electrical conductivity (EC), ranges between 0.4 and 8.0 dS m^{-1}. Chickpea genotypes were grown in long rows through an area of varying salinity levels (Fig. 1). The crop was harvested in 1.0-m segments whose EC up to 60-cm soil depth was estimated. For each genotype, biomass and seed yield were regressed against EC. Genotypic differences in salinity tolerance were estimated by comparing slopes of regression curves, and EC levels that caused a 50% reduction in biomass or yield.

The differences in salinity response among genotypes were not large and possible significance was masked by experimental error (e.g., Fig. 2). We also found little genotypic variation in pot studies, where experimental variability is under better control. Thus, to find sources of significant salinity tolerance in chickpea, it seems necessary to examine a more diverse range of germplasm than we have investigated to date. Further, it would seem obligatory to screen under controlled environmental conditions rather than in naturally saline fields.

The results of both pot (ICRISAT Annual Report 1985, pp. 143-144) and field studies (Fig.

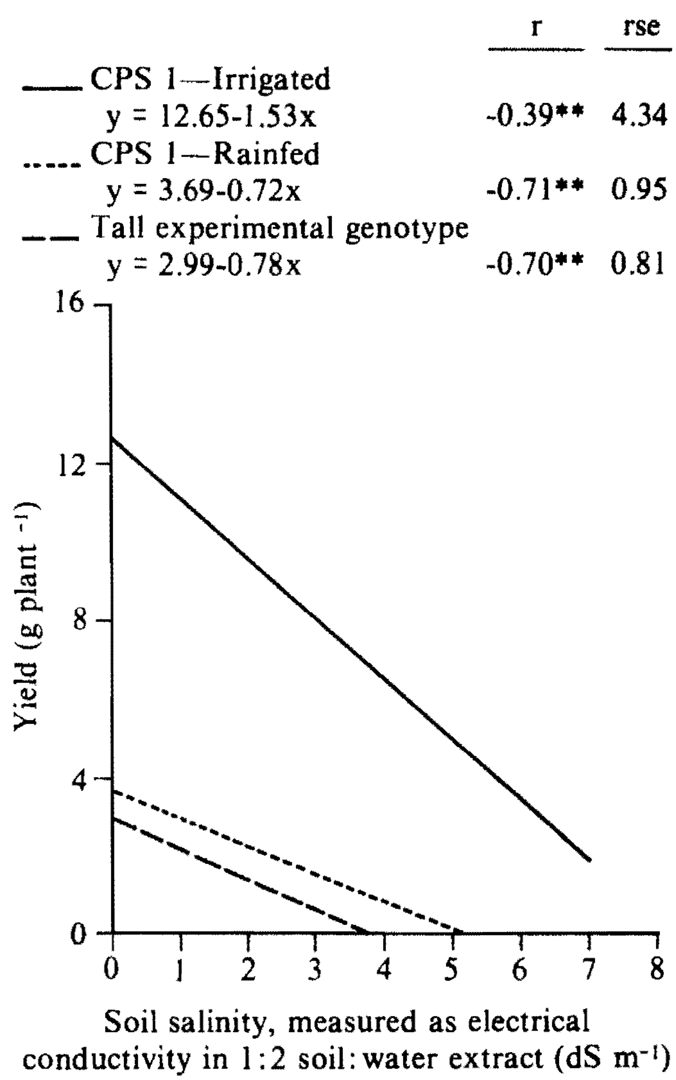


Figure 2. Relationship between yield (g $plant^{-1}$) and soil salinity (EC, dS m^{-1}) in chickpea CPS 1 (with and without irrigation), and a tall experimental genotype (rainfed) on a naturally occurring saline Vertisol, ICRISAT Center, 1984/85.

2) indicate that the effects of salinity on chickpea can, to some extent, be alleviated by proper management of irrigation, for instance, by a system of sprinkler irrigation designed to flush salt through the soil profile. For the time being at least, alleviation of salinity effects on chickpea will have to rely on management rather than on genetic solutions.

Tolerance to Low Temperature During Flowering and Pod Set

Night temperatures below 8°C that occur in parts of northern India during flowering, cause failure of pod set in chickpea. This may be one of the reasons why chickpea yields in those regions are particularly unstable. Failure to set pods also

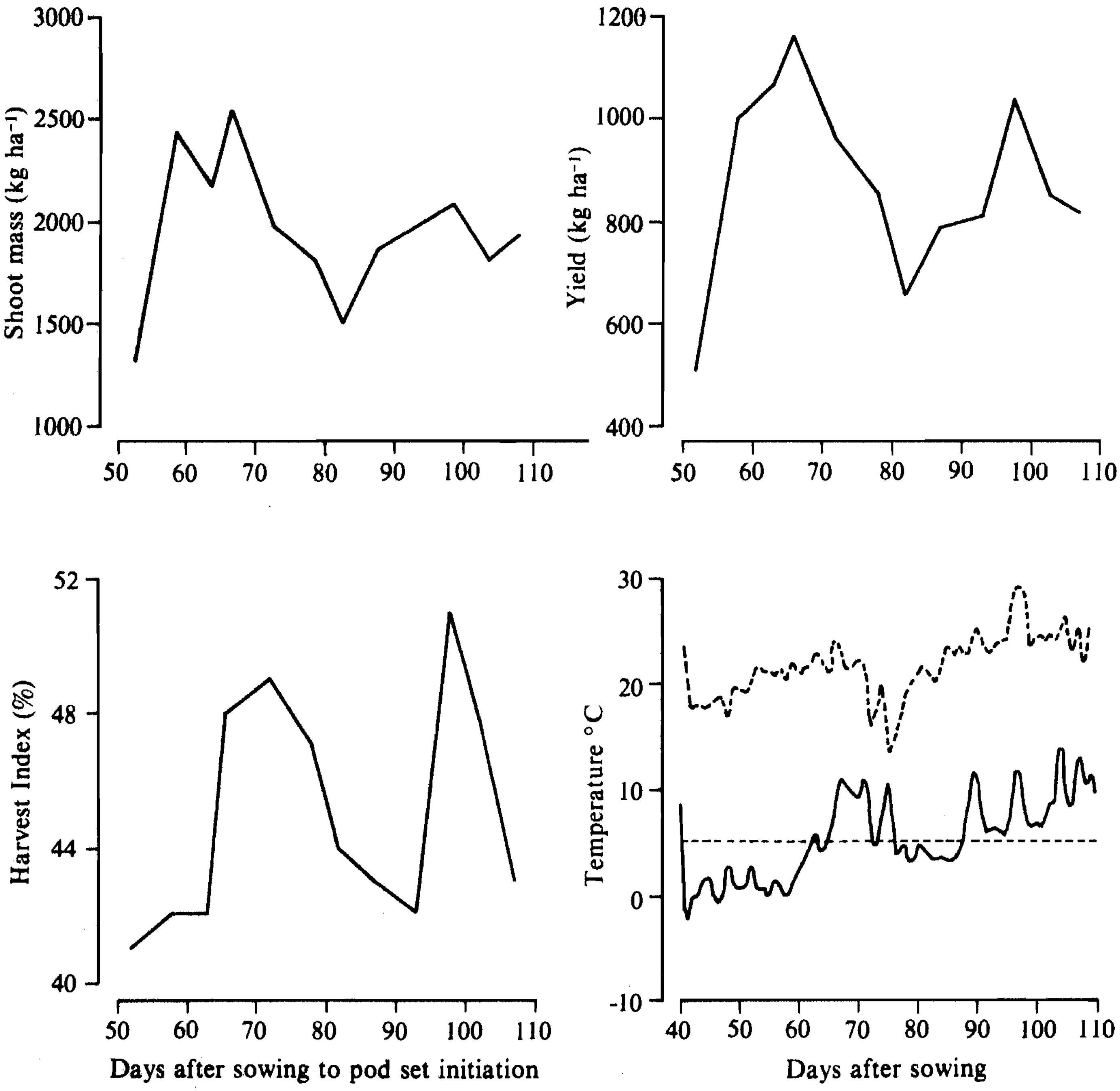


Figure 3. Shoot mass, seed yield, and harvest index of 12 chickpea populations selected for their ability to set pods at different times during the winter period. Maximum and minimum temperatures prevailing during pod set are also shown. Hisar, postrainy season 1986/87.

encourages excessive vegetative growth, resulting in a low harvest index.

To test the above hypothesis, 12 populations with 10 single-plant progenies in each, were created from the segregating populations of six crosses made for cold-tolerance breeding. When sown in mid-November at Hisar (29° 10'N, 75° 44'E, altitude 221 m), onset of flowering and pod set in these populations ranged between the third week of December and the middle of February, the coldest period of the year. Preliminary data, based on single-row plots 4-m long, suggest that it is indeed possible to increase yield by advancing flowering and pod set into the coldest months (Fig. 3). An associated increase in biomass in the group of genotypes that set pods between 60–70 DAS (Fig. 3) was observed at harvest, most of which was partitioned into the seed, as reflected in the increase in harvest index.

Table 1. Effect of fertilizer application (0 or 200 kg DAP[1] ha^{-1}) on grain yield (t ha^{-1}) of chickpea ICCV 6 (ICCC 32) at three sowing dates, Gwalior, 1986/87.

Sowing date	DAP (kg ha^{-1}) 0	DAP (kg ha^{-1}) 200	Mean yield (t ha^{-1})
26 Oct	1.93	2.10	2.02
26 Nov	1.64	1.77	1.71
11 Dec	1.32	1.60	1.46
SE	±0.143[2]	±0.118	
Mean	1.63	1.83	
SE	±0.065		

1. DAP = diamonium phosphate.
2. The standard error for comparing fertilizer levels at the same sowing date is ±0.113.

Effect of Management Factors on Late-sown Chickpea

To accommodate chickpea into the changing cropping systems in the northern Indian environment, it is often necessary to delay sowing until December. While we have been trying to identify genotypes better suited to late sowing, we have also been exploring management options to improve yield in late sowings. We have been examining the effects of fertilizer, irrigation, and plant density on late sowing at our cooperative research station, Gwalior. In the 1985/86 season, delaying sowing of K 850 from 29 Nov to 9 Dec reduced yield by 20–28% (ICRISAT Annual Report 1986, p. 133). In 1986/87, the effects of the above factors were examined in a split-split plot design, with irrigation in the main plot, dates of sowing in the subplot, and factorial combinations of diammonium phosphate (DAP) × plant density in the sub-subplots, with four replications. Delaying sowing from 26 Oct to 26 Nov reduced yield of ICCV 6 (ICCC 32) by 15% and delaying until 11 Dec caused a 28% yield reduction (Table 1). This yield reduction could primarily be attributed to shortening the podding duration. The harvest index was high at the latest sowing (47%), and similar to indices normally obtained in peninsular India; the 26 Oct sowing, in comparison, had a harvest index of only 38%.

Apart from the sowing date, the only other significant main effect was from the application of DAP that increased yield more at the latest sowing date (Table 1). Increasing population density from 33 to 50 plants m^{-2} did not significantly improve the yield of the latest-sown crop. However, there were significant combined effects of both DAP and irrigation in increasing yield at the latest sowing (e.g., at 30 × 10-cm spacing, Irrigation + DAP = 1.96, Irrigation only = 1.55, DAP only = 1.26, and neither = 1.01 t ha^{-1}). Thus, in this environment, fertilizer and irrigation can partially compensate for yield loss incurred by delayed sowing.

Genotypic Differences in Contrasting Environments

Genotypic differences in growth, phenology, and yield were studied amongst cultivars released

Table 2. Analysis of growth parameters of chickpea cultivars released by the Indian National Program to date, 1986/87.

Location	Years of release	Number of cultivars	Time to 50% flowering (d)	Crop duration (d)	Irrigation	Shoot mass (t ha^{-1})	Grain yield (t ha^{-1}) Min	Max	Mean	Harvest index (%)
ICRISAT Center (17°N)	1940-1985	10	39-44	83-93	-	2.5-2.9	1.1	1.6	1.2	44-57
					+	5.7-6.3	2.5	3.2	2.1	30-52
Gwalior (26°N)	1956-1984	14	51-79	128-141	-	2.9-5.0	1.3	2.4	1.7	44-58
					+	4.1-6.6	1.7	2.3	2.0	35-50
Hisar (29°N)	1958-1984	16	70-100	130-160	-	3.7-5.9	1.5	2.2	1.7	29-45
				(91-116)[1]	+	6.7-9.9	1.6	3.3	2.7	26-42

1. Data in parentheses refer to days from sowing to pod initiation.

at different times for three regions in India represented by:
ICRISAT Center (17°N) — peninsular region.
Gwalior (26°N) — central region.
Hisar (29°N) — northern and northwest region.

Crop duration and time to 50% flowering increased with latitude, corresponding with progressively cooler crop-growing seasons (Table 2). For each set of cultivars at each location, the range of yields obtained can be taken to approximate the extent of genetic yield improvement over years. At ICRISAT Center and Hisar without irrigation, and with irrigation at Gwalior, this was of the order of 0.7 t ha^{-1}. For the nonirrigated crop at Gwalior, yields differed by up to 1.1 t ha^{-1}. However, comparison of yield potential among genotypes was complicated by the occurrence of different diseases at each location. These trials are continuing in the 1987/88 season with extra precautions being taken against disease and using more released cultivars in larger plots. We hope to be able to quantify the extent of varietal improvement over time and, by detailed growth analysis, pinpoint the reasons for the improvement.

Improving the Growth of Chickpea Plants in Pots

Under experimental conditions at ICRISAT Center, *Cicer* plants produced twice as much biomass and seed when grown in the open in white pots than when grown in black pots (ICRISAT Annual Report 1986, p. 133). The difference in pot color caused a difference in soil temperature of up to 4°C at 15-cm depth. A similar pot experiment was conducted in 1986/87, but here, four different chickpea varieties were tested, and the cooling effect of the white-pot treatment was amplified by a superimposed water-cooling treatment. The water-cooling treatment was achieved using a drip system and by covering the pot with a white cloth (Fig. 4). The experiment thus had 12 treatments: 4 varieties × 3 pot types (black, white, and water-cooled) and was sown on 23 Sep 1986. Initially, when the weather was warm and sunny, the growth differences between the treatments were very clear, but when, from the last week of October, the weather became more cloudy and cool, the differences became less conspicuous. On 21 Oct, plant samples were assessed for nodulation and dry mass of the aerial parts (Table 3).

Pant G 114, a long-duration desi chickpea, and Rabat, a long-duration kabuli chickpea, produced approximately twice as much dry matter in the white pots as in the black pots, while Annigeri and ICCV 2 (ICCL 82001) showed a less pronounced response. Pant G 114 and ICCV 2 (ICCL 82001) reacted most favorably to water cooling.

Harvesting started from 16 Dec 1986 and was completed by 6 Mar 1987. Dry shoot masses and

Figure 4. Chickpea plants raised in black, white, and water-cooled pots, ICRISAT Center, 1986.

Table 3. Dry masses of chickpea plants and nodulation scores for different pot treatments at ICRISAT Center, 21 Oct 1986.

	Mean nodulation score[1]			Dry mass aerial parts (g $plant^{-1}$)		
	Pot treatment			Pot treatment		
Variety	Black	White	Cooled	Black	White	Cooled
Annigeri	1.0	1.9	2.3	0.55	0.71	0.89
Pant G 114	1.1	1.4	1.1	0.29	0.60	1.24
ICCV 2 (ICCL 82001)	1.3	1.7	3.7	0.85	0.87	1.69
Rabat	1.0	1.5	1.2	0.58	1.08	1.09
Mean	1.1	1.6	2.1	0.57	0.82	1.23
SE		±0.37			±0.22	
CV (%)		3.3			35	

1. 0 = no nodulation; 5 = heavily nodulated.

Table 4. Dry shoot mass at harvest and seed yield of chickpeas from different pot treatments, ICRISAT Center, 1986/87.

	Dry shoot mass (g pot^{-1})			Seed yield (g pot^{-1})		
	Pot treatment			Pot treatment		
Variety	Black	White	Cooled	Black	White	Cooled
Annigeri	21	29	25	39	37	42
Pant G 114	29	26	47	32	41	49
ICCV 2 (ICCL 82001)	13	15	26	41	38	55
Rabat	40	54	64	24	24	24
Mean	26	31	41	34	35	42
SE		±3.7			±7.7	
CV (%)		11			21	

seed yields are presented in Table 4. Obviously, the initial differences between the treatments, except for ICCV 2 (ICCL 82001), were not proportionately maintained until harvest. The trial results show the sensitivity of chickpeas to soil temperatures (measured daily for 10 days at 1400 h at 15-cm depth), which were 33.0°C for the black pots, 29.8°C for the white pots, and 25.3°C for the water-cooled pots over a period of 10 days.

Soil-cover Trials

Pot experiments with *Cicer* species, including chickpeas, suggest that soil temperatures have a marked effect on plant growth and biomass production under conditions prevailing at ICRISAT Center (ICRISAT Annual Report 1986, p. 133; and 1987, see above). We were therefore interested to know if such temperature effects also affect field-grown chickpea crops. We conducted trials in two different fields with three different varieties, in soil covered with different materials to lower its temperature. We used short- and medium-duration kabulis ICCV 2 (ICCL 82001) and ICCV 6 (ICCC 32), and a short-duration desi ICCC 37. The soil was covered by mulches of sorghum straw, and rice straw, a thin sprayed-on layer of kaolin, and white cotton cloth (Fig. 5). The net plot size was 2 rows each 3.5-m long. The trials, with 2 replications of ICCV 2 (ICCL 82001) and with 3 replications of ICCV 6 (ICCC 32) were sown on 1 Nov 1986, and with 5 replications of ICCC 37 on 17 Oct 1986. Soil temperatures were recorded in 2 replications only during 10 days for ICCC 37 (Table 5).

As is obvious, the white cotton cloth cover caused increases in yield of ICCV 6 (ICCC 32) (33%) and ICCC 37 (17%), but not of ICCV 2 (ICCL 82001). The results seem somewhat comparable with those of the pot trial described in Table 3: Annigeri, ICCC 37, and ICCV 2 (ICCL 82001) adapted to the growing conditions of peninsular India performed similarly in that respect while ICCV 6 (ICCC 32), Pant G 114, and Rabat are more suited for areas of higher latitude, and seem more responsive to the black and white pot difference. The data further suggest that soil temperatures, within the normal range observed at ICRISAT Center, affect chickpea crop growth, that genotypic differences exist, and that deliberate screening for resistance to high soil temperatures can possibly add to the stability of the crop under the conditions existing in peninsular India.

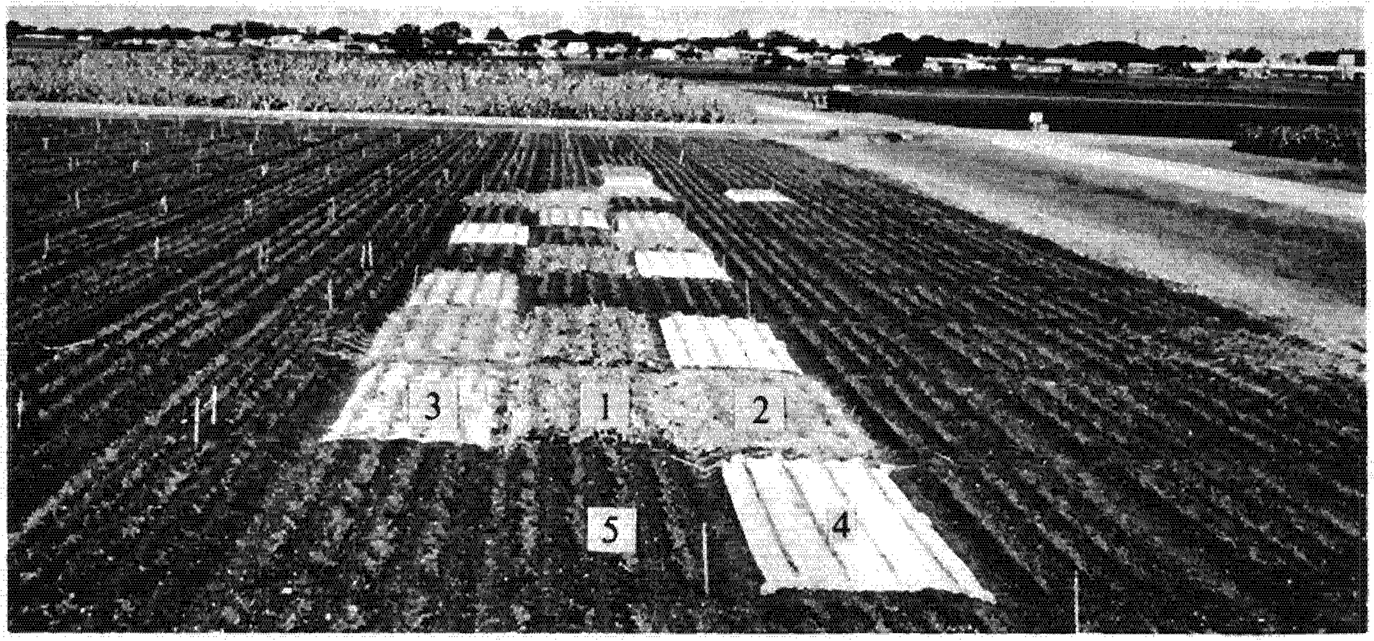


Figure 5. Soil cover trial with chickpea variety ICCC 37, ICRISAT Center, postrainy season 1986/87. (1. Sorghum straw, 2. Rice straw, 3. Kaolin, 4. White cotton cloth, and 5. Control).

Table 5. Soil temperature at 10-cm depth, time to 50% flowering, time to maturity, and seed yield for three chickpea varieties in soil-cover trials, ICRISAT Center, postrainy season 1986/87.

	Soil temp (°C)	Time to 50% flowering (d)			Time to maturity (d)	Seed yield (t ha^{-1})		
Treatment	ICCC 37	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)	ICCC 37	ICCC 37	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)	ICCC 37
Sorghum mulch	27.9	35	61	43	95	0.6	0.8	2.1
Rice mulch	29.8	34	64	43	94	0.7	0.7	2.0
Kaolin spray	30.1	33	60	40	92	0.5	0.7	2.2
Cotton cloth	28.9	33	59	41	93	0.7	1.0	2.3
Control	31.4	33	62	39	92	0.8	0.8	1.9
SE	±0.22	±0.5	±0.5	±0.8		±0.12	±0.06	±0.12
Trial mean	29.6	34	61	41		0.6	0.8	2.1
CV (%)	3.3	2.3	1.4	4.6		25	14	13

Biotic Stresses

Diseases

Disease Situation

We observed the sporadic incidence of botrytis gray mold (*Botrytis cinerea*), ascochyta blight (*Ascochyta rabiei*), and alternaria blight (*Alternaria alternata*) in parts of Bihar, Haryana, Uttar Pradesh, and West Bengal states of India and the Terai region of Nepal. Ascochyta blight is reported to have caused considerable damage in the Punjab and Northwest Frontier Province of Pakistan and in Syria. High incidence of stunt caused by bean leaf-roll virus (BLRV) occurred

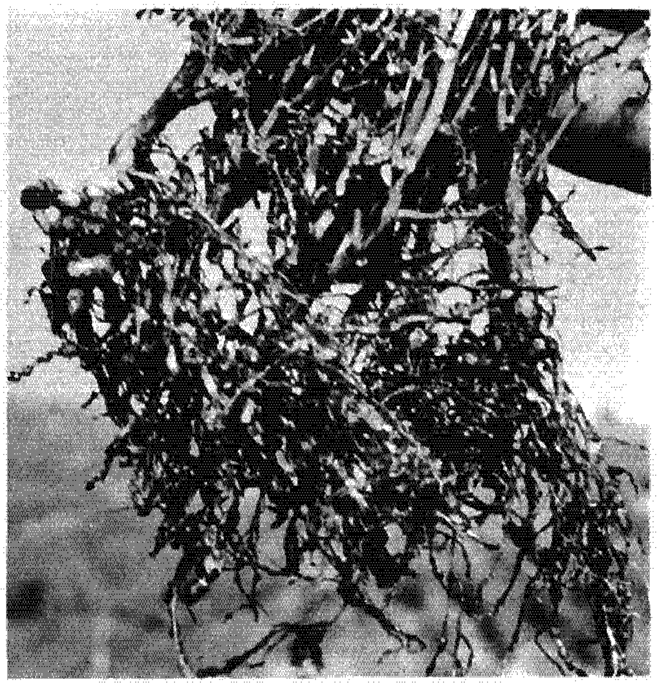


Figure 6. Chickpea plants showing galls on roots caused by root-knot nematode *Meloidogyne* sp, Rampur, Nepal, 1987.

in parts of peninsular and western India and in Ethiopia. Root-knot nematodes (*Meloidogyne* sp) destroyed all the chickpea trials at Rampur in Nepal (Fig. 6).

Fusarium Wilt (*Fusarium oxysporum* f.sp *ciceri*)

Wilt-resistant, large-seeded desi lines. Although some wilt resistant/tolerant cultivars such as No. 10, S 26, G 24, C 214, Pusa 212, and many resistance sources have been identified, most of them are small-seeded types (100-seed mass <20 g). In order to identify large-seeded lines with wilt resistance, we have been screening desi germplasm accessions from the ICRISAT gene bank since the 1982/83 season.

During the 1982/83 season, 372 accessions were sown in the wilt and root rots sick plot at ICRISAT Center. Each accession was sown in a 4-m row with about 50 seeds in each replication. The seeds collected from the surviving plants in these accessions were bulked and retested in the same sick plot in the two following seasons (1983/84 and 1984/85). The disease incidence in all three seasons for the accessions that showed less than 20% mortality in the third season is given in Table 6. These six lines, each with a 100-seed mass of more than 30 g, were purified for wilt resistance. All the lines were tested against Race 1 of *F. oxysporum* f.sp *ciceri* in pots in a greenhouse during 1986 and these remained completely free from wilt. Fusarium wilt was the predominant disease in the sick plot in all three testing seasons. There was a low incidence of the root-rot fungi *Rhizoctonia bataticola*, *R. solani*, and *F. solani*.

The absence of wilt in these lines when tested in pots and the mortality of some plants in the field can be attributed to the presence of root-rot fungi in the field.

Multiple race resistance. At least four races of *F. oxysporum* f.sp *ciceri* are present in India. The isolate prevalent at ICRISAT Center belongs to Race 1. We have so far identified 160 germplasm accessions resistant to Race 1. We screened all these accessions in pots in a greenhouse against Race 2 (Kanpur) and Race 4 (Hisar) to identify lines with multiple race resistance.

Table 6. Chickpea desi germplasm accessions with bold seeds and fusarium wilt (*Fusarium oxysporum* f.sp *ciceri*) resistance, ICRISAT Center, 1983–1985.

Germplasm accession	Wilt incidence (%) 1982/83	1983/84	1984/85	100-seed mass (g)
ICC 1442	73	49	20	31.4
ICC 4874	39	28	10	34.8
ICC 5909	38	32	13	37.9
ICC 6121	55	45	5	32.8
ICC 11146	43	50	13	30.2
ICC 11147	53	40	13	31.2
Control				
JG 62[1]	100	100	100	12.1

1. Susceptible to wilt and root rots.

We root-inoculated 7-day-old seedlings with 7-day-old inoculum and transplanted them into 15-cm plastic pots containing preirrigated sterilized soil (Vertisol + sand 1:1). We observed the plants for symptoms of wilt for over 60 days and found 52 lines resistant to Races 2 and 4.

Off-season screening for wilt and root rots resistance at ICRISAT Center. At ICRISAT Center we only screen chickpeas for wilt and root rots resistance in the field during the postrainy season. Large-scale field screening in both the main (postrainy) season and off-season (rainy) could accelerate our resistance breeding work. In 1986, we attempted to evaluate breeding material for wilt and root rot resistance during the rainy season in the multiple disease-sick plot using plastic shelters. A total of 380 lines were sown on ridges 60-cm apart on 31 Jul 1986, with the wilt-susceptible control line JG 62 repeated after every 8 test rows.

Wilt became apparent in the susceptible control 15 days after sowing (DAS); there was 100% mortality a month later. Dry root rot (*R. bataticola*) became apparent after about 2 months, when the maximum temperature exceeded 40°C. Screening for wilt and dry root rot resistance was effective and there was a good correlation between postrainy and rainy seasons in the reaction of the lines to wilt. However, dry root rot incidence was highest and earlier in the rainy season compared to the postrainy season.

In the 1987 rainy season, we again successfully screened under the plastic shelters. The plants were also successfully screened for wilt and root-rots resistance in the open field. But in the open field, along with wilt, black root rot (*Fusarium solani*) was found to be the predominant pathogen and not *R. bataticola*. The high soil moisture seems to have favored black root rot incidence in the rainy season. The crop was sprayed with Dithane M 45® to control colletotrichum blight (*Colletotrichum capsici*).

Dry Root Rot (*Rhizoctonia bataticola*)

Influence of cropping systems and rotations. *Rhizoctonia bataticola*, which causes dry root rot in chickpea, also affects pigeonpea, groundnut, sorghum, pearl millet, and many other crops. Obtaining resistance/tolerance to a fungus with such a wide host range is difficult. Finding a cropping system or crop rotation that reduces the fungal population in the soil will be very useful in the management of diseases caused by *R. bataticola*.

The sclerotial population of *R. bataticola* was estimated by the Resource Management Program (RMP) in an agronomy experiment where the long-term effects of different cropping systems and rotations on the soil fertility of a Vertisol at ICRISAT Center are being studied. The experiment has 15 cropping systems and rotations and the sclerotial population before and after the 5th year of the experiment is given in Table 7. The sclerotial population before sowing was generally higher in the cropping systems where chickpea was the last crop and lower where safflower was last. The sclerotial estimations at crop harvest indicate that the population was generally higher in systems where a sorghum/pigeonpea intercrop was grown. Inoculum density in the soil was generally reduced where the plots were left fallow in the rainy season. Also, sole cropping systems in general, reduced the fungal population, compared to mixed cropping.

Rust (*Uromyces ciceri-arietini*)

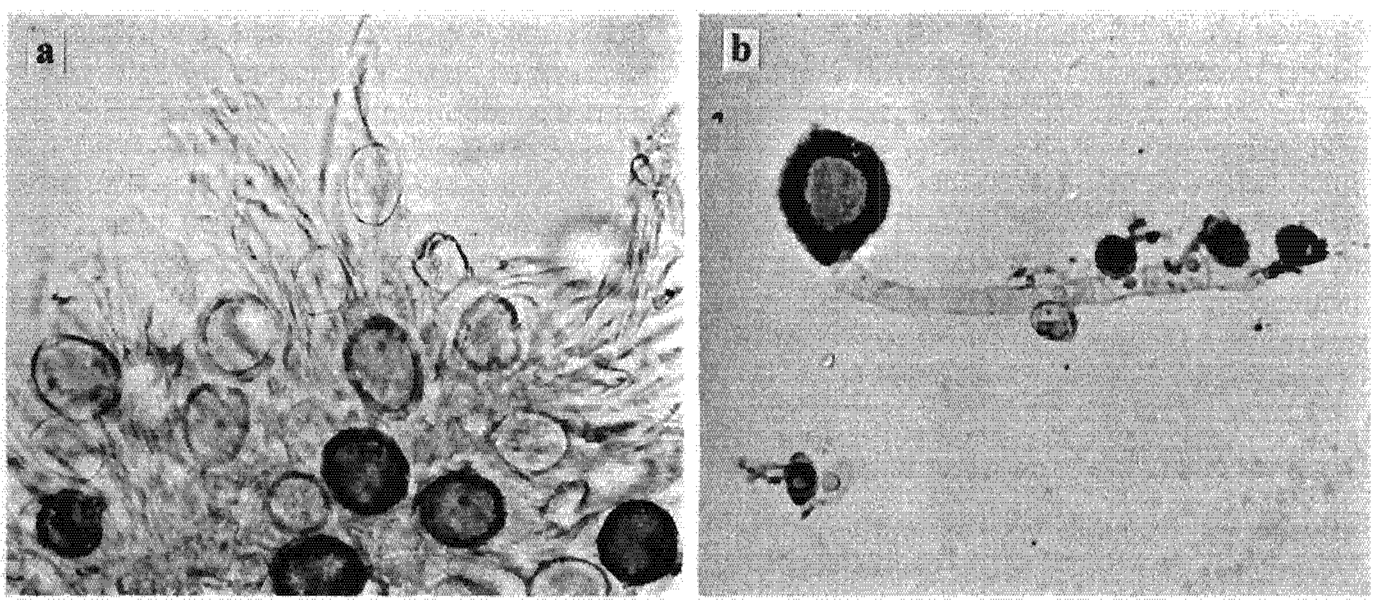
Life cycle. Rust occurs in varying intensity wherever chickpea is cultivated. Its occurrence is more common in northern latitudes where the climate during the chickpea-growing season is cooler and more humid. The life-cycle of this pathogen is, as yet, not known in detail. We therefore studied the life cycle of the fungus. We observed that chickpea rust is macrocyclic; that is, it produces uredial, telial, basidial, pycnial, and aecial stages (Fig. 7 a and b). All these stages are found on chickpea. Therefore, it is an autoecious rust. It can over-winter in its uredial or telial stages on chickpea or on a collateral host (*Trigonella polycerata*). It is also quite possible that it may have a wider host range.

Table 7. Inoculum density of *Rhizoctonia bataticola* before sowing and at harvest of rainy-season crops in the season of the Vertisol cropping-system experiment, ICRISAT Center, 1987.

Crop combination[1,2]					
First year		Second year		Sclerotia (g^{-1}) dry soil	
Rainy season	Postrainy season	Rainy season	Postrainy season	Before sowing	At harvest
S/PP	S/PP	S	SF	1.8 (1.3)[3]	9.3 (3.1)
S	SF	S	SF	0.0[4]	1.5 (0.9)
S/PP	S/PP	S	CP	6.0 (2.4)	14.5 (3.8)
S	SF	S	CP	10.8 (3.3)	3.8 (2.0)
S	SF	C/PP	C/PP	7.0 (2.6)	4.2 (2.0)
S	CP	S/CP	S/CP	9.7 (3.1)	4.2 (2.0)
F	S	F	CP	12.7 (3.5)	2.5 (1.6)
F	S	F	S	9.2 (3.0)	5.5 (2.3)
S	CP	S/PP	S/PP	9.8 (3.1)	2.8 (1.7)
M	S	M	S	8.8 (3.0)	6.0 (2.4)
F	CP	F	S	9.5 (3.1)	3.5 (1.8)
S/PP	S/PP	S/PP	S/PP	6.7 (2.6)	21.0 (4.6)
S	CP	S	SF	3.2 (1.8)	1.8 (1.1)
C/PP	C/PP	S	SF	0.3 (0.3)	10.7 (3.3)
S	SF	S/PP	S/PP	6.3 (2.5)	4.7 (2.1)
SE				(±0.19)	(±0.32)

1. Repeated in 2-year cycles.
2. C = Cowpea, CP = Chickpea, F = Fallow, M = Mung bean, PP = Pigeonpea, SF = Safflower, S = Sorghum.
3. Figures in parentheses are square root transformations.
4. Excluded from SE calculation.

Figure 7. Uredial (a) and telial (b) stages of rust fungus *Uromyces ciceri - arietini* on chickpea, Pantnager, postrainy season 1987. (Magnification × 400).



Gray Mold (*Botrytis cinerea*)

Selective medium for *Botryis cinerea*. We developed a selective medium to recover *B. cinerea* from plant debris, leaves, flowers, etc., The medium consists of desi chickpea meal broth made at ICRISAT Center (ICRISAT Annual Report 1986, p. 133-134), chloramphenicol, copper sulphate, tannic acid, pentachloronitrobenzene (PCNB), and manganous ethylene bisdithio carbamate (Maneb). After incubation at 15°C for 7-10 days under cycles of 12 h of near ultraviolet light and 12 h of darkness, *B. cinerea* produces a characteristic, whitish to yellow-brown mycelium and conidia on the agar (Fig. 8). Fungi such as *Ascochyta rabiei, Phoma medicaginis, Alternaria alternata, Sclerotinia sclerotiorum,* and *Colletotrichum dematium* do not grow on this medium when incubated under the same conditions.

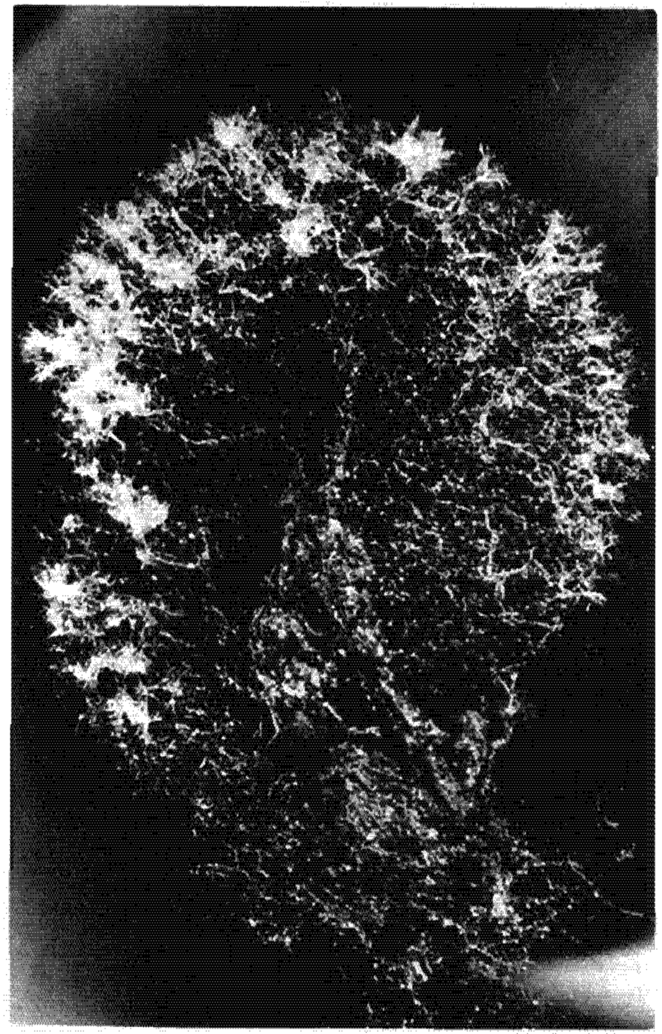


Figure 8. *Botrytis cinerea*, growing out from the host tissue placed on the medium. (Magnification × 4).

Sources of resistance. More than 7000 chickpea accessions from ICRISAT's germplasm collection have been screened for resistance to botrytis grey mold under artificial epiphytotics in a field at Pantnagar in northern India. This screening has been in progress since the 1980 postrainy season. Each entry is grown in a 3-5 m row with the susceptible cultivar H 208 repeated after every two test entries. The nursery is inoculated by spraying a spore suspension of *B. cinerea* multiplied on sterilized marigold flowers at the time of about 25% flowering and 2-3 times at 10-15 day intervals. The nursery is frequently irrigated to maintain humid conditions. The accessions that show a rating of 5 or less on a 1-9 scale, where 1 = disease free and 9 = killed, are re-evaluated in the following seasons. Cultivars that are rated 5 or less under field conditions are evaluated in pots in a greenhouse at ICRISAT Center against two isolates (Aurangabad and Pantnagar) of *B. cinerea*.

A list of 17 accessions found promising in field screening for 1-4 seasons and their reactions in greenhouse screening against the two isolates is given in Table 8. Most of the accessions with low disease ratings in field screening also had low ratings when screened in a greenhouse. ICC 1069, ICC 4071, and ICC 4111 were rated higher in the greenhouse than in the field.

Stunt (CpSV)

Epidemiology. Stunt caused by a luteovirus serologically related to bean leaf-roll virus (BLRV) is the most important viral disease of chickpea. It is not seedborne. Under natural field conditions the disease is transmitted by *Aphis craccivora*. At Hisar in northern India, we monitored the dispersal flights of this aphid over recent cropping seasons by installing yellow sticky traps and yellow pan water traps in the

Table 8. Performance of 17 chickpea cultivars against botrytis gray mold (*Botrytis cinerea*) in field tests at Pantnagar, 1983/84 to 1986/87, and in a greenhouse at ICRISAT Center, 1987.

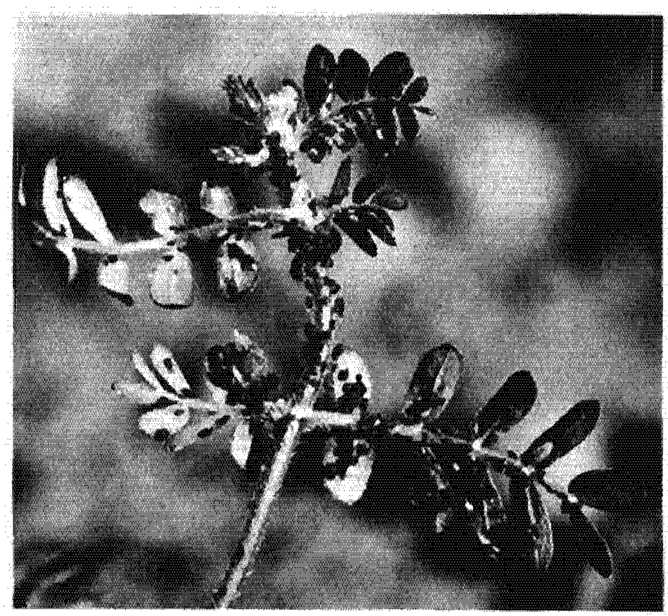
	Rating at Pantnagar[1]			Rating in greenhouse[1]	
Cultivar	No. of tests	Mean rating	SE	Aurangabad isolate	Pantnagar isolate
ICC 10302	2	2.0	±1.00	NT	NT
ICC 1069	4	2.5	±0.50	5	7
ICC 12961	2	3.0	±0.00	NT	NT
ICC 4111	3	3.3	±0.67	3	7
ICC 478	3	3.7	±0.67	5	2
ICC 3390	3	3.7	±0.67	3	4
ICC 3671	3	3.7	±0.67	3	4
ICC 4071	3	3.7	±0.67	3	8
ICC 5893	3	3.7	±0.67	NT	NT
ICC 6299	3	3.7	±0.67	1	4
ICC 1762	2	4.0	±1.00	5	2
ICC 2547	2	4.0	±1.00	3	5
ICC 2548	2	4.0	±1.00	3	5
ICC 2690	2	4.0	±1.00	3	3
ICC 3603	4	4.0	±0.58	3	4
ICC 3118	4	4.5	±0.96	1	5
ICC 3598	1	5.0	±0.00	5	3

1. Based on a 1-9 scale, where 1 = no symptoms, 9 = killed, and NT = not tested.

CpSV nursery. We observed peak aphid catches in November, closely followed by the appearance of stunt symptoms in the crop.

Investigations were carried out to find out how and where the aphid vector and CpSV survive in the off (rainy)-season. Rainy-season food legumes such as cowpea (*Vigna sinensis*), groundnut, and greengram (*Phaseolus aureus*) commonly grown around Hisar were found not to harbor the aphid vector and CpSV. However, surveys during the 1986/87 cropping season around Hisar showed *A. craccivora* to extensively colonize *Tribulus terrestris* (family: Zypophyllaceae), a common weed seen along the field bunds and irrigation channels (Fig. 9). When these aphids were transferred onto pot-grown healthy chickpea plants of stunt-susceptible WR 315, they produced CpSV symptoms indicating that *T. terrestris* harbored the virus.

Figure 9. *Aphis craccivora*, a vector of chickpea stunt virus colonizing leaflets of *Tribulus terrestris*, an alternate weed host, Hisar, 1986/87.



Causal agent. We collected chickpea plants showing typical stunt symptoms and maintained a culture by aphid and graft inoculation. We purified the luteovirus in infected plants by extraction in a phosphate buffer of low pH, treatment with celluclast, precipitation with polyethylene glycol, pelleting in a sucrose cushion followed by a rate zonal density gradient centrifugation in sucrose solutions. About a milligram of virus was obtained from 900 gm of tissue. We produced an antiserum in rabbits which reacted with CpSV both in enzyme-linked immunosorbent assay (ELISA) and immunosorbent electronmicroscopy tests. We are currently determining the serological relationships between various isolates of CpSV and other luteoviruses.

Multiple Disease Resistance

Evaluation of wild *Cicer* species for multiple disease resistance. Ascochyta blight, gray mold, wilt, and root rots are the major diseases of chickpea. Although good sources of resistance to wilt are available in the cultivated chickpea (*Cicer arietinum*), there is a need to identify lines with resistance to ascochyta blight, gray mold, root-rots, and multiple disease resistance. We have not yet found good sources of resistance to these diseases in the available *C. arietinum* germplasm.

We evaluated collections of wild *Cicer* spp available in the gene bank for wilt, root rots, ascochyta blight and botrytis gray mold resistance. Wilt and root rots resistances were evaluated in the wilt and root rots nursery at ICRISAT Center. For each accession, 50 seeds were sown in a 4-m row in a single replication. Accessions were screened for blight and gray mold resistance in pots in a greenhouse using Hisar isolates of *A. rabei* and *B. cinerea*. For each accession, 10 seeds were sown in a 15-cm pot in a single replication. The reactions to wilt, root rots, ascochyta blight, and gray mold are given in Table 9.

One accession each of *C. bijugum* No. 201, and *C. judaicum* No. 185 (Fig. 10) and two accessions of *C. pinnatifidum* No. 188, No. 199

Figure 10. *Cicer judaicum* No. 185, a wild chickpea species (right) showing resistance to ascochyta blight, while the cultivated chickpea cultivars ILC 1929 and ILC 191 show susceptibility, greenhouse experiment, ICRISAT Center, postrainy season 1986/87.

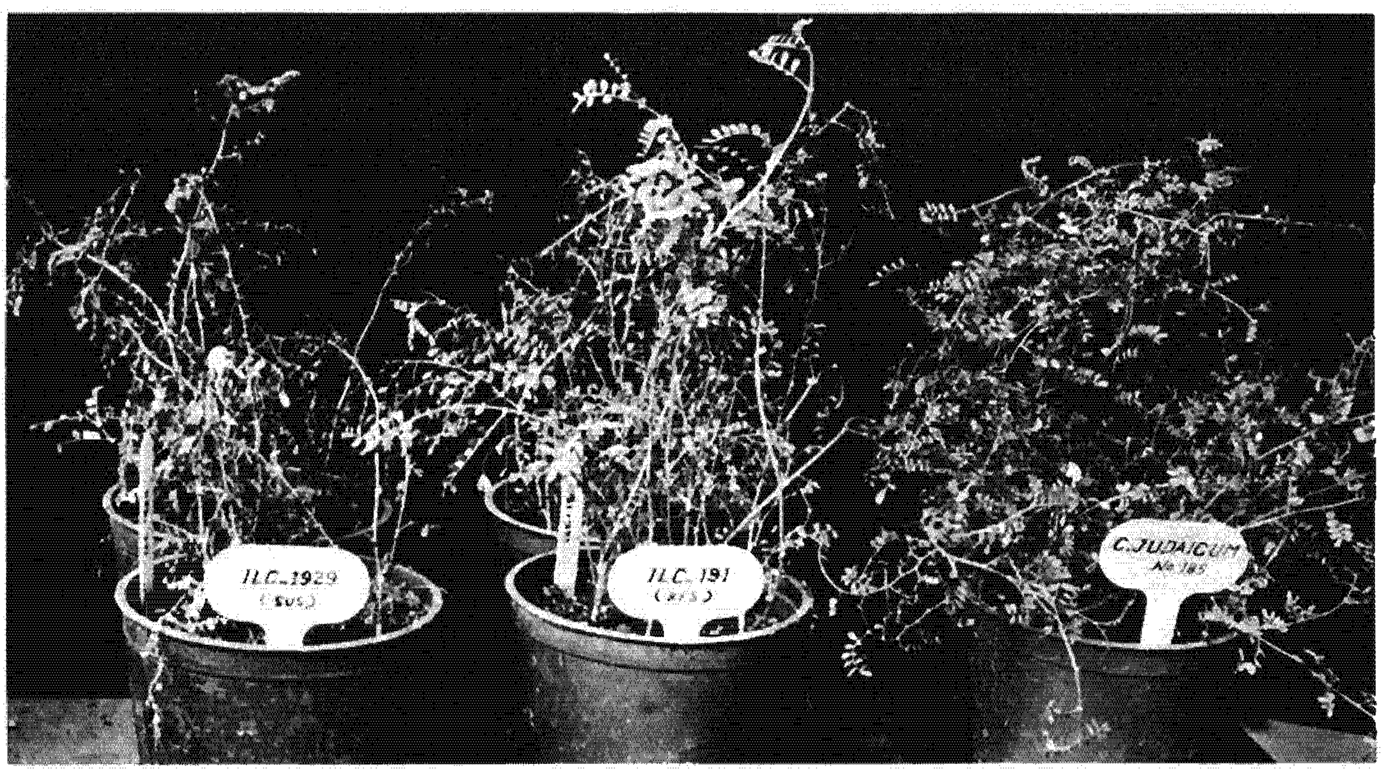


Table 9. Reaction of wild *Cicer* species to ascochyta blight (*Ascochyta rabiei*) and botrytis gray mold (*Botrytis cinerea*) in the greenhouse and to wilt (*Fusarium oxysporum* f.sp *ciceri*) and root rots (*Rhizoctonia bataticola, R. solani, F. solani*) in field tests, ICRISAT Center 1987.

	Ascochyta blight		Botrytis gray mold		Wilt and root rots	
Wild *Cicer* spp accession	Total plants	Disease rating[1] after 21 days	Total plants	Disease rating[1] after 21 days	Total plants	Mortality (%)
C. bijugum No.200	10	5	10	4	26	0
C. bijugum No.201	9	4	10	4	20	5
C. bijugum JM 2103	10	6	10	6	30	17
C. bijugum JM 2113	10	5	10	4	24	8
C. chorassanicum JM 2230	6	9	8	9	9	22
C. cuneatum SL 157	9	7	10	8	73	31
C. echinospermum No.204	NT[2]	NT	NT	NT	16	94
C. echinospermum No.2133	10	7	10	5	NT	NT
C. judaicum No.182	10	5	10	5	72	33
C. judaicum No.183	11	5	10	7	86	21
C. judaicum No.185	10	3	10	6	97	44
C. judaicum	9	5	8	5	90	31
C. pinnatifidum No.188	10	3	10	8	77	29
C. pinnatifidum No.189	10	5	8	8	63	11
C. pinnatifidum No.199	10	3	10	8	68	98
C. reticulatum No.205	NT	NT	NT	NT	43	10
C. reticulatum JM 2100	10	7	10	5	35	100
C. reticulatum JM 2105	10	7	10	5	25	88
C. reticulatum JM 2106	9	7	9	5	26	92
C. reticulatum JM 2106 (a)	10	7	10	5	27	100
C. reticulatum JM 2106 (a-1)	NT	NT	NT	NT	24	100
C. yamashitae JM 2021	10	9	7	9	46	91
C. yamashitae JM 2022	11	8	10	8	44	93
Controls						
Pb 7[3]	10	9	NT	NT	NT	NT
H 208[4]	NT	NT	10	9	NT	NT
JG 62[5]	NT	NT	NT	NT	55	100

1. Based on a 1-9 scale, where 1 = unaffected and 9=killed.
2. NT = not tested.
3. Susceptible to blight.
4. Susceptible to botrytis gray mold.
5. Susceptible to wilt and root rots sown after every two test rows.

had resistance to ascochyta blight. Three accessions of *C. bijugum* No. 200, No. 201, and JM 2113 had resistance to botrytis gray mold. Three accessions of *C. bijugum* No. 200, no. 201, JM 213 had resistance to both wilt and root rots (Fig. 11). A single accession of *C. bijugum* No. 201 had resistance to all four diseases.

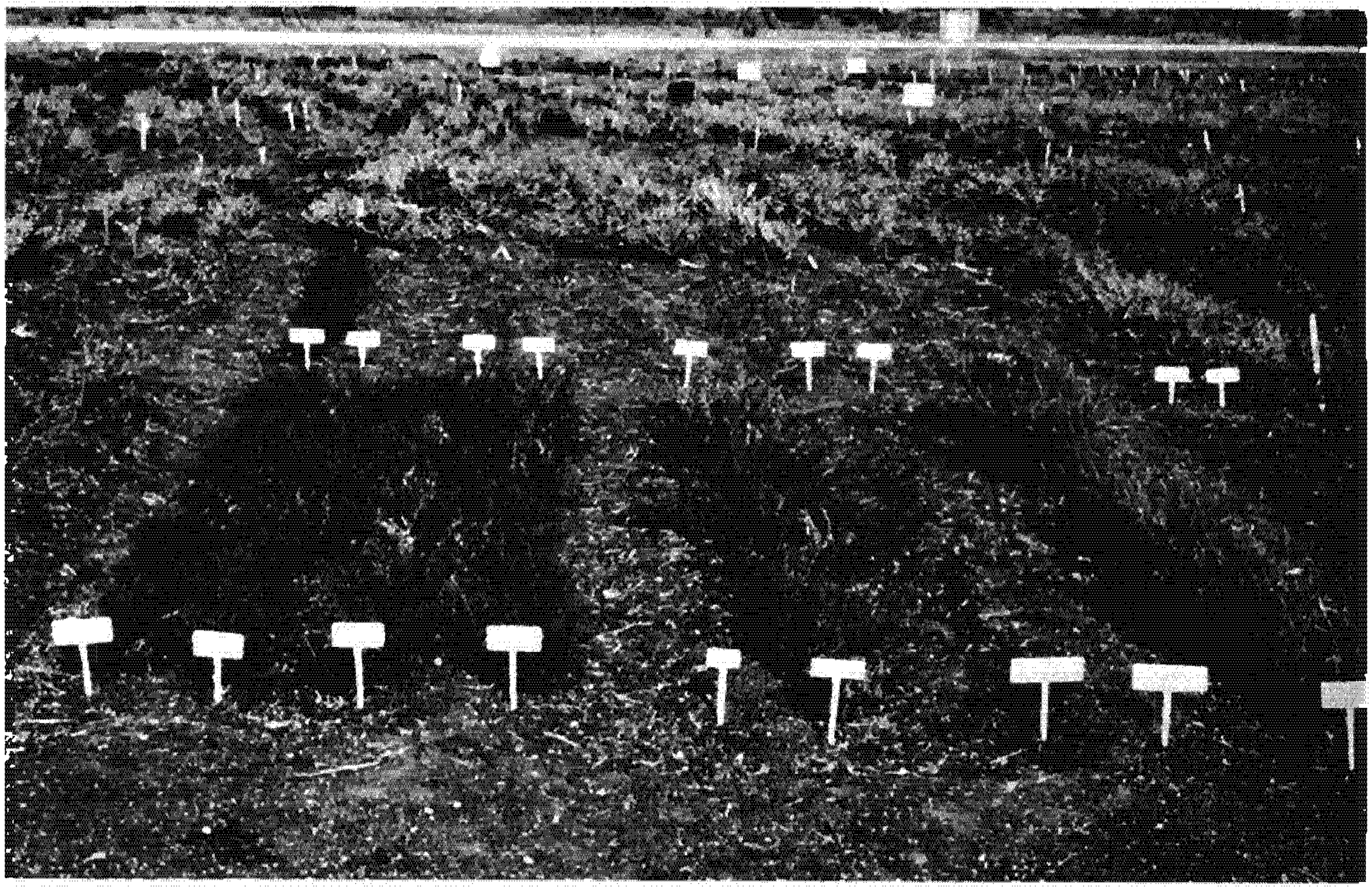


Figure 11. Wild *Cicer* species *Cicer bijugum* No. 200, *C. bijugum* No. 201, and *C. bijugum* JM 2113 and six others showing resistance to wilt and root rots in the wilt and root rots nursery, ICRISAT Center, postrainy season, 1986/87.

Screening chickpeas for wilt and stunt resistance. For the past 3 years (1985-87), we have screened chickpea genotypes against wilt and stunt in a 1.3-ha area at Hisar. Wilt (*F. oxysporum* f. *ciceri*) is soilborne while stunt is transmitted by an aphid vector, *A. craccivora*. The wilt and stunt disease nurseries were made wilt sick by incorporating infected chickpea debris for several years and stunt screening was also conducted in the same area. In order to attract the winged aphids that carry the stunt pathogen to the disease nursery, we sowed mixtures of legumes such as cowpea, mungbean, lentil, alfalfa, and lathyrus, in 10-m rows around and within the nursery. These legumes were sown 20-30 days before the chickpea crop was sown in mid-October.

Additionally, since 1987, we have retained the rows of alfalfa in the disease nursery by frequently trimming them so that their fresh leafy growth acts as a bait for the winged aphids throughout the year.

Previous studies at Hisar showed that stunt incidence was high in widely spaced crops (row distance 75 cm or more) sown early; i.e., in the first week of October. In order to monitor wilt and stunt incidence, the susceptible control cultivars for wilt (JG 62) and stunt (WR 315) were repeated alternately after every two test entries. Over the years, wilt incidence in the susceptible control has been high (100%), but stunt incidence in the susceptible control varied from 50-90% over different years. In future years, we hope to improve our screening against stunt.

Every year we screen elite lines and segregating breeding materials to note their reactions to wilt and stunt. In 1987, we screened over 2700 germplasm accessions and breeding materials for wilt and stunt, and found that germplasm accessions ICC 2210, ICC 2442, ICC 8241, ICC

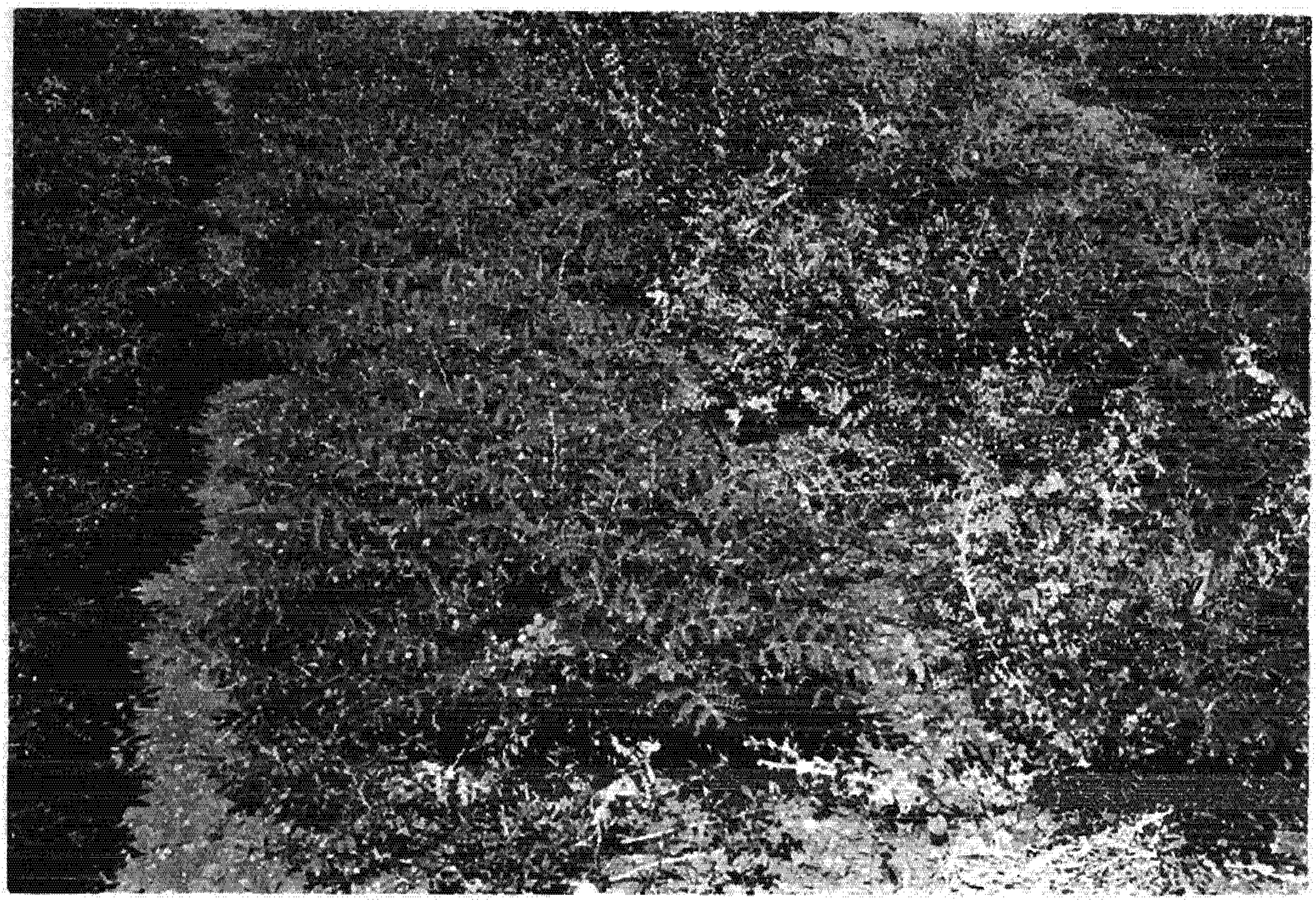


Figure 12. A chickpea breeding line, ICC × 730020 (left) showing resistance to fusarium wilt (*Fusarium oxysporum* f. sp. *ciceri*) and stunt, ICRISAT Center, postrainy season 1986/87.

105503, ICC 10805, ICC 11502, ICC 11551, and the breeding line ICCX 730020-11-1-1H-BH showed less than 20% wilt and stunt (Fig. 12). In segregating breeding materials, resistant plants/progenies were advanced for further evaluation. We found that the cultivars developed at Hisar have a higher level of tolerance to stunt than those bred at ICRISAT Center.

Insect Pests

Pest Incidence

Heliothis armigera was the dominant insect pest on chickpea in 1986/87 at ICRISAT Center, and at all other locations that were surveyed. This insect is strongly attracted to the crop from the seedling stage onwards and the larvae can thrive by feeding only on leaves as well as on flowers or pods. In southern India, chickpea often suffers severe damage during the vegetative stage, with the plants being eaten down to bare stalks. But, the plants recover from such damage and although flowering is delayed, yields can be good, provided the climate and soil moisture are conducive to prolonged survival. At ICRISAT Center, *Heliothis* populations on chickpea were higher than average, with more than 50% of the pods bored by larvae in fields that were not protected by insecticide. In northern India, the vegetative growth stage occurs during winter when *Heliothis* is not active, so every year there is a race between the build-up of the insect populations and the maturation of the crop. This year, *Heliothis* populations built up to very high levels before the pods ripened, so damage levels of 60% and more were recorded in some unprotected fields.

Other pests are relatively minor, but can cause substantial yield loss in some areas and seasons. Of the other lepidoptera, cutworms (*Agrotis* spp) have frequently been reported to kill large numbers of seedlings in some areas of central India, but no reports were received of extensive damage this year. Semilooper caterpillars (*Autographa nigrisigna*) and *Spodoptera exigua*, both green larvae that are often confused with *Heliothis*, were found feeding on leaves and pods but only in small numbers.

In the lighter soils in northern India, termites (*Microtermes* sp) were found tunneling in the roots of wilted chickpea plants. In most cases, such attacks were secondary, for the plants had already been damaged by mechanical cultivation or by fusarium wilt, but in some instances, the damage appeared to be primary. Aphids, *Aphis craccivora*, were found on the stems of some plants, particularly at Hisar. This insect is important as a vector of the bean leaf-roll virus, which causes stunt disease in chickpea.

In Ethiopia, *Heliothis armigera* was seen to be the main pest, but it occurred sporadically in chickpea fields grown by farmers. In the Mediterranean region, the leaf miner (*Lyriomyza cicerina*) was reported to be more damaging than usual this year.

Heliothis armigera

Host-plant resistance. This year screening for resistance to *Heliothis* at ICRISAT Center was hampered by drought from early September 1986. This prevented us from sowing most of our screening trials as irrigation facilities are not available in the pesticide-free area where we normally sow such trials. The seed for these trials was kept in cold storage to be sown next season.

We sowed some trials in the pesticide-treated area of ICRISAT Center where irrigation facilities are available. Unfortunately, this field had a high inoculum level of *Fusarium oxysporum* f. sp *ciceri* and so the wilt-susceptible genotypes were devastated by this disease. However, some entries gave good yields with relatively little wilt incidence or borer damage. For example, ICCL 86105 yielded 2.03 t ha^{-1} with 16.4% borer damage, which was a significant improvement on the control cultivar K 850 in the same trial, that yielded only 1.35 t ha^{-1} and had 35.6% pod damage.

At Hisar, our screening trials suffered from patches of salinity, wilt, and root rot diseases, but plant growth was generally good and *Heliothis* populations were high, so screening was successful. Several genotypes yielded more than 2.0 t ha^{-1} without pesticide protection, and some had pod-damage levels of less than 30%, while susceptible genotypes had well over 70% pod damage.

Resistance mechanisms. We conducted both oviposition preference tests and larval feeding tests for antibiosis in the laboratory, using moths and larvae produced in our rearing facility. We also collaborate with scientists at the Max-Planck Institute (MPI) for Biochemistry at Munich, Federal Republic of Germany in research on the chemicals involved in the resistance/susceptibility of our chickpea selections. As larval and oviposition nonpreference has been found to be important in the resistance of some of our selections, it seemed likely that volatile plant chemicals may play an important role in resistance/susceptibility by acting as attractants (kairomones).

Work at MPI, using olfactometer bioassays of volatile chemicals, released from the powder of seeds from a susceptible chickpea, initially showed that the terpenoid fraction was the most effective in attracting both larvae and egg-laying females. This terpenoid fraction was analyzed by combined gas chromatography and mass spectrometry. Such analyses showed that about 200 individual compounds are present in this fraction. Of these, the chemical compositions of 125 compounds have been identified. Sixteen of the most prominent compounds were individually tested in olfactometer bioassays and four of these showed marked attraction to *Heliothis*. These were; pentan-1-ol and three terpenes, delta-3-carene, myrcene, and alpha-pinene. A synthetic mixture of these four compounds, blended in the same proportion as found in the seed aroma, proved to be a highly active kairomone for *Heliothis* when tested under laboratory conditions. The activity of this synthetic kairomone will be tested under field conditions and, if effective, may be useful in trapping *Heliothis* moths. A knowledge of the attractant chemicals may also help us identify plants with high or low attraction to this pest.

Monitoring populations. Our earlier collaboration with the Tropical Development and Research Institute (TDRI), UK, now Overseas Development Natural Resources Institute (ODNRI), led to the development of a pheromone trap that is successful in trapping large numbers of *Heliothis armigera* males that are attracted to a synthetic pheromone impregnated on a rubber septum. At the International Workshop on *Heliothis* Management held at ICRISAT in 1981, it was pointed out that although pheromone traps will not be directly useful in controlling *Heliothis*, they will be useful in monitoring *Heliothis* populations. However, no published evidence was then available of their monitoring efficiency. Consequently, ICRISAT agreed to conduct trials over several years in which catches in pheromone traps would be compared with catches of *Heliothis* moths in light traps and with counts of larvae on all host plants at ICRISAT Center.

From 1981, we recorded catches in two light traps at ICRISAT Center, one on an Alfisol and the other on a Vertisol. Two pheromone traps are positioned 150 m to the northwest and southeast of each of these light traps. Our pest surveillance unit counted *Heliothis* larvae on samples every week on all crops growing at the Center, which has a total area of 1394 ha. From these counts, we estimated the numbers of larvae present each week.

Figure 13 shows the mean trap catch and larval population data per standard week averaged

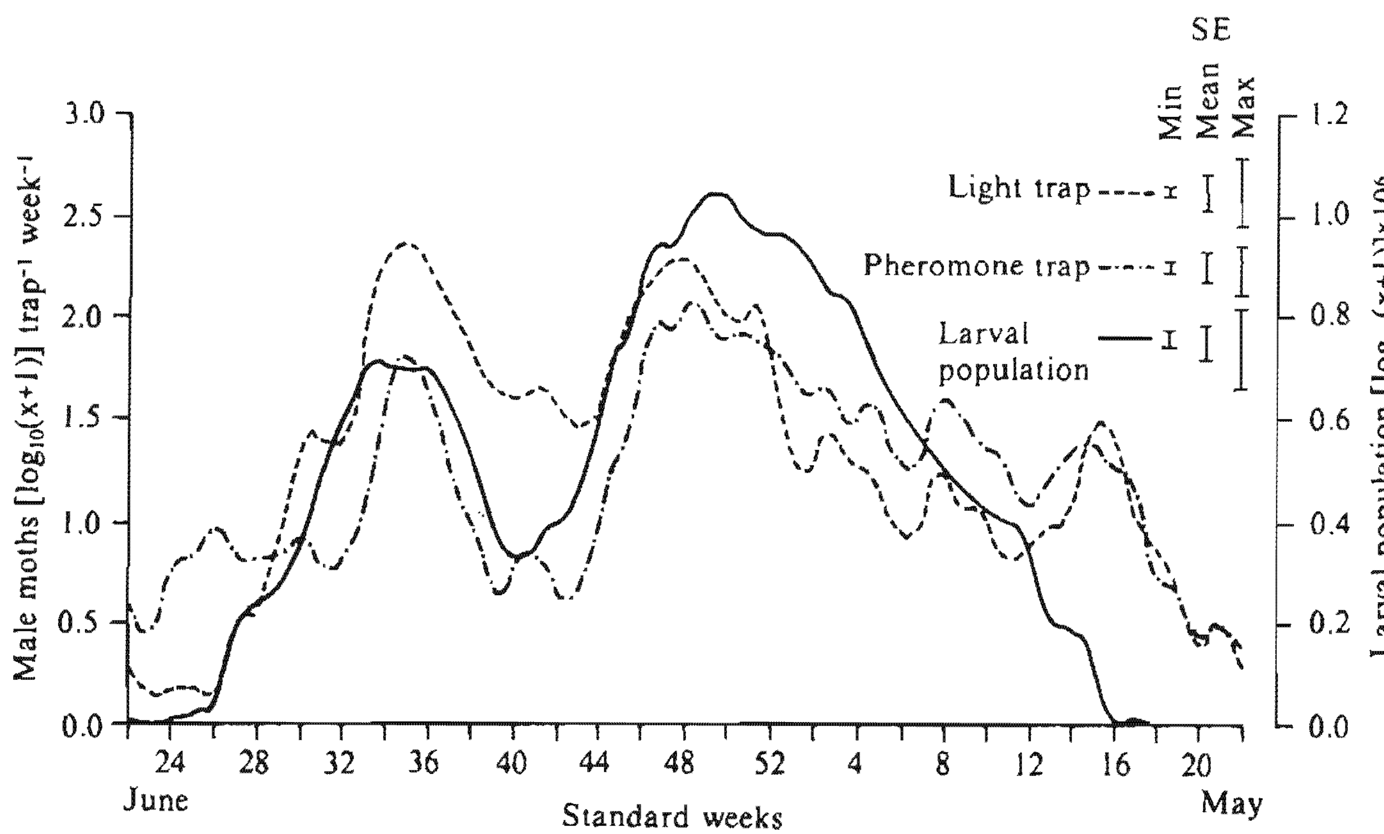


Figure 13. Mean catches standard week^{-1} of *Heliothis armigera* male moths in light and pheromone traps and the larval populations, estimated from counts on all hosts, ICRISAT Center, June 1981-May 1987.

over the last 6 years. It can be seen that the light and pheromone trap catch data differ considerably at different times of the year. For example, from standard week 30 (late July) the light trap catches are higher than the pheromone trap catches and from week 52 (end of December) to week 16 (mid April) the light trap catches are lower than the pheromone trap catches.

Analyses showed that correlations of the weekly catches in the pheromone and light traps averaged r = 0.6, thus explaining less than 40% of the variation. This low correlation is partly explained by lunar effects that greatly reduce catches in light traps, but not in pheromone traps, during full-moon periods. However, at this time we have no convincing explanation for the considerable seasonal deviations that are evident between catches in Figure 13. As reported earlier (ICRISAT Annual Report 1986, p. 183), pheromone traps seem to be generally less efficient in recording invading moth populations that lay eggs in our crops, but are much more efficient in recording moths that emerge from pupae, resulting from the larvae that have attacked the crops. Thus, these traps seem to be of little use in predicting damaging attacks.

At ICRISAT Center, *Heliothis* attacks on crops grown on Vertisols are usually much more severe than those on crops grown on Alfisols. Such differences are also reflected in catches in the light and pheromone traps on these soil types; catches in Vertisol traps are often ten times greater than those in the Alfisol traps. Such differences are reflected in the relatively low correlation of r = 0.77 (n = 310), which has been recorded between the weekly catches in the light traps on Alfisols and Vertisols. With such low correlations, it is questionable whether these traps are of any use in "monitoring" the *Heliothis* populations on our farm.

However, coefficients of variation among the pheromone trap catches at Hisar [CV(%) = 43] are much lower than those at ICRISAT Center [CV(%) = 71]. The correlation between the weekly light- and pheromone-trap catches at Hisar was r = 0.95, and so was considerably higher than the correlations recorded at ICRISAT Center (r = 0.67). These lower coefficients of variation and higher correlations at Hisar are largely explained by the more extreme climatic conditions at that location, for both the light- and pheromone-trap catches are very low both during the winter months and the hot summer, when few *Heliothis* moths are active.

Pheromone trap network. In cooperation with ODNRI, in recent years we have supplied pheromone traps to cooperators at several locations in Bangladesh, India, Pakistan, and Sri Lanka. We have conducted a preliminary analysis of the data supplied regularly by different cooperators. The mean weekly catches, averaged over 3–6 years from some of these locations are illustrated in Figure 14. It can be seen that there are obvious changes with latitude in the patterns of catches. In the more northerly traps, peak catches occur around standard week 15 (late April). These moths are thought to have bred mainly on chickpeas. At some of these northerly locations, there is also a smaller peak of catches around week 42 (mid-October). These moths are likely to have bred on short-duration pigeonpea and cotton. The cold winters in these northern locations limit *Heliothis* activity between November and February, as night temperatures can drop below 0°C.

In most southern locations (Coimbatore and Paiyur), the pheromone trap catches are generally lower than those recorded in northern India, and without well-defined seasonal peaks. At these locations, night temperatures (<10°C) during winter are not low enough to limit *Heliothis* activity. Although the hot dry seasons (April-June) could be expected to result in a reduction in *Heliothis* populations because of lack of suitable plant hosts, there are plenty of irrigated hosts available, particularly on research stations where these pheromone traps are located.

One interesting feature to emerge from the analyses is that catches in 1984/85 at 33 out of 35 locations were considerably lower than the average for other years. Such widespread synchrony of population reduction is difficult to explain. Every year, some areas in India have droughts and others floods, so climatic conditions that could limit populations do not occur evenly across the subcontinent in any one year.

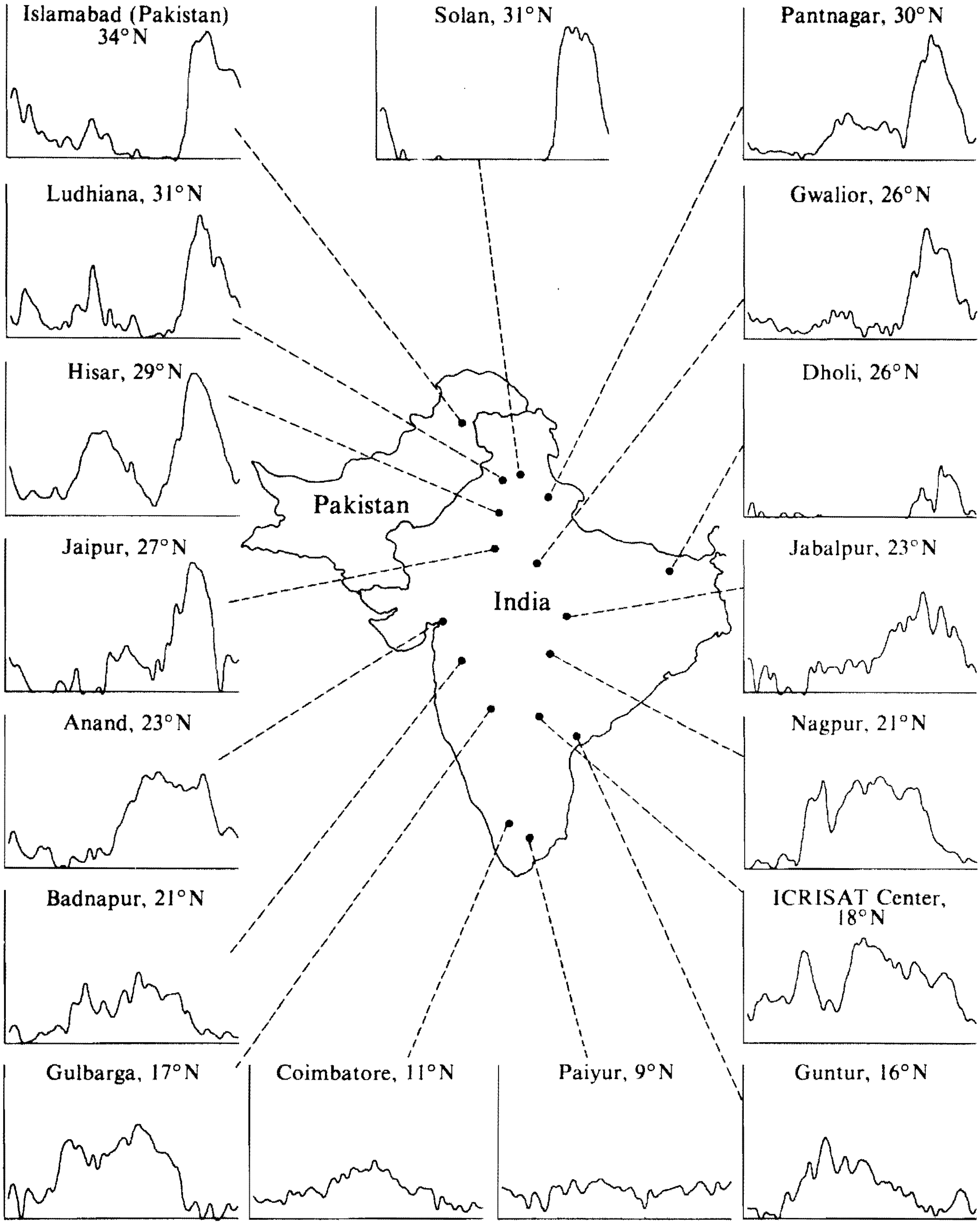


Figure 14. Mean weekly catches ($\log_{10}$ (x=1) trap^{-1} from standard week 23 (4 Jun) to week 22 (28 May) from 17 locations in the ICRISAT *Heliothis* pheromone network in parts of India and Pakistan, June 1981-May 1987.

A comprehensive report on these pheromone and light trap data is being prepared, and an attempt is being made to analyze climatic and crop influences on the catches. When these analyses have been completed, we will decide whether such international pheromone trap networks are likely to be of any practical value. Until then, we will continue to support this network, for most cooperators are anxious to continue the trapping and several consider the catch data to be useful in insecticide use decision making, particularly in the northern locations.

Plant Nutrition

We are trying to develop appropriate methods to identify and correct nutritional imbalances in chickpea. Our major emphasis is on the enhancement of symbiotic nitrogen fixation. We are also hosting a Government of Japan Special Project that is examining interactions between mineral nutrition and soil-moisture availability in chickpea.

Fertilizer Application Method and Phosphorus Response

Chickpea and pigeonpea are generally considered to be less responsive to phosphorus (P) fertilizer application than cereals. Under field conditions, the effectiveness of fertilizer-P is expected to be strongly influenced by the method of application because of the limited mobility of P and its fixation by soil colloids. For Alfisols and Vertisols, it is usually considered that band application of fertilizer-P would be more effective for chickpea as it places the P in a zone where roots proliferate and thus minimizes P fixation. However, in the 1986 rainy season, pigeonpea responded well to P application both in Alfisols and Vertisols when the fertilizer was mixed in the top 15 cm of the soil. We therefore considered it necessary to carefully evaluate methods of applying fertilizer-P to chickpea.

An experiment was conducted in the 1986/87 postrainy season in 7 m^2 plots on Alfisol and Vertisol fields of low available P status. Three fertilizer treatments were applied as single superphosphate at 5.2 g P m^{-2}: by banding at 15-cm depth; by mixing in the top 15 cm of soil; and no P addition. The treatments were compared with and without irrigation.

Grain yield of chickpea was significantly better when fertilizer-P was mixed in soil (306 g m^{-1}) than with the other two treatments (227 g with no P and 239 g m^{-2} with band application of P) on the irrigated Vertisol. There were no significant treatment differences on the nonirrigated Vertisol or in the Alfisol. Growth and yields were generally poor on Alfisol ($<$100 g m^{-2} grain yield with irrigation). These results suggest that P fixation was not a problem in this Vertisol. They also demonstrate the interaction between P response and soil-moisture availability, with P responses only likely under well-watered conditions. These interactions are being further investigated.

Natural Occurrence of Nonnodulating Genotypes in Chickpea

Last year we reported the identification of a nonnodulating genotype from germplasm line ICC 435 (ICRISAT Annual Report 1986, p. 144). In the 1986/87 postrainy season, we examined the frequency of natural occurrence of nonnodulating plants in ICC 435 and three other varieties, Annigeri, G 130, and K 850, that have long been used in the main chickpea-growing regions of India. Nonnodulating plants of all four genotypes were found when plants were uprooted 22 DAS from Vertisol well-endowed with chickpea rhizobia. The frequency of such plants in K 850 was 120 per million, in Annigeri 150 per million, in G 130, 220 per million, and in ICC 435, 470 per million. The nonnodulating characteristic was confirmed by repotting uprooted plants without nodules, collecting seed, and growing the progeny in pots containing soil heavily inoculated with chickpea rhizobia. This finding suggests the possibility of developing nonnodulating reference plants for each chickpea genotype, for use in quantifying nitrogen fixation by that genotype.

Interaction between Soil Solarization and *Rhizobium* Inoculation

Soil solarization, by covering the soil with transparent polythene sheets during hot weather to increase soil temperature, effectively controls fusarium wilt disease in chickpea, but it also reduces populations of useful microorganisms such as rhizobia, and hence nodulation (ICRISAT Annual Report 1985, pp. 145-147; 1986, pp. 137-138). We examined whether rhizobial inoculation could adequately compensate the adverse effects of solarization. After solarization in summer 1986, we grew a cover crop of sorghum (CSH 6) to decrease the soil nitrate level in solarized and nonsolarized plots, so that we could make a better assessment of symbiotic performance. In the 1986/87 postrainy season, we sowed chickpea cultivar Annigeri in the same plots. *Rhizobium*-inoculation treatments, applied as a liquid slurry of peat-based *Rhizobium* strain IC 59, comprised application at sowing to both sorghum and chickpea, application to chickpea alone, and no inoculation.

Solarization reduced numbers of chickpea rhizobia in the top 15 cm of soil, estimated on the day after solarization treatments stopped by a most-probable number technique, to 4.19 rhizobia g^{-1} dry soil, compared with 4.52×10^3 rhizobia g^{-1} dry soil in nonsolarized plots. Solarization significantly reduced nodule number $plant^{-1}$ at 20 DAS and the dual inoculation with rhizobia significantly enhanced it in solarized plots (Table 10). A similar trend was observed for nodule number at 51 DAS, for nodule mass at both samplings, and in final shoot dry matter and grain yield (Table 10).

Thus, rhizobial inoculation can adequately compensate the adverse effects of solarization on soil rhizobial populations. We are now testing the effectiveness of solarization in reducing native rhizobial populations to an extent where inoculated strains can establish, compete, and survive. The proportions of nodules formed by the inoculant strain on the plots that were solarized in the preceding summer season will be measured in following seasons.

Table 10. Effect of soil solarization and *Rhizobium* inoculation on nodule number at 20 DAS, shoot dry matter, and grain yield of chickpea Annigeri, Vertisol, ICRISAT Center, postrainy season 1986/87.

	Nodule number $plant^{-1}$			Shoot dry matter (t ha^{-1})			Grain yield (t ha^{-1})		
Inoculation treatment	+Sol[1]	-Sol	Mean	+Sol	-Sol	Mean	+Sol	-Sol	Mean
Dual inoculation (sorghum and chickpea)	27	32	30	1.83	2.04	1.93	1.19	1.34	1.27
Single inoculation (chickpea only)	15	31	23	1.78	2.05	1.92	1.16	1.36	1.26
Noninoculated control	14	28	21	1.55	1.80	1.68	1.00	1.19	1.10
SE	±1.6		±1.1	±0.071		±0.050	±0.049		±0.035
Mean	19	30		1.72	1.97		1.12	1.30	
SE	±0.9			±0.041			±0.028		
CV (%)	16			9			10		

1. Sol = Solarization.

Grain and Food Quality

Cooking Quality and Consumer Acceptance

To identify the major food preparations of chickpea, a questionnaire on its utilization was sent to 386 scientists in 47 countries in 1986. During this year, we compiled the results of responses that we received from 138 scientists, representing 30 countries. Dhal and food items prepared from *besan*, (dhal flour) are the major forms of chickpea consumption in India, Pakistan, and Bangladesh. In some other Asian countries, Afghanistan, and Nepal, *besan* preparations are not common. It appears that a considerable proportion of chickpea is consumed in the form of whole seed in Australia, Ethiopia, Mexico, Sudan, Tanzania, Turkey, UK, and USA. In India, *phutana* (roasted grains), *pakora* (oil fried), *kadi* (boiled in buttermilk), *roti* (chickpea flour in combination with wheat flour), and *dhokla* (fermented product) are important *besan* preparations. It is also used to make some sweets. Germinated whole seeds are also consumed to a considerable extent in India, while chickpea soup and salad are common in Greece, Israel, Spain, Tunisia, and Turkey.

The roasting quality of chickpea is important to consumers. We examined the roasting quality of desi G 130 and kabuli ICCV 6 (ICCC 32) chickpea cultivars grown at Hisar with the help of local traders in Hyderabad. Whole seeds of these genotypes were roasted at about 250° C for 2 min. The roasting quality of G 130 was better than that of ICCV 6 (ICCC 32) as shown in Table 11. We noticed that the original light yellow cotyledon color of ICCV 6 (ICCC 32) changed to light brown when roasted; this resulted in lower consumer acceptability of the roasted grains. The deep-fried product (*pakora*) of chickpea *besan* is a common household preparation. Considering the increasing cost of edible oil, a reduced consumption of oil for such preparations would be welcome. To determine the relative consumption of oil in *pakora* preparation, we studied the oil retention by *pakora* made of desi and kabuli cultivars. Oil retention increased up to 3 min of frying and then showed a declining trend. About 30% of the total mass of *pakora* was the result of oil retention during frying. We also noticed that oil retention was slightly higher in ICCV 6 (ICCC 32) than in K 850. We plan to do more work on the roasting quality and the quality of *pakoras* of desi and kabuli cultivars.

To confirm our earlier results on the relationship between seed size and cooking time, we determined the cooking quality of whole seed and dhal samples of 125 genotypes with large variations in 100-seed mass [range 10.4–36.7 g(100 seeds)$^{-1}$]. The cooking time of whole seed among these genotypes varied between 52 and 98 min, again showing a large variation. Cooking time of dhal varied from 26 to 46 min, with a mean of 32 min. We noticed a positive and signif-

Table 11. Roasting quality of chickpea desi and kabuli genotypes, Hisar 1985/86.

	Sensory evaluation[1]				
Genotype	Color	Texture	Flavor	Taste	General acceptability
G 130	3.8	3.3	3.3	3.2	3.5
ICCV 6 (ICCC 32)	1.7	2.8	2.8	2.5	2.3
SE	±0.18	±0.12	±0.09	±0.13	±0.11

1. Average of eight panel members.
Rating score : 1 = poor, 2 = fair, 3 = good, and 4 = excellent.

Table 12. Correlation matrix on 100-seed mass, protein content, and cooking quality of 125 chickpea genotypes, ICRISAT Center, 1986/87[1].

	Whole seed					Dhal	
	100-seed mass (g)	Seed coat (%)	Protein (%)	Cooking time (min)	Water absorption (g g^{-1})	Protein (%)	Cooking time (min)
Whole seed							
Seed coat (%)	-0.64						
Protein (%)	0.26	-0.28					
Cooking time (min)	0.71	0.54	0.36				
Water absorption (g g^{-1})	-0.68	-0.51	-0.37	-0.93			
Dhal							
Protein (%)	0.01	-0.03	0.83	0.19	-0.20		
Cooking time (min)	0.59	-0.26	0.33	0.53	-0.52	0.53	
Water absorption (g g^{-1})	-0.57	0.25	-0.30	-0.52	0.55	-0.05	-0.98

1. For 123 degrees of freedom, the correlation values at 5% level of significance are ± 0.17 and those at 1% level of significance are ± 0.23.

icant correlation ($P < 0.01$) between cooking time of whole seed and 100-seed mass, suggesting that larger seeds require longer cooking time. Protein content was positively and significantly correlated with the cooking time of whole seed and dhal (Table 12). Interestingly, there was a positive and significant ($P < 0.01$) correlation between the cooking times of dhal and whole seed.

Effect of Dry and Wet Heat Treatments on the Physicochemical Properties of Starches

Efforts were made to isolate starches from desi (Annigeri) and kabuli (L 550) genotypes using raw, boiled (98°C for 40 min), and roasted (250°C for 2 min) samples. We observed that roasting (dry heat treatment) had no noticeable effect on the isolation of starches, whereas boiling (wet heat treatment) considerably reduced the extraction of starches from both desi and kabuli types.

Microscopic examination of the size and shape of the granules of isolated starches of desi and kabuli genotypes showed no clear-cut difference between these two groups. As mentioned earlier, a browning effect as a result of dry heat treatment was noticed only on the cotyledons of the kabuli genotype. We also noticed that the swelling capacity and solubility index of the isolated starches of the roasted grains were lower in L 550 than in Annigeri.

Protein and Amino Acids

We analyzed whole seed samples of 1106 germplasm accessions for their protein content, which ranged from 15.0 to 28.8% and determined the protein content in 442 seed samples from the breeding program. The protein content of these samples varied between 14.4 and 28.1%. We examined the effect of the application of nitrogen fertilizer on nonprotein nitrogen (NPN) and total nitrogen (TN) of the seed. Annigeri and K 850, grown in four replications, each receiving 100 and 400 kg N ha^{-1} were analyzed for TN and NPN. NPN was determined in the supernatant of 10% trichloroacetic acid (TCA) that precipitated proteins in the extract. It was observed that nitrogen application significantly ($P < 0.01$) increased both NPN and TN, and that there was no interaction between the genotypes and N application in this respect.

We have continued our efforts to analyze germplasm accessions and new collections, for their amino-acid contents, to find out if any high sulphur amino-acid sources exist. During this period, we were able to analyze several wild species accessions for their amino-acid composition as follows : 5 *Cicer bijugum*, 1 *C. cuneatum*, 1 *C. echinospernum*, 4 *C. judaicum*, 3 *C. pinnatifidum*, 6 *C. reticulatum*, and 2 *C. yamashitae*. We analyzed defatted dhal samples of these accessions and found that their protein content ranged from 26.4% in *C. yamashitae* to 33.7% in *C. bijugum*. In general, the amino-acid composition of the wild species was comparable with that of the cultivated species. No large variability was observed in the levels of important essential amino acids, lysine, methionine, and cystine.

Effect of Cooking on Amino-acid Composition

Although heat treatment improves palatability and digestibility of legumes, it changes the concentration of some other important nutrients. We studied the amino-acid composition of roasted and boiled dhal of Annigeri and L 550, and compared the results with those of the raw samples. We roasted whole seeds by heating them at 250° C for about 2 min in a sand bath, and boiled samples in water at 98° C for 40 min. After boiling, the whole content (including broth) was dried in the oven at 50° C. As shown in Table 13, the concentrations of methionine and cystine did not change as a result of the different heat treatments, while lysine and histidine levels were slightly reduced. There was a slight change in the protein content of Annigeri, but the protein content of L 550 increased considerably after roasting, and this may have been due to the reduction in 100-seed mass after roasting.

Dehulling Quality

We examined the effect of dehulling on nutrient losses. Samples of Annigeri were dehulled for 0, 2, 4, 8, and 12 min in a Tangential Abrasive Dehulling Device (TADD). Dhal and powder fractions were collected and analyzed. As a control, the seed coat was manually removed. As expected the grain mass of dhal decreased substantially with increase in dehulling time, indicating that the outer layers of the cotyledons are lost progressively in the form of a powder fraction that subsequently increased.

The levels of protein, sugar, and fiber, of dhal declined as dehulling time increased (Table 14).

Table 13. Effect of cooking on important amino acids [g $(100\ g)^{-1}$ protein] of dhal of chickpeas Annigeri and L 550, ICRISAT Center 1986/87.

	Annigeri			L 550		
Amino acid	Raw	Roasted	Boiled[1]	Raw	Roasted	Boiled[1]
Lysine	7.2	6.7	7.0	7.7	6.6	7.2
Histidine	3.2	2.7	2.5	3.2	2.8	2.7
Threonine	4.2	3.8	3.7	3.7	3.8	3.9
Cystine	1.4	1.4	1.4	1.5	1.4	1.5
Methionine	1.5	1.5	1.5	1.6	1.6	1.5
Protein (%)	23.4	23.2	23.7	19.3	22.8	19.9

1. After boiling, oven-dried at 50°C.

Table 14. Composition [g (100 g)$^{-1}$ sample] of chickpea dhal and powder fraction[1], ICRISAT Center, 1986/87.

Dehulling time (min)	Dhal					Powder				
	Protein	Sugar	Starch	Fiber	Ash	Protein	Sugar	Starch	Fiber	Ash
0	18.6	6.8	56.2	1.2	1.2	-	-	-	-	-
2	18.0	6.5	57.8	1.1	2.6	23.6	12.1	48.0	1.7	4.1
4	17.5	6.3	57.8	1.0	2.7	21.8	10.5	50.3	1.4	3.6
8	17.5	6.0	58.0	0.9	2.5	19.8	9.5	52.0	1.2	3.4
12	16.4	6.1	60.8	1.0	2.6	18.9	8.6	55.4	1.0	3.3
SE	±0.18	±0.21	±0.31	±0.08	±0.14	±0.21	±0.13	±0.51	±0.09	±0.12

1. Fractions obtained by using the Tangential Abrasive Dehulling Device (TADD).

On the other hand, starch content appeared to be concentrated in the inner parts of the cotyledon, as its concentration increased with increasing dehulling time. We observed that the powder fraction is a richer source of protein and ash (mineral contents), suggesting that these constituents are lost during dehulling.

Polyphenolic Compounds in *Heliothis*-Resistant and-Susceptible Genotypes

Pod damage and foliage removal have been observed to influence *Heliothis* attack in chickpea. We extended collaborative work to pulse entomology, and estimated polyphenolic compounds in the foliage, pod wall, and seed samples of *Heliothis*-resistant (ICC 506) and-susceptible (ICC X730266-3-4-1) varieties after removing 50% of their foliage at the vegetative stage and mechanically damaging 50% of their pods. This study did not reveal any large difference between treatments and genotypes (Table 15). Earlier, we also observed that the phenolic compounds of *Heliothis*-resistant and-susceptible lines did not show a large variation [Grain Quality and Biochemistry Progress Report no. 3/86. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)]

Table 15. Total polyphenolic compounds of foliage, pod wall, and seed of *Heliothis*-resistant and-susceptible chickpea genotypes, ICRISAT Center, 1986/87.

Genotype	Treatment[1]	Foliage	Pod wall	Seed
		mg (100 g)$^{-1}$		
ICC 506	T_1	14.04	12.04	5.88
	T_2	14.10	12.68	6.28
ICC×730266-3-4-1	T_1	14.68	11.92	6.84
	T_2	15.07	12.70	5.74
SE		±0.35	±0.20	±0.51

1. T_1 = 50% pod damaged and 50% foliage removed manually at vegetative stage, T_2 = control.

Plant Improvement

Breeding Short- and Medium-duration Desi Types

Biotic stresses that affect crops grown in short- and medium-duration chickpea environments are caused by fusarium wilt, root rots, and *Heli-*

Table 16. Numbers of chickpea populations and progenies evaluated at ICRISAT Center and Hisar, 1986/87.

Generation	Materials grown in				Materials selected	
	Normal field	Wilt-sick field	Nonsprayed field	Ascochyta blight nursery	Bulks	Single plants
ICRISAT Center						
Desi short- and medium-duration						
F_1 crosses	167	0	0	0	167	0
F_2 populations	0	180	0	0	136	0
F_3 populations/progenies	0	266	423	0	248	188
F_4 populations/progenies	380	0	194	0	9	2149
F_5 progenies	2783	2699	2786	0	330	0
F_6 progenies	466	64	473	0	142	0
F_7 progenies	341	66	401	0	109	0
F_8 progenies	122	0	156	0	38	0
Total	4259	3275	4433	0	1179	2337
Hisar						
Desi long-duration						
R_1 crosses	266	0	0	0	266	0
F_2 populations	82	436	0	0	379	281
F_3 populations/progenies	161	3006	0	0	2466	2
F_4 progenies	631	1022	244	0	1024	401
F_5 populations/progenies	4060	4197	232	0	291	297
F_6 progenies	734	986	952	503	354	303
F_7 progenies	489	555	562	483	116	218
Total	6423	10202	1990	986	4896	1502
ICRISAT Center and Hisar						
Kabuli						
F_1 crosses	117	0	0	0	117	0
F_2 populations	144	0	0	0	66	0
F_3 populations/progenies	437	482	0	29	277	4
F_4 progenies	9	9	0	0	0	2
F_5 progenies	34	103	32	32	8	460
F_5/F_6 progenies	13	13	6	6	2	8
F_6 progenies	9	9	9	9	2	1
F_7+ progenies	63	63	54	54	20	9
Total	826	679	101	130	492	484

othis. Abiotic stress factors are drought and salinity. Most of our efforts are directed to incorporating resistances to these factors in high-yielding backgrounds. We made 215 crosses with the above mentioned objectives in mind. A total of 446 populations and 2 829 advanced progenies were screened in wilt-sick plots and 4 433 progenies in nonsprayed fields (Table 16). We selected 2 337 single plants and 1 179 bulks in various generations. In preliminary and advanced yield trials, 850 lines were tested for yield and other agronomic attributes. Medium-duration materials were also tested at Gwalior. Backcrosses were made to incorporate large seed size, double pods, and *Heliothis* resistance. We have initiated a joint multilocational breeding project with some centers of the Indian National Program aimed at developing resistance to wilt, root rots, and *Heliothis* and wide adaptation to southern Indian environments. Thirty-five strains were contributed to the International Chickpea Screening Nursery Desi Short Duration (ICSN-DS), and 20 to the International Chickpea Screening Nursery-Desi Medium Duration (ICSN-DM).

Performance of *Heliothis*-Resistant Strains in Nonsprayed Fields

Annigeri is a generally high-yielding cultivar under sprayed conditions. However, it is susceptible to *Heliothis* and its yields can be low in *Heliothis*-infested fields. *Heliothis*-resistant lines developed at ICRISAT yielded almost twice as much as Annigeri in nonsprayed areas at ICRISAT Center (Table 17).

We compared the proportion of pods damaged by *Heliothis* in Annigeri and a resistant strain ICCL 86111, grown under a net in shelters. ICCL 86111 had 5.9% damaged pods compared to 14% damaged in Annigeri.

Table 17. Performance of *Heliothis*-resistant chickpea trial entries in nonsprayed fields, ICRISAT Center, 1986/87.

Line/entry	Time to 50% flowering (d)	100-seed mass (g)	*Heliothis* damage (%)	Seed yield (t ha^{-1})
***Heliothis* Resistance and Wilt Resistance Trial**				
ICCX 800584-32P-1P-3PLB-3PUY-BP	50	20.1	43.3	1.9
ICCX 800584-32P-1P-4PLB-1PLB-BP	49	20.6	43.0	2.0
ICCX 800584-32P-1P-3PLB-5PLB-BP	50	20.9	28.0	1.9
ICCX 800584-32P-1P-5PLB-1PLB-BP	49	21.3	34.6	2.0
Controls				
ICC 506 EB	45	18.1	36.8	1.9
Annigeri	46	19.5	66.8	1.1
SE	±0.6	±0.56	±3.99	±0.13
Trial mean (25 entries)	47.9	20.73	43.12	1.6
CV (%)	2.0	4.7	16	14
***Heliothis* Resistance/High Yield Trial**				
ICCX 790197-23PLB-11PLB-12PUY-5PLB-2PLB-BPLB	45	19.0	37.7	1.9
ICCX 780288-4PLB-5PLB-5PUY-2PLB-1PUY-BPLB	44	16.1	30.1	2.0
ICCX 780288-8PLB-5PLB-12PLB-2PLB-2PLB-BPLB	48	14.9	32.6	2.0
Controls				
ICC 506 EB	44	18.5	32.7	1.9
Annigeri	45	22.8	64.8	1.0
SE	±0.6	±0.28	±3.77	±0.06
Trial mean (25 entries)	45.1	18.36	38.34	1.7
CV (%)	2.3	2.6	17	6.5

Breeding Long-duration Desi Types

As reported earlier (ICRISAT Annual Report 1986, p. 149), our aim is to incorporate resistance to major diseases prevalent in long-duration environments and to *Heliothis* into good agronomic backgrounds. Important diseases in such environments are fusarium wilt, root rots, stunt, ascochyta blight, and botrytis gray mold while soil salinity and low temperatures form the major abiotic constraints.

We made 266 crosses during this year. Of these, 117 were single, 98 three-way, and 51 double crosses. We tried to combine high yield potential with resistance to more than one factor in the single crosses. The three-way and double crosses were intended to add more resistances that were missing in single-cross combinations. Forty single crosses were made to study the inheritance of ascochyta blight and botrytis gray mold resistance.

We screened F_2 and F_3 populations in the wilt-sick plots at ICRISAT Center and Hisar to select plants with resistance to fusarium wilt (Table 16). We evaluated 10 200 progenies and progeny bulks in wilt-sick plots. All progenies in F_5, F_6, and F_7 generations were evaluated in both normal and wilt-sick fields, and where seed was available, also in nonsprayed fields, for *Heliothis* screening, and in the ascochyta blight nursery. Details of progenies grown and single plants and progeny bulks selected are given in Table 16.

We conducted replicated yield trials of promising bulked lines in the F_6 to F_8 generations. During this year, we tested 414 lines in 18 preliminary yield trials (PYT), and 158 lines in 7 advanced yield trials (AYT). Many test entries have given significantly higher yields than the controls H 208 or Pant G 114 (Table 18). Two entries in AYT (ICCX 770382-BP-1H-1H-1H-2H-BH and ICCX 770913-BH-6H-BH), were top yielders in last year's PYT (ICRISAT Annual Report 1986, p. 151). During these years, the entry ICCX 770382-BP-1H-1H-1H-1H-2H-BH gave a yield 51% higher than the control H 208, and the entry ICCX 77013-BH-6H-BH gave a yield 43% higher than the control H 208.

From the PYT and AYT's we contributed 39 lines to the International Chickpea Screening Nursery Desi Long Duration (ICSN-DL), and 18 lines to the ICSN-DM.

Breeding Kabuli Chickpea

In addition to wilt resistance, ascochyta blight resistance is important in kabuli-growing areas. We made 117 crosses to combine resistance to these two diseases with large seed size. Details of populations and breeding lines grown and bulks and single plants selected are given in Table 16.

Five PYTs and two AYTs were conducted at Hisar. One of the AYT's was also sown at Gwalior. High yields were obtained at Hisar (Table 19). However, several of the trial entries showed rather high mortality in the wilt-sick plot.

Kabulis are not traditionally grown in southern Indian environments. We have developed several wilt-resistant and short-duration kabuli varieties, of which ICCV 2 (ICCL 82001) and 5 (ICCL 83009) are in great demand. These have produced yields in excess of 2 t ha^{-1} in maximization trials at ICRISAT and also at other southern Indian locations. Large-scale multiplication and farmers' field tests of these cultivars have been undertaken in four states in southern India.

Extending Chickpea Adaptation

Because of changing cropping patterns and the introduction of input-responsive varieties of cereals, the traditional sowing time for chickpea is being changed to suit the production of other crops. There are also situations where the land is left fallow after rice, and such areas could be used for chickpeas. There is now a need to breed and select varieties suited to the changed sowing dates.

Early Sowing at Lower Latitudes

Studies conducted at ICRISAT Center over the last 7 years have shown that early sowing during mid-September results in higher yields than

Table 18. Performance of the highest-yielding entries in long-duration desi chickpea yield trials, Hisar, India, 1986/87.

Line/Entry	Time to 50% flowering (d)	100-seed mass (g)	Seed yield (t ha^{-1})
Advanced Yield Trial			
ICCX 770382-BP-1H-1H-1H-2H-BH	80	20.0	3.5
ICCX 790414-BH-BH-21H-2H-BH	81	12.6	3.3
ICCX 770913-BH-6H-BH	71	14.4	3.1
Controls			
Pant G 114	89	13.2	2.6
H 208	81	12.6	1.8
SE	±1.7	±0.55	±0.18
Trial mean (25 entries)	87	14.7	2.5
CV (%)	4	7	14
Preliminary Yield Trial			
ICCX 810274-BH-BH-40H-BH	82	14.5	4.7
ICCX 810274-BH-BH-10H-BH	76	14.1	4.4
ICCX 810321-BH-BH-19H-BH	84	15.1	4.2
Controls			
Pant G 114	81	13.1	3.5
H 208	80	11.5	3.3
SE	±1.6	±0.46	±0.32
Trial mean (25 entries)	83.6	12.72	3.7
CV (%)	4	7	18

Table 19. Performance of the highest-yielding kabuli chickpea entries in a Preliminary Yield Trial, Hisar, India, 1986/87.

Line/Entry	100-seed mass (g)	Seed yield (t ha^{-1})
ICCX 790506-BH-BH-18H-1H-1H-BH	31.7	4.1
ICCX 770173-BH-BH-6H-1H-1H-1H-BH	30.1	3.7
Control		
L 550	25.3	2.7
SE	±0.68	±0.23
Trial mean (25 entries)	31.1	3.4
CV (%)	4.4	14

normal sowing during mid-October (ICRISAT Annual Report 1983, p. 136; 1985, p. 161; 1986, p. 155). The yield advantage of early over late sowing under rainfed conditions ranged from 35% to 120%. The early versus normal yield trial of the 1987 season was affected by seedling mortality and wilt, and hence no useful data were obtained. Promising lines need to be re-tested next year. During the year, we made 12 single and 13 three-way crosses to incorporate disease and *Heliothis* resistance into high-yielding varieties. We screened 28 F_2 populations in the wilt-sick plot and selected resistant plants for advancing to F_3. From 580 F_5/F_6 progenies, we selected 69 promising progeny bulks for replicated tests, and 210 single plants for progeny testing next year.

We conducted three early-sown PYTs containing F_6/F_7 bulked lines, and one trial with selected germplasm lines. Some F_6/F_7 bulked lines outyielded the control Annigeri. We will include these in AYTs next year.

Late Sowing at Higher Latitudes

In many parts of south and southeast Asia, there is an increasing trend to grow chickpeas after the harvest of such rainy-season crops as rice, maize, or cotton. These crops are often harvested late and the sowing of the succeeding chickpea crop is thus delayed. We are therefore trying to identify cultivars that are suitable for late sowing. We made 14 three-way and 7 single crosses to combine high yield potential with resistance to wilt, ascochyta blight, botrytis grey mold, chickpea stunt, and *Heliothis*. We screened 50 F_2 populations in wilt-sick fields. The F_4, F_7, and F_8 progenies were evaluated for yield, and also tested for resistance to wilt, stunt, ascochyta blight, and *Heliothis*. We selected 35 progenies for replicated testing, and conducted two PYTs and two AYTs at Hisar. Data for the highest-yielding entries from one of the AYTs is presented in Table 20. In addition to high yields, these lines also have large seeds.

Genotype × Environment Interaction

Large yield differences in chickpea have been reported over years and across locations, but detailed systematic research in this field is scarce. We conducted a multilocational, International Chickpea Adaptation Trial (ICAT), that included one kabuli and 7 desi cultivars from different parts of India, and 8 kabuli cultivars from west Asian countries at 17 locations in 1981/82, 31 locations in 1982/83, and 22 locations in 1983/84. The cultivars differed in their growing duration, seed size, and yield potential. Four locations were common over the 3 years, 8 locations were

Table 20. Performance of the highest-yielding desi chickpea entries in a late-sown Advanced Yield Trial, Hisar, India, 1986/87.

Line/Entry	100-seed mass (g)	Seed yield (t ha^{-1})
ICCX 790514-17H-BH-1H-1H-BH	14.7	2.8
ICCX 790529-24H-BH-1H-1H-BH	25.1	2.7
Control		
H 208	13.3	1.8
SE	±0.88	±0.28
Trial mean (25 entries)	18.2	2.1
CV (%)	10	27

common for the first 2 years and 13 for the last 2 years. Combined analyses of variance in different combinations showed that locations accounted for 50–60% of the total variation, genotypes × years interaction for 7.5–23%, and genotypes for 2.5–8%. The contributions due to years and their interactions were relatively small. In general, the desi types yielded more than the kabuli types but L 550, a kabuli cultivar from India, yielded almost as well as the large-seeded desi cultivar K 850, which was the highest yielder across years and locations. This study therefore does not support the general belief that kabuli and large-seeded cultivars are low yielders, and shows that increases in seed size may even result in higher yields. The study emphasizes the need for multi-locational testing to identify stable genotypes. The mean performance of entries, if recorded over a number of locations, may be sufficient indication of their behavior over years.

Breeding and Genetic Studies

Mutation Breeding

Seed batches of two kabulis, ICCV 6 (ICCC 32) and ICCV 2 (ICCL 82001), were subjected to gamma radiation in October 1986. Table 21

Table 21. Radiation doses, seed quantities, 100-seed masses, and moisture contents of chickpea varieties ICCV 6 (ICCC 32) and ICCV 2 (ICCL 82001) used for gamma ray treatment, ICRISAT Center, 1986/87.

	Seed quantity (kg)					
	Gamma radiation (K Rad)					
Variety[1]	15	30	45	0 (Control)	100-seed mass (g)	Moisture content (%)
ICCV 6 (ICCC 32) Sp	1.5	1.5	1.5	1.5	20.7	9.4
ICCV 6 (ICCC 32) B	-	1.5	-	1.5	19.6	8.8
ICCV 2 (ICCL 82001) Sp	0.5	0.5	0.5	0.5	22.5	8.9
ICCV 2 (ICCL 82001) B	1.0	1.0	1.0	1.0	24.7	8.5

1. Sp = Single plant offspring; B = Bulk sample.

Table 22. Effect of radiation on emergence, plant stand at harvest, 100-seed mass, and seed yield for chickpea varieties ICCV 2 (ICCL 82001) and ICCV 6 (ICCC 32) single-plant offsprings, ICRISAT Center, 1986/87.

	Emergence (%)		Plant stand at harvest (%)		100-seed mass (g)		Seed yield (t ha^{-1})	
Radiation doses (KR)	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)	ICCV 2 (ICCL 82001)	ICCV 6 (ICCC 32)
15	46	54	43	54	25	18	1.1	1.6
30	26	26	23	25	23	19	0.8	0.7
45	48	49	43	51	23	18	1.6	1.6
0	36	51	33	48	23	19	1.0	1.5
SE	±6.1		±5.8		±0.5		±0.17	
Mean	39	45	36	45	24	19	1.1	1.4
CV (%)	33		33		5.0		28	

shows radiation doses, seed quantities, and some seed characteristics of the two varieties.

The main objectives of the treatment were to increase seed size, induce resistance to foliar diseases and salinity, and generate the character for determinate growth.

The radiated seeds were sown on 31 October 1986 in a randomized block designed trial with four replications, in 4-row plots each 4-m long. Summarized results are shown in Table 22.

Apart from the deviating stand counts and yields for the 30 kR doses, and for the yield of ICCV 2 (ICCL 82001) treated with 45 kR, differences between treatments were insignificant.

Cooperative Activities

Asian Grain Legumes Network (AGLN)

The AGLN was established in 1986 as a result of the recommendation made by the Consultative Group Meeting for Asian Regional Research on Grain Legumes in 1983 (ICRISAT Annual Report 1983, p.148), and subsequently ratified by the Review and Planning Meeting on Grain Legumes in 1985 (ICRISAT Annual Report 1985, p.173). Its broad objective is to facilitate testing and dissemination of appropriate varieties and technologies to increase production of groundnut, chickpea, and pigeonpea in the Asian region, including the host country, India with which ICRISAT has a special relationship involving many collaborative studies with ICAR scientists.

The AGLN coordinator had discussions with donor agencies and Institutions in the region, notably the ACIAR, Economic and Social Commission for Asia and the Pacific (ESCAP) Regional Coordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber Crops in the Humid Tropics of Asia and the Pacific (CGPRT Centre), the Canadian International Development Agency (CIDA), the European Economic Community (EEC), FAO, the International Development Research Centre (IDRC), the United States Agency for International Development (USAID), and Winrock International. The discussions centered around coordinating and strengthening relationships between donor agencies and ICRISAT to avoid duplication of efforts.

Memoranda of Understanding

Although ICRISAT has been collaborating with many Asian countries in the past, Memoranda of Understanding (MOUs) were signed to facilitate the movement of material and scientists for collaborative research activities. During April, the Director General signed an MOU with the Minister for Agricultural Development and Research, Sri Lanka; and in December, another with the Secretary of Agriculture, His Majesty's Government of Nepal. The MOU's with Indonesia and the People's Republic of China were revised, and are expected to be signed early in 1988. There are already MOU's with Bangladesh, Burma, Pakistan, the Philippines, and Thailand. During the year initial contacts were established with Afghanistan, the Democratic People's Republic of Korea, and Vietnam.

Work Plans

Meetings were held in Bangladesh, Burma, Nepal, and Sri Lanka to develop detailed yearly Work Plans bearing in mind constraints to yield, and research needs in each country, and their capabilities. Requirements for training and special research projects have also been identified. The Asian Development Bank (ADB) has agreed to provide financial support to these four south Asian countries to enable the implementation of their Work Plans and each country has identified coordinator(s) who will liaise with AGLN. A special Work Plan for Pakistan with emphasis on pigeonpea, and tentative work plans for Indonesia, People's Republic of China, the Philippines, and Thailand have been developed.

Other Activities

ICRISAT scientists undertook crop surveys, monitored international and national trials, and participated in germplasm collection as part of agreed Work Plans.

The first issue of an AGLN Cooperators Report was distributed, it covers the activities of the AGLN since its inception and summarizes the Work Plans developed for each country. The report also gives details of trials available from ICRISAT; and a list of future workshops and meetings to be organized by ICRISAT.

AGLN is supporting the posting of a chickpea breeder in Nepal for one year to help the Grain Legume Improvement Program (GLIP). He will assist GLIP in research on chickpea and pigeonpea improvement.

As a part of an exchange of visits, two scientists each from Sri Lanka and Nepal and one from Bangladesh visited ICRISAT to become acquainted with ongoing research and to discuss collaborative research with the concerned ICRISAT scientists.

AGLN was also involved in various workshops and meetings. These are dealt with under 'Workshops, Conferences, and Seminars' below.

International Trials and Nurseries

During 1986/87, we sent 11 different types of international trials and nurseries to collaborators. Table 23 lists these and shows how many of each type were sent, and Table 24 details names of countries and number of trial sets sent. As in 1986, (F_2 and F_3) early-generation trials were not formed and distributed; instead F_2 populations were sent against specific requests for disease resistance, maturity periods, and high yield. The trials and nurseries were sent to 21 different countries and more trials were required in Nepal than in previous seasons. Along with the trials and nurseries, 228 F_2 populations were distributed.

As in previous seasons, location and variety interactions were very evident in all trials. The highest-yielding entries are presented in Table 25, with their average increase in yield over the controls.

Under the multilocational testing program, the International Chickpea *Heliothis* Resistance Nursery (ICHRN) seed for 34 trials, of short-, medium-, and long-duration groups, were supplied to 18 cooperators in India and seeds for 9 trials were supplied to Brazil, Pakistan, and

Table 23. International chickpea trials and nurseries sent to collaborators in 1986/87.

Trial/Nursery	Number of sets dispatched
Breeding	
International Chickpea Screening Nursery Desi Short Duration (ICSN-DS)	11
International Chickpea Screening Nursery Desi Medium Duration (ICSN-DM)	11
International Chickpea Screening Nursery Desi Long Duration (ICSN-DL)	9
International Chickpea Cooperative Trial Desi Short Duration (ICCT-DS)	16
International Chickpea Cooperative Trial Desi Medium Duration (ICCT-DM)	9
International Chickpea Cooperative Trial Desi Long Duration (ICCT-DL)	10
International Chickpea Cooperative Trial Kabuli (ICCT-K)	8
Pathology	
International Chickpea Root Rot and Wilt Nursery (ICRRWN)	27
Entomology	
International Chickpea *Heliothis*-Resistant Nursery Desi Short Duration (ICHRN-DS)	2
International Chickpea *Heliothis*-Resistant Nursery Desi Medium Duration (ICHRN-DM)	5
International Chickpea *Heliothis*-Resistant Nursery Desi Long Duration (ICHRN-DL)	5

Tunisia. At most of these locations, *Heliothis armigera* was found to be the major pest, *H. zea* and *H. virescens* were reported as pod borers affecting chickpea in Mexico. In these tests, our *Heliothis*-resistant selections showed a low level of borer damage at most locations; controls and susceptible selections showed greater susceptibility. We are now evaluating the performance of different selections at various locations to ascertain their level of *Heliothis* resistance and regional adaptability.

Table 24. Countries to which chickpea trials and nurseries were distributed from ICRISAT Center, 1986/87.

Country	Number sent
Argentina	1
Bangladesh	6
Burma	7
Chile	1
Egypt	1
Ethiopia	3
India	131
Italy	1
Kenya	1
Mexico	4
Nepal	7
Pakistan	10
Peru	1
Philippines	2
Spain	1
Sudan	1
Tanzania	3
Thailand	4
Total	185

Distribution of Breeders Material

We supplied 259 samples of breeding materials to cooperators in 19 countries against specific requests.

Cooperation with AICPIP

Our cooperation with AICPIP remained fruitful. We contributed seven new desi lines (ICCV 17, 18, 19, 23, 24, 27, and 28) to AICPIP coordinated trials for testing in the 1987/88 season. Our entries from the 1986/87 trials were promoted or retained for further testing. The most promising variety was probably ICCV 10 that was ranked first in the Central, Southeast and Southern zones. ICCC 42, with its large attractive seeds, also did well in the Southern zone.

Table 25. Average yield of best-performing ICRISAT entries in international trials, at 7–10 locations, 1986/87.

Trial	Highest-yielding entry	Yield (t ha^{-1})	Average yield as percentage of control
International Chickpea Screening Nursery			
Desi short duration	ICCL 86224	1.7	121
Desi medium duration	ICCL 86301	1.4	130
Desi long duration	ICCL 86445	3.1	128
International Chickpea Cooperative Trial			
Desi short duration	ICCL 84204	1.5	106
Desi medium duration	ICCL 85333	1.8	122
Desi long duration	ICCL 85401	2.5	102
Kabuli	ICCL 86504	2.3	100

ICCV 13, a kabuli, yielded most in the Northwest Plain zone, while ICCC 42 yielded most in the Gram Coordinated Variety Trials for late sowing in the Central zone.

We supplied 1-kg batches of seed of ICCV 6 (ICCC 32) for minikit trials in the states of Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, and Uttar Pradesh.

We supplied promising chickpea strains in large quantities to six states in India for adaptation trials to be conducted in 1987/88. In Andhra Pradesh, 35 kg seed each of ICCV 2 (ICCL 82001) and ICCV 5 (ICCL 83009), 51 kg seed of ICCC 37, and 1 kg seed of ICCV 1 (ICCC 4) were sent to four locations. In Karnataka, 6 kg seed of ICCV 2 (ICCL 82001) and 5 kg seed of ICCV 5 (ICCL 83009) were sent to two locations. In Madhya Pradesh, 5 kg seed each of ICCV 2 (ICCL 82001), ICCV 4 (ICCL 83004), and ICCV 5 (ICCL 83009), 50 kg seed of ICCV 6 (ICCC 32), and 58 kg seed of ICCC 42 were sent to two locations. The largest quantities were supplied to Maharashtra, including 37 kg seed of ICCV 2 (ICCL 82001), 87 kg seed of ICCV 5 (ICCL 83009), 130 kg seed of ICCV 6 (ICCC 32), 145 kg seed of ICCC 37, and 210 kg seed of ICCC 42 to 7 locations. To Orissa, 50 kg seed of ICCV 4 (ICCL 83004) and 55 kg seed of ICCC 37 were supplied, and to Tamil Nadu, 1 kg seed of ICCV 2 (ICCL 82001) was sent to conduct trials in collaboration with national scientists.

Cooperation with ICARDA

The objective of the ICARDA/ICRISAT Kabuli Chickpea Project is to develop stable high-yielding cultivars and genetic stocks for different agroecological conditions, mainly in West Asia and northern Africa. ICRISAT has a breeder and a pathologist stationed at ICARDA for this purpose, and support in other disciplines is provided by ICARDA.

Major goals are to increase yield by introducing winter sowing in the Mediterranean region and by developing irrigation-responsive cultivars for the Nile Valley and Central America, and to stabilize production by developing genotypes resistant to physical stresses such as cold and drought, and biotic stresses such as ascochyta blight, fusarium wilt, leaf miner and cyst nematodes. The work on fusarium wilt is conducted in collaboration with the Department de Patologia Vegetal, Cordoba, Spain and on cyst nematode with the Instituto di Nematologia Agraria, CNR, Bari, Italy.

Physical Stress

Cold tolerance. We evaluated 750 lines and rated them on a 1-9 scale, where 1 = unaffected, 5 = tolerant, and 9 = killed. No line was rated at 1 or 2, but 6 lines were rated 3 and 30 lines at 4. One hundred and twenty-eight lines were tolerant (rating 5) (Table 26). Tolerant lines included FLIP 82-85C, FLIP 82-131C, FLIP 84-112C, FLIP 85-4C, FLIP 85-49C, and FLIP 85-81C.

Response to irrigation. We grew two trials, each comprising 24 genotypes, one rainfed (Trial 1) and the other (Trial 2) with supplemental irrigation (120 mm in the season) during the 1986/87 winter, at Tel Hadya. A randomized block design with three replications was used. All 48 genotypes had been screened during 1985/86.

Seed yield following supplemental irrigation increased by 74% in Trial 1 and by 70% in Trial 2. Most genotypes produced more than 3 t ha^{-1} with irrigation and less than 2 t ha^{-1} without irrigation. ILC 237 produced the highest yield (4.5 t ha^{-1}) when irrigated, giving an increase of 91% over its yield in the nonirrigated trial.

Screening for 2 years has helped to identify irrigation-responsive lines. The performance of five such lines is shown in Table 27. Seed yield under rainfed conditions almost doubled with supplemental irrigation. Lines that responded most to irrigation were average-to-poor yielders, but some of these lines also produced high yields under rainfed conditions. Such lines could be considered drought-tolerant because Tel Hadya is a low-rainfall location and chickpea is not grown by farmers under these conditions.

Table 26. Response of chickpea FLIP lines to ascochyta blight (*Ascochyta rabiei*), leaf miner (*Liriomyza cicerina*), and cold, Tel Hadya, Syria, during 1985/86 and 1986/87.

	Ascochyta blight		Leaf miner		Cold	
Rating[1]	No. of entries	Percentage of total	No. of entries	Percentage of total	No. of entries	Percentage of total
<2	0		0		0	
3	42	6.1	0	0.0	6	0.8
4	55	8.0	0	0.0	30	4.0
5	100	14.5	2	0.3	128	17.1
6	128	18.6	58	7.9	161	21.5
7	156	22.6	652	88.4	165	22.0
8	20	2.9	25	3.4	175	23.3
9	188	27.3	0	0.0	85	11.3
Total	689	100	737	100	750	100

1. Measured on a 1–9 scale, where 1 = unaffected, 5 = tolerant, and 9 = highly susceptible.

Table 27. Mean seed yield (t ha^{-1}) of the five chickpea lines most responsive to irrigation and the five highest-yielding lines under rainfed conditions, Tel Hadya, Syria, 1985/86 and 1986/87[1].

	1985/86				1986/87				Mean			
			Increase				Increase				Increase	
Genotype	Rainfed	Irrigated	(t ha^{-1})	(%)	Rainfed	Irrigated	(t ha^{-1})	(%)	Rainfed	Irrigated	(t ha^{-1})	(%)
Irrigation-responsive lines												
ILC 202	1.05	2.15	1.10	105	1.33	2.83	1.49	112	1.19	2.49	1.30	109
FLIP 83-53C	1.41	2.79	1.37	97	1.79	3.48	1.69	94	1.60	3.13	1.53	96
FLIP 83-69C	1.25	2.45	1.20	96	1.68	3.15	1.47	87	1.47	2.80	1.33	91
FLIP 83-71C	1.31	2.56	1.25	95	1.85	3.33	1.48	80	1.58	2.94	1.36	86
ILC 142	2.11	3.69	1.58	75	1.76	3.43	1.68	95	1.93	3.56	1.63	84
Drought-tolerant lines												
ILC 1272	3.13	3.25	0.13	4	2.27	4.28	2.01	89	2.70	3.77	1.07	40
ILC 100	2.44	2.66	0.22	9	2.58	2.95	1.37	53	2.51	3.30	0.79	32
ILC 613	2.56	2.75	0.20	8	2.43	3.70	1.27	52	2.49	3.23	0.80	32
ILC 1929	2.75	3.18	0.42	15	2.09	3.40	1.30	62	2.42	3.29	0.86	36
ILC 136	2.32	3.15	0.83	36	2.53	3.76	1.23	49	2.42	3.45	1.03	79

1. The ten entries were spread in 6 trials during 1985/86 and 2 trials during 1986/87.

Biotic Stresses

Screening for Multiple Stresses

In the past two seasons, efforts were made to screen about 800 breeding lines for resistance to ascochyta blight (*Ascochyta rabiei*), leaf miner (*Lyriomyza cicerina*), cyst nematode (*Heterodera ciceri*), and fusarium wilt (*Fusarium oxysporum* f. sp. *ciceri*). The results are briefly described below.

Ascochyta blight screening. Forty-two lines were found resistant to ascochyta blight with a rating of 3 on a 1-9 scale (Table 26), when screened in the field against a mixture of races 1, 2, 3, and 4. Many other lines showed ratings of 4 (moderately resistant) and 5 (tolerant). For a commercial cultivar with field resistance, ratings of 4 and 5 are acceptable.

We screened 740 breeding lines in a plastic house against the six races of *Ascochyta rabiei* between November 1986 and April 1987, when the temperature was favorable for disease development. While no line scored 1 on a 1–9 rating scale, there were several which showed resistance to individual races, except to race 6, to which only one line showed resistance. Promising lines will be evaluated in replicated trials next season.

Using the facilities of a Conviron® environmental growth chamber, promising chickpea lines were screened against race 6 and isolate F (isolated from the disease nursery). Isolate F was more aggressive than race 6. Four lines, FLIP 85-57C, FLIP 85-84C, FLIP 85-131C, and ICC-4475,showed a tolerant reaction to races 6 and F.

Pathological variability in *Ascochyta rabiei*. During 1986/87, over 100 isolations of *A. rabiei* were made from resistant and susceptible chickpea lines growing in the disease nursery and at several other locations on the Tel Hadya farm. They were arranged into eight groups, on the basis of their morphological characters (Table 28). These groups were then studied for their reactions on 15 chickpea differentials.

The studies were carried out in a Conviron® chamber at 20°C and 12-h daylength. Seven-day old seedlings were inoculated with spore suspensions (20000 spores mL^{-1}) and 100% humidity was maintained for 5 days. Observations were recorded 10 and 15 days after inoculation, and the experiments were repeated to confirm the results.

The present isolates (A to H) could be classified into either 'mild' or 'aggressive' groups on the basis of their capacity to infect the plants. Isolates A, B, C, and G were mild in their reactions across the chickpea lines, whereas isolates D, E, F, and H were aggressive. Isolate F was more frequently isolated from Tel Hadya farm this season. The differences in disease reactions were not clear enough to classify them into races. Isolates showed variable aggressiveness rather than virulence.

Occurrence of a perfect state of *A. rabiei*. *Mycosphaerella rabiei* Kovachevski, the perfect state of *Ascochyta rabiei* (Pass.) Labrousse, was first discovered on overwintered chickpea debris

Table 28. *Ascochyta rabiei* isolates grouped on the basis of morphological characters from Tel Hadya farm, Syria, February–April 1987.

Group (source)	Colony color	Pycnidia (μ)	Pycnidiospores (μ)	No. of isolates
A. Host debris[1] (Jun 86), chickpea volunteers from Field 30 (AB Nursery 86)	Brown	154 × 178	3.8 × 9.3	10
B. AB Nursery (87)-ILC 263 and other infected lines	Dark brown	204 × 251	2.9 × 10.7	17
C. AB Nursery (87)-ILC 3279 Field 9-ILC 482	Dark brown	164 × 218	3.2 × 8.9	12
D. AB Nursery (87) from leaf spots, also from Fields 9 and 36	Dark brown	190 × 218	3.5 × 10.2	13
E. ILC 1929 from pots on the hill, host debris from AB Nursery (87)	Light brown	154 × 168	3.0 × 9.4	9
F. AB Nursery (87)-ILC 72	Dark black	266 × 315	5.2 × 10.7	32
G. From single perithecium	Black	151 × 177	3.1 × 9.1	3
H. Host debris (Jun 86)	Dark black	167 × 191	4.3 × 10.2	4

1. Isolate used in studies and stored as group representative.

in Bulgaria in 1936 and subsequently reported from USSR and Greece. Recently it has been reported from Hungary and USA.

At Tel Hadya, *M. rabiei* was discovered on overwintered chickpea debris, particularly on stem pieces in a field that was sown with chickpea in December 1985 and had produced a crop severely infected with ascochyta blight. The field was plowed in the summer of August 1986 and was sown with wheat in December. From November 1986 until February 1987, temperatures were low, ranging from -2°C to +15°C. From November 1986, chickpea debris, lying on the surface of the soil, was regularly collected and critically examined under the microscope for the presence of perithecia.

At the beginning of March 1987, perithecia were observed on overwintered chickpea debris, intermingled with empty pycnidial bodies embedded in plant tissues. They were prominent when the shredded bark was removed from the stem. Several observations confirmed that the formation of perithecia was restricted to infected plant tissue.

The perithecia were dark brown to black, globose with a perithecial beak, ostiolate, and measured 82-156 μ × 125-255 μ. The asci were cylindrical, clavate, curved, pedicellate, measuring 51-70 μ × 10-16 μ. The asci contained eight hyaline, ovoid ascospores divided into two unequal cells constricted at the septum, measuring 13-20 μ × 5.5-7.5 μ. Isolations from single perithecia yielded cultures of *A. rabiei*, which were pathogenic to chickpea.

Epidemiology of ascochyta blight. In January 1987, healthy and surface-sterilized (2.5% sodium hypochlorite, 5 min) chickpea seeds of blight-susceptible ILC 1929 were sown in 60 plastic pots containing sterilized soil in a plastic house. These pots were then distributed over 20 locations in Tel Hadya in early February. The plants were examined after every 2 days in the early hours of the morning for ascochyta blight symptoms. The weather in March 1987 was quite favorable for ascochyta blight development.

The occurrence of ascochyta blight infection on the leaflets of ILC 1929 during March strongly supported the hypothesis that the inoculum could be disseminated by wind.

Fusarium wilt. A total of 734 breeding lines was sown with two susceptible controls JG 62 and PV 60, in a wilt-sick plot during 1986/87 at Santaella, Spain. Both susceptible controls were sown after every 10 test entries. The material was evaluated by determining the percentage of dead plants after 2 months and again a month later. The duration of the crop was three and a half months. PV 60 had a mortality rate between 80 and 100% throughout the nursery, but mortality varied in JG 62. Six lines were resistant; FLIP 82-78C, 84-43C, 84-130C, 85-29C, 85-30C, and 85-37C (Table 29). These will be sown again to confirm these results.

Cyst nematode. We screened 740 breeding lines in a greenhouse using nematode-susceptible ILC 1929 as a control. Ten seeds of each line were sown in two 5-L pots filled with sterilized soil (20.1% sand, 33.2% silt, 46.0% clay, and 0.6% organic matter), artificially infested with cysts of a Syrian population of *Heterodera ciceri* to give 20 eggs and juveniles cm^{-3} soil. The greenhouse temperature ranged from 16-25°C. Fifty days after emergence, the plants were up-

Table 29. Response of chickpea FLIP lines to cyst nematode (*Heterodera ciceri*), Tel Hadya, Syria, 1986/87 and to fusarium wilt (*Fusarium oxysporum*), Santaella, Spain, 1986/87.

	Cyst nematode		Fusarium wilt	
Rating[1]	No. of entries	Percentage of total	No. of entries	Percentage of total
1	0	0.0	0	0.0
2	5	0.8	6	0.7
3	86	11.6	8	1.1
4	178	24.1	18	2.5
5	471	63.5	704	95.8
Total	740	100.0	736	100.1

1. Measured on 1-5 scale, where 1 = unaffected, 3 = tolerant, and 5 = killed.

rooted, the roots gently washed, and the number of female namatodes counted. Lines were rated by using a 1–5 rating scale, where 1 = no infestation, 2 = 1–5 females, 3 = 6–20 females, 4 = 21–50 females, and 5 > 50 females (plant root)$^{-1}$.

No line was nematode-free, but five lines were rated 2 and another 86 lines were found tolerant (Table 29). All these will be rescreened next season.

Leaf miner. On the Tel Hadya farm, both the 1985/86 and 1986/87 seasons were favorable for screening against leaf miner. A total of 737 breeding lines were evaluated on a 1-9 scale where 1 = highly resistant, 5 = tolerant, and 9 = highly susceptible. None of the lines showed a rating of 1-4 and only two lines, FLIP 82-3C and FLIP 84-92C, had a rating of 5. The remaining lines showed susceptibility (ratings of 6–9) (Table 26).

Plant Improvement

Segregating populations. We made 450 crosses in 1987 including 350 crosses for breeding in Syria, and the remaining for Italy, Spain, and graduate students from the ICARDA training program. For the first time we succeeded in making 50 crosses during the off season at Terbol. We grew 300 F_2 bulks and 15 000 F_4 to F_6 progeny rows in the ascochyta blight disease nursery. Due to the appearance of a new virulent race of *A. rabiei* the crop had to be protected with fungicides. The F_2 generation was bulk harvested and 8000 single plants selected from F_4 and F_5 generations based on maturity, height, and seed size. Four hundred and eighty uniform and promising progenies were bulked. When these bulked lines were grown for seed increase in the off season, only 300 produced seed.

Yield trials for winter and spring sowing. We evaluated approximately 300 lines for yield at Tel Hadya and Jinderiss in Syria, and Terbol in Lebanon in both winter and spring sowing in several trials. A large number of lines outyielded. the control cultivar, ILC 482, by a significant margin, unlike earlier years, when only a few lines significantly outyielded the control (Table 30), indicating a gradual improvement in yield. The coefficients of variation of the trials were low, suggesting that the trials were well-managed.

Table 30. Performance of newly developed chickpea lines during winter and spring at Tel Hadya and Jinderiss, Syria and Terbol, Lebanon, 1986/87.

Location	Number of entries tested	Number of entries exceeding controls[1]	Number of entries significantly exceeding controls (P = 0.05)	Range of CV (%)
Winter sowing				
Tel Hadya	376	69	5	9.9–27
Jinderiss	301	128	6	12 –31
Terbol	322	106	13	6.7–21
Spring sowing				
Tel Hadya	323	145	4	12 –24
Jinderiss	242	103	19	11 –31
Terbol	258	62	13	10 –33

1. The best control was ILC 482.

Yields were not so high as in the past because they were adversely affected by the unusually high temperatures during the later part of April.

Release of cultivars by national programs. One of the major aspects of the program is to strengthen the research of the national agricultural research systems. We supply diverse international nurseries. For example, during 1987 we furnished 500 sets of 11 different types of nurseries to 35 countries. A total of 16 lines have been released in seven countries, following their selection by national programs from the international nurseries (Table 31). Fourteen of these have been released for winter sowing in the Mediterranean region, where the crop is now spring sown. Two are released for spring sowing in the Mediterranean region and one for the subtropics, indicating that material generated in a Mediterranean environment at ICARDA can also be used in the subtropics.

Two lines, ILC 482 and FLIP 83-98C, are in the final stage of evaluation and prerelease multiplication in Lebanon. Jordan has included FLIP 83-46C in large-scale demonstrations. Three varieties, namely FLIP 81-293C, FLIP 82-161C, and FLIP 83-71C, have been included in the cultivar catalog in Morocco. Tunisia has selected FLIP 82-239C and FLIP 84-182C and Algeria ILC 482, ILC 3279, FLIP 84-139C, FLIP 84-60C, and FLIP 84-182C for the final stages of evaluation and prerelease multiplication. In Syria, FLIP 82-115C and FLIP 82-150C are in the final year of on-farm trials. Italy has included ILC 72 and ILC 3279 in prerelease multiplication trials and France has included FLIP 81-293C.

Cooperation with National Programs

Performance of Ghab 1 and Ghab 2 in village projects in Syria. In collaboration with the Syrian Ministry of Agriculture and Agrarian Reform (SMAAR), ICARDA conducted village projects at 11 sites in Syria. The objective of

Table 31. Kabuli chickpea lines selected from international nurseries and released as cultivars by national programs, ICARDA, 1986/87.

Country	Cultivars released[1]	Year of release	Specific features
Cyprus	Yialousa (ILC 3279)	1984	Tall
	Kyrenia (ILC 464)	1987	Large seeded
Morocco	ILC 195	1987	Tall
	ILC 842	1987	High yielding, wide adaptation
Spain	Fardan (ILC 72)	1985	Tall, high yielding
	Zegri (ILC 200)	1985	Mid-tall, high yielding
	Almena (ILC 2548)	1985	Tall, high yielding
	Alcazaba (ILC 2555)	1985	Mid-tall, high yielding
Sudan	Shendi (ILC 1335)	1987	High yielding
Syria	Ghab 1 (ILC 482)	1982–86	High yielding, wide adaptation
	Ghab 2 (ILC 3279)	1986	Tall, cold tolerant
Tunisia	Chetoui (ILC 3279)	1986	Tall
	Kassab (FLIP 83-46C)	1986	Large seeded, high yielding
	Amdoun 1 (Be-sel-81-48)	1986	Large seeded
Turkey	ILC 195	1987	Tall, medium seed, cold tolerant
	ILC 482	1987	High yielding, wide adaptation

1. All are resistant to ascochyta blight and released for winter sowing except Amdoun 1, which is resistant to fusarium wilt and released for spring sowing; ILC 482 released for spring sowing in Turkey; and Shendi, which is responsive to irrigation and adapted to a subtropical climate.

these projects was to demonstrate the performance of newly released chickpea cultivars in large plots. Ghab 1 and Ghab 2 were winter-sown on 1–10-ha plots and weeds were controlled by herbicides. All the farmers had sown chickpea during spring on plots ranging from 1–6-ha in adjacent fields and yields also were recorded from those plots. Because of the large plot size, yields were sampled from four randomly chosen 100-m^2 plots. Results are presented in Table 32. Ghab 1 yielded 1.69 t ha^{-1}, an increase of 70% over the local spring-sown control. Ghab 2 gave an increase of 53% over the local control. These results demonstrated the increased yield potential of winter-sown Ghab 1 and Ghab 2 over a spring-sown local control variety.

Economic feasibility of winter sowing. A survey was conducted by ICARDA and ICRISAT involving nine farmers in Syria, who had sown chickpea during winter and spring on plots larger than 1 ha. The study indicated that the winter-sown crops yielded twice as much as the spring-sown crops. Both Ghab 1 and Ghab 2 were equally profitable because Ghab 1 produced more yield and Ghab 2 more straw. The selling price of Ghab 1 and Ghab 2 was slightly higher than that of the local chickpeas because they are new cultivars, but after a few years the price difference may disappear. If the net return is calculated on the same selling price as the local, then winter sowing of Ghab 1 and 2 still shows a large profit.

Cooperation with Pakistan

An ICRISAT Plant Breeder is stationed at the National Agricultural Research Center (NARC), in Islamabad (34°N, 73°E), to work on 'strengthening chickpea research in Pakistan.' The major objectives of this project are to stabilize yield through development of ascochyta blight resistant lines and to further improve yield. The program has facilities for off season sowing at the Kaghan Valley.

Breeding Medium- and Long-duration Desi Types

The breeding materials of various generations grown in the Pathology block of the Pulses Program of NARC are detailed in Table 33.

We grew a number of F_1s and three PYTs. The F_1s were advanced to get sufficient F_2 populations and F_3-F_7 bulks or single-plant progenies (SPP) or progenies of single plants that were earlier selected for their resistance to blight and bulked individually as single-plant bulks (SPB). All these were grown in plots where diseased plant debris and inoculum of *Ascochyta rabiei* were applied to create a high inoculum potential for blight disease. Only those that had blight ratings of 1–5 on a 1–9 scale were selected as bulks or single plants (Table 33).

We also grew some F_4 and F_5 SPBs which earlier showed resistance to blight, for preliminary yield evaluations.

Table 32. Yield of chickpea entries (t ha^{-1}) in village projects in Zone 1 and 2, Syria, 1986/87.

Location/ Zone[1]	Efrin Maharda 1	Damkheih 1	Kattineh 1	Sheikh Ahmed 2	Ain Dara 1	Alka-mieh 1	Sheikh Yousef 1	Asha-reneh 1	Zetan A-Masna 2	Skel-beih 1	Mean	Rank
Ghab 1 (winter sown)	1.73	3.41	1.87	1.23	1.58	1.84	1.63	1.72	1.00	1.50	1.69	1
Ghab 2 (winter sown)	1.77	2.11	1.82	1.10	–[2]	–	–	1.38	–	1.70	1.52	2
Local control (spring sown)	0.94	1.20	–	0.53	0.94	1.38	0.61	1.20	1.08	1.20	0.99	3

1. Zone 1 = >350 mm annual rainfall; Zone 2 = 275–350 mm annual rainfall.
2. – = Not included.

Table 33. Chickpea populations and progenies with resistance to ascochyta blight at NARC, Islamabad, 1986/87.

		Selections made	
Material	Available number	Bulks	Single plants
F_2 Bulk	66	12	-[1]
F_3 SPP	142	-	42
F_4 Bulk	16	3	-
F_4 SPB	75	-	71
F_4 SPP	1134	-	675
F_5 SPB	5	4	-
F_5 SPP	366	-	263
F_6 SPP	86	-	14
F_7 SPP	65	-	16
Total	1955	19	1081

1. - = No selections made.

We sowed 65 lines, varieties, or cultivars, of both desi and kabuli types, either developed locally or introduced from abroad at the normal sowing time and a month later, to select parents for future crossing programs.

We conducted three PYTs, with advanced-generation materials and lines developed locally or introduced from ICRISAT and ICARDA, using CM 72 or C 44 as controls. Four F_5 SPBs developed at NARC significantly outyielded CM 72 (Table 34).

Cooperation with Provincial Institutions

We were actively involved with Pakistani provincial chickpea research institutes or stations, particularly with the Ayub Agricultural Research Institute in the Punjab, the Pulses Research Station in Sind, the Agricultural Research Institute in Baluchistan, and the Gram Research Station in the Northwest Frontier Province. Segregating and nonsegregating materials, developed at NARC or brought from ICRISAT and ICARDA, were supplied to all these institutions for evaluation and selection.

Off-Season Seed Increase

We sowed, for seed increase, about 0.5 ha with F_6 populations of four crosses (Table 33), Pakistan Agricultural Research Council (PARC) at the high-altitude research station in the Kaghan Valley. About 60 kg of seed was produced and distributed to 20 locations in Pakistan for yield tests.

Table 34. Performance of four advanced chickpea breeding materials sown at NARC, Islamabad, 1986/87.

Cross	Ascochyta blight rating[1]	Time to 50% flowering (d)	Yield (t ha^{-1})
PK 51825 × CM 72	3	141	1.3
PK 51832 × CM 72	3	131	1.1
PK 51835 × CM 72	3	131	1.7
PK 51863 × NEC 138-2	1	133	1.1
Control			
CM 72	6	127	0.5
SE	±0.1	±2.2	±0.05
CV (%)	2.9	3.3	9

1. Based on a 1-9 scale, where 1 = unaffected, and 9 = killed.

Workshops, Conferences, and Seminars

Chickpea Scientists's Meet

The annual Chickpea Scientists' Meet was held 9-11 February at ICRISAT Center. Participants included 36 scientists from India, 2 from Ethiopia, 1 from Nepal, 1 from Pakistan, as well as ICRISAT scientists based in Pakistan and Syria.

Most participants at such meets are breeders who use these occasions to select advanced crop materials. A major feature of these events, therefore, is the visit to experimental fields for a critical review of materials.

Reports from Ethiopia, Nepal, and Pakistan were presented, they covered production trends, problems, and achievements relating to chickpea in each country. Later, topics of general importance and special relevance to conditions similar to those found in peninsular India were discussed, including mutation breeding and early sowing.

ACIAR/AGLN Workshop on Management of Legume Pests

A Workshop on the Management of Legume Pests was cosponsored by ACIAR and AGLN. The workshop was held 31 August-3 September 1987 at Khon Kaen, Thailand; and 7-10 September 1987 at Malang, Indonesia. Considering the importance of other legumes in both countries, mung bean, soybean, and cowpea were included along with groundnut and pigeonpea. ACIAR sent a professional pest manager and ICRISAT an entomologist to conduct the workshop with help from local entomologists. In each country 12 participants discussed various aspects of pest management including: pests and their distribution; biology, ecology, and damage by major pests; sampling and survey procedures and yield loss assessment; insects as disease vectors; insecticides; biological control; host-plant resistance and integrated pest management principles. The participants were asked to evaluate the usefulness of the course. They were all appreciative and requested more information/literature on pest management principles.

AGLN Chickpea Coordinators Work Planning Meeting

The AGLN Chickpea Coordinators Work Planning Meeting was held 4-6 August 1987 at ICRISAT Center, to develop a regional Work Plan for chickpea improvement. Coordinators from Bangladesh, India, Nepal, and Pakistan participated. Nonrealization of potential yield and instability of chickpea yield in farmers' fields were debated; the participants identified the following factors/constraints:

- Poor plant stands due to poor seed quality, poor seedbed preparation, inadequate soil moisture, seed and seedling rotting;
- Diseases — wilt, root rot, botrytis gray mold, and ascochyta blight;
- *Heliothis* pod borer;
- Drought stress, especially during the reproductive phase; and
- Nonavailability of input-responsive varieties, and varieties for late sowing.

The participants agreed to conduct yield maximization trials in their countries to identify factors and technologies responsible for the high yield in chickpea, and subsequently to lay out trials in farmers' fields to demonstrate the potential yield of chickpea.

Publications

Institute Publications

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. International Chickpea Newsletter nos. 16 and 17. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2508. (NCE)

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Coordination of grain legumes research in Asia: summary proceedings of the Review and Planning Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 16-18 Dec 1985, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 96 pp. ISBN 92-9066-120-8. (CPE 040)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Research on grain legumes in eastern and central Africa: summary proceedings of the Consultative Group Meeting for Eastern and Central African Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 8-10 Dec 1986, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. Patancheru, A.P. 502 324, India: ICRISAT. 128 pp. ISBN 92-9066-129-1. (CPE 042)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 184 pp. ISBN 92-9066-130-5. (CPE 043)

Journal Articles

Ananda Rao, P.K., and **Haware, M.P.** 1987. Inheritance of dry root rot (*Rhizoctonia bataticola*) resistance in chickpea (*Cicer arietinum*). Plant Breeding 98(4):349-352. (JA 643)

Haware, M.P., Nene, Y.L., and Mathur, S.B. 1986. Seed-borne diseases of chickpea. Technical Bulletin no. 1. Copenhagen, Denmark: Danish Government Institute of Seed Pathology for Developing Countries, and Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 32 pp. 34 ref. ISSN 0901-1773. (Misc)

Itoh, Sumio. 1987. Characteristics of phosphorus uptake of chickpea in comparison with pigeonpea, soybean, and maize. Soil Science and Plant Nutrition 33(3):417-422. (JA 571)

Nene, Y.L. 1986. Opportunities for research on diseases on pulse crops. Indian Phytopathology 39(3):333-342. (JA 575)

Nene, Y.L. 1987. Indian plant pathology–2000 A.D. Indian Phytopathology 40(1):1-13. (JA 688)

Nene, Y.L., and **Reddy, M.V.** 1987. Chickpea diseases and their control. Pages 233-270 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 510)

Reed, W., Cardona, C., Sithanantham, S., and **Lateef, S.S.** 1987. Chickpea insect pests and their control. Pages 283-318 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 514)

Rupela, O.P., and **Saxena, M.C.** 1987. Nodulation and nitrogen fixation in chickpea. Pages 191-206 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 595)

Rupela, O.P., Toomsan, B., Mittal, S., Dart, P.J., and **Thompson, J.A.** 1987. Chickpea *Rhizobium* populations: survey of influence of season, soil depth and cropping pattern. Soil Biology and Biochemistry 19(3):247-252. (JA 550)

Singh, Harjit, Kumar, J., Haware, M.P., and **Smithson, J.B.** 1987. Complementation between genes for resistance to race 1 of *Fusarium oxysporum* f. sp. *ciceri* in chickpea. Plant Pathology 36:539-543. (JA 373)

Williams, P.C., and **Singh, U.** 1987. Nutritional quality and the evaluation of quality in breeding programmes. Pages 329-356 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 469)

Conference Papers

Campbell, W.V., and **Reed, W.** 1987. Limits imposed by biological factors-pests. Pages 128-137 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 315)

Chauhan, Y.S. 1987. Screening for tolerance to salinity and waterlogging: case studies with pigeonpea and chickpea. Pages 93-103 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 388)

Gowda, C.L.L. 1987. The potential of chickpea after rice. Pages 220-221 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 270)

Johansen, C. 1987. Mechanisms of salt tolerance and their relevance. Pages 109-113 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 385)

Nene, Y.L. 1987. Overview of pulses research at ICRISAT. Pages 7-12 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 384)

Reddy, M.V. 1987. Diseases of pigeonpea and chickpea and their management. Pages 175-184 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 282)

Reed, W. 1987. Increase of productivity of crops: control of pre- and post-harvest losses. Presented at the International Meeting on Towards a second Green Revolution: from chemical to New Biological Technologies in Agriculture in the Tropics, 8-10 Sep 1986, Rome, Italy. Rendiconti della Accademia Nazionale delle Scienze detta dei XL, Memorie di Scienze Fisiche e Naturali, Serie 5, 11 (Part 2):249-258. (CP 311)

Rupela, O.P., and **Kumar Rao, J.V.D.K.** 1987. Effects of drought, temperature, and salinity on symbiotic nitrogen fixation in legumes, with emphasis on chickpea and pigeonpea. Pages 123-131 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 383)

Saxena, N.P. 1987. Screening for adaptation to drought: case studies with chickpea and pigeonpea. Pages 63-76 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 389)

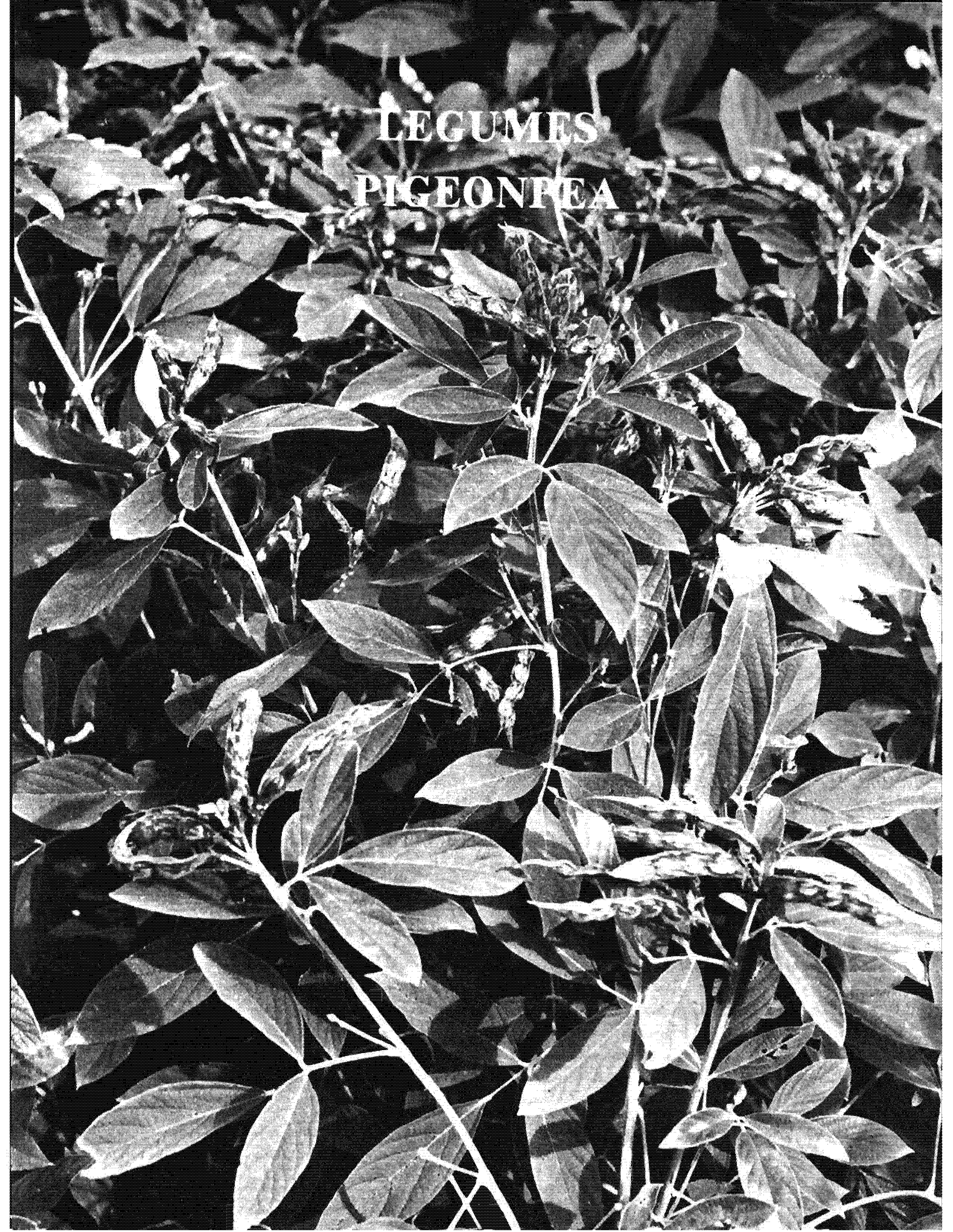
Saxena, N.P. 1987. Problems and prospects to screen and breed for tolerance to soil salinity: a case study with chickpea. Pages 115-120 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 387)

Sithanantham, S. 1987. Insect pests of pigeonpea and chickpea and their management. Pages 159-173 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, CPPTI, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 341)

Thesis

Bejiga, Geletu. 1987. Relationships among the F_2 to F_6 generations, and effect of spacing and selection in F_4 on performance in F_5 generation in chickpea. Ph.D. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 149 pp.

LEGUMES
PIGEONPEA



Contents

Cover photo: New short-statured, extra short-duration pigeonpea bred for higher latitudes and nontraditional areas, ICRISAT Center, rainy season, 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India.

PIGEONPEA

Pigeonpea (*Cajanus cajan*) ranges from full-season perennials to extra short-duration (90 days to maturity) types. This means it can be grown in a wide range of environments. Our research activities are being increasingly focused on yield improvement and stability in the short-duration group, to adapt them to existing and new areas of production. Geographically, we will enhance our cooperative work in southeast Asia [through the Asian Grain Legumes Network (AGLN)] and in Africa through network initiatives.

In India, our research activities are concentrated at three locations: ICRISAT Center (18°N, 78°E, 760 mm annual rainfall); Hisar (29°N, 75°E, 450 mm rainfall) in cooperation with Haryana Agricultural University (HAU); and Gwalior (26°N, 78°E, 840 mm rainfall) in cooperation with Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) College of Agriculture.

Next year, cooperative work initiated in 1987 will be strengthened in the areas of genetic improvement and agronomic management of pigeonpea for rice fallows, multiple cropping, higher latitudes (short-duration), and for increased biomass production for food, fodder, and fuel in annual and perennial production systems (long-duration). In the short- and medium-duration group, our efforts will continue, to search for cultivars that are less susceptible to *Heliothis*, and that combine disease resistance with suitability for intercropping and for use as a vegetable.

Work on resistance to phytophthora blight (*Phytophthora drechsleri* f.sp *cajani*) disease will be intensified in the light of the breakdown of available resistance in 1987. We will extend our hybrid pigeonpea breeding program to long-duration and extra-short duration groups through a recently initiated network of cooperators under the All India Coordinated Pulses Improvement Project (AICPIP).

We will continue studies to better understand drought and salinity response in pigeonpea and to identify and confirm sources of tolerance. We will also initiate studies to find genotypes with optimum nitrogen-fixing capability. Characterization of residual nitrogen left by pigeonpea in different cropping systems will continue.

We will investigate the potential of pigeonpea for use as fermented foods in southeast Asia, and as animal feed.

Physical Stresses

An attempt is being made to quantify factors of the physical environment that limit growth and yield of pigeonpea and to alleviate these constraints through both management and genetic improvement. We are screening short- and medium-duration genotypes for tolerance to drought and genotypes in all maturity groups for waterlogging and salinity tolerance. Our research aims to improve the performance of short-duration pigeonpea in rotations with wheat in the northern Indian environment and in multiple harvest systems where winters are warmer. However, we have recently begun studies on adapting pigeonpea to rice fallows and fitting extra-short duration pigeonpea into restricted rainfall patterns.

Moisture Response in Short-duration Pigeonpea

Short-duration pigeonpea can face intermittent drought stress during the 'rainy' season. In the 1986 rainy season, we screened 30 short-duration genotypes for their response to a moisture gradient created by line-source sprinklers. In that year, rainfall during September, the postflowering period for most genotypes,was sparse and so irrigation treatments were applied.

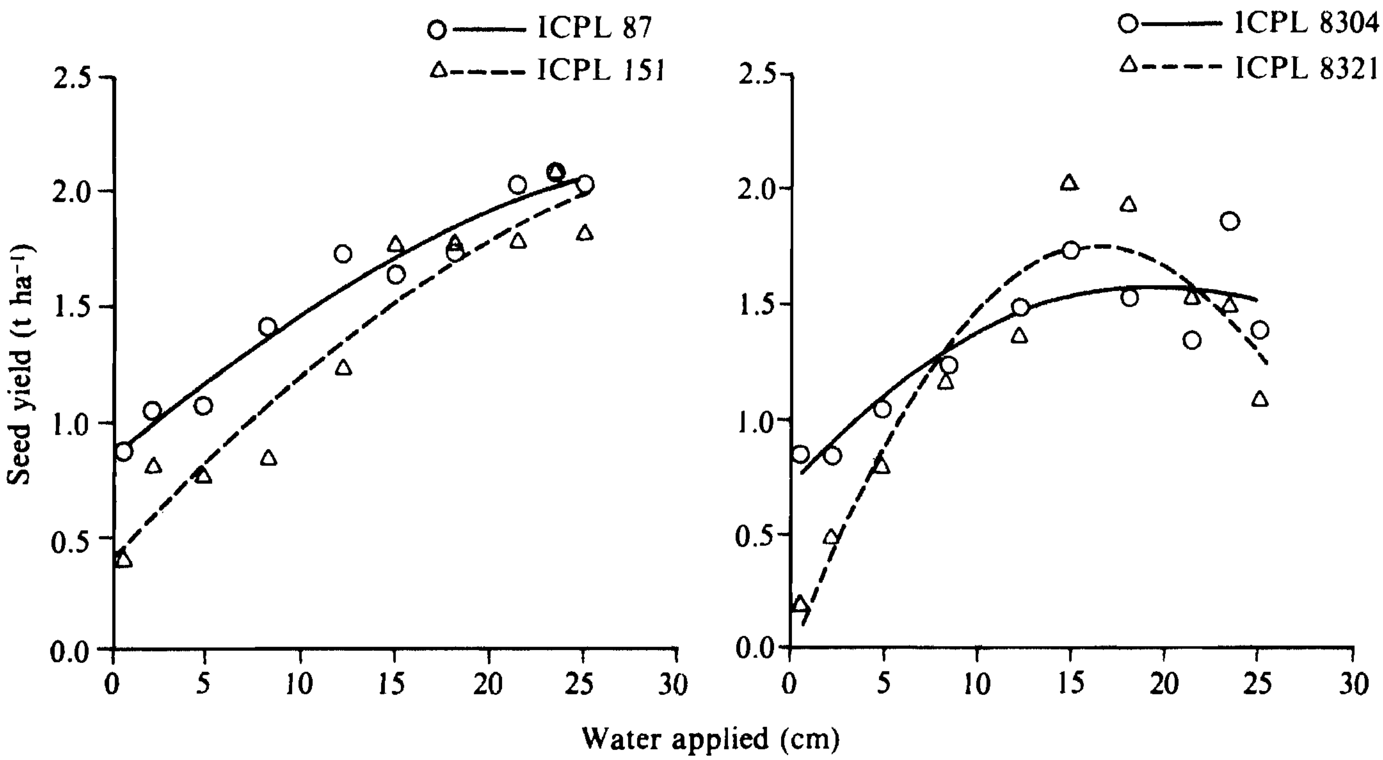
Figure 1 indicates some of the diverse nonlinear responses to moisture levels. In some cases (e.g., ICPL 8321), there was a depression in both growth and yield at the highest moisture levels. This indicates waterlogging effects and suggests that the line-source sprinkler system could be used to simultaneously screen for both drought and waterlogging tolerances.

Figure 1 indicates that ICPL 151 has a relatively greater drought sensitivity than ICPL 87. It also shows the response of a relatively drought-tolerant genotype, ICPL 8304 and a susceptible one, ICPL 8321. Other drought-tolerant genotypes identified were; ICPL 81, ICPL 8319, ICPL 84059, ICPL 85035, ICPL 85052, ICPH 8, and ICPH 9. It was interesting to note that the two hybrids, ICPH 8 and ICPH 9, performed better at all moisture levels than their respective male parents, ICPL 161 and ICPL 87 (data not presented). Apart from ICPL 151 and ICPL 8321, other genotypes relatively sensitive to drought stress were; ICPL 161, ICPL 228, ICPL 84023, and ICPL 85010.

This screening is continuing in 1987 with 46 genotypes under test. Studies are also underway to determine the physiological basis of these genotypic differences in moisture response.

Salinity Response of Wild Species Related to Pigeonpea

In our attempts to find sources of improved salinity tolerance in pigeonpea, we screened a range of its wild relatives including 13 species of *Atylosia, Rhynchosia albiflora*, and *Dunbaria*



ICPL 87 $y = 0.829+0.071x-0.001x^2$ $r^2=0.95$, rse=0.094
ICPL 151 $y = 0.395+0.090x-0.001x^2$ $r^2=0.89$, rse=0.190
ICPL 8304 $y = 0.694+0.090x-0.002x^2$ $r^2=0.73$, rse=0.178
ICPL 8321 $y = -0.040+0.214x-0.006x^2$ $r^2=0.88$, rse=0.201

Figure 1. Response of seed yield of some short-duration pigeonpea genotypes to water applied by line-source sprinklers, Alfisol, ICRISAT Center, rainy season 1986.

ferruginea. Plants were grown in sand culture flushed with a nutrient solution that included nitrogen. The plants were not inoculated with *Rhizobium*. They were treated with salt (NaCl + $CaCl_2$) concentrations that varied in electrical conductivity up to 12 dS m^{-1}.

The range of responses relative to the control is illustrated in Figure 2. *Atylosia platycarpa, A. albicans, A. cajanifolia*, and *D. ferruginea* were more tolerant to salinity than the cultivated pigeonpea controls. All species died at 12 dS m^{-1}, but *A. platycarpa* could set pods at 10 dS m^{-1}. *Rhynchosia albiflora* was the most salt-sensitive of the species tested. Thus, there appear to be potential sources for enhancing salt tolerance of pigeonpea among its wild relatives. But, the realization of this potential in *A. platycarpa* will depend on the development of hybridization techniques (see ICRISAT Annual Report 1986, pp. 203-204).

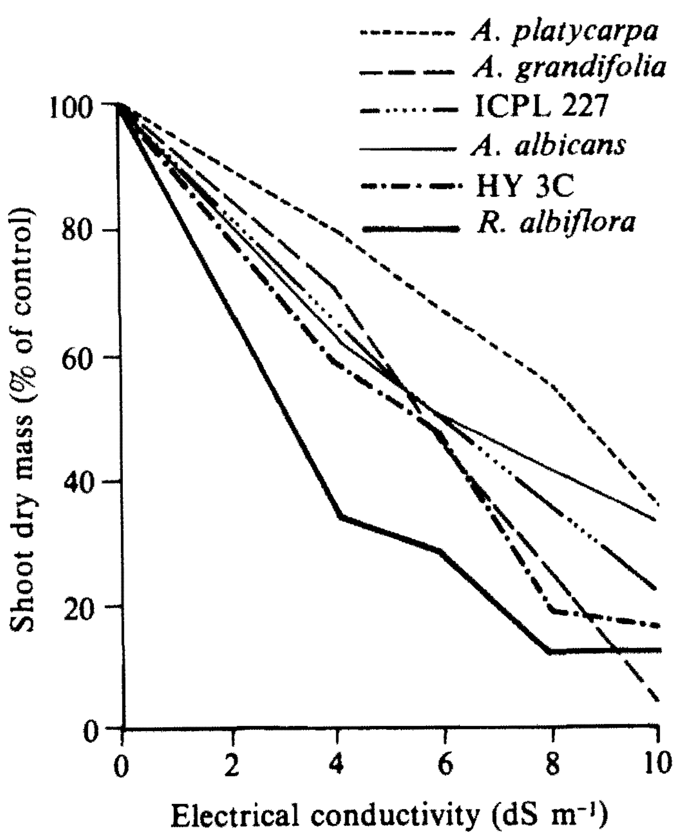


Figure 2. Response of four wild species related to pigeonpea and two cultivated pigeonpea genotypes to salinity (measured as electrical conductivity) in sand culture, ICRISAT Center, 1987.

Biotic Stresses

Diseases

Disease Situation

In 1986/87, sterility mosaic (SM) was a serious problem for long-duration pigeonpea in the Indian states of Uttar Pradesh and Bihar, and the Terai region of Nepal. During a survey in March, we found 100% disease incidence in several farmers' fields. There is an immediate need to introduce lines with SM resistance in these areas. Fusarium wilt (*Fusarium udum*) was not common in these areas, but alternaria blight (*Alternaria alternata*) incidence was increasing. This latter disease has the potential to damage pigeonpea and should be monitored.

Visits in September and October to the short-duration pigeonpea-growing areas in the Indian states of Uttar Pradesh, Haryana, and Rajasthan indicated phytophthora blight (*Phytophthora drechsleri* f.sp *cajani*) (PB) and SM to be the most common diseases, but their incidence was low. Phytophthora blight occurred in association with phoma blight (*Phoma cajani*), macrophomina blight (*Macrophomina phaseolina*), bacterial leaf spot and stem canker (*Xanthomonas cajani*). Fusarium wilt was not a serious problem in short-duration pigeonpeas.

Fusarium Wilt (*Fusarium udum*)

Incidence. While screening pigeonpea genotypes of different maturity groups, in the wilt-sick plots at ICRISAT Center, we observed that the short-duration types showed less wilt incidence than medium- and long-duration types (Fig. 3). Wilt incidence in different Arhar Coordinated Trials (ACTs) during the 1984/85 and 1985/86 seasons (Table 1) support this observation. The average wilt incidence in short-duration genotypes in Arhar Coordinated Trials, (EXACT, EACT, and ACT 1) was 35–62%, compared with 82–87% in the medium- and long-duration genotypes in ACT 2 and ACT 3.

Figure 3. A short-duration pigeonpea line (middle two rows) showing less incidence of fusarium wilt compared to a medium-duration variety (lateral two rows).

Table 1. Pigeonpea wilt (*Fusarium udum*) incidence in different AICPIP Arhar Coordinated Trials (ACTs) in wilt-sick plots, ICRISAT Center, rainy seasons 1984 and 1985.

	1984/85		1985/86	
Trial	No. of entries	Wilt (%)[1]	No. of entries	Wilt (%)[1]
EXACT	10	50 (31- 69)	18	36 (71-100)
EACT	15	59 (5- 83)	19	43 (51- 97)
ACT 1	19	76 (50-100)	17	27 (40- 95)
Average		62		35
ACT 2	20	85 (22-100)	13	94 (70-100)
ACT 3	11	78 (69-100)	25	80 (56- 97)
Average		82		87

1. Average of entries in each maturity group. Values in parentheses represent range of wilt incidence.

Sterility Mosaic

Survival of the pathogen and mite vector during summer. We undertook an extensive survey in June 1987 in parts of eastern Uttar Pradesh to study the reservoirs of the SM pathogen and its eriophyid mite vector, *Aceria cajani* during the summer months. During this survey, we traversed a total distance of 1400 km in 10 districts (Azamgarh, Ballia, Deoria, Ghazipur, Gorakhpur, Jaunpur, Kanpur, Lucknow, Raebareli, and Sultanpur). We found 312 SM-infected pigeonpea leaf samples that had live eriophyids associated with them, albeit in low numbers.

The major off-season reservoir of SM and its mite vector is the pigeonpea that is grown around borders of irrigated sugarcane fields and also volunteer and ratooned pigeonpeas seen in and around sugarcane fields. Pigeonpeas grown on bunds of irrigation channels and in kitchen gardens appear to be secondary off-season reservoirs. *Atylosia scarabaeoides*, which is the other known host of *A. cajani*, was not observed in the surveyed areas.

Phytophthora Blight (*Phytophthora drechsleri* f.sp *cajani*)

Effect of plant age on blight susceptibility. During the 1986 rainy season, PB occurred naturally in the multiple-disease nursery at ICRISAT Center in the first week of July, when the plants were about one month old. The initial occurrence of the disease was patchy; all the lines in the low-lying areas where water had stagnated were killed. In August, the blight occurred uniformly throughout the field. ICPV 1 (ICP 8863), was sown throughout the field at frequent intervals as an SM-susceptible control; some plants of this cultivar were killed in July but the survivors were not affected in August.

To investigate whether the age of pigeonpea plants has any effect on their blight susceptibility, we conducted two pot-culture experiments in the greenhouse, one in 1986 and another in 1987. In the first experiment; 15-, 30-, 45-, and 60-day old plants of ICPV 1 (ICP 8863) and HY 3C, known blight-susceptible cultivars, were spray-inoculated with the P3 isolate of the blight pathogen. The blight susceptibility of both cultivars decreased with plant age. In cultivar ICPV 1 (ICP 8863), 93% of seedlings died when inoculated at 15 days, but no 60-day old inoculated plants died (Fig. 4). In the second experiment, 10 more cultivars were tested and similar results obtained (Table 2).

Bacterial Leaf Spot and Stem Canker (*Xanthomonas cajani*)

Relationship between stem color and disease susceptiblity. A severe outbreak of the disease was observed in many pigeonpea germplasm accessions when they were grown in an SM nursery during the 1985/86 season at ICRISAT Center. The 235 germplasm accessions grown in the nursery originated from Kenya (140), India (79), Tanzania (11), the Philippines (4), and Mozambique (1). The disease is observed every season at ICRISAT Center but is not normally serious. The favorable weather conditions for disease development that prevailed in June and July (rainfall 262 mm, temperatures 22–23°C, relative humidity 60–90%), coupled with the presence of the susceptible exotic germplasm seemed to have favored disease development in this particular field.

While a large proportion of the germplasm accessions from Kenya, Tanzania, Mozambique, and the Philippines showed high susceptiblity to the disease, the Indian cultivar BDN 1, sown after every 12 rows of germplasm accessions as an SM-susceptible control, showed a moderate level of resistance. In general, lines with green stems showed higher susceptibility (84%) than lines with purple stems (10%) (Fig. 5). Even within the same germplasm accessions that showed segregation for stem color, the plants with green stems were more susceptible than those with purple stems.

Of the 235 germplasm accessions evaluated, seven lines; ICP 12807, ICP 12848, ICP 12849, ICP 12937, ICP 13051, ICP 13116, and ICP

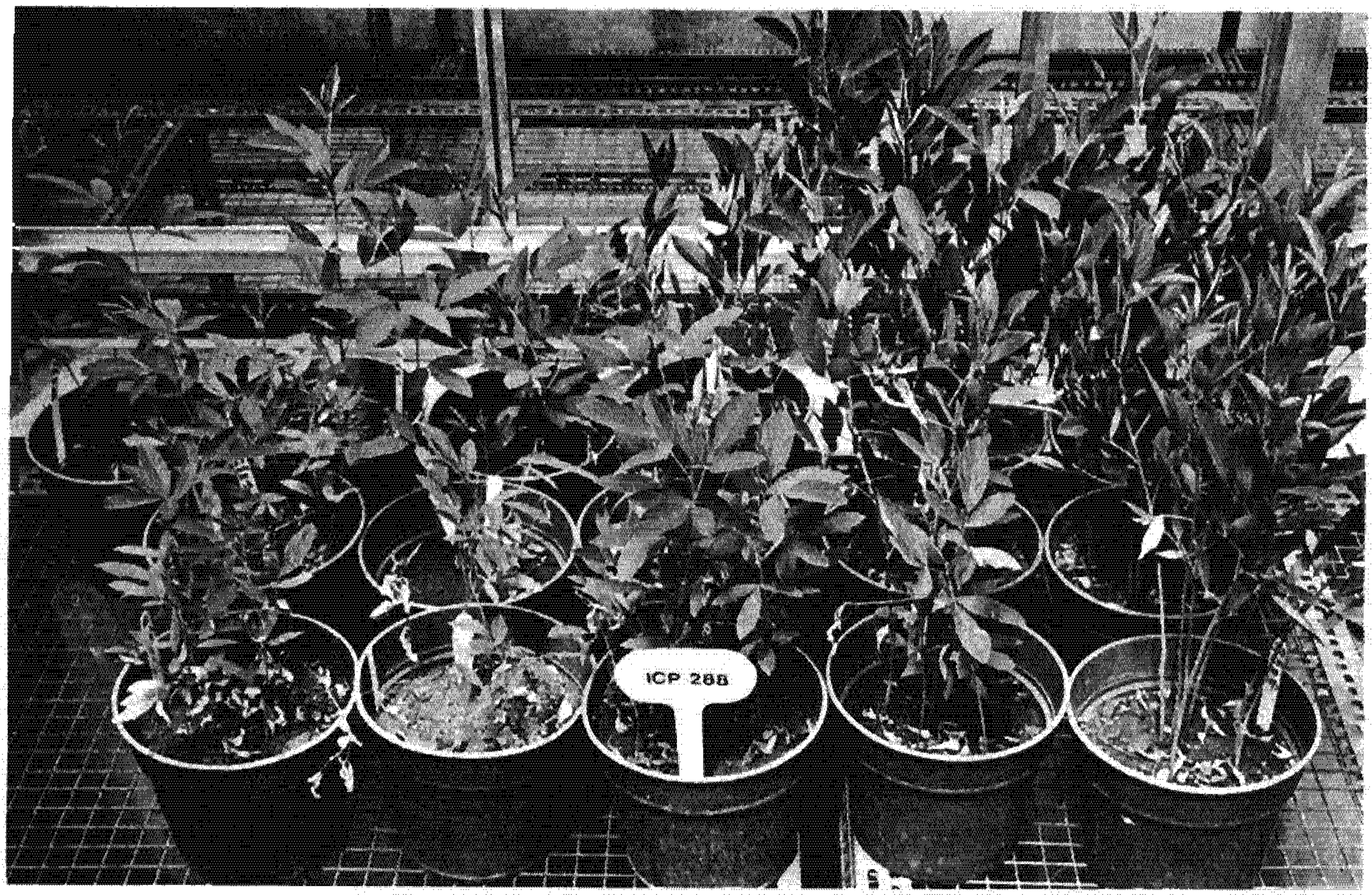


Figure 4. Younger pigeonpea plants (left) showing more susceptibility to phytophthora blight compared to the older plants (right). The row at far right is a noninoculated control.

Table 2. Effect of age of pigeonpea plants on susceptibility measured as blight incidence (%) to phytophthora blight (*Phytophthora drechsleri* f.sp *cajan*), greenhouse experiment, ICRISAT Center, 1987.

	Age (d)			
Genotypes	15	30	45	60
ICP 113	12.2(±5.7)[1]	27.5(±8.2)	0	0
ICP 4135	5.9(±4.0)	31.3(±9.1)	0	0
ICPV 1 (ICP 8863)	33.6(±7.4)	53.3(±8.9)	0	0
ICP 11290	37.3(±7.5)	40.0(±8.2)	22.4(±8.1)	0
ICP 11302	22.2(±6.8)	8.9(±4.9)	0	0
ICP 11303	56.1(±7.8)	10.3(±4.8)	0	0
ICP 11304	26.2(±7.4)	9.0(±6.0)	0	0
ICPL 161	8.7(±4.7)	33.1(±8.8)	0	0
ICPL 288	45.8(±8.4)	0.1(±0.1)	0	0
KPBR 80-1-4	6.5(±4.4)	0	0	0
ICP 2376	19.1(±6.9)	22.5(±6.9)	29.3(±8.3)	0
ICP 7119	70.2(±7.4)	44.6(±9.4)	3.1(±3.0)	15.2(±5.1)

1. Values in parentheses are standard errors (SEs).

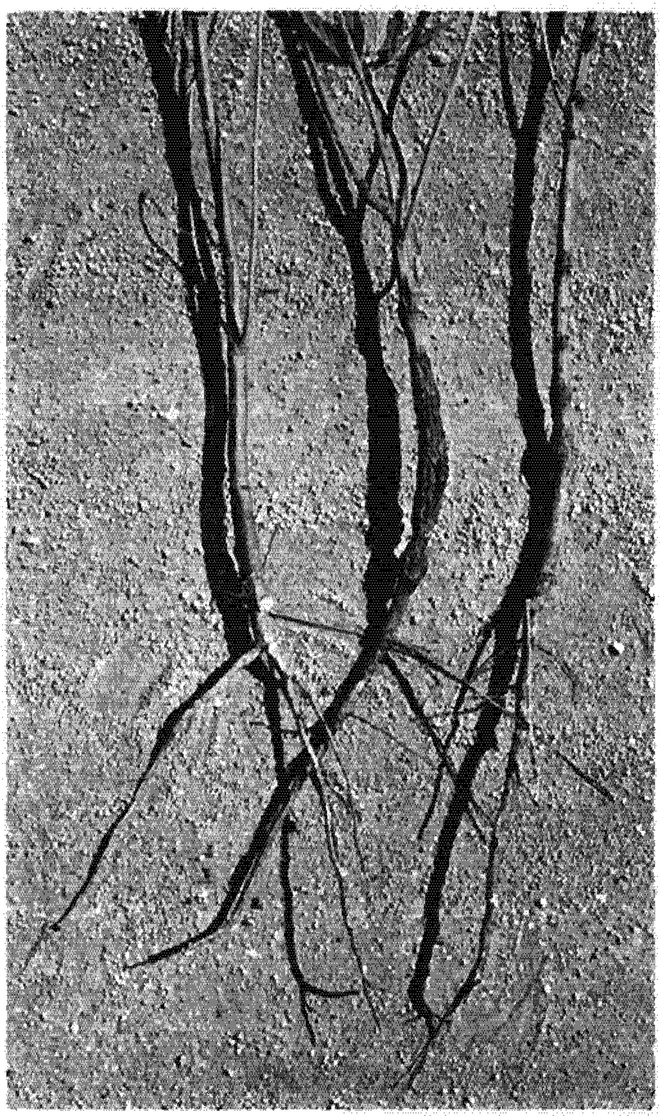


Figure 5. Pigeonpea plant with purple stem color (left), showing less susceptibility to bacterial stem canker compared to the green stem types (right).

13148 showed high levels of resistance to the disease.

Multiple Disease Nurseries

Fusarium wilt, SM, and PB are the three major diseases of pigeonpea in India. Multiple disease nurseries have been developed at ICRISAT Center, to identify sources of resistance and to evaluate segregating materials for multiple disease resistances. Screening for SM and wilt resistance is being carried out in a 2-ha Vertisol field (Fig. 6) where the incidence of both diseases is very high. During the 1986/87 season, the wilt-susceptible control ICP 2376 showed an average of 97% wilt (94–99%) and the SM-susceptible control ICPV 1 (ICP 8863) showed 100% disease.

To evaluate pigeonpea materials for resistance to wilt, SM, and PB, a 1-ha Alfisol field is used. During the 1986/87 season, wilt incidence was 92% (87–95%), SM incidence was 100%, and PB incidence was 90% (86–94%) in susceptible controls.

Many germplasm and breeding lines were evaluated in the two multiple-disease nurseries in the 1986/87 season. While several genotypes showed resistance to wilt and SM, relatively few showed resistance to all three diseases. The new germplasm lines that showed less than 20% wilt and SM were; ICP 12825, ICP 12924, ICP 13235, ICP 13237, PR 5149, and PI 397430 and those with less than 20% wilt, SM, and PB were; ICP 11290, ICP 11304, and KPBR 80-1-4.

Breeding for Disease Resistance

In medium-duration pigeonpea, we concentrated on breeding for resistance to fusarium wilt and SM diseases and to the pod borer *Heliothis armigera*.

We started a backcross program to develop high-yielding and SM-resistant lines using adapted genotypes as recurrent parents. The progenies from BDN 1 and C 11 backcrosses, previously found resistant to SM (ICRISAT Annual Report 1986, p. 180), were again screened in the SM nursery. All the progenies from the BDN 1 backcross (BC_3F_5) and seven from the C 11 backcross (BC_2F_5) were completely free from disease. These progenies were selected for yield evaluation and other agronomic traits in 1987 in replicated trials.

Three backcross progenies (BC_1F_5) of a cross between a wilt-susceptible cultivar, LRG 30, and a resistant donor, cultivar 15-3-3, were retested in the wilt-sick nursery. Wilt incidence in the progenies ranged from 13 to 17% and the resistant plants were bulked progeny-wise for yield evaluation. In addition, 156 M_3 single-plant

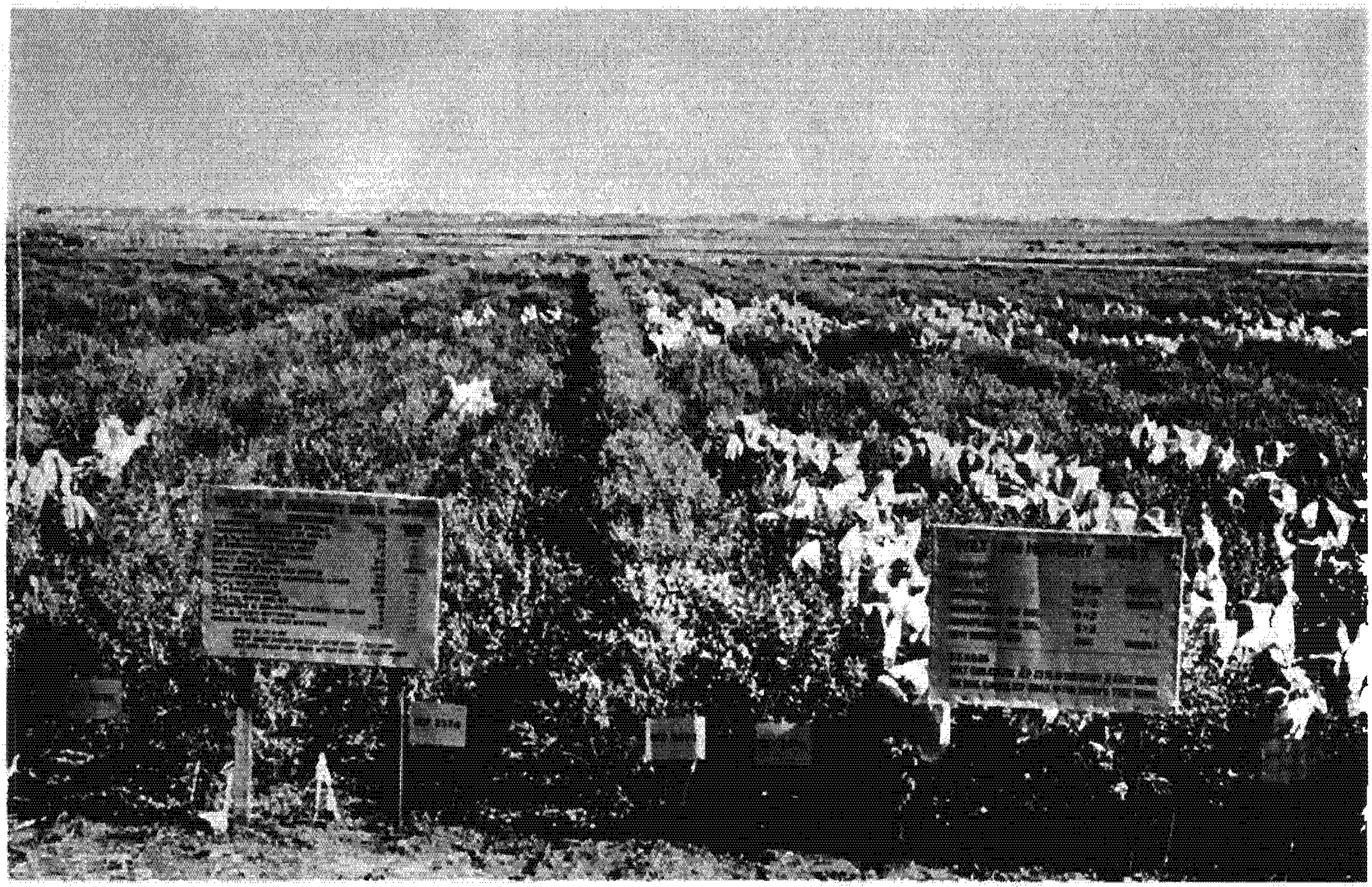


Figure 6. A view of the pigeonpea wilt and sterility mosaic screening nursery, ICRISAT Center, rainy season 1986.

progenies of cultivar LRG 30 were also screened in the wilt-sick nursery. Sixteen progenies were found resistant to wilt (up to 10% incidence) and will be tested for yield.

In the multilocational Medium-duration Pigeonpea Adaptation Yield Trial (MPAY), four wilt-resistant lines yielded more than the control cultivars (C 11 and BDN 1). The best line ICPL 85066, yielded 2.6 t ha^{-1} (Table 3). Because of its good performance, this line has been entered in the AICPIP ACT 2 multilocational trial for the 1987 rainy season.

Nematode Diseases

In the 1984/85 postrainy season, we began to identify the various nematodes affecting pigeonpea, to study their effects on growth and yield, and to develop suitable control measures. Understanding the relationship between nematodes and wilt disease in pigeonpea is another area of interest.

Survey. Our surveys at ICRISAT Center indicated that the major nematodes on pigeonpea included the pigeonpea cyst nematode, *Heterodera cajani* on Vertisols, and the reniform nematode, *Rotylenchulus reniformis* (Fig. 7), and lance nematode, *Hoplolaimus seinhorsti*, on Alfisols.

Five genera of plant parasitic nematodes were recorded in the pigeonpea fields at our cooperative research station, Gwalior, with *Rotylenchulus reniformis* the most prominent. In some portions of the fields, the nematode density was as high as 44 nematodes cm^{-3} soil.

Effect on plant growth. The pigeonpea cyst nematode, *H. cajani*, the reniform nematode,

Table 3. Performance of pigeonpea entries in the Medium-duration Pigeonpea Adaptation Yield Trial (MPAY) at two Indian locations, rainy season 1986.

	ICRISAT Center						Anand	
Entry	Time to 50% flowering (d)	Time to maturity (d)	100-seed mass (g)	Wilt incidence (%)	Wood yield (t ha^{-1})	Grain yield (t ha^{-1})	Grain yield (t ha^{-1})	Mean grain yield (t ha^{-1})
ICPL 85066	114	173	10.3	13	3.46	2.05	3.14	2.60
ICPL 84008	108	165	10.0	4	2.84	1.87	2.68	2.28
ICPL 85061	116	177	10.0	16	2.95	1.77	2.37	2.07
ICPL 85062	114	171	9.2	13	2.92	1.61	2.54	2.08
Controls								
C 11	120	185	11.0	74	3.02	2.03	1.60	1.82
BDN 1	106	162	9.5	98	1.50	1.46	1.38	1.42
SE	±0.2	±0.3	±0.14	±0.19	±0.10	±0.26	-	-
Trial mean (12 entries)	114	172	10.4	2.66	1.65	1.89	-	-
CV %	0.4	0.4	3	14	12	28	-	-

Figure 7. Microscope photograph of an adult female reniform nematode feeding on a pigeonpea root.

R. reniformis, and *H. seinhorsti* significantly reduced the plant growth of ICP 2376 under greenhouse conditions. The adverse influence of nematodes on growth was visible 40 days after inoculation. The relationship between initial nematode density and growth reduction was quadratic. *Heterodera cajani* and *H. seinhorsti* severely reduced root growth, while the effect of *R. reniformis* was more pronounced on shoot growth. Most growth parameters were significantly affected by 500–1000 nematodes 500 cm^{-3} soil (Fig. 8).

Effect on fusarium wilt. In greenhouse experiments, the presence of *H. cajani* and *R. reniformis* along with the wilt pathogen *Fusarium udum* advanced wilt incidence in wilt-susceptible ICP 2376. The reactions of wilt-tolerant (BDN 1) and wilt-resistant ICPV 1 (ICP 8863) lines were not affected by these nematodes, indicating that these lines are either resistant to nematodes, or that wilt resistance in these lines is due to restriction of fungal colonization and not to infection.

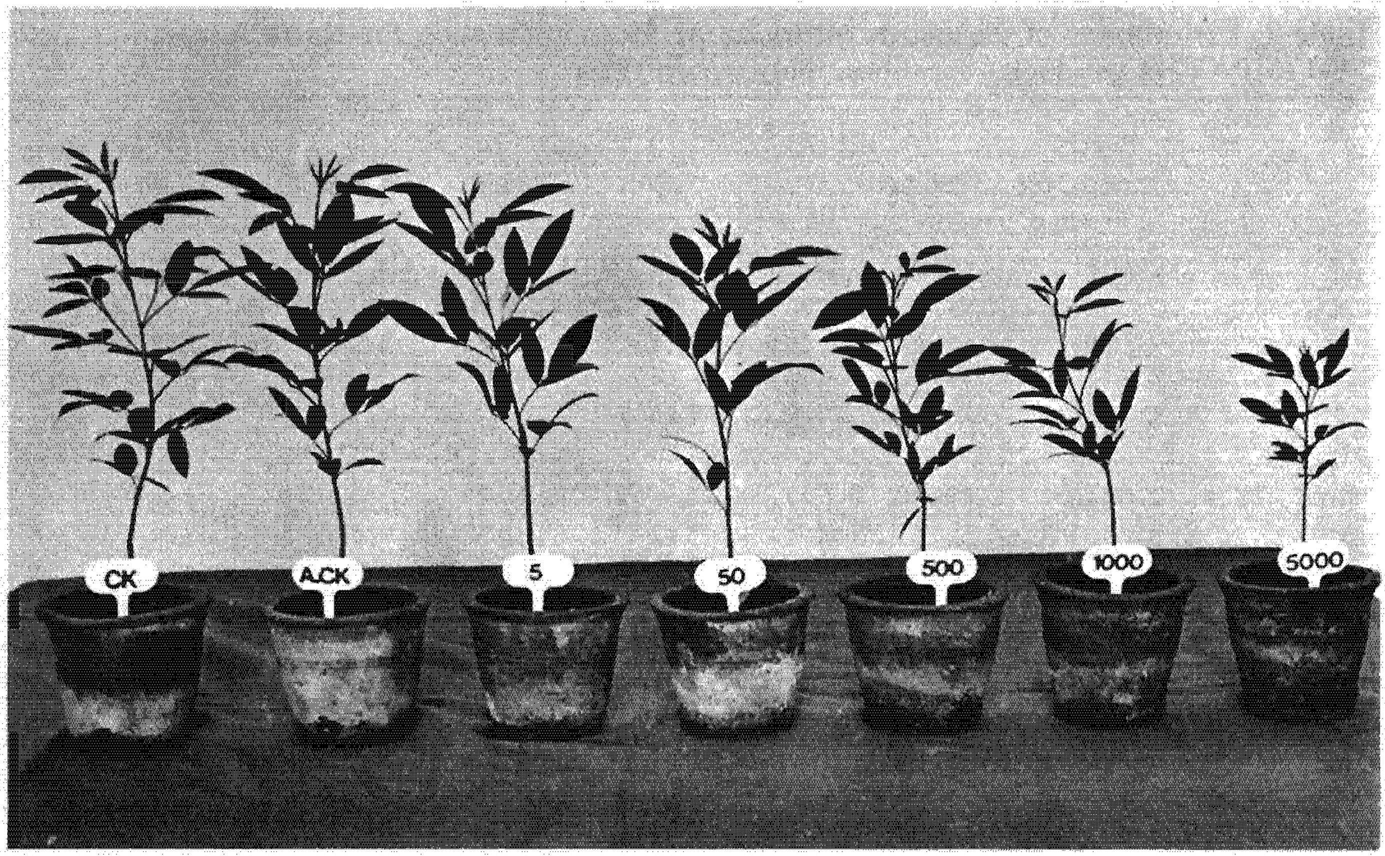


Figure 8. Effect of cyst nematode populations on the growth of pigeonpea cultivar ICP 2376 (CK=no nematode, A.CK=water suspension, 5,50,500, 1000, and 5000 = larvae 500 cc^{-1} soil).

Insect Pests

Pest Incidence

In 1986/87, as in all previous years, the pod borer, *Heliothis armigera* was the most damaging insect pest of pigeonpea at ICRISAT Center and throughout southern India. The extra short-, short-, and medium-duration pigeonpeas were severely damaged by the larvae of this insect, so yields were very low in fields that were not protected by insecticides. However, *Heliothis* was less abundant than usual from October to early November and so the medium-duration genotypes that were podding during that period escaped severe damage. In northern India, short-duration pigeonpea that matures before (Nov/Dec) winter was severely damaged by *Heliothis*, but yielded well when adequately protected by insecticide.

Several other lepidopteran larvae were common on the crop including the leaf webber (*Cydia critica*) and the spotted borer (*Maruca testulalis*). However, at Hisar these insects were again less common than usual, so our trials designed to investigate the management of these pests and to select resistant plants were not very successful.

Podfly (*Melanagromyza obtusa*), the second most important pigeonpea pest in India, was very common and damaging, particularly on the long-duration pigeonpeas grown in central and northern India. In Africa, *M. chalcosoma*, the predominant podfly species was common in farmers' fields in Kenya this year.

A variety of sucking pests attacked pigeonpea from the seedling stage to harvest. Jassids (*Empoasca* spp) were common during the vegetative growth stage in northern India and very severe attacks were noticed in some fields in

Kenya. Pod-sucking bugs, particularly *Clavigralla* spp, caused considerable damage to nonsprayed crops in many parts of India. These insects not only reduce yields but also adversely affect the quality of harvested seed. This year, the dry spell from early September favored their buildup at ICRISAT Center. In Kenya, pod-sucking bugs were particularly numerous this year, and some of the local entomologists consider these to be the most damaging pests of this crop. Some pigeonpea genotypes have been reported to possess considerable resistance to these insects in Kenya.

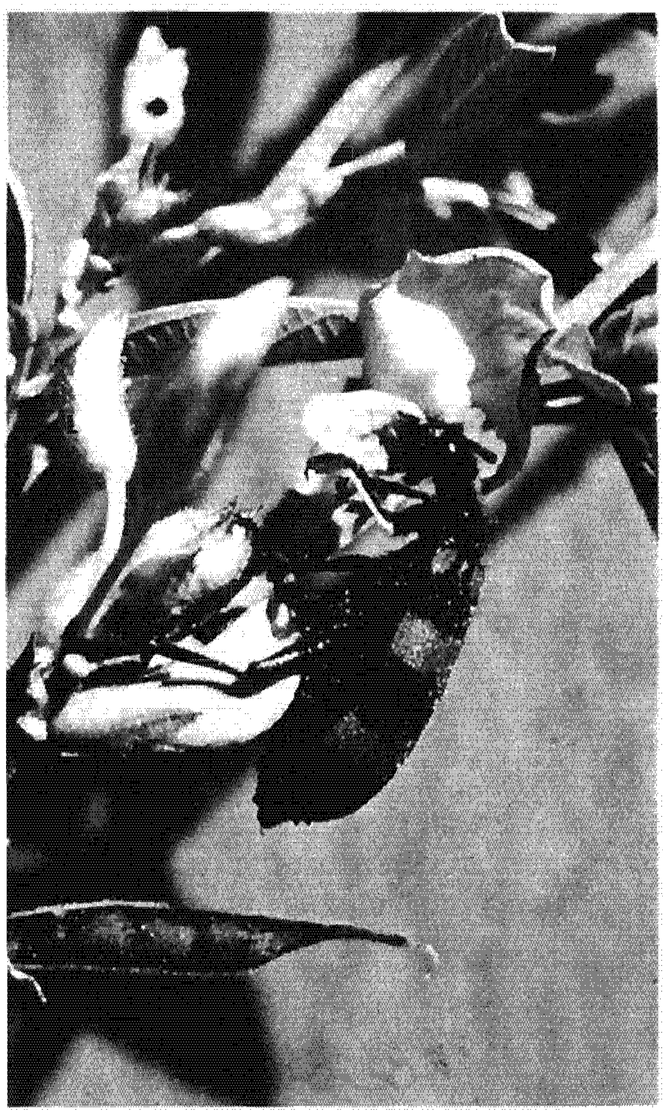


Figure 9. Pigeonpea flowers being damaged by blister beetle, *Mylabris pustulata*.

The hymenopteran pest (*Tanaostigmodes cajaninae*) was again common and very damaging at ICRISAT Center and at some other research stations in India, but very rare in farmers' fields. Of the other pests, the blister beetle (*Mylabris pustulata*) was very common and damaged short-duration pigeonpea. During larval stage, this insect feeds on other insects in the soil, and is usually considered a beneficial species. However, the adult (Fig. 9) feeds on flowers of pigeonpea and other legumes and can considerably reduce the number of pods that are set. In southern India, these beetles are very common from August to late October and so are very important for short-duration pigeonpea crops. They are particularly harmful to the small plots that we grow in farmers' fields to demonstrate the potential of our package of practices for sole crop, short-duration pigeonpea. When such plots contain the only legumes flowering in the area, blister beetles congregate on them and have to be manually removed, since insecticides do not effectively control them. Once the demonstration plot phase is over and farmers grow large areas of this type of pigeonpea, the beetles will spread over larger areas and their population densities are not high enough to cause serious damage or merit control. Indeterminate-type pigeonpeas are generally less susceptible to most insect pests than the determinate types, but we have observed that these beetles prefer the former.

Bruchids (*Callosobruchus* spp) were again fairly common on pods that were left on the plants for a few more days after maturity and were the most damaging pests in seed stores. Prompt harvesting, sun-drying seeds, and storage in insect-proof containers reduces losses caused by these pests.

Heliothis armigera

Insecticide use. We are becoming increasingly concerned that the *Heliothis* populations in some areas of India seem to become more and more resistant to several of the commonly used insecticides. Earlier, our collaboration with the

Overseas Development Natural Resources Institute (ODNRI) showed that *Heliothis* larvae collected at ICRISAT Center were 70 times more resistant to DDT than a control, laboratory-reared culture. Research at the Indian Agricultural Research Institute (IARI) has also indicated that *Heliothis* is becoming resistant to other insecticides.

We have successfully used endosulfan for *Heliothis* control at ICRISAT Center over the last 10 years, and ODNRI found that larvae collected from ICRISAT were as susceptible to this insecticide as their control laboratory culture. However, this year, we were not very successful in controlling *Heliothis* with endosulfan, and so have submitted new samples of the local *Heliothis* populations for tests. Even more ominously, at the end of 1987 we received reports from farmers in Andhra Pradesh that they were unable to control *Heliothis* larvae on their cotton crops, even with heavier than recommended doses of locally available insecticides, including synthetic pyrethroids. This apparent resistance to synthetic pyrethroids was not expected so soon, for these insecticides have only been widely available in this area for 2 or 3 years and they have not been extensively used on *Heliothis*-prone crops other than cotton. However, similar rapid development of resistance to synthetic pyrethroids occurred in Australia a few years ago. Such developments make our search for alternative means of *Heliothis* management even more important and urgent.

Collaboration with ODNRI . This year, the Tropical Development and Research Institute (TDRI) changed its name to the Overseas Development Natural Resources Institute (ODNRI) and will soon move its base to Chatham in UK. These changes have not affected our close collaboration on *Heliothis* research. An ODNRI entomologist continued to work at ICRISAT Center throughout 1987 and several specialists visited us on short-term assignments, particularly to study the buildup and dispersal of the highly mobile *Heliothis* moth populations with the aid of radar, infra-red beam, and flight-mill equipment. With the apparent, recent enhancement of insecticide resistance in *Heliothis*, such studies have assumed greater importance.

Moth dispersal. In 1986/87, the ODNRI flight-mill and night-time observations (ICRISAT Annual Report 1986, p. 183-184) were successfully continued at ICRISAT Center and the data from these will soon be published. In addition, the short-range dispersal of moths emerging from a pigeonpea field was studied by recapturing moths labeled with the trace element, strontium. This was sprayed as an aqueous solution of $SrCl_2$ (at 10 kg ha^{-1}) on a pigeonpea crop infested with larvae, which also labeled emerging adults. During the period of emergence, all the moths captured in an array of light and pheromone traps placed in surrounding crops were analyzed at ODNRI for strontium using atomic absorption spectrophotometry. Emergence inside cages set over the crop enabled the estimation of the total adults emerged and the marking efficiency.

An estimated 48 000 moths, about half of those emerged, were unequivocally labeled above background Sr levels. The low proportion (9.8% ; 30 out of a total of 306 moths analyzed) of marked moths recaptured in a light trap in the sprayed field strongly suggested a rapid dispersal and dilution by immigrant moths: all trap catches indicated a substantial influx of immigrants at the time of local emergence. About the same number of marked moths were recaptured in a light trap in an adjacent, downwind pigeonpea field (4.3% ; 34 out of a total of 796 moths analyzed), but very few in adjacent chickpea and flowering sorghum fields. Some moths were recaptured in more distant pheromone traps in pigeonpea fields at a distance of 200-300 m, both upwind and downwind, and over various crops in farmers fields, 650 m downwind. Labeled moths were also recaptured in two pheromone traps over groundnut, 2 km upwind and 3 km away at right angles to the prevailing southeast winds.

From these and radar observations, it was apparent that moths dispersed predominantly with the wind between 3 and 40 m above ground and early in the night, although there was clearly some movement upwind or crosswind from the site of origin. Pigeonpea and groundnut were apparently preferred to sorghum and chickpea as destinations of labeled moths, even in adjacent fields.

Host-plant resistance. We continued intensive efforts to screen pigeonpea germplasm and breeding material for resistance to *Heliothis*. This year we gave increased attention to screening short-duration genotypes, because it is apparent that this group has the most potential for increased production, and it is not vulnerable to *Heliothis* attack. Earlier, we had considerable success selecting medium-duration genotypes that have useful levels of resistance to *Heliothis*. Several of these selections have been used in crosses to combine this resistance with other desirable plant characters.

We earlier reported that for chickpea, differences in the damage caused by *Heliothis* to our resistant and susceptible selections tended to diminish with increasing proximity to one another (ICRISAT Annual Report 1985, p. 151). Large plots of these selections showed much greater differences in pod damage than adjacent resistant and susceptible plants. In 1986, we grew resistant [ICPL 332 (ICP 1903)] and susceptible (ICP 1691) medium-duration pigeonpea genotypes in separate plots, in alternating rows, and as alternating plants within rows, as three treatment comparisons in a 3-replicate randomized block design trial (plot size 54 m^2). The mean of counts of *Heliothis* eggs and larvae, and percentages of pods damaged are summarized in Table 4. The differences between the two genotypes for damage and larvae $plant^{-1}$ were greatest where they were grown in separate plots. It is evident that much of the difference in susceptibility to this pest between these two genotypes is a result of differences in oviposition preferences, for nearly six times as many eggs were laid on ICP 1691 as on ICPL 332. However, the ratio of larvae counted on the susceptible and resistant genotypes was reduced from 5.4:1, when the genotypes were grown in separate plots to 1.6:1 when the plants were adjacent to one another. The most obvious explanation for this is that the larvae disperse from plant to plant, so obscuring the benefits of resistance due to ovipositional nonpreference. The ratios of pod damage percentage in the two genotypes were reduced even more drastically, for they fell from 2.3:1, when

Table 4. Mean numbers of eggs and larvae of *Heliothis armigera* counted per plant and percentage pod damage on *Heliothis*-resistant ICPL 332 (ICP 1903) and-susceptible (ICP 1691) medium-duration pigeonpea genotypes, when grown separately in 54-m^2 plots in alternate rows, and alternate plants within rows, ICRISAT Center, rainy season 1986.

	Genotypes grown in			
Genotype	Separate plots	Alternate rows	Alternate plants	SE[1]
Heliothis eggs $plant^{-1}$				
ICPL 332 (ICP 1903)	0.8	1.4	0.9	±0.31
ICP 1691	4.4	7.1	6.5	±1.61
Heliothis larvae $plant^{-1}$				
ICPL 332 (ICP 1903)	1.5	5.6	6.0	±0.69
ICP 1691	8.1	9.4	9.7	±0.59
Pods damaged (%)				
ICPL 332 (ICP 1903)	23.1	35.2	36.8	±2.11
ICP 1691	52.9	39.7	39.8	±4.10

1. Means are from four separate counts on 3 replicates from 14 plant samples.

the genotypes were in separate plots, to 1.1:1 when the susceptible and resistant plants were adjacent.

This experiment confirmed our earlier observations (ICRISAT Annual Report 1985, p. 192-193) that there is considerable dispersal of larvae from plant to plant. A larva can disperse by crawling from one plant to another where the branches touch or by dropping from a silk thread produced by a spinneret (Fig. 10). This creates a problem in selecting resistant plants from populations that are segregating for resistance/susceptibility. In chickpea, this problem can be overcome by sowing such populations at wide spacing, so the plants do not touch each other. However, in pigeonpea, wide-spaced plants grow to fill the available space and we would need a plant-to-plant spacing of more than 1 m to prevent the plants from touching each other at the podding stage. This would

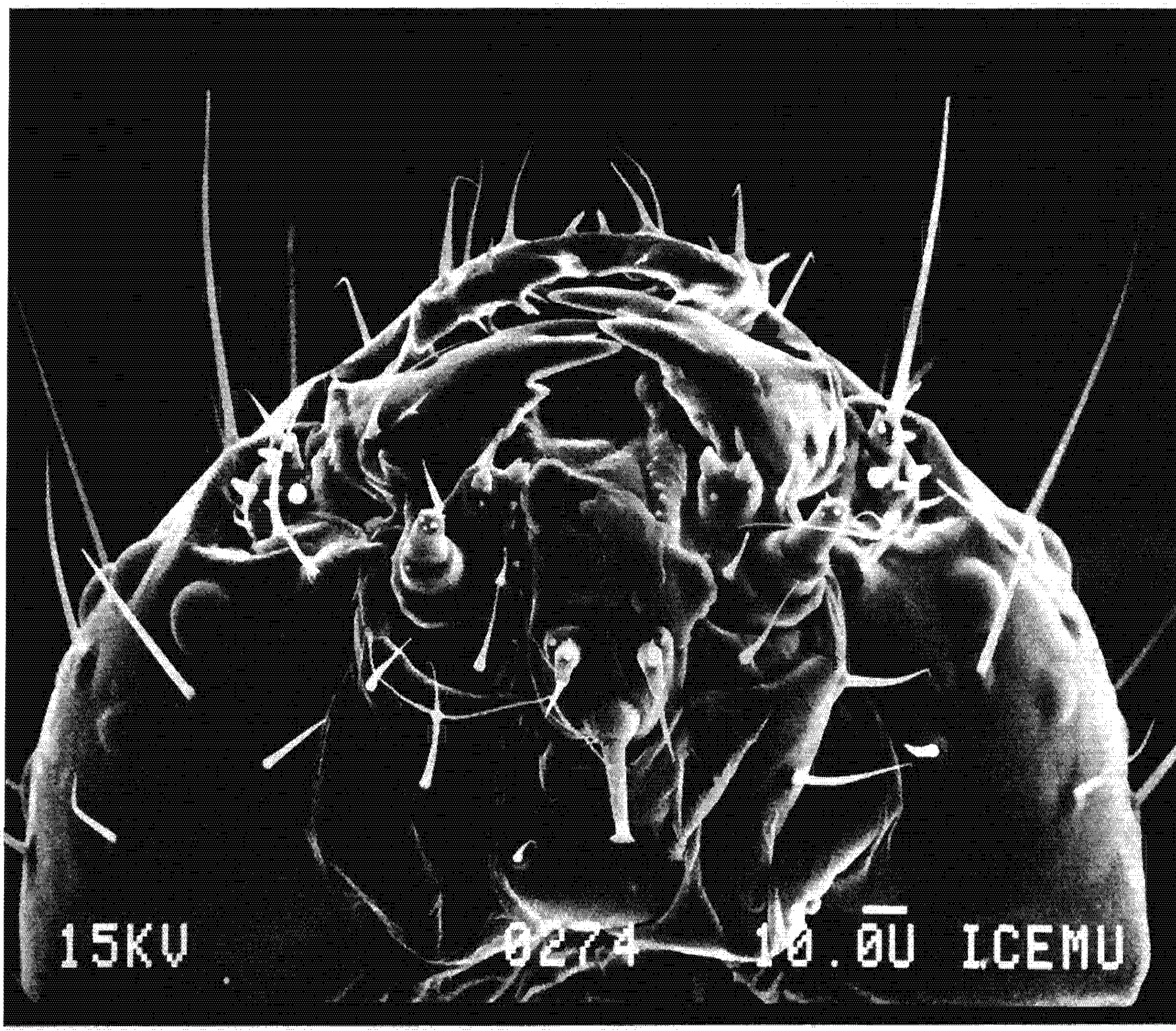


Figure 10. A ventral view of the head of a first-instar larva of *Heliothis armigera*. The tube-like structure at the lower center is the spinneret that produces a silk thread, from which the larva suspends itself when dropping from the plant.

greatly increase our costs, particularly as such a spacing would allow weed growth throughout the season.

Breeding for resistance. Last year (ICRISAT Annual Report 1986, p. 187-188) we reported the performance of some *Heliothis*-resistant lines. This year they remained resistant and produced good yields in a pesticide-free yield trial. On the basis of mean performance over 2 years, the selected lines produced similar or more yield than both the controls (C 11 and ICPL 332). C 11 produced 1.2 t ha^{-1} and ICPL 332 (resistant control) 1.3 t ha^{-1} (Table 5). The selected lines also have larger seeds than the resistant control (6.8 g 100 $seeds^{-1}$).

Podfly (*Melanagromyza obtusa*)

Population monitoring. We continued to research methods that will enable us to adequately monitor the populations of this insect. The egg, larval, and pupal stages all develop inside the pods with no external symptoms, so we can only monitor these by destructive sampling of pods. Such sampling is tedious, consumes many skilled man-hours, and wastes valuable plant materials. It is obviously desirable to develop methods of estimating populations through counts of the adult flies. We have searched, over several years, for attractants/traps that will enable us to catch and count the flies. In our early research we found that vertical white or transparent sticky traps held at, or just above, crop canopy levels caught the maximum number of podflies when compared with other trap types. Unfortunately, these traps also caught many other insects; the separation and counting of podflies was difficult and less than five flies $week^{-1}$, were being caught, even when podfly populations were known to be high.

We continued our attempts to find attractants for podfly adults. There has been no detectable pheromonal attraction to virgin females or to males. In the last 2 years, tests of a wide range of volatile chemicals showed that traps baited with ammonium sulphide, ammonium nitrate, ethanol, and molasses all attracted significantly more podfly adults than nonbaited control traps. However, the levels of catches in such traps are still not sufficient for monitoring purposes.

Table 5. Performance of some pigeonpea entries in insect-resistant pigeonpea lines yield trials grown in a pesticide-free field, ICRISAT Center, rainy seasons 1985 and 1986.

Entry	Time to 50% flowering (d)		Borer-damaged pods (%)		Grain yield (t ha^{-1})		Mean yield (t ha^{-1})
	1985	1986	1985	1986	1985	1986	
ICPL 84060	114	117	9.8	10.3	1.45	1.56	1.51
ICPX 76239-B-12-E1-EB-EB	113	117	8.7	12.7	1.47	1.53	1.50
ICPX 80321-E34-E1-EB	98	106	9.8	13.7	1.62	1.30	1.46
ICPX 80322-E1-E1-EB	109	116	8.5	14.7	1.37	1.23	1.30
Controls							
ICPL 332 (Resistant)	115	117	8.2	14.9	1.17	1.43	1.30
C 11 (Susceptible)	121	128	18.0	38.6	1.34	1.05	1.20
SE	±0.5	±0.7	±2.10	±2.7	±0.13	±0.08	
Trial mean[1]	116	112	17.5	14.7	1.2	1.3	
CV (%)	1	1	24	31	22	13	

1. Based on 30 entries in 1985 and 1 entry in 1986.

Table 6. Mean percentage of pods damaged by podfly (*Melanagromyza obtusa*), grain yield, and 100-seed mass in 25 F_4 progenies of single-plant selections from crosses intended to produce podfly-resistant pigeonpea, Gwalior, India, rainy season 1986.

Selections and controls	Podfly damage (%)	Grain yield (g $plant^{-1}$)	100-seed mass (g)
Mean of 25 F_4 progenies	18	133	8.5
Controls			
Gwalior 3	34	147	8.7
NP(WR) 15	22	117	7.5
SE	±4.8	±16	±0.21

Host-plant resistance. We intensified our screening for resistance to podfly at Gwalior, where the long-duration genotypes are severely attacked by this pest every year. This year we grew several trials and made further selections. One example of the progress is shown in Table 6, where the mean data from the progenies of 25 single-plant selections from F_4 products of podfly-resistant crosses are compared with the common controls. We earlier reported (ICRISAT Annual Report 1986, p. 188) that most of our podfly-resistant selections had small pods and seeds.

Plant Nutrition

We are studying the mineral nutrition of pigeonpea, particularly to identify any mineral nutrient limitations and to establish the most economic means of alleviating them. Experiments in which nitrogen fertilizer is added at different growth stages of ICPL 87 are being continued at different locations, so that we may better assess the scope for improving symbiotic nitrogen fixation in pigeonpea. Studies have been initiated to quantify the effect of nitrogen fixed by short-duration pigeonpea on following cereal crops. We have also been refining our procedure for conducting small plot trials to detect *Rhizobium*, nitrogen, or phosphorus limitations in particular fields. Work is progressing under a Government of Japan Special Project that is examining phosphorus nutrition and its interaction with soil-moisture availability in pigeonpea.

Effect of Nodule Damage by *Rivellia angulata* on Pigeonpea Growth and Yield

We previously reported (ICRISAT Annual Report 1986, p. 189) that we could quantify effects of nodule damage caused by *Rivellia* larvae by caging adult flies with pots growing pigeonpea. The infestation resulted in a large percentage of nodule damage. We present here (Table 7) the effects of infestation on reducing shoot dry mass (22% overall), seed dry mass (14%), and total N (29%) and P (18%) uptake. These effects are most severe on Vertisols low in N, where pigeonpea is more reliant on symbiosis for its N requirements. Considering the difficulties in using insecticides against this soil insect (see ICRISAT Annual Report 1986, p. 189), to alleviate this problem, we may have to rely on selection of genotypes with nodular tissue relatively unattractive to the larvae of *Rivellia angulata*.

Comparative Mycorrhizal Responses of Pigeonpea and Sorghum

A possible reason why pigeonpea responds less to P application than does sorghum (ICRISAT Annual Report 1986, p. 193-194), is its dependence on vesicular arbuscular mycorrhizal (VAM) associations that permit better utilization of available soil P (ICRISAT Annual Report, 1985, pp. 197-198). We compared the response of ICPL 87 and CSH 5 to mycorrhizal inoculation in a pot experiment using sterilized soil and different levels of P application. A Vertisol with

Table 7. Effect of artificial infestation of pot-grown pigeonpea (ICPL 87) plants with *Rivellia angulata* under three levels of soil nitrogen on plant growth and nutrient uptake at crop maturity, ICRISAT Center, rainy season 1986.

N level[1]	*R. angulata* infestation (+/-)	Shoot dry mass (g pot^{-1})	Root + nodule dry mass (g pot^{-1})	Seed dry mass (g pot^{-1})	Total N uptake (mg pot^{-1})	Total P uptake (mg pot^{-1})
Low N	+	2.8	0.65	0.02	40	6.1
	–	10.6	3.12	0.27	264	21.9
	Mean	6.7	1.88	0.15	152	14.0
Normal N	+	25.6	6.95	3.20	538	48.4
	–	30.2	8.44	4.03	636	53.6
	Mean	27.9	7.69	3.62	587	51.0
Added N	+	26.8	6.80	3.82	504	49.6
	–	29.7	8.16	3.90	615	51.9
	Mean	28.3	7.48	3.86	559	50.8
Average of low N + normal N + added N	+	18.4	4.80	2.35	361	34.7
	-	23.5	6.57	2.73	505	42.5
	Mean	21.0	5.69	2.54	433	38.6
SE (N levels)		±0.87	±0.23	±0.42	±18.0	±1.47
SE (Infestation levels)		±0.71	±0.19	±0.34	±14.7	±1.20
SE (Interaction)		±1.22	±0.33	±0.60	±25.5	±2.07

1. Low N = soil depleted of available N by first growing sorghum and then mixing in rice straw.
Normal N = soil left undisturbed.
Added N = soil with 20 kg ha^{-1} N as urea added at sowing of the test genotype, ICPL 87.

low available soil P status (1.5 mg kg^{-1} Olsen's P), and an Alfisol with low available soil P status (3.0 mg kg^{-1} Olsen's P) were used. Phosphorus treatments were applied as single superphosphate and a mixed culture of VAM fungi was inoculated. Inoculation of VAM enhanced pigeonpea growth over a wide range of P levels on both soils (Fig. 11). However, sorghum only responded to VAM inoculation at low P levels on the Vertisol; there was no response on the Alfisol. Without P addition, VAM inoculation enhanced plant growth provided the plants survived; on the Alfisol, sorghum seedlings in both inoculated and noninoculated treatments died. These data illustrate that pigeonpea is more dependant than sorghum on mycorrhizal associations, especially at low levels of available P. The survival of pigeonpea on the Alfisol without addition of VAM or P may be attributed to its special ability to utilize sparingly available P in the Alfisol.

Mechanism of P Absorption in Pigeonpea

Last year we found that pigeonpea could absorb P much better on an Alfisol than on a Vertisol but the reverse was true of chickpea, soybean, sorghum, pearl millet, and maize (ICRISAT Annual Report 1986, pp. 193-194). Alfisols have most of their P in an iron-bound form whereas in Vertisols, there is a greater proportion of calcium-bound P. Table 8 shows the various forms of P in Alfisols and Vertisols, and the available P that can be measured by commonly used extraction procedures. It may therefore be speculated that pigeonpea is better able to utilize iron-

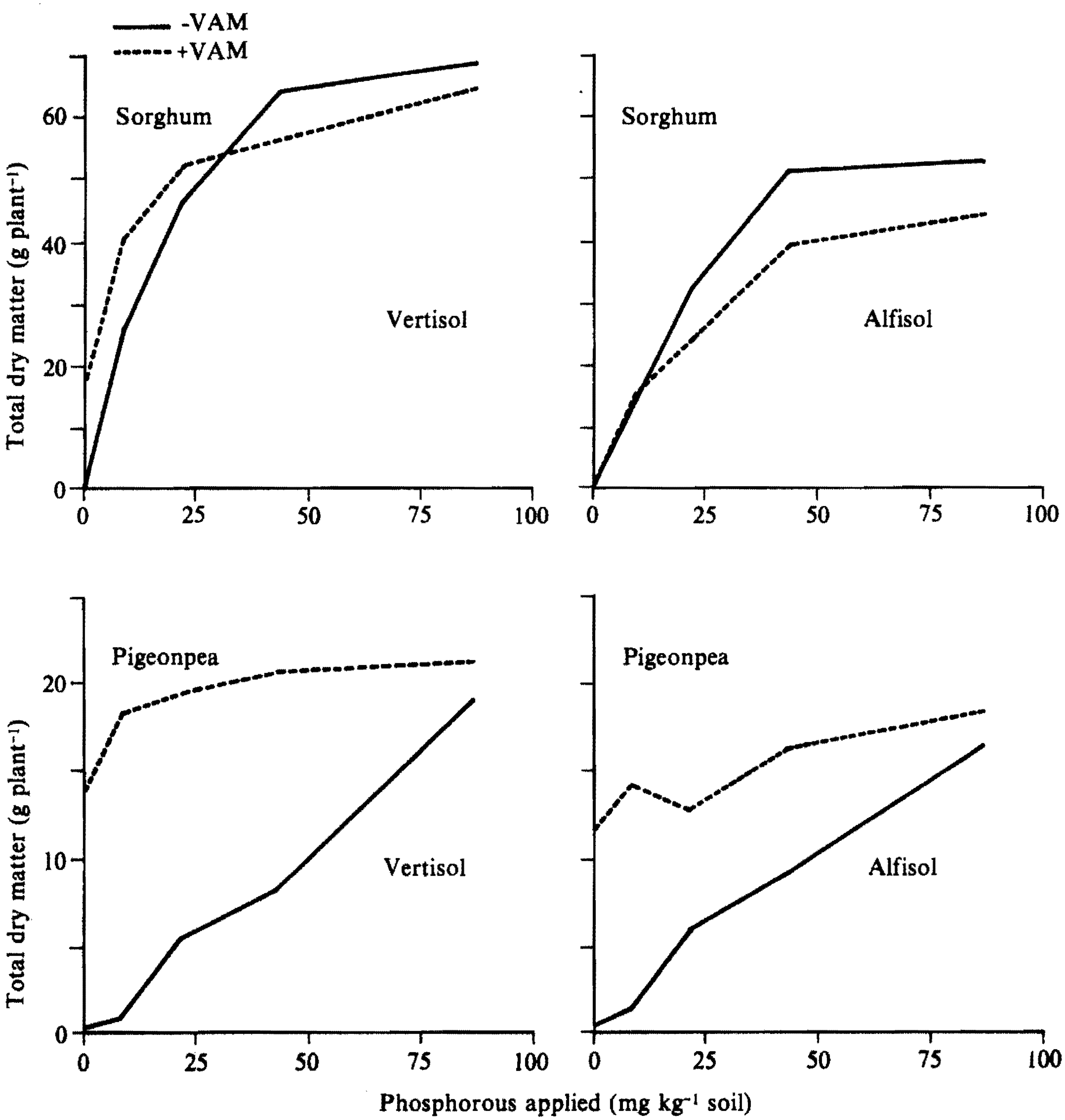


Figure 11. The effect of VAM fungi on the growth (total dry matter) of sorghum and pigeonpea in sterilized Vertisols and Alfisols in pots, ICRISAT Center, 1987.

Table 8. Phosphorus contents ($mg\ kg^{-1}$) of typical Alfisols and Vertisols without fertilizer at ICRISAT Center, 1987.

	Soil	
Form of P	Alfisol	Vertisol
Ca-P	3.8	52.8
Al-P	8.1	18.1
Fe-P	51.3	77.4
Olsen's P	4.1	0.7
Truog	7.6	48.3
Ca-lactate	2.3	10.8
Bray No.1	3.9	0.5
Bray No.2	6.0	20.2

bound P than other crops. This hypothesis was tested by comparing the response of a range of crops to aluminium phosphate (Al-P), dibasic calcium phosphate (Ca-P), and ferric phosphate (Fe-P) in a sand-vermiculite mixture flushed with a nutrient solution. Most species grew best with Ca-P, followed by Al-P, and then Fe-P. Pigeonpea grew equally well with each source but much better than the other species with Fe-P (Fig. 12). It thus appears that only pigeonpea of the crops tested has the capacity, to solubilize and utilize Fe-P. Characteristics of the root exudates of pigeonpea are therefore now being examined in detail.

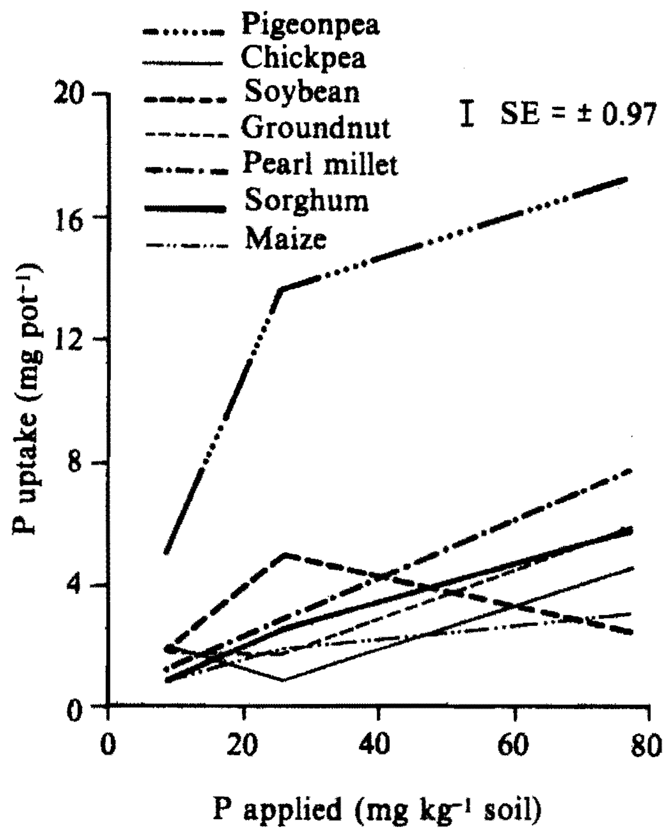


Figure 12. Effect of phosphorus ($mg\ kg^{-1}$ soil), applied as ferric phosphate on P uptake ($mg\ pot^{-1}$) by various crops in pots. Each crop was harvested just before it flowered at ICRISAT Center, 1987.

Grain and Food Quality

Chemical Composition

We determined the composition of two high-protein lines (HPL 8 and HPL 40) developed by the breeding program and compared the results with those of two control genotypes that have normal protein levels (C 11 and ICPL 211). Dhal protein content of the high-protein genotypes was significantly ($P < 0.01$) higher than in the controls and this was balanced by reduced levels of starch in high-protein lines (Table 9). Analysis of other constituents also revealed differences between these two groups.

Cooking Quality and Consumer Acceptance

We continued monitoring the cooking quality of advanced breeding lines. We determined the cooking quality of 18 genotypes grown at the Caribbean Agricultural Research Development Institute, Belize. Cooking time of whole-seed of these genotypes varied from 52 min to 76 min, with a mean of 61 min. Cooking time of dhal of these genotypes ranged between 22 and 43 min, with a mean of 29 min. Seed coat color had no relationship with cooking time of whole seed and dhal samples. However, we noted that these genotypes had lower protein values (15.7–18.9%) than normally expected.

ICPL 87 has become a widely adopted cultivar. Cooking time and consumer acceptance of

Table 9. Composition (%) of dhal made from high-protein (HPL) and control pigeonpeas, ICRISAT Center, 1986/87.

Genotype	Protein	Starch	Soluble sugars	Fat	Ash	Crude fiber
HPL 8	25.7	53.2	5.0	2.3	4.4	1.3
HPL 40	27.8	53.9	5.7	2.2	4.6	1.0
Controls						
C 11	22.6	57.8	5.1	2.6	4.4	1.1
ICPL 211	20.9	58.4	4.6	2.8	4.5	1.3
SE[1]	±0.09	±0.31	±0.06	±0.02	±0.03	±0.03

1. Based on two determinations for each genotype.

dhal of ICPL 87 grown at ICRISAT Center, Hisar, and Gwalior were determined and we observed no remarkable differences due to location. Analysis of high, normal, and low-protein lines grown at ICRISAT Center, Gwalior, S.K. Nagar, and Jalna showed that cooking time and protein content of whole seed varied significantly ($P < 0.01$) between lines irrespective of location (Table 10).

Biological Evaluation of Protein Quality

Protein digestibility is of increasing interest in grain legumes in general, and pigeonpea in particular. Pigeonpea generally has a lower protein digestibility than other grain legumes, even after cooking. We examined the effect of cooking on protein digestibility, biological value, and net

Table 10. Protein contents and cooking time of whole seed of high- (HPL), medium- (MPL), and low-protein (LPL) genotypes of pigeonpea, grown at four different locations, 1986/87.

	ICRISAT Center		Gwalior		S.K. Nagar		Jalna	
Genotype	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)
HPL 25	25.7	53	26.8	50	25.2	52	27.6	50
HPL 35	25.2	47	26.6	50	23.9	49	28.2	56
MPL 1	23.7	57	20.9	60	21.8	62	23.4	63
MPL 9	23.9	54	19.4	53	22.9	52	24.0	59
LPL 1	21.9	56	20.3	56	18.9	50	21.6	60
LPL 12	18.6	48	19.2	44	17.3	47	19.1	46
Controls								
C 11	20.9	55	19.8	51	19.4	54	21.6	54
BDN 1	21.0	54	19.9	54	19.5	50	21.0	52
SE[1]	±0.21	±0.54	±0.19	±0.32	±0.30	±1.12	±0.27	±1.32

1. Based on two determinations for each genotype.

protein digestibility by conducting rat-feeding trials on raw and cooked whole seed and dhal samples of C 11. Protein digestibility significantly ($P<0.01$) increased with cooking and the effect was more pronounced in whole seed than in dhal samples (Table 11). Interestingly, the biological value of the cooked samples decreased in both whole seed and dhal while net protein utilization increased; this may be due to an increase in the protein digestibility after cooking.

In order to study the effect of polyphenols on protein digestibility, we conducted a rat-feeding trial using pigeonpea cultivars that differed in seed coat color (C 11-brown and Nylon-white) and determined net protein utilization, protein digestibility, and biological value. Earlier we reported a direct relationship between seed coat color and total seed polyphenols in pigeonpea (Annual Report 1981, p 141). Net protein utilization of cooked whole seed of Nylon was significantly ($P>0.05$) higher than cooked whole seed of C 11. Dhal samples of these cultivars did not reveal such a difference, indicating that observed differences in the protein digestibility of whole seed might have been due to polyphenols contained in the seed coat.

A comparision of protein digestibility, net protein utilization (NPU), and utilizable protein (NPU × protein %) of dhal and whole seed samples of high-protein lines (HPL 40 and HPL 8) and control cultivars (C 11 and ICPL 211) showed no significant differences. However, utilizable protein of whole seed of high-protein lines was considerably higher (9.5%) than that of the control cultivars (7.3%).

Protein and Amino Acids

We determined the protein concentration in 1305 whole seed and 979 dhal samples obtained from the breeding program. Protein content of whole seed samples varied from 14.5 to 25.2% and of dhal samples from 19.9 to 34.7%. We also analyzed 1074 whole seed samples of germplasm accessions. Protein content of these accessions ranged between 16.0 and 26.8%. We also analyzed the high-protein genotypes for amino-acid composition and observed no large differences in the levels of lysine, cystine, and methionine, indicating that an increase in protein content need not adversely affect the protein quality (Table 12).

Vegetable Pigeonpea

We analyzed green and mature seed samples of

Table 11. Effect of cooking on biological value, protein digestibility, and net protein utilization in pigeonpea C 11, ICRISAT Center, 1986/87.

Treatment	Food consumed (g)	Biological value (%)	True protein digestibility (%)	Net protein utilization (%)
Whole seed				
Raw	44.2	70.5	61.1	43.1
Cooked	41.0	64.7	77.8	50.3
SE[1]	±3.32	±2.05	±1.13	±1.80
Dhal				
Raw	41.9	77.7	71.0	55.2
Cooked	44.7	69.6	83.0	57.8
SE[1]	±1.87	±1.37	±1.60	±1.63

1. Based on five determinations for each treatment.

Table 12. Protein contents (%) and essential amino acid [g (100g)$^{-1}$ protein] contents of high-protein (HPL) and control pigeonpea cultivars, ICRISAT Center, 1986/1987.[1]

Genotype	Protein (%)	Lysine	Histidine	Threonine	Cystine	Methionine
		[g (100g)$^{-1}$ protein]				
HPL 8	26.9	6.3	3.7	3.4	0.9	1.2
HPL 40	29.1	6.6	3.7	3.3	0.9	1.1
Controls						
C 11	23.6	6.4	3.6	3.4	0.8	1.2
ICPL 211	21.9	6.5	3.6	3.2	0.8	1.2
SE[2]		±0.11	±0.03	±0.07	±0.01	±0.02

1. Analysis of defatted dhal samples using amino-acid analyzer.
2. Based on two determinations for each genotype.

45 vegetable pigeonpeas for protein, soluble sugars, and crude fiber contents; important factors in their utilization. Protein, soluble sugars, and crude fiber contents of green seeds were considerably higher than in mature seeds in some genotypes, in others mature seeds contained more sugar than green seeds. There was no correlation between green and mature seeds with respect to protein, soluble sugars, and crude fiber content for all the genotypes tested.

There is usually a 3–4 day gap between the date of harvesting of green pods for vegetable purposes and the time they are eaten. In order to assess the changes in quality traits during this period, we studied the effect of storage time on cooking quality. Green pods were harvested and

Table 13. Effect of storage time on cooking quality of vegetable pigeonpea (Nylon) stored at two different temperatures, ICRISAT Center, rainy season 1986/87[1].

	Room temperature (25° C)				Cold-room temperature (5° C)			
			Texture (hardness)[2]				Texture (hardness)[2]	
Storage time (d)	Moisture (%)	Cooking time (min)	Raw	Boiled (10 min)	Moisture (%)	Cooking time (min)	Raw	Boiled (10 min)
0	63.7	13	9.88	3.75	63.7	-[3]	-	-
1	61.6	15	12.28	4.66	61.6	13	10.85	4.05
2	61.0	15	12.85	4.66	61.1	13	11.65	4.19
3	59.7	16	16.05	5.05	60.9	13	12.52	4.43
4	59.6	18	-	7.36	60.7	15	13.68	4.71
SE	±0.56	±0.24	±0.84	±0.43	±1.06	±0.3	±0.34	±0.18

1. Pods were harvested at the vegetable stage and stored at two different temperatures up to 4 days.
2. Peak area (cm^2) measured using an extrusion cell in Instron Food Tester®.
3. – = Not determined.

separately stored at 5 and 25°C. After storage, the pods were shelled and the moisture content, cooking time, and texture (hardness) of peas was determined. Storage at room temperature increased the cooking time of green peas and this observation was substantiated by the results on texture (hardness) (Table 13). However, it was observed that storage at low temperature for up to 3 days did not cause any noticeable changes in cooking quality.

Plant Improvement

Short-duration Pigeonpea

We have emphasized improvement of short-duration pigeonpeas (maturing in 90–150 DAS) to suit different cropping systems. Stability of production is sought by incorporating resistance to major diseases, low susceptibility to pod borers, and superior mean yield over a range of growing conditions.

We identified superior lines in all the three major phenological types in the short-duration group (I. Prabhat group, II. UPAS 120 group, and III. T 21 group). ICPL 84023 (Prabhat group) flowered in 55 days and matured in 90 days at ICRISAT Center, and at Hisar, it flowered in 60 days and matured in 100 days. At three sowing dates at Hisar (April, June, and July 1986) it yielded 3.0, 2.0, and 2.4 t ha^{-1}, compared with 2.5, 2.1, and 1.7 t ha^{-1} for ICPL 4 (Prabhat). It had larger seeds, 8.2 g (100 seeds)$^{-1}$ than ICPL 4, 6.6 g (100 seeds)$^{-1}$. This line has been selected for AICPIP multilocational trials in 1987. Other lines in this group that are superior in seed size and yield to Prabhat were identified for further evaluation. These are; ICPL 86005, 86010, 87092, 87093, 87094, 87095, and 87103. All these lines flowered between 53 and 65 days and matured in less than 110 days at Hisar, had seed masses of 9 to 13 g (100 seeds)$^{-1}$, and mean yield of over 3 t ha^{-1}, compared to 6.5 g (100 seeds)$^{-1}$ and a yield of about 2 t ha^{-1} of ICPL 4 (Prabhat). This is a significant step forward in yield and seed size improvement in the extra short-duration group.

This phenological group is relatively insensitive to photoperiod and temperature variations, so much so that some genotypes were successfully grown from the equator to 40° N and 48° S latitudes. The availability of these genotypes creates a potential for commercial pigeonpea production in nontraditional growing areas.

We tested short-duration lines for insensitivity to photoperiod under extended light (16 h) provided by 100-W incandescent bulbs under field conditions. The test lines could be classified into two response groups; the less-sensitive group where flowering was delayed by extending the photoperiod by about 20 days, and the more-sensitive group where flowering was delayed by 30–40 days (Table 14). This observation indicates that all short-duration genotypes may not adapt to higher latitudes and that only less-sensitive types should be tested at such locations.

To observe responses to higher temperatures (maximum temperatures around 40° C), we grew 127 short-duration genotypes in the 1987 summer season at ICRISAT Center. Interestingly, genotypic differences in response to high temperatures were similar to their response to extended daylength. Mean days to 50% flowering was 66 days and when sown on 18 February, the lines ICPL 83006, 84023, 85012, 85043, and 86018 recorded yields of 0.7–1.0 t ha^{-1}.

We continued our efforts to develop superior lines in the UPAS 120 group, in which ICPL 87 has officially been released in peninsular India (ICRISAT Annual Report 1986, p 198) and ICPL 151 identified for multiple cropping with irrigated wheat in northern and central India. Four determinate advanced lines that were significantly higher in yield than ICPL 151, and indeterminate controls (H77-216/UPAS 120) in different advanced-line tests at Hisar were identified for further evaluation (Table 15). Three indeterminate advanced lines, having significantly higher yields and larger seeds than UPAS 120 in different advanced-line tests at Hisar, were also identified for further evaluation (Table 15). In the indeterminate group, all the released cultivars have small seeds, 6-8 g (100 seed)$^{-1}$. However, the seed size in the above selected lines ranged from 9.1 to 12.7 g (100 seeds)$^{-1}$.

Table 14. Mean days to flowering of some extra-short-duration pigeonpea lines under normal and extended (16-h) photoperiods, ICRISAT Center, rainy seasons 1986 and 1987.

	1986			1987		
Lines	Normal daylength	Extended daylength	Difference	Normal daylength	Extended daylength	Difference
Less-sensitive group						
ICPL 85010	53 (± 0.4)[1]	74 (± 2.0)	21	65 (± 1.0)	82 (± 3.0)	17
ICPL 85024	51 (± 0.3)	70 (± 1.5)	19	62 (± 0.7)	77 (± 2.6)	15
ICPL 316	53 (± 0.4)	74 (± 2.8)	21	57 (± 0.8)	73 (± 1.6)	16
Mean	52.3	72.7	20.3	61.3	77.3	16.0
More-sensitive group						
ICPL 84019	52 (± 0.4)	87 (± 4.5)	35	57 (± 1.1)	90 (± 2.9)	33
ICPL 85043	53 (± 0.3)	81 (± 1.1)	28	62 (± 1.0)	97 (± 2.1)	35
ICPL 86001	52 (± 0.5))	83 (± 1.5)	31	56 (± 1.0)	89 (± 2.5)	33
ICPL 86003	53 (± 0.4)	90 (± 2.2)	37	57 (± 1.0)	99 (± 1.9)	42
QPL 94	53 (± 0.4)	96 (± 2.6)	43	58 (± 1.1)	93 (± 2.3)	35
QPL 137	54 (± 0.6)	84 (± 1.3)	30	62 (± 1.1)	98 (± 3.1)	36
Mean	52.8	86.8	34.0	58.6	94.3	35.7

1. Values in parentheses are standard errors (SEs).

To develop short-duration white-seeded lines similar to ICPL 87, we had initiated a backcross program in 1984 using ICPL 289 and ICPL 83023 as white-seeded donors. In the 1987 rainy season, selected white-seeded BC_1F_4 progenies were tested with ICPL 87 for overall agronomic performance. White-seeded lines with other plant and seed characters similar to those of ICPL 87, were selected for multilocational tests. Their performance is shown in Table 16.

In the T 21 group (about 75 days to 50% flowering), a line (ICPL 83024) was identified for inclusion in the AICPIP multilocational trials in 1987. This line has a seed mass of over 17 g (100 seeds)$^{-1}$, as against 7.0 g (100 seeds)$^{-1}$ for T. 21. It is the first determinate line in this group to enter the All India Coordinated trials, and has also performed well in Thailand. To identify better genotypes in the T 21 group, we evaluated the collection available with the Genetic Resources Unit (GRU) in six growing conditions (on Alfisols and Vertisols, normal and delayed sowing, and under rainfed and irrigated conditions) at ICRISAT Center in 1986. On the basis of mean performance over the various growing conditions, we selected ICP 7100, 7104, 7457, and 3251 for further testing.

Hybrids

The short-duration pigeonpea hybrid ICPH 8 has shown a distinct yield advantage in many yield trials (ICRISAT Annual Report, 1985, pp. 205-206; ICRISAT Annual Report, 1986. p. 200). In the AICPIP Extra-early Arhar Coordinated Trial (EACT), this hybrid had a yield advantage of 44% over the national control, UPAS 120, despite the severe drought experienced during the cropping season.

During 1986, a total of 144 new short-duration hybrids were tested. Of these, 33 exhibited more than 20% yield advantage over the best control

Table 15. Performance of pigeonpea lines superior to ICPL 151 in advanced line tests at Hisar, rainy seasons 1986, 1987.

Lines	Dry grain yield (t ha^{-1})		Dry stem yield (t ha^{-1}) air dried		Time to 50% flowering (d)		Time to maturity (d)		100 -seed mass (g)	Seed color[1]
	1986	1987	1986	1987	1986	1987	1986	1987		
Determinate										
ICPL 87109	3.06	4.25	17.80	12.82	75	77	121	139	13.8	C
ICPL 87107	3.00	4.06	14.70	11.34	73	72	114	141	11.6	C
Controls										
ICPL 151	2.81	2.93	12.90	7.68	61	67	108	128	12.1	C
H77-216/ UPAS 120[2]	2.68	2.87	13.80	12.41	79	85	110	122	8.3	B
SE	±0.22	±0.24	±2.00	±0.72	±0.4	±0.7	±0.7	±0.7	±0.16	
Trial mean (Entries)	2.60 (16)	3.01 (18)	15.10	9.43	72	71	121	134	11.9	-
CV (%)	17	14	13	13	1	2	1	1	3	
ICPL 86012	3.56	4.08	11.70	8.06	62	68	111	129	12.6	C
Controls										
ICPL 151	2.67	3.22	9.60	7.92	60	66	101	122	11.8	C
H77-216/ UPAS 120[2]	2.99	3.11	12.40	10.45	79	85	111	128	7.9	B
SE	±0.18	±0.16	±0.58	±0.72	±0.6	±0.6	±0.5	±0.6	±0.15	
Trial mean (Entries)	2.76 (16)	3.30 (18)	8.60	8.31	66	70	108	125	10.7	-
CV (%)	14	8	14	15	2	1	1	1	3	
ICPL 85027	3.44	3.55	14.00	9.63	75	77	107	130	12.4	C
Controls										
ICPL 151	2.60	2.94	8.10	7.68	63	67	107	128	12.1	C
H77-216/ UPAS 120[2]	2.45	2.87	9.90	12.41	75	85	109	122	8.3	B
SE	±0.24	±0.24	±1.00	±0.72	±0.8	±0.7	±1.6	±0.7	±0.35	
Trial mean (Entries)	2.72 (16)	3.01 (18)	11.00	9.43	68	71	112	134	11.3	-
CV (%)	15	14	16	13	2	2	3	1	5	

Continued.

Table 15. *Continued.*

Lines	Dry grain yield (t ha^{-1}) 1986	Dry grain yield (t ha^{-1}) 1987	Dry stem yield (t ha^{-1}) air dried 1986	Dry stem yield (t ha^{-1}) air dried 1987	Time to 50% flowering (d) 1986	Time to 50% flowering (d) 1987	Time to maturity (d) 1986	Time to maturity (d) 1987	100 -seed mass (g)	Seed color[1]
Indeterminate										
ICPL 87114	3.31	3.65	12.20	8.87	82	87	114	139	10.0	C
Control										
UPAS 120	2.46	2.86	11.70	11.47	78	93	122	138	8.0	B
SE	±0.22	±0.28	±0.70	±0.86	±0.4	±0.8	±0.7	±0.5	±0.24	
Trial mean (Entries)	2.61 (16)	2.86 (18)	9.50	8.92	72	89	108	137	8.7	-
CV (%)	17	17	15	17	1	2	1	1	6	
ICPL 87115	3.21	4.07	13.50	10.56	83	89	127	139	9.1	B
Control										
UPAS 120	2.37	2.86	12.00	11.48	82	93	127	138	8.3	B
SE	±0.24	±0.28	±0.80	±0.86	±0.7	±0.8	±0.8	±0.5	±0.30	
Trial mean (Entries)	2.23 (16)	2.86 (18)	11.60	8.91 (18)	79	89	114	137	9.9	-
CV (%)	23	17	14	17	2	2	1	1	5	
ICPL 85058	3.32	3.36	18.40	8.52	83	96	131	142	12.7	C
Control										
UPAS 120	2.52	2.86	13.60	11.48	80	93	108	138	8.6	B
SE	±0.24	±0.28	±0.94	±0.86	±0.8	±0.8	±0.7	±0.5	±0.30	
Trial mean (Entries)	2.73 (16)	2.86 (18)	12.60	8.91	72	89	110	137	9.8	-
CV (%)	18	17	16	17	2	2	1	1	6	

1. Seed color, B = Brown; C = Cream.
2. UPAS 120 in 1986 and H77-216 in 1987.

cultivar. The performance of some of the outstanding new hybrids is summarized in Table 17. Two determinate hybrids, ICPH 73 and ICPH 61, yielded about 3.5 t ha^{-1} in just over 100 days at Hisar. We plan to produce enough seed of the promising hybrids for further testing.

For farmers to accept hybrids, the cost of seed should be relatively low. In the absence of cytoplasmic male sterility in pigeonpea, various alternative hybrid seed production systems are being tested to produce hybrid seed at a low cost. Experiments at ICRISAT Center have shown that the cost of pigeonpea hybrid seed can be reduced substantially by exploiting its ratooning ability and perenniality. This can produce more than one harvest from the same plants within a year, removing the necessity to rogue fertiles from the male-sterile rows in subsequent crops.

Table 16. Performance of some white-seeded ICPL 87-type backcross pigeonpea progenies (BC_1F_4) at ICRISAT Center, rainy season 1987.

Entry	Time to 50% flowering (d)	Time to maturity (d)	100-seed mass (g)	Yield (t ha⁻¹)
(ICPL 87 × ICPL 289) × ICPL 87				
-2-4-B	70	121	10.1	3.25
-34-3-B	72	125	10.7	3.19
-20-4-B	73	124	9.3	3.00
-2-2-B	67	119	10.8	2.85
Controls				
ICPL 87	74	125	9.9	2.78
ICPL 289	63	115	10.5	1.66
SE	±2.0	±2.4	±0.21	±0.28
Trial mean (25 entries)	71	123	10.0	2.47
CV (%)	4	3	3	16
Efficiency (%)[1]	77	76	78	97
(ICPL 87 × ICPL 83023) × ICPL 87				
-27-5-B	74	125	10.9	2.71
-31-1-B	70	119	9.4	2.50
-31-3-B	74	123	9.8	2.48
-26-5-B	69	116	10.6	2.47
Control				
ICPL 87	73	121	9.7	2.41
SE	±0.9	±1.3	±0.24	±0.29
Trial mean (36 entries)	74	124	10.0	2.20
CV (%)	2	2	3	18
Efficiency (%)[1]	107	102	142	102

1. Efficiency of lattice design over randomized block design (RBD).

In 1986, from the crop sown on 16 July, as many as six harvests were made up to December 1987; this system can be further extended to the next cropping season.

Physiological Basis of Heterosis in a Short-duration Pigeonpea Hybrid

We compared the growth and yield characteristics of ICPH 8 and its parents, ICPL 161 and Male Sterile (MS) Prabhat, to determine the physiological basis of yield improvement in the hybrid. Growth analysis studies were conducted during the 1986/87 season at Hisar, Gwalior, and ICRISAT Center. The yield advantage of the hybrid was highest at Gwalior, where it yielded 76% more than the best parent (Table 18). The increased yield of the hybrid was primarily related to its increased biomass production, which was apparent from the early growth stages onwards (Fig. 13). The hybrid also had

Table 17. Performance of some new short-duration pigeonpea hybrids, Hisar, rainy season 1986.

Entry	Time to maturity (d)	Plant height (cm)	100-seed mass (g)	Grain yield (t ha^{-1})
Trial 1 (Indeterminate)				
ICPH 156	115	241	8.7	3.01
ICPH 169	114	233	8.5	3.00
ICPH 158	116	244	8.5	2.94
Control				
UPAS 120	113	197	8.8	2.46
SE	±1.3	16.7	±0.17	±0.33
Trial mean (16 entries)	115	235	8.7	2.62
CV (%)	1	6	4	26
Trial 2 (Indeterminate)				
ICPH 140	114	237	8.4	3.57
ICPH 138	116	228	8.7	3.22
ICPH 153	116	219	7.8	3.17
Control				
UPAS 120	117	202	8.4	2.49
SE	±1.3	±10.4	±0.16	±0.35
Trial mean (10 entries)	115	217	8.5	2.83
CV (%)	2	10	4	25
Trial 3 (Determinate)				
ICPH 73	104	160	7.5	3.57
ICPH 61	106	139	7.1	3.45
Controls				
Prabhat	103	138	5.9	1.45
ICPL 151	113	151	10.4	2.84
SE	±1.6	±14.0	±0.31	±0.36
Trial mean (14 entries)	107	151	8.6	2.27
CV (%)	2	13	5	22
Trial 4 (Determinate)				
ICPH 88	124	181	10.1	3.16
ICPH 106	116	187	8.7	3.09
ICPH 80	114	181	7.7	3.01
Controls				
Prabhat	112	174	6.4	1.95
ICPL 131	118	173	11.6	2.44
SE	±1.7	±3.5	±0.20	±0.30
Trial mean (16 entries)	117	179	9.8	2.4
CV (%)	3	4	4	25

Table 18. Growth parameters of the short-duration pigeonpea hybrid ICPH 8 and its parents ICPL 161 and MS Prabhat, Gwalior, rainy season 1986.

Growth parameter[1]	ICPH 8	ICPL 161	MS Prabhat	SE
Yield (t ha^{-1})	2.77	1.34	1.57	±0.26
Total dry matter (t ha^{-1})	13.62	9.23	9.86	±1.06
Harvest index (%)	19.9	14.4	16.1	±1.9
Pods m^{-2}	1170	590	930	±123
100-seed mass (g)	6.7	8.9	7.3	±0.35
Seeds pod^{-1}	3.6	2.5	2.4	±0.17

1. Values averaged over populations of 17, 33, and 66 plants m^{-2}.

a marginally better harvest index (Table 18). While the hybrid had smaller seeds than of its parents, it had more pods m^{-2} and seeds pod^{-1} (Table 18).

Vegetable Pigeonpea

In many parts of the semi-arid tropics, green pigeonpea seed is commonly used as a vegetable in the same way that green peas (*Pisum sativum*) are used. In general, pigeonpea lines with large pods and large sweet seeds are preferred as vegetables. In our breeding program, short-duration, relatively photoinsensitive, vegetable-type lines are being bred to produce green pods throughout the year. In the medium-duration group, our attempt is to develop high-yielding lines suitable for both vegetable and dry-seed production, and we have identified lines with good yield potential, large seeds, and tolerance to diseases (Table 19). ICPL 87048, which has larger seeds than the control C 11, has performed well for 3 years at ICRISAT Center (Table 20). This line is tolerant to wilt disease.

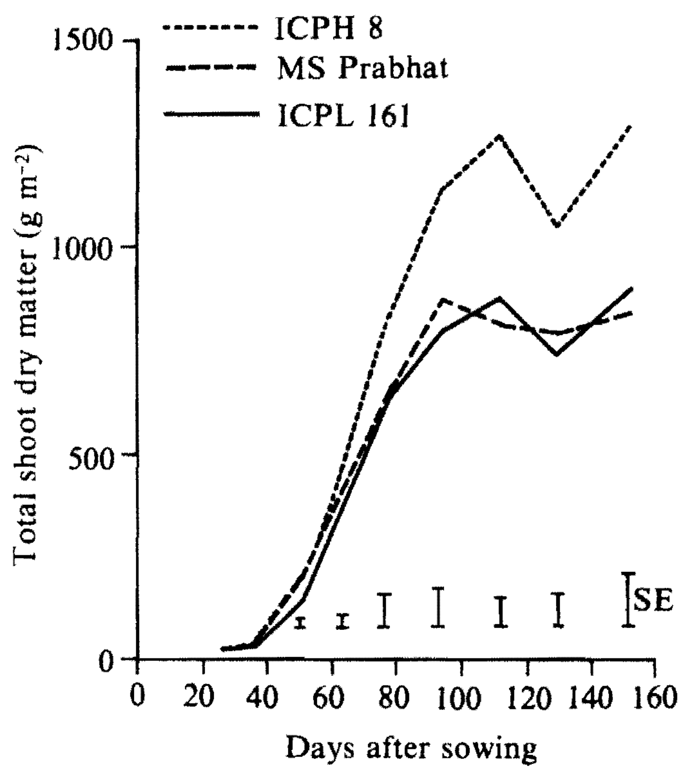


Figure 13. Total shoot dry matter (g m^{-2}) accumulation with time of pigeonpea hybrid ICPH 8 and its parents ICPL 161 and MS Prabhat grown at Gwalior, rainy season 1986.

Long-duration Pigeonpea

In the long-duration group, we continued to breed lines with resistance to diseases and insect pests so as to stabilize crop productivity. One advanced line, ICPL 366 continued to perform well in northern Madhya Pradesh with a 16% yield superiority over the control cultivar Gwalior 3 (Table 21). ICPL 366 has resistance to SM disease, which was in epidemic form in 1986 in the northeastern parts of India and the Terai area of Nepal. This line has been identified for

Table 19. Performance of promising medium-duration, vegetable-type pigeonpea lines, ICRISAT Center, rainy season 1986.

Entry	Time to 50% flowering (d)	Time to maturity (d)	Seeds pod^{-1}	100-seed mass (g)	Grain yield (t ha^{-1})	Reaction to:[1] Wilt	SM
ICPL 87048	127	177	3.9	13.0	2.04	T	S
ICPL 87049	128	173	4.3	14.9	1.75	R	R
ICPL 87051	131	179	4.1	14.6	1.60	T	R
ICPL 87052	129	177	4.3	14.4	1.57	S	T
Controls							
C 11	128	174	3.7	10.7	2.02	T	S
BDN 1	116	162	2.9	10.7	1.52	T	S
SE	±1.3	±2.0	±0.20	±0.39	±0.14		
Trial mean (16 entries)	128	176	4.0	13.4	1.52		
CV (%)	2	2	9	5	16		

1. R = resistant, T = tolerant, and S = susceptible.

on-farm trials in this region for the 1987 season. A SM tolerant line ICPL 8398 has also performed well in northern Madhya Pradesh (Table 21), with an average superiority of 10% over the control cultivar Gwalior 3.

We began evaluating medium- and long-duration pigeonpea genotypes with resistances to fusarium wilt and/or SM diseases, for perenniality and total biomass production for fuel, fodder, and grain. In 1986, 24 entries were sown at row and plant spacings of 120 × 30 cm on 4 August and 30 × 10 cm on 16 September. Dry mature pods were harvested in January and March 1987 and clippings of the top third of the plants were made for green fodder on 17 April, 25 May, and 13 July 1987. The trial will continue until 1989. The production recorded for these harvests is given in Table 22.

Appropriate Canopy Type for Long-duration Pigeonpea in an Intercrop

In India, long-duration pigeonpea is normally intercropped with a cereal. It is therefore necessary to understand the most suitable canopy type for intercropping, especially in view of the fact that breeding for improvement of long-duration pigeonpea is done in sole stands. Thus, six long-duration genotypes with either spreading (Gwalior 3, ICPL 360), semi-spreading (T 7, ICPL 366), or erect (Bahar, PDA 10) growth habits were compared as sole crops and as intercrops with the pearl millet genotype BJ 104. The experiment was conducted during 1986/87 at the ICRISAT Cooperative Research Station at Gwalior.

Intercropping significantly reduced the mean yield of pigeonpea by 10% and there were significant differences between pigeonpea genotypes (Table 23). However, the interaction between cropping system and genotype was not significant, suggesting that yield in the intercrop was not related to plant type. A similar result was also obtained from the same experiment conducted in the previous season.

ICPL 366 gave the highest yield of 2.4 t ha^{-1}, in both sole- and intercrops. It matured 20–36 days later than other genotypes, mainly because its podset was more delayed by the cool winter

Table 20. Performance of pigeonpea line ICPL 87048, ICRISAT Center, rainy seasons 1984-1986.

Entry	1984	1985	1986	Mean
Yield (t ha^{-1})				
ICPL 87048	2.65	1.50	2.04	2.06
Controls				
BDN 1	1.82	1.93	1.52	1.76
C 11	2.53	1.85	2.02	2.13
SE	±0.18	±0.93	±0.14	-
Trial mean (16 entries)	2.02	1.45	1.52	-
CV (%)	15	11	16	-
Time to 50% flowering (d)				
ICPL 87048	118	139	127	128
Controls				
BDN 1	110	122	116	116
C 11	118	136	128	127
SE	±0.9	±2.0	±1.3	-
Trial mean (16 entries)	115	13.4	127.6	-
CV (%)	1	3	2	-
100-seed mass (g)				
ICPL 87048	12.3	13.7	13.0	13.0
Controls				
BDN 1	10.5	10.3	10.7	10.5
C 11	9.9	10.6	10.7	10.4
SE	±0.37	±0.32	±0.39	-
Trial mean (16 entries)	11.9	12.78	13.35	-
CV (%)	5	4	5	-
Time to maturity (d)				
ICPL 87048	168	211	177	185
Controls				
BDN 1	162	180	162	168
C 11	172	194	174	180
SE	±2.4	±1.8	±2.0	-
Trial mean (16 entries)	170	197.7	175.8	-
CV (%)	2	2	2	-

Table 21. Comparative yield of two long-duration advanced pigeonpea lines over 5 years, Gwalior and Morena, 1982-1987.

Year	No. of trials	ICPL 366	Control (Gwalior 3)	SE	No. of trials	ICPL 8398	Control (Gwalior 3)	SE
1982/83	4	2.82	3.07	±0.10	2	3.30	2.85	±0.16
1983/84	5	2.71	2.38	±0.13	5	2.24	2.10	±0.11
1984/85	11	2.30	2.17	±0.07	5	2.33	2.54	±0.10
1985/86	8	1.97	1.27	±0.07	7	1.30	1.29	±0.08
1986/87	8	1.99	1.25	±0.09	5	1.80	1.20	±0.12
Mean		2.36	2.03			2.19	2.00	

Table 22. Performance of top entries in a trial of perennial pigeonpea, ICRISAT Center, 1986/87.

	Dry grain yield (t ha^{-1}): total of 2 harvests		Green fodder yield (t ha^{-1}): total of 3 harvests	
Entry	Wide[1] spacing	Close[2] spacing	Wide spacing	Close spacing
ICPL 8398	2.38	3.09	10.54	15.59
ICP 8860	2.29	2.24	7.44	10.51
MA 95-2	2.19	2.90	12.73	12.85
ICP 11291	1.96	2.52	12.48	14.74
T 17	2.15	2.60	9.71	10.67
C 11	2.13	2.50	10.45	13.02
SE	±0.17	±0.18	±0.85	±0.91
Trial mean	1.56	2.07	8.69	10.58
CV (%)	15	13	14	12

1. Wide spacing = 120 × 30 cm.
2. Close spacing = 130 × 10 cm.

weather. It therefore had a longer period of reproductive growth during favorable weather conditions. Such factors as this may be more important than canopy structure in determining the yield of long-duration pigeonpeas.

Cooperative Activities

Asian Grain Legumes Network (AGLN)

The AGLN was established in 1986 as a result of the recommendation made by the Consultative Group Meeting for Asian Regional Research on Grain Legumes in 1983 (ICRISAT Annual Report 1983, p.148), and subsequently ratified by the Review and Planning Meeting on Grain Legumes in 1985 (ICRISAT Annual Report 1985, p.173). Its broad objective is to facilitate testing and dissemination of appropriate varieties and technologies to increase production of groundnut, chickpea, and pigeonpea in the Asian region, including the host country, India with which ICRISAT has a special relationship in-

Table 23. Effect of intercropping on grain yield (t ha^{-1}) of six long-duration pigeonpea genotypes, Gwalior, 1986/87.

Genotype	Sole crop	Intercrop[1]
Gwalior 3	2.13	1.80
ICPL 360	2.13	1.92
T 7	2.13	1.78
ICPL 366	2.44	2.41
Bahar	1.75	1.50
PDA 10	1.53	1.51
SE	±0.145[2]	
Mean	2.02	1.82
SE	±0.042	

1. Intercropped with pearl millet BJ 104.
2. Except when comparing means within a cropping treatment, ± 0.152.

volving many collaborative studies with ICAR scientists.

The AGLN coordinator had discussions with donor agencies and institutions in the region, notably the ACIAR, Economic and Social Commission for Asia and the Pacific (ESCAP) Regional Coordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber Crops in the Humid Tropics of Asia and the Pacific (CGPRT Center), the Canadian International Development Agency (CIDA), the European Economic Community (EEC), FAO, the International Development Research Centre (IDRC), the United States Agency for International Development (USAID), and Winrock International. The discussions centered around coordinating and strengthening relationships between donor agencies and ICRISAT to avoid duplication of efforts.

Memoranda of Understanding

Although ICRISAT has been collaborating with many Asian countries in the past, Memoranda of Understanding (MOUs) were signed to facilitate the movement of material and scientists for collaborative research activities. During April, the Director General signed an MOU with the Minister for Agricultural Development and Research, Sri Lanka; and in December, another with the Secretary of Agriculture, His Majesty's Government of Nepal. The MOU's with Indonesia and the People's Republic of China were revised, and are expected to be signed early in 1988. There are already MOU's with Bangladesh, Burma, Pakistan, the Philippines, and Thailand. During the year initial contacts were established with Afghanistan, the Democratic People's Republic of Korea, and Vietnam.

Work Plans

Meetings were held in Bangladesh, Burma, Nepal, and Sri Lanka to develop detailed yearly Work Plans bearing in mind constraints to yield, and research needs in each country, and their capabilities. Requirements for training and special research projects have also been identified. The Asian Development Bank (ADB) has agreed to provide financial support to these four south Asian countries to enable the implementation of their Work Plans and each country has identified coordinator(s) who will liaise with AGLN. A special Work Plan for Pakistan with emphasis on pigeonpea, and tentative work plans for Indonesia, People's Republic of China, the Philippines, and Thailand have been developed.

Other Activities

ICRISAT scientists undertook crop surveys, monitored international and national trials, and participated in germplasm collection as part of agreed Work Plans.

Two pigeonpea scientists monitored trials in Burma, and held discussions on the potential of short-duration pigeonpeas in the semi-arid regions of Burma. Tentative plans were made to conduct large-scale demonstration tests next season.

AGLN staff attended the review and planning meetings of ACIAR on pigeonpea and groundnut in Indonesia and Thailand to develop joint programs on these crops. Some of these activities are supported by funds from ADAB and ACIAR.

The first issue of an AGLN Cooperators Report was distributed, it covers the activities of the AGLN since its inception and summarizes the Work Plans developed for each country. The report also gives details of trials available from ICRISAT; and a list of future workshops and meetings to be organized by ICRISAT.

AGLN is supporting the posting of a chickpea breeder in Nepal for one year to help the Grain Legume Improvement Program (GLIP). He will assist GLIP in research on chickpea and pigeonpea improvement.

As a part of exchange of visits, two scientists each from Sri Lanka and Nepal and one from Bangladesh visited ICRISAT to become acquainted with ongoing research and to discuss collaborative research with the concerned ICRISAT scientists.

AGLN was also involved in various workshops and meetings. These are dealt with under 'Workshops, Conferences, and Seminars' below.

National and International Trials

As in previous years, we offered the Pigeonpea Observation Nursery (PON) and adaptation yield trials to cooperators in Asia, Africa, and the Americas. We also supplied seed material in response to specific requests. The results are summarized in Table 24.

We supplied perennial pigeonpea seed for testing in the shifting-cultivation systems of the northeast hilly regions of India. This cooperative program with AICPIP was initiated in early 1987. Our agronomists and breeders initiated a cooperative program with Andhra Pradesh Agricultural University (APAU) (India), to develop production systems incorporating pigeonpea in rice fallows in the coastal areas.

Regional adaptation trials of short-duration pigeonpea in eastern Africa were initiated with cooperators in Kenya, Malawi, and Tanzania at locations near the equator ranging in altitude from 50 m to nearly 2000 m.

Arhar Regional Trial (ART). In 1986, the Arhar Regional Trial was conducted at seven Vertisol and four Alfisol locations in Andhra Pradesh, Karnataka, and Maharashtra states in India. On the basis of mean performance at three locations with CV (%) up to 20; ICPL 270 had the highest mean yield in 1986 compared with all the controls. On the basis of the mean of two Alfisol locations also with CV (%) up to 20, ICPL 270 was the highest-yielding entry. This line has been tested for 4 years in this trial and it consistently outyielded the control varieties (Table 25). This line is now in the 2nd year of on-farm/adaptive trials in the states of Andhra Pradesh and Karnataka and is likely to be released as a variety.

Introducing Pigeonpea into Rice Fallows

In 1986/87, ICRISAT breeders and agronomists began collaborative studies with Andhra Pradesh Agricultural University, on screening pigeonpea genotypes for suitability to rice fallows of the Krishna Delta region of coastal Andhra Pradesh. Normally, these rice fallows are sown to black gram (*Vigna mungo*) and farmers can achieve good yields, of the order of 2 t ha^{-1}, with this pulse crop. Our aim is to introduce pigeonpea as a mixture with black gram and obtain a pigeonpea harvest in addition to that of the black gram. The growth patterns of these two crops are such that they should not seriously compete with each other.

Fifty genotypes ranging from short- to long-duration were compared, as sole stands and as intercrops with black gram at the normal sowing time (17 Nov 1986), and as a sole crop at a later sowing time (25 Nov 1986). Despite an unusually dry growing season as well as heavy *Heliothis armigera* infestation (even with insecticide application), genotypes that matured at an optimum time (in early March, soon after the harvest of black gram) were identified, and showed promising yield potential (0.8–1.0 t ha^{-1}, 2-row plots). These included the short-duration lines;

Table 24. Performance of some pigeonpea entries in international trials, 1985-1987.

Country/ Location	Performance of promising entries: Date sown	Entry	Time to maturity (d)	Yield (t ha⁻¹)	Trial mean (entries)	SE	CV (%)
Malawi							
Makoka	28 Nov 1986	ICPL 269	103	1.36	1.07 (6)	±0.10	14
		ICPL 87	99	1.15			
Chitala	17 Dec 1986	ICPL 87	108	2.22	1.52 (5)	±0.23	21
		ICPL 146	107	1.92			
Tanzania							
Ilonga	6 Feb 1987	ICPL 87	118	2.08	1.75 (6)	±0.17	17
		ICPL 146	116	2.07			
Guyana							
Georgetown	25 Nov 1986	ICPL 87006	100	1.54	0.99 (10)	±0.24	43
		ICPL 87002	100	1.26			
Mexico							
Vera Cruz	17 Jul 1985	ICPL 365	-[1]	4.40	2.42 (24)	±0.33	19
		ICP 7035	-	3.57			
		ICPL 87	-	2.94			
Thailand							
Khon Kaen	11 Aug 1986	ICPL 8324	111	2.02	1.57 (18)	±0.09	12
		ICPL 85033	111	2.08			
Taphra	5 Aug 1986	ICPL 8324	109	2.14	1.27 (18)	±0.09	13
		ICPL 85033	110	1.62			
The Philippines							
Batac	Oct 1986	ICPL 87	120	3.70	3.0 (10)	-	18
		ICPL 151	109	3.70			
		ICPL 8324	120	3.60			
Ilocos Norte	Oct 1986	ICPL 85016	109	3.70	2.8 (16)	-	10
		ICPL 151	106	3.30			
		ICPL 85014	104	3.30			
Bangladesh							
Ishurdi	29 Sep 1985	ICPL 6	179	2.86	1.9 (20)	±0.25	21
		ICPL 87	178	2.83			
		ICPL 4	180	2.80			
Pabna	6 Oct 1985	ICPL 6	189	1.78	1.0 (20)	±0.10	17
		ICPL 292	187	1.72			
		ICPL 186	187	1.70			
		ICPL 87	188	1.52			

1. - = Data not available.

Table 25. Mean performance of ICPL 270 in Arhar Regional Trial (ART) grown at Vertisol locations in India, during rainy seasons 1983-1986.

	ICRISAT Center							
Entry	Time to 50% flowering (d)	Time to maturity (d)	100-seed mass (g)	Yield ($t\ ha^{-1}$) 1983	1984	1985	1986	Mean
ICPL 270	110	167	11.0	1.72(4)[1]	1.70(3)	1.71(2)	1.62(3)	1.68
Controls								
BDN 1	105	161	9.9	1.43(4)	1.51(3)	1.07(2)	1.45(3)	1.36
C 11	121	179	10.3	1.63(4)	1.53(3)	1.36(2)	1.56(3)	1.52
LRG 30	126	177	7.0	1.82(4)	1.82(3)	-	1.30(3)	1.65
Hy 4	89	145	10.6	-	-	0.87(2)	1.19(3)	1.03

1. Figures in parentheses denote number of locations with CV up to 20% for yield.

ICPL 87, 151, 83006, 84052, and 85048 and the medium-duration lines; ICPL 265, 270, and 84060. In the 1987/88 season, experiments are continuing to compare yields of promising pigeonpea lines in larger plots and to establish optimum proportions of pigeonpea and black gram for hand-broadcasting as mixture into standing rice.

On-farm Adaptation Trials for Short-duration Pigeonpea

During the 1987 rainy season, ICRISAT's breeders, agronomists, and economists collaborated in conducting a series of adaptation trials with short-duration pigeonpeas, mainly ICPL 87 and ICPL 151, on farmers fields in villages in Andhra Pradesh and Maharashtra. The breeders and agronomists were interested in validating their proposed package of practices for these genotypes, especially the multiple-harvest system for ICPL 87. The economists were primarily interested in studying the introduction of new cropping technologies into traditional cropping systems, and in comparing the economics of the different systems. Irrigated and rainfed 0.1-ha plots were grown in different fields within a village. The farmers carried out all operations themselves, with guidance from ICRISAT staff. It was noted that the farmers had little difficulty executing most of the procedures specified by the researchers. However, the major difficulty was *Heliothis* control, particularly at some locations where infestation was severe and the insecticide used seemed ineffective. Considering the general drought in this season, the growth of short-duration pigeonpea crops at most sites was good to excellent. As an example, the first-flush yield of ICPL 87 from a field at Kanzara village in Akola District, Maharashtra, was 1.9 $t\ ha^{-1}$.

Adaptation trials with short-duration pigeonpea were conducted at higher latitudes in USA and South Korea. At Prosser, Washington State, USA (46°N latitude), extra-short duration cultivars sown in May 1987 produced dry grain yields well before the first frost. ICPL 83004, 85010, 85024, and 86010 were chosen for further testing in the Columbia basin of that State. In San Leandro, California (37°N latitude), pigeonpea was sown on 20 April, and 9, 17, and 27 May in 1986. Varieties ICPL 151 and ICPL 312 produced over 2 $t\ ha^{-1}$ dry grain yield and matured in 120–130 days. In Suwan, South Korea (37°N latitude), ICPL 179 produced 2.1 $t\ ha^{-1}$ and ICPL 4 produced 1.6 $t\ ha^{-1}$ when sown on 10 May 1986 at 30 × 10 cm spacing. They matured in 115 days.

Workshops, Conferences, and Seminars

Pigeonpea Scientists' Meet

ICRISAT organizes Pigeonpea Scientists' Meets every year to bring together scientists to exchange information, visit field experiments, and select germplasm of their interest. In 1987, a Scientists' Meet was held in Nairobi, Kenya, during 2-5 June. It was the first such meeting to be held outside India. The choice of an African country for this meeting reflected our commitment to stimulate research and development of pigeonpea for food, fodder, and fuel in countries of Africa where the crop has great potential.

The participants from Ethiopia, ICRISAT Center, Kenya, Malawi, Nigeria, Tanzania, and Zimbabwe, held discussions on on-going research and proposed future programs. They made field visits to the National Dryland Research Centre at Katumani and a pigeonpea-growing site on the Mombasa road.

Hybrid Pigeonpea Training Course

We organized the first-ever training program on hybrid pigeonpea during 12-15 October 1987 at ICRISAT Center to give practical training in various aspects of hybrid seed production technology. The course was attended by 14 participants from Indian agricultural universities, the Indian Council of Agricultural Research, the National Seeds Corporation, and Indian private seed organizations. At the end of the course we developed an outline of a cooperative network to produce and evaluate experimental hybrids of short- and long-duration pigeonpeas.

ACIAR/AGLN Workshop on Management of Legume Pests

A Workshop on the Management of Legume Pests was cosponsored by ACIAR and AGLN. The workshop was held 31 August to 3 September 1987 at Khon Kaen, Thailand; and 7-10 September 1987 at Malang, Indonesia. Considering the importance of other legumes in both countries, mung bean, soybean, and cowpea were included along with groundnut and pigeonpea. ACIAR sent a professional pest manager and ICRISAT an entomologist to conduct the workshop with help from local entomologists.

In each country 12 participants discussed various aspects of pest management including: pests and their distribution; biology, ecology, and damage by major pests; sampling and survey procedures and yield loss assessment; insects as disease vectors; insecticides; biological control; host-plant resistance, and integrated pest management principles. The participants were asked to evaluate the usefulness of the course. They were all appreciative and requested more information/literature on pest management principles.

Publications

Institute Publications

Plant Material Description

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Pigeonpea male-sterile line ICPM 1. Plant Material Description no. 10. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-127-5. (PME 010)

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Coordination of grain legumes research in Asia: summary proceedings of the Review and Planning Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 16-18 Dec 1985, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 96 pp. ISBN 92-9066-120-8. (CPE 040)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Research on grain legumes in eastern and central Africa: summary proceedings of the Consultative Group Meeting for Eastern and Central African Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 8-10 Dec 1986, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. Patancheru, A.P. 502 324, India: ICRISAT. 128 pp. ISBN 92-9066-129-1. (CPE 042)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 184 pp. ISBN 92-9066-130-5. (CPE 043)

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. International Pigeonpea Newsletter no. 6. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0255-786X. (NPE)

General Audience Publication

Faris, D.G., Saxena, K.B., Mazumdar, S., and **Singh, Umaid.** 1987. Vegetable pigeonpea: a promising crop for India. Patancheru, A.P. 502 324, India: ICRISAT. 14 pp. (GAE 017)

Journal Articles

Chauhan, Y.S., Venkataratnam, N., and **Sheldrake, A.R.** 1987. A perennial cropping system from pigeonpea grown in post-rainy season. Indian Journal of Agricultural Sciences 57(12):895-899. (JA 684)

Chauhan, Y.S., Venkataratnam, N., and **Sheldrake, A.R.** 1987. Factors affecting growth and yield of short-duration pigeonpea and its potential for multiple harvests. Journal of Agricultural Science, Cambridge 109:519-529. (JA 654)

Chauhan, Y.S., Sheldrake, A.R., and **Venkataratnam, N.** 1987. Effect of harvest methods on the second flush yield of short-duration pigeonpea (*Cajanus cajan*). Journal of Agricultural Science, Cambridge 109:591-593. (JA 637)

Kannaiyan, J., and **Nene, Y.L.** 1986. Screening pigeonpea for resistance to alternaria blight. Indian Phytopathology 39(4):547-549. (JA 513)

Kumar Rao, J.V.D.K., and **Dart, P.J.** 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (*Cajanus cajan* (L.) Millsp.) of different maturity groups. Plant and Soil 99(2-3):255-266. (JA 552)

Kumar Rao, J.V.D.K., Thompson, J.A., Sastry, P.V.S.S., Giller, K.E., and **Day, J.M.** 1987. Measurement of N_2-fixation in field-grown pigeonpea [*Cajanus cajan* (L.) Millsp.] using ^{15}N-labelled fertilizer. Plant and Soil 101(1):107-113. (JA 599)

Nene, Y.L. 1986. Opportunities for research on diseases on pulse crops. Indian Phytopathology 39(3):333-342. (JA 575)

Saxena, K.B., Faris, D.G., Singh, U., and **Kumar, R.V.** 1987. Relationship between seed size and protein content in newly developed high protein lines of pigeonpea. Qualitas Plantarum: Plant Foods for Human Nutrition 36(4):335-340. (JA 499)

Saxena, K.B., Sharma, D., and **Faris, D.G.** 1987. Ineffectiveness of wrapped flower in inhibiting cross-fertilization in pigeonpea. Euphytica 36(1):295-297. (JA 578)

Conference Papers

Campbell, W.V., and **Reed, W.** 1987. Limits imposed by biological factors: pests. Pages 128-137 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 315)

Chauhan, Y.S. 1987. Screening for tolerance to salinity and waterlogging: case studies with pigeonpea and chickpea. Pages 93-103 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 388)

Chauhan, Y.S., Venkataratnam, N., and **Johansen, C.** 1987. The agronomy of multiple harvest pigeonpea. Page 234 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 272)

Faris, D.G., Saxena, K.B., Singh, U., and **Reddy, L.J.** 1987. The promise of high protein pigeonpea. Pages 311-312 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 278)

Gupta, S.C., Saxena, K.B., Faris, D.G., and **Sharma, D.** 1987. Promising pigeonpea varieties from ICRISAT. Page 314 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 276)

Jain, K.C., and **Faris, D.G.** 1987. The potential of medium-duration pigeonpea. Page 238 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 273)

Johansen, C. 1987. Mechanisms of salt tolerance and their relevance. Pages 109-113 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 385)

Lateef, S.S., Sithanantham, S., and **Reed, W.** 1987. Insect-resistant pigeonpea is feasible. Pages 291-292 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 277)

Nene, Y.L. 1987. Overview of pulses research at ICRISAT. Pages 7-12 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 384)

Raju, T.N., and **Nene, Y.L.** 1987. The value of disease-resistant pigeonpea. Page 297 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 275)

Reddy, M.V. 1987. Diseases of pigeonpea and chickpea and their management. Pages 175-184 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 282)

Reed, W. 1987. Increase of productivity of crops: control of pre- and post-harvest losses. Presented at the International Meeting on Towards a Second Green Revolution: from Chemical to New Biological Technologies in Agriculture in the Tropics, 8-10 Sep 1986, Rome, Italy. Rendiconti della Accademia Nazionale delle Scienze detta dei XL, Memorie di Scienze Fisiche e Naturali, Serie 5, 11 (Part 2): 249-258. (CP 311)

Rupela, O.P., and **Kumar Rao, J.V.D.K.** 1987. Effects of drought, temperature, and salinity on symbiotic nitrogen fixation in legumes, with emphasis on chickpea and pigeonpea. Pages 123-131 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 383)

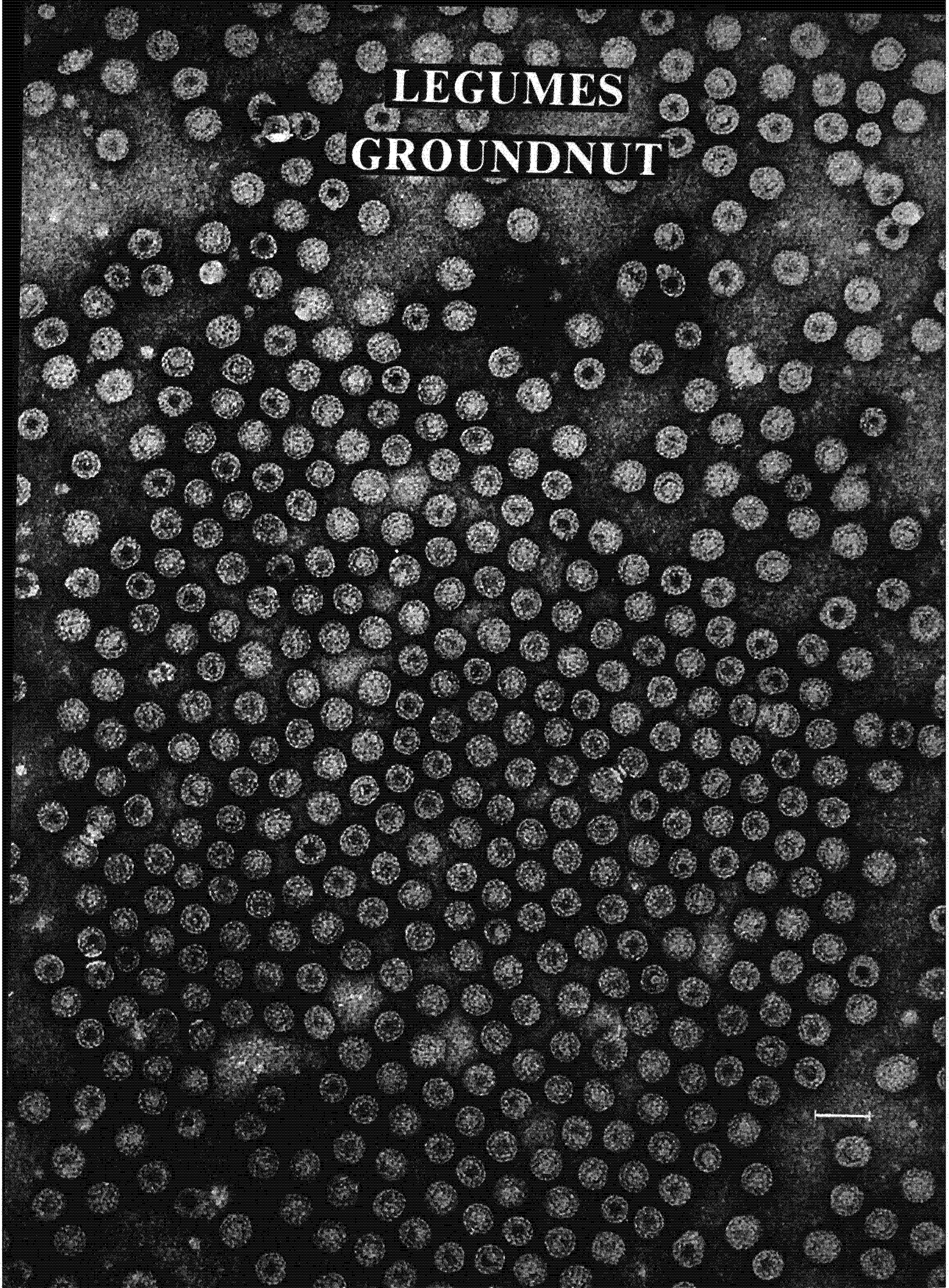
Saxena, K.B., Faris, D.G., and **Gupta, S.C.** 1987. The potential of early maturing pigeonpea hybrids. Pages 321-322 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 271)

Saxena, N.P. 1987. Screening for adaptation to drought: case studies with chickpea and pigeonpea. Pages 63-76 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 389)

Saxena, N.P. 1987. Problems and prospects to screen and breed for tolerance to soil salinity: a case study with chickpea. Pages 115-120 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 387)

Sithanantham, S. 1987. Insect pests of pigeonpea and chickpea and their management. Pages 159-173 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, CPPTI, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 341)

Singh, U., Jambunathan, R., Saxena, K.B., and **Faris, D.G.** 1987. Nutritive value of green and mature pigeonpea seed. Page 332 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 274)


LEGUMES
GROUNDNUT

Contents

Cover photo: Purified preparation of peanut chlorotic streak virus particles (bar represents 85 nm) ICRISAT Center, 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Legumes Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India.

GROUNDNUT

The importance of groundnut as a food and oil crop, and as a cash source in the agrarian sector of the semi-arid tropics (SAT) is as well known as the suboptimal production levels of groundnut in this climatic zone. ICRISAT's attempts at improving this situation in the SAT are illustrated by three activities during 1987.

The difference in the productivity of fields at research stations and farmers' fields is well known. This year, a new unit, the Legumes On-Farm Testing and Nursery Unit (LEGOFTEN), was set up to transfer some of the technology used at ICRISAT to farmers' fields. This was a joint venture with State Programs, carried out at the request of the Government of India.

Pest and virus problems of groundnut crops in southeast Asia are becoming acute. Special workshops in Indonesia and Thailand enabled local scientists, overseas specialists, and members of ICRISAT staff to exchange information on approaches to alleviate these constraints.

A survey of farms in southern Africa provided documentary evidence of the pest problems of the groundnut crop in that region and revealed new pest problems. Defining constraints is the first step to removing them.

For several years, groundnut researchers in Southern Africa have been concerned about a disease, which, although localized in distribution and usually present at low incidence, causes about 70% yield loss on a per-plant basis. Detailed observations and follow-up research in the 1986/87 season showed that the disease, now called groundnut streak necrosis disease, is spread by the cotton aphid *Aphis gossypii*, and is caused by the sunflower yellow blotch virus.

At the same time, the groundnut group continued to develop pest-, disease-, and drought-resistant cultivars from the gene pool represented by the cultivated groundnut *Arachis hypogaea* and wild *Arachis* species. The year 1987 was special at ICRISAT Center because the infestation pattern of foliar diseases was such that we were able to screen for resistance to early leaf spot (*Cercospora arachidicola*). Resistance was found in more than 30 genotypes, including those with resistance to rust and late leaf spot. Resistance to early leaf spot and groundnut rosette virus in a wild *Arachis* sp was also confirmed in Malawi. This is an incentive to screen more wild species and to transfer their beneficial genes to the cultivated groundnut in a bid to counteract these intractable diseases that are of widespread importance.

The emphasis of the breeding program is changing. We shall concentrate on developing cultivars that are adapted for yield stability in given environments. This involves collaborating with agroclimatologists to define these environments. The major biotic and abiotic constraints of the geographical zoning they represent will then be considered.

The groundnut program in West Africa gained momentum in 1987 with the appointment of a plant breeder and a pathologist. An evaluation of the problems facing groundnut growers has pointed to drought, foliar diseases, groundnut rosette, peanut-clump, aflatoxin contamination, soil pests (millepedes, nematodes, and termites), adaptation of varieties, cropping systems, and the complex of edaphic factors that can cause uneven crop growth as being of prime importance. Our research program in West Africa has been oriented to counteracting these factors by locational research backed by the evaluation of breeding material from ICRISAT Center and the ICRISAT Regional Groundnut Improvement Program for Southern Africa.

Physical Stresses

Genotype and Drought Interaction

To understand the basis for the differential response of genotypes to water deficit, we subjected 10 selected genotypes to drought in a field experiment by withholding water from 90–130 days after sowing (DAS). We measured soil water content with a neutron probe at weekly intervals at a series of stations down the soil profile to a depth of 105 cm. ICGV 86707 (a drought-tolerant genotype) extracted water from the soil profile sooner and lower than the drought-susceptible genotype ICG 2716. We measured leaf photosynthesis and transpiration rates in four other genotypes and found a large amount of variation in transpiration rates. For example, ICGV 86707 had a higher transpiration rate than ICG 2716 for most of the drought period. We also found significant differences between genotypes for leaf photosynthesis per unit of transpiration.

Root Respiration

A knowledge of the structure and functions of the root system is fundamental to understand and improve the drought tolerance of groundnut plants. We know little about the physiology of roots and their associated nodules and its relationship to water uptake under various conditions of drought stress. In particular, we have yet to define the role of a genotype in this system.

Therefore, in collaboration with the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and the University of Bonn, Federal Republic of Germany, we began greenhouse experiments, initially to examine the factors that influence the growth and respiration of root systems in groundnut genotypes whose response to drought is known.

We grew two groundnut genotypes,drought-tolerant ICGV 86707 and drought-susceptible ICG 2716, in plastic pots containing sand, treated either with *Bradyrhizobium* strain NC 92 or supraoptimal concentrations of nitrogen. The N treatment was to suppress the development of nodules, so as to minimize the contribution they made to below-ground respiration. The control treatment had neither N nor *Bradyrhizobium*. All pots were supplied daily with a full-strength nutrient solution. Diurnal changes in CO_2 level in the root zone were monitored from 40 to 96 DAS at 30-min intervals using an infrared gas analyzer. Root-zone temperatures were recorded using thermocouples 10 cm below the soil surface. We found a close relationship between root-zone temperature and CO_2 evolution between 10–40°C. The two genotypes had the same Q_{10} values, the mean of which was 1.85. A Q_{10} is the change in the rate of a biological process that occurs in response to a 10°C temperature change.

Detailed growth analysis 96 DAS showed that the roots of ICGV 86707 grew faster than those of ICG 2716 under well-watered conditions (Table 1), suggesting that the greater root mass of the drought-tolerant genotype was achieved by greater partitioning of assimilates to roots.

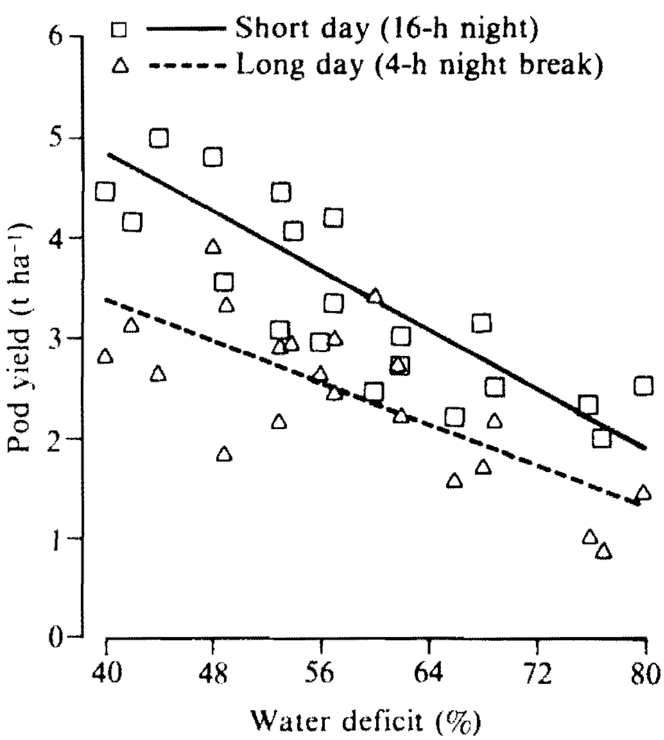
Table 1. Root growth and root respiration rates of two groundnut genotypes grown in sand culture with a complete nutrient solution, ICRISAT Center, 1986.

Genotype	Treatment	Root growth rate: Dry mass (mg d^{-1})	Root growth rate: Length (m d^{-1})	Specific root mass (mg m^{-1})	Root respiration rate: (mg CO_2 mg root $^{-1}$ d^{-1})	Root respiration rate: (mg CO_2 m root $^{-1}$ d^{-1})
ICGV 86707 (Drought-tolerant)	+N	122.0 ± 18.5	7.11 ± 0.62	17.3 ± 1.9	0.35 ± 0.79	5.9 ± 1.1
	+ NC 92	57.5 ± 10.9	1.90 ± 0.69	18.8 ± 4.6	0.32 ± 0.10	9.6 ± 4.2
	Control	44.5 ± 11.1	1.60 ± 0.46	22.9 ± 4.1	0.31 ± 0.14	8.5 ± 4.0
ICG 2716 (Drought-susceptible)	+N	84.6 ± 11.2	5.72 ± 0.75	14.5 ± 0.9	0.34 ± 0.07	5.1 ± 1.0
	+NC 92	34.8 ± 9.1	3.05 ± 0.39	12.4 ± 1.9	0.91 ± 0.3	10.4 ± 2.4
	Control	24.5 ± 9.8	1.58 ± 0.60	14.1 ± 2.3	0.75 ± 0.34	11.6 ± 4.0

This observation is consistent with the lower yield potential of drought-tolerant genotypes under well-watered conditions. ICGV 86707 generally had a higher specific root mass and lower respiration rate per mg of root compared to ICG 2716.

Photoperiod and Drought Interaction

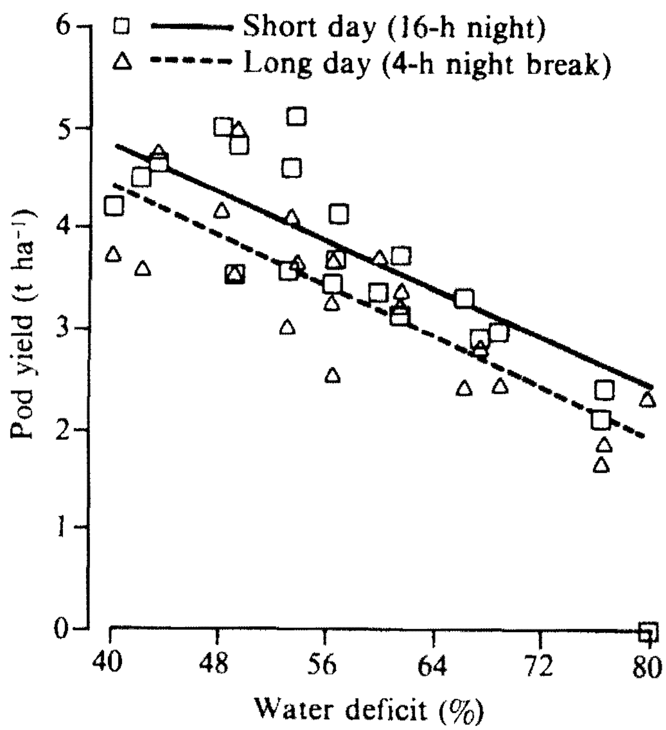
Just as the extent of root development influences drought tolerance, photoperiod sensitivity may indirectly influence genotypic sensitivity to drought by affecting root development. We conducted a field experiment in the 1986/87 postrainy season to examine photoperiod and drought interaction using two genotypes; TMV 2 (low sensitivity to photoperiod), and ICG 1712 (photoperiod-sensitive). From flowering these genotypes were subjected to two photoperiod treatments, a short-day (8 h) and long-day (4-h night break) treatments, i.e., water deficits were created within each photoperiod treatment during the pod-filling phase (82–130 DAS), using a line-source sprinkler technique. The reduction in pod yield of both genotypes was proportional to the amount of water deficit. However, the long-day treatment reduced the pod yields of the photoperiod-sensitive genotype ICG 1712 more at all water deficits than did the short-day treatment (Fig. 1). The reponse of TMV 2 to drought was not affected by photoperiod (Fig. 2). However, the response of total dry matter (TDM) (vegetative + pods) of ICG 1712 to water deficits



□ y = 7.74(±0.80) - 0.0007(±0.0001)x
r = -0.78**; rse = 0.6926

Δ y = 5.39(±0.64) - 0.0005(±0.0001)x
r = -0.73**; rse = 0.5557

Figure 1. Effect of photoperiod on pod yield (t ha^{-1}) of groundnut ICG 1712 at different water deficits, ICRISAT Center, postrainy season 1986/87. (Values in parentheses are SEs).



□ y = 7.57(±0.62) - 0.006(±0.0011)x
r = -0.84**; rse = 0.4913

Δ y = 6.86(±0.60) - 0.006(±0.0010)x
r = -0.81**; rse = 0.5191

Figure 2. Effect of photoperiod on pod yield (t ha^{-1}) of groundnut TMV 2 at different water deficits, ICRISAT Center, postrainy season 1986/87. (Values in parentheses are SEs).

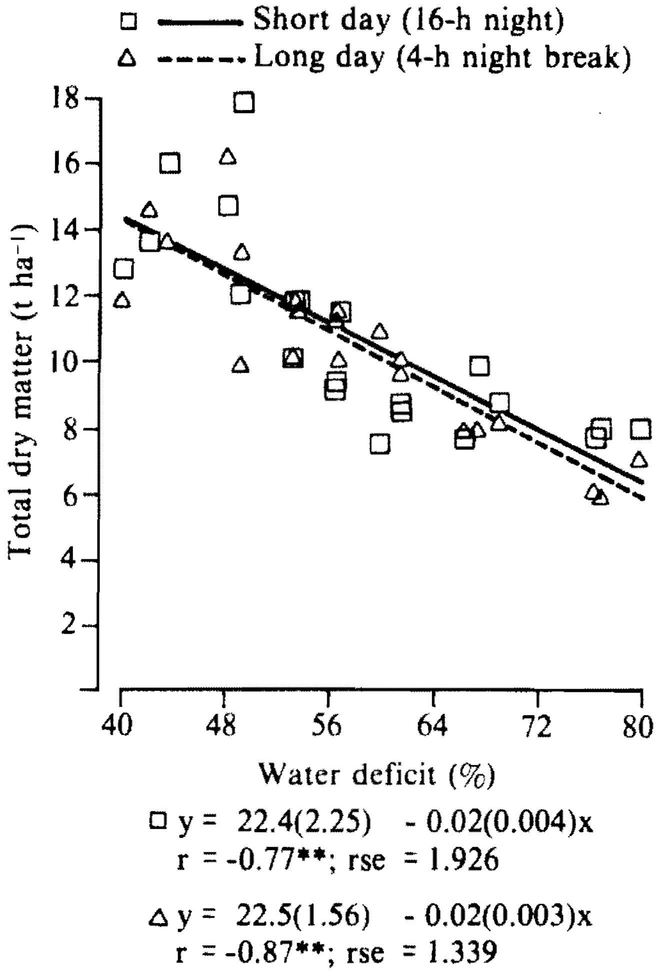


Figure 3. Effect of photoperiod on total dry matter (vegetative + pod) produced by groundnut ICG 1712 ($t\ ha^{-1}$) at different water deficits, ICRISAT Center, postrainy season 1986/87. (Values in parentheses are SEs).

was not affected by photoperiod treatments (Fig. 3) suggesting that long days influence the distribution of assimilates in photoperiod-sensitive genotypes.

Biotic Stresses

Foliar Fungal Diseases

Screening for resistance to early leaf spot (*Cercospora arachidicola*) has not previously been possible at ICRISAT Center because of the dominance of late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*). In 1987, collaborative trials were planned with the University of Agricultural Sciences, Pantnagar, Uttar Pradesh, in northern India, where early leaf spot is commonly severe. This initiative coincided with an unusually severe attack of early leaf spot and only late and light attacks by rust and late leaf spot at ICRISAT Center in the 1987 rainy season. It was therefore possible for the first time, to extensively screen germplasm and breeding lines for resistance to early leaf spot at ICRISAT Center.

Resistance Screening

Early Leaf Spot (*Cercospora arachidicola*). Of the 618 germplasm lines screened in 1987 for resistance to early leaf spot, 33 had satisfactory resistance or tolerance and were retained for further testing. Similarly, 3 out of 641 breeding lines and 5 out of 1665 interspecific hybrid derivatives were retained for further testing. There was good agreement between the results from Pantnagar and ICRISAT Center (Table 2). Eight lines with multiple resistance to foliar diseases have now been identified (Table 3). This is of particular significance to our program in southern Africa where early leaf spot is a major constraint.

Resistance Breeding

Postrainy-season trials 1986/87. We evaluated several advanced foliar diseases-resistant selections during the postrainy season at Bhavanisagar and ICRISAT Center to evaluate their yield potential under different photoperiod and temperature regimes and low disease pressure. At Bhavanisagar, we tested 96 elite selections with resistance to rust and/or late leaf spot for yield, using the rust-resistant parent ICG 1697 (NC Ac 17090), an advanced rust-resistant breeding line, ICGV 87157, and two foliar diseases-susceptible cultivars, JL 24 and ICGS 11, as controls. ICGV 86590 significantly out-

Table 2. Reaction of groundnut germplasm and breeding lines to early leaf spot during field screening, ICRISAT Center and Pantnagar, rainy season 1987.

		Reaction to early leaf spot[1]	
Entry	Original name	ICRISAT Center	Pantnagar
ICG 1703	NC Ac 17127	4.7	-
ICG 2711	NC 5	4.5	4.6
ICG 6284	NC Ac 17500	5.0	-
ICG 6349	NC Ac 1121	3.6	5.0
ICG 6709	NC Ac 16163	3.6	4.3
ICG 7291	PI 262128	3.0	4.8
ICG 7406	PI 262121	3.0	5.0
ICG 7630	204/66	4.8	4.8
ICG 7878	NC Ac 10811A	5.0	-
ICG 7892	PI 393527-B	4.1	4.0
ICG 9990	US 409 (Flesh)	5.0	4.5
ICG 10040	PI 476176 (SPZ 451)	5.0	-
ICG 10946	PI 476176	5.0	-
ICGV 86690		5.0	5.0
Susceptible controls			
ICG 799	Kadiri 3 (Robut 33-1)	7.0	
ICG 221	TMV 2	8.0	
SE[2]		±0.48	±0.98
CV (%)[2]		7.0	17.3

1. Field disease scored on a 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.
2. SE and CV(%) calculated on the basis of all genotypes tested (n = 65).

yielded all the four controls and produced 27% higher pod yield than the best control, ICG 1697 (NC Ac 17090).

At ICRISAT Center, the same trial was conducted in Alfisol and Vertisol fields. In general, the yields were higher in Alfisols, the best entry, ICGV 87357, giving a pod yield of 5.64 t ha^{-1}. Five selections significantly outyielded the best control, ICGS 11, which produced a pod yield of 4.71 t ha^{-1} (Table 4). In the Vertisols, eight resistant selections gave significantly higher yields than the best control, ICGS 11.

We also conducted a preliminary yield trial at ICRISAT Center comprised of 141 resistant selections, one advanced resistant breeding line, ICGV 87157, and two susceptible cultivars, ICGS 11 (ICGV 87123) and JL 24. Four selections gave significantly higher pod yields than the best control cultivar, ICGS 11. The top yielding selection yielded 5.97 t pods ha^{-1} compared to the 4.99 t ha^{-1} of ICGS 11.

Rainy-season trials 1987. Seventy-seven elite, 77 advanced, and 60 preliminary foliar diseases-resistant selections were yield tested at ICRISAT Center in three separate trials using one resistant breeding line, ICG(FDRS) 4 and three susceptible varieties, Kadiri 3 (Robut 33-1), JL 24, and ICGS 44-1 as controls. Rust and late leaf spot were present at low levels in 1987 but early leaf spot was severe. Several resistant selections significantly outyielded the most productive sus-

Table 3. Reaction of some groundnut germplasm lines with resistance to early (*Cercospora arachidicola*) and late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*), ICRISAT Center, rainy season 1987.

		Disease reaction[1]		
Entry	Original name	Early leaf spot	Late leaf spot	Rust
ICG 1703	NC Ac 17127	4.7	5.0	4.7
ICG 6284	NC Ac 17500	5.0	7.0	3.3
ICG 7340	198/66 Coll 182	5.7	5.1	2.7
ICG 9294	58-295	5.1	6.0	2.7
ICG 10010	PI 476143	5.7	5.1	4.1
ICG 10040	PI 476176 (SPZ 451)	5.0	4.7	3.7
ICG 10900	PI 476033	5.3	4.7	4.1
ICG 10946	PI 476176	5.0	6.0	4.1
Susceptible controls				
ICG 799	Kadiri 3 (Robut 33-1)	8.0	7.0	7.0
ICG 221	TMV 2	8.0	8.0	8.0
SE[2]		±0.48	±0.7	±1.1
Trial mean (n = 500)		6.9	6.5	4.9
CV (%)[2]		7.0	11	22

1. Based on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage destroyed, mean of three replicates, 1 plot = 2 × 4-m rows.
2. SE and CV (%) calculated on the basis of all genotypes tested.

ceptible cultivar (Table 5) even under low disease pressure.

The elite lines trial was conducted at ICRISAT Center, Bhavanisagar, and Dharwad. The resistant selections significantly outyielded the best control at ICRISAT Center and Bhavanisagar (Table 5). At ICRISAT Center, 22 elite resistant selections had significantly higher pod yields than the best control, JL 24. The top-yielding entry, ICGV 87237 gave 73% greater pod yield than JL 24 and was tolerant to the groundnut leaf miner. At Bhavanisagar, four resistant selections significantly outyielded the best control, JL 24. The best entry, ICGV 87229 yielded 3.75 t pods ha^{-1}, 35% more than JL 24.

In the advanced yield trial (AYT) at ICRISAT Center, 12 resistant selections had significantly higher pod yields than the best control, JL 24. The best was ICGV 87287 which gave a 52% higher yield than JL 24.

In the preliminary yield trial (PYT), 20 resistant selections significantly outyielded the best control, JL 24. The best entry, ICGV 87868 showed 52% pod yield superiority over JL 24.

Soilborne Fungal Diseases

The Aflatoxin Problem

In the 1987 rainy season, rainfed trials were carried out on Alfisols and Vertisols at ICRISAT Center, on Alfisols at Anantapur, and on Vertisols at Parbhani and Dharwad. The *A. flavus*-resistant genotypes (Ah 7223, J 11, UF 71513, and PI 337394F) had significantly lower levels of *A. flavus* infection and aflatoxin B_1 contamination of seeds than the susceptible genotypes (TMV 2, JL 24, NC Ac 17090, and EC 76446(292))

Table 5. Performance of some rust (*Puccinia arachidis*) and late leaf spot (*Phaeoisariopsis personata*) resistant groundnut lines, at two locations, rainy season 1987.

Trial/Location/Entry	Pod yield (t ha⁻¹)	Shelling (%)	100-seed mass (g)
Elite, ICRISAT Center[1]			
ICGV 87237	2.11	63	27.0
ICGV 86691	2.05	62	33.5
ICGV 86675	2.05	68	32.7
ICGV 86698	2.00	61	32.2
Control			
JL 24	1.22	69	38.6
SE	±0.10		
Trial mean (81 entries)	1.25		
CV (%)	13		
Efficiency over RBD (%)	113		
Elite, Bhavanisagar[2]			
ICGV 87229	3.75	68	33.3
ICGV 87254	3.61	71	36.8
ICGV 87281	3.55	71	25.7
Control			
JL 24	2.77	69	34.5
SE	±0.24		
Trial mean (81 entries)	2.77		
CV (%)	16		
Efficiency over RBD (%)	110		
Advanced, ICRISAT Center[1]			
ICGV 87287	2.28	68	31.0
ICGV 87292	2.19	67	27.9
ICGV 87308	2.15	71	31.4
ICGV 87288	2.14	68	30.0
Control			
JL 24	1.50	63	33.1
SE	±0.09		
Trial mean (81 entries)	1.33		
CV (%)	13		
Efficiency over RBD (%)	115		
Preliminary, ICRISAT Center[3]			
ICGV 87868	2.19	65	30.1
ICGV 87815	2.13	59	32.2
ICGV 87837	2.08	62	32.0
ICGV 87860	2.08	68	33.4
Control			
JL 24	1.44	66	32.2
SE	±0.11		
Trial mean (64 entries)	1.64		
CV (%)	13		
Efficiency over RBD (%)	98		

1. 9 × 9 triple lattice, plot size 13.5 m^2. 2. 9 × 9 triple lattice, Plot size 6.0 m^2. 3. 8 × 8 triple lattice, plot size 6.0 m^2.

Table 4. Performance of some rust (*Puccinia arachidis*) and/or late leaf spot (*Phaeoisariopsis personata*) resistant groundnut lines on Alfisols and Vertisols[1], ICRISAT Center, postrainy season 1986/87.

Trial/Entry	Dry pod yield ($t\ ha^{-1}$)
Elite Alfisol	
ICGV 87357	5.64
ICGV 86605	5.48
ICGV 86684	5.38
ICGV 86600	5.37
ICGV 86619	5.36
Controls	
ICGS 11[2]	4.71
SE	±0.21
Trial mean (100 entries)	4.57
CV (%)	8
Efficiency over RBD (%)	130
Elite Vertisol	
ICGV 86635	5.21
ICGV 86685	4.75
ICGV 86671	4.75
ICGV 86677	4.69
ICGV 86672	4.59
ICGV 86638	4.56
ICGV 86606	4.51
ICGV 86691	4.40
Controls	
ICGS 11[2]	3.67
SE	±0.25
Trial mean (100 entries)	3.58
CV (%)	12
Efficiency over RBD (%)	103
Preliminary Alfisol	
ICGV 87192	5.97
ICGV 87234	5.95
ICGV 87195	5.87
ICGV 87774	5.87
Controls	
ICGS 11[2]	4.99
SE	±0.29
Trial mean (144 entries)	4.70
CV (%)	11.0
Efficiency over RBD (%)	107

1. Triple lattice, plot size 6.0 m^2.
2. High yielding rust- and late leaf spot-susceptible control.

in all trials. Levels of *A. flavus* infection and aflatoxin contamination were significantly higher in seeds from Alfisol fields than in seeds from Vertisol fields (Table 6).

There were significant interactions between soil types and genotypes, especially *A. flavus*-susceptible genotypes, for seed infection by *A. flavus* and such other fungi as *Aspergillus niger, Macrophomina phaseolina, and Penicillium* spp.

Breeding for *A. flavus* resistance. We analyzed the multiyear-multilocational data on pod yield and in vitro seed colonization by *Aspergillus flavus* (IVSCAF) collected from a set of advanced-generation breeding lines and resistant and susceptible controls to compare the stability of resistance to IVSCAF between the breeding lines and the sources of resistance. We

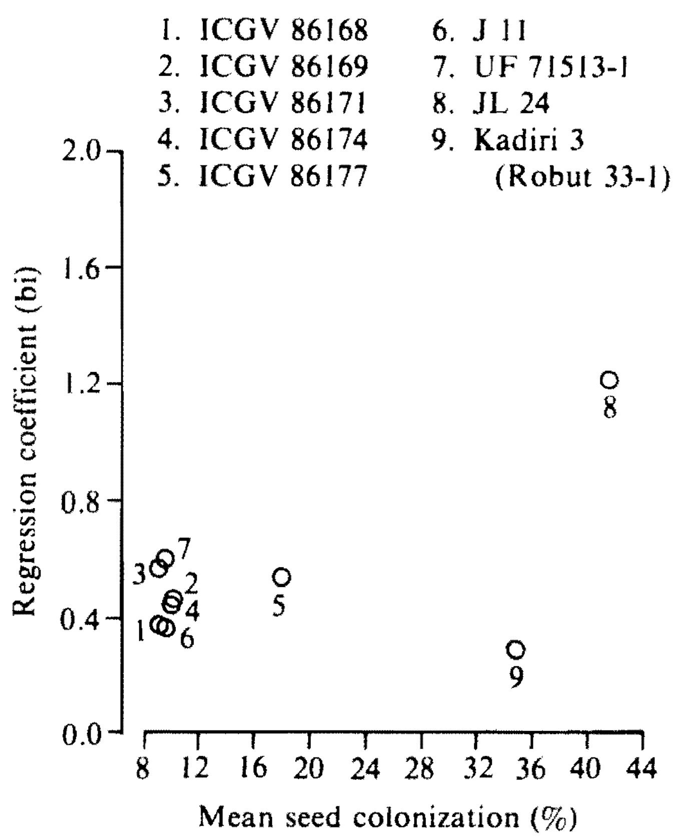


Figure 4. Stability of seed coat resistance in nine groundnut varieties to in vitro seed colonization by *Aspergillus flavus* in multilocational trials at seven Indian locations, rainy season 1986.

Table 6. Seed infection by *Aspergillus flavus* and aflatoxin contamination in groundnut genotypes grown in different soils, at various Indian locations, rainy season 1987.

	Seed infected by *A. flavus* and aflatoxin contamination							
	Alfisols				Vertisols			
	ICRISAT Center							
	Field 1		Field 2	Anantapur	ICRISAT Center		Parbhani	Dharwad
Genotypes	1st[1]	2nd[2]			1st[1]	2nd[2]		
ICG 3700	0.9[3]	1.1	0.9	0.5	0.1	0.1	0.1	0.0
	(0.0)[4]	(0.0)	(0.5)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
ICG 1326	1.0	1.0	1.0	0.7	0.0	0.0	0.0	0.0
	(0.5)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
ICG 7633	1.0	1.0	0.9	0.7	0.1	0.0	0.0	0.0
	(0.0)	(0.0)	(0.5)	(1.0)	(0.0)	(0.0)	(0.0)	(0.0)
ICG 4749	1.2	1.2	1.4	0.6	0.0	0.0	0.0	0.1
	(0.0)	(1.2)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
SE[5]			±0.19				±0.07	
			(±0.46)				(±0.00)	
TMV 2	4.7	5.1	4.9	3.4	0.4	0.4	0.1	0.4
	(1.0)	(0.0)	(2.9)	(0.5)	(0.0)	(0.0)	(0.0)	(1.0)
JL 24	11.9	10.1	12.9	9.2	1.1	1.2	0.4	1.0
	(2.9)	(8.7)	(10.5)	(0.0)	(0.0)	(0.0)	(0.0)	(0.5)
ICG 1697	17.2	12.4	14.6	9.9	1.2	1.5	0.5	1.2
	(2.5)	(3.5)	(8.4)	(1.0)	(0.0)	(0.0)	(0.8)	(0.0)
ICG 2716	21.4	14.5	17.2	10.6	1.5	1.7	0.6	1.1
	(12.2)	(8.7)	(13.4)	(4.0)	(0.0)	(1.0)	(0.0)	(0.5)
SE[5]			±1.18				±0.19	
			(±2.30)				(±0.39)	

1. 1st sowing on 17 June 1987.
2. 2nd sowing on 2 July 1987.
3. Seeds infected by *A. flavus* (%).
4. Aflatoxin B_1 content ($\mu g\ kg^{-1}$).
5. SEs apply to nonzero mean values.

studied the stability of resistance in these lines, to evaluate data collected from four environments in the 1984 rainy season and seven in the 1986 rainy season (Fig. 4). The regression coefficient [b_i] for resistance plotted against the mean percentage seed colonization indicated that the selected breeding lines exhibited resistance as high and as stable as that of the resistance source lines.

Stem and Pod Rots

During the 1986/87 postrainy season we screened 450 genotypes for resistance to stem and pod rots caused by *Sclerotium rolfsii.* In one trial with 225 breeding lines and interspecific hybrid derivatives, the incidence of stem rot in different genotypes varied from 1 to 68%, and of pod rot from 2 to 78%. The control cultivar Kadiri 3 (Robut 33-1), which was sown between every 15 test genotypes, had high incidences of both stem rot (27-50%), and pod rot (46-64%).

In another trial with 225 germplasm accessions and breeding lines, the incidence of stem rot in different genotypes ranged from 5 to 65%, and of pod rot from 4 to 73%. Nine interspecific hybrid derivatives and breeding lines had consistently low levels of stem rot (<10%) and pod rot (<10%) compared to >46% for stem rot and >56% for pod rot in the susceptible control. These will be further tested in the 1987/88 post-rainy season to confirm their resistance.

Nematode Diseases

Survey. Lesion nematodes *Pratylenchus* sp and stunt nematodes, *Tylenchorhynchus* sp are the most common species attacking groundnuts in the Alfisol fields at ICRISAT Center and in 10 groundnut-growing areas of Rayalaseema and coastal Andhra Pradesh, India. Other nematodes found associated with groundnut plants are; the ring nematode *Circonemoides* sp, the lance nematode *Hoplolaimus* sp, the spiral nematode *Helicotylenchus* sp, the root-knot nematode *Meloidogyne* sp, and the reniform nematode *Rotylenchulus reniformis.*

Virus Diseases

Bud Necrosis Disease (BND)

Causal agent. We developed a method of purifying tomato spotted wilt virus (TSWV), the causal agent of BND of groundnut, so as to achieve a lower level of host cell contamination than was previously possible. It involves extracting frozen tissue in a low molarity phosphate buffer containing thioglycerol and diethyldithiocarmabic acid (DIECA), clarification, precipitation of the virus in clarified extracts with 2% polyethylene glycol (PEG), the resuspension of PEG precipitates in low molar phosphate buffer containing sodium sulfite, and clarification. Further purification of clarified extracts is achieved by one cycle of rate- and two cycles of quasi-equilibrium-zonal density gradient centrifugation. The purified virus contains four polypeptides when analyzed by polyacrylamide gel electrophoresis.

Resistance screening. Several high-yielding germplasm and breeding lines with resistance to the thrips vector of BND (ICRISAT Annual Report 1986, p. 225) were tested under laboratory conditions for resistance to TSWV. ICGV 86029 and 86031 showed tolerance to TSWV. This is the first time that any kind of resistance or tolerance to TSWV has been found in groundnut.

Peanut Clump Virus (PCV)

Polypeptides from purified PCV were transferred electrophoretically onto nitrocellulose sheets. By immobilizing polypeptides in nitrocellulose and probing them with PCV antisera and enzyme-labelled antirabbit immuno gamma globulins produced in goats by the western blot procedure, we detected broader serological cross-reactions among the five PCV isolates that occur in India than we can get with the enzyme-linked immunosorbent assay (ELISA) tests (ICRISAT Annual Report 1985, p. 224). However, the method appears to be less suitable than C-DNA probes (ICRISAT Annual Report 1986, p. 226) for detecting the presence of all five PCV isolates.

Transmission. All ELISA-positive seed transmitted PCV in growing-out tests. However, 0.4% of ELISA-negative seed also contained the virus when grown-out, indicating that the ELISA test failed to detect PCV in a small proportion of infected seed.

Evidence accumulated to date indicates that the fungus *Polymyxa graminis* can transmit PCV (ICRISAT Annual Report 1986, p. 226). We have been able to establish a healthy culture of *P. graminis* on *Sorghum bicolor* roots. Utilizing soakates from roots of PCV-infected *S. bicolor* containing cystosori of the fungus, we were able to infect groundnut, *Phaseolus vulgaris,* and several graminaceous hosts with PCV. For the first time in 1987 we are able to detect cystosori of *P. graminis* in groundnut and *P. vulgaris.*

Peanut Mottle Virus (PMV)

Resistance screening. In the 1986/87 postrainy season and the 1987 rainy season, we screened a total of 275 breeding lines for resistance to PMV. Fifteen lines showed less than 5% yield loss from PMV-infected plants in tests conducted in both seasons. We also tested 40 selections derived from crosses involving NC Ac 2240 (ICRISAT Annual Report 1986, p. 226), a genotype known to be tolerant to PMV (ICRISAT Annual Reports 1982, p. 189; 1983, p. 199). We identified three breeding lines that showed less than 5% yield loss, and are currently evaluating them in a replicated trial. We also found that two genotypes, EC 76446 (292) and NC Ac 17133(RF), did not transmit PMV through seed (ICRISAT Annual Report 1986, pp. 226-227). High-yielding crosses involving these genotypes were tested for nonseed transmission. ICG 1697 and crosses derived from this genotype did not transmit PMV through the seed (Table 7). We are currently testing these breeding lines in the USA, Thailand, and Indonesia where disease caused by PMV can be economically important.

Table 7. Transmission of peanut mottle virus (PMV) through seed from inoculated groundnut genotypes derived from crosses involving ICG 1697 (NC Ac 17090).

Entry	No. of seeds tested	Seed transmission of PMV (%)
ICG 1697	19028	0
ICGV 86705	16464	0
ICGV 86600	21163	0.04
ICGV 86703	18970	0
ICGV 86704	20988	0.01

Peanut Yellow Spot Virus (PYSV)

Purified PYSV contains four polypeptides, as determined by polyacrylamide gel electrophoresis of solubilized proteins. Tests indicated that TSWV and PYSV are not serologically related, despite their similarity in structure and chemical properties.

Peanut Chlorotic Leaf Streak Virus (PCLSV)

We first collected plants infected with samples of PCLSV nearly 10 years ago during one of our disease surveys in India. We recently established that it is a "caulimovirus" (see cover photo) and, as such, contains a 35S transcriptional promoter so that it can act as a gene vector. We collaborated with the University of Kentucky, USA, on the mapping of the PCLSV gene. This was achieved by cutting off the purified DNA with a series of restriction endonucleases. Large segments of cleaved DNA were cloned and found infectious. Full-length DNA was reconstructed from cloned fragments.

Peanut Stripe Virus (PStV)

Symptoms of PStV were detected on groundnut at several locations in India. The presence of PStV was confirmed by serological and host-range tests. We are cooperating with scientists of the National Board for Plant Genetic Resources (NBPGR) in locating the origins of these infestations and in containing any further spread in the subcontinent. In cooperation with the National

Institutes, Moros Research Institute for Food Crops (MORIF) and Malang Research Institute for Food Crops (MARIF), and the Australian Centre for International Agricultural Research (ACIAR), in two field trials in South Sulawesi (Baru) and East Java (Mueneng) in Indonesia, we screened over 6000 genotypes for resistance to PStV; 22 showed either low incidence or were not infected.

Insect Pests

Incidence at ICRISAT Center

The insect pest situation during the 1986/87 post-rainy season was more or less as expected. Thrips in the proportion of 10 *Scirtothrips dorsalis* to 1 *Frankliniella schultzei* damaged young groundnut plants. There was an average of 6 second-generation groundnut leaf miners $leaf^{-1}$, falling to 0.5 larvae $plant^{-1}$ in the third generation. This is well below the damage threshold. Jassids (*Empoasca kerri*) were inconspicuous in 1987. Defoliating caterpillars caused little damage, but it is worth recording that 21% of the leaflets were damaged by *Heliothis armigera* or *Spodoptera litura* in plots where insecticides had been applied, compared to 6% damaged leaflets in areas that had not been sprayed.

In the rainy season, a prolonged dry spell allowed aphids to build up to densities sufficient to cause stunting and distortion of their hosts. The effect was severe where insecticide could not be applied, but the natural enemies of aphids and heavy rainfall reduced their density drastically after about 3 weeks. The main entomological feature of the rainy season was the high incidence of groundnut leaf miner in July and August and its almost complete disappearance in September. The damage to seedlings was sufficient to cause a 35% loss in seed yield in unprotected Kadiri 3 (Robut 33-1).

Host-Plant Resistance

Aphids (*Aphis craccivora*). The high incidence of aphids in July 1987 allowed us to evaluate the response of *A. craccivora* to eight genotypes in a randomized block experiment. The experiment confirmed laboratory and greenhouse trials that showed ICG 5240 is resistant in field conditions to this important vector of virus diseases (Table 8). The data from this experiment also alerted us to the possibility that ICG 2827 has some resistance to aphids. Other experiments on groundnut aphids are discussed in the context of virus diseases in southern Africa.

Table 8. Number of aphids on 20 plants (mean from eight randomized replicates) on eight groundnut genotypes on 27 July 1987, 20 days after sowing (DAS), ICRISAT Center, rainy season 1987.

	Mean	
Genotypes	n	log n
ICG 5240	167	2.22
ICG 7827	235	2.37
ICGS 44	377	2.58
ICG 2271	436	2.64
ICGS 11	503	2.70
ICG 9883	620	2.79
ICG 156	782	2.89
ICG 5043	1377	3.14
SE		±0.12
CV %		14

Integrated Control

The environment: relationship between insect density and drought. In the 1985/86 postrainy season there was an indication that the termite *Microtermes obesi* was most active where soil was moist. Another experiment in the 1986/87 postrainy season confirmed this observation. Termite baits (10-cm diameter cellulose discs) were placed in a 150 × 60 cm (row-width) grid in a drought screening experiment that used line-source irrigation. Baits at one end of the gradient were in contact with dry soil, those at the other end were in soil that was approaching field

Table 9. Effect of defoliation by *Spodoptera litura* (five 4th-instar larvae) on some pest-resistant groundnut lines at different growth stages (80 plants plot⁻¹), ICRISAT Center, postrainy season 1986/87 and rainy season 1987.

	Postrainy season 1986/87		Rainy season 1987	
Growth stage/Genotype	Defoliation (%)	Yield plant^{-1} (g)	Defoliation (%)	Yield plant^{-1} (g)
Seedling (10 DAE)[1]				
ICGV 86031	86	10.0	100	4.5
ICG 5240	61	8.4	100	10.5
ICGV 86030	87	5.8	100	4.6
ICGV 86535	83	10.2	100	3.9
ICG 156	100	6.1	100	4.7
ICG 221	100	4.4	100	1.7
SE	±11	±1.2	±0.0	±1.1
Flowering (30 DAE)				
ICGV 86031	58	11.7	45	9.2
ICG 5240	70	8.3	54	10.0
ICGV 86030	59	6.4	58	12.4
ICGVGV 86535	68	11.7	47	9.2
ICG 156	75	13.3	44	10.7
ICG 221	91	7.9	50	4.0
SE	±6.4	±1.2	±4.62	±0.89
Pegging (50 DAE)				
ICGV 86031	37	15.0	64	10.8
ICG 5240	44	6.9	67	13.3
ICGV 86030	47	7.2	68	11.6
ICGV 86535	54	10.4	64	10.9
ICG 156	41	13.1	60	10.2
ICG 221	50	10.0	69	5.3
SE	±12	±1.8	±4.64	±1.2
Pod filling (70 DAE)				
ICGV 86031	22	18.8	35	10.1
ICG 5240	11	14.5	24	12.0
ICGV 86030	14	12.2	36	12.3
ICGV 86535	12	12.8	26	9.6
ICG 156	28	17.1	38	12.6
ICG 221	18	12.8	39	5.4
SE	±7	±1.6	±7.6	±1.1
Sprayed[2] controls				
ICGV 86031	0	18.3	0	11.4
ICG 5240	0	14.5	0	14.7
ICGV 86030	0	11.1	0	11.1
ICGV 86535	0	12.5	0	12.0
ICG 156	0	17.9	0	10.4
ICG 221	0	13.7	0	5.4
SE		±1.4		±1.1

1. DAE = days after emergence.
2. Sprayed with Nuvan® applied 3 times at 200 mL a.i. ha^{-1}.

capacity throughout the experimental period. The abundance of *M. obesi* changed from being uniform along the gradient 50 days after emergence (DAE) to being concentrated at the wet end 90 DAE. *Odontotermes* spp showed no clear response.

Spodoptera litura. *S. litura* has been selected as one of our key insects because of its importance as a groundnut pest throughout Asia. Our work also has relevance to several other parts of the world where members of the same genus defoliate groundnut crops.

Host-plant resistance has been reported in previous years. It was evaluated in a field trial in the 1986/87 postrainy and the 1987 rainy seasons (Table 9). Plants at four stages of development were tested under high infestation pressure (5 fourth instar larvae $plant^{-1}$). The degree of defoliation varied little between the genotypes, although the stage of development of the plant had a marked effect, as expected. The main difference between genotypes was in yield, following severe defoliation. ICGV 86535 (postrainy season) and ICG 5240 (rainy season) were outstanding in this regard. In an experiment comparing the degree of defoliation of the same genotypes in a choice/no choice situation under field conditions in the 1987 rainy season, the defoliation in three of the lines with resistance was markedly lower than in the controls (Table 10).

Table 10. Performance of some selected pest-resistant lines against defoliation by *Spodoptera litura* in choice and no-choice situations, ICRISAT Center, rainy season 1987.

	Defoliation (%)[1]	
Genotype	Choice situation	No-choice situation
ICG 5240	15 (23)[2]	39 (39)
ICGV 86031	18 (24)	30 (32)
ICGV 86030	21 (27)	55 (48)
ICGV 86535	8 (10)	30 (32)
Susceptible controls		
ICG 221	56 (49)	58 (50)
ICG 156	31 (34)	64 (53)
SE	(±4.2)	(±5.5)

1. 22 egg masses $plot^{-1}$ and three 4th instar larvae $plot^{-1}$ released (plot size 5 × 1 m, 80 plants $plot^{-1}$).
2. Numbers in parentheses are arc sine transformed values.

A review of the last five seasons' observations on the natural enemies of *S. litura* indicated that the tachinid, *Paribaea orbata* (a fly, superficially similar to a housefly) was the most prevalent. This species lays eggs on the skin of the caterpillar, where the larvae develop. The mean level of larval parasitism did not exceed 9%.

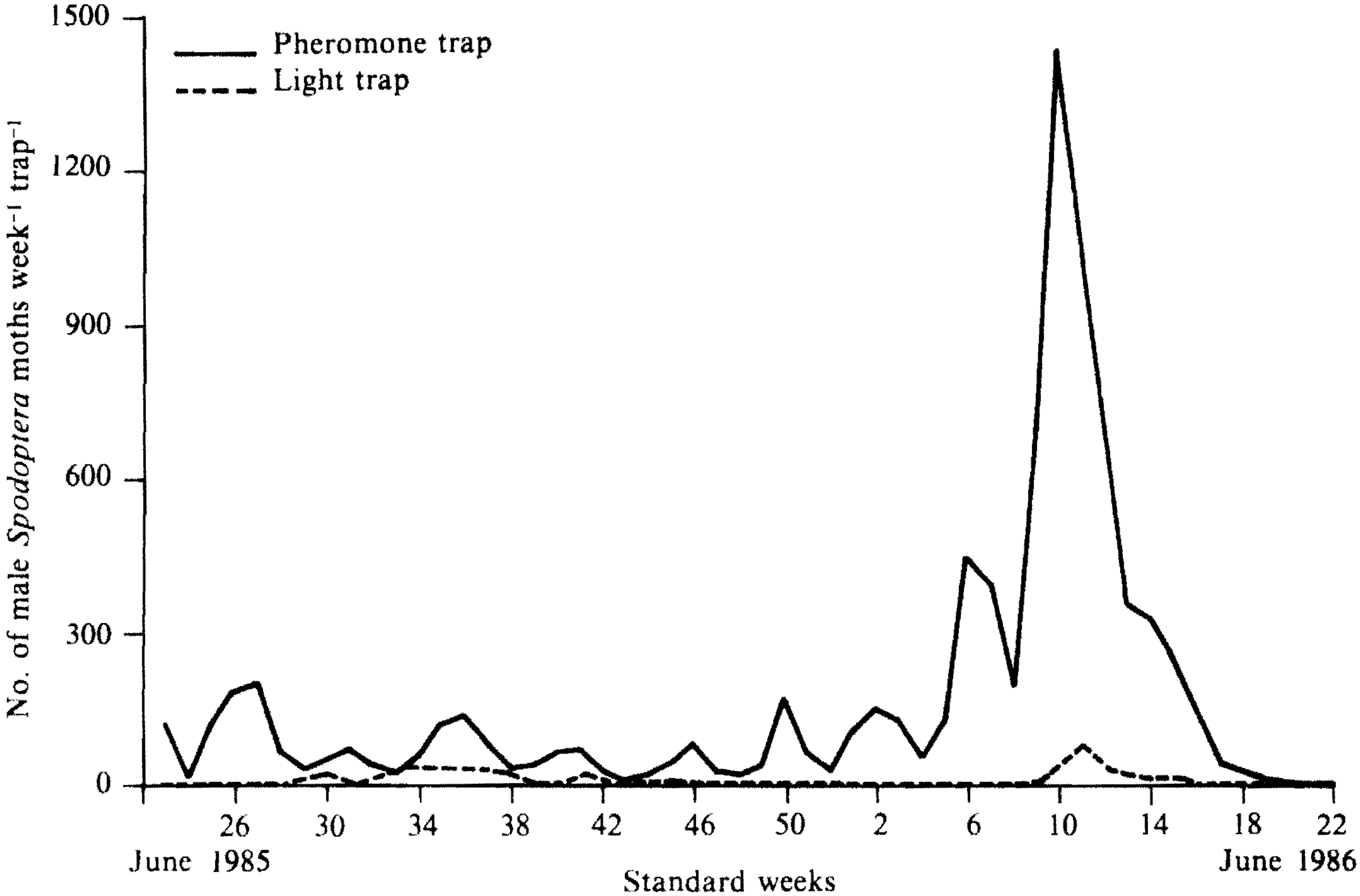
A comparison of light trap and pheromone trap records indicates that the former have given misleading information by indicating that *S. litura* adults are not active during the prerainy season period (standard weeks 18-30) (Fig. 5). It can also be seen that the pheromone trap caught more *S. litura* than did the light trap.

Pheromone trap height (range 0.5-4.0 m) had considerable influence over the number of moths caught during the season. In the seedling stage they flew low (0.5-1.0 m). During vegetative growth, most were caught 4.0 m above the ground. The pattern became confused later in the season, but after harvest, the 4.0-m trap again caught most moths. Taking the season as whole, there was little difference between the 1.0, 1.5, 2.0, and 4.0-m traps.

Groundnut leaf miner (*Aproaerema modicella*) parasitism. A research scholar initiated a project in which he will model the groundnut plant pest (groundnut leaf miner) natural enemy (parasites, pathogens, etc.) system. The high incidence of leaf miner in the 1987 rainy season enabled him to obtain an indication of the influence of an early attack of this species on the yield. The soil-incorporated, systemic insecticide isofenphos (2 kg a.i. ha^{-1}) gave as good control of the leaf miner as 3 foliar sprays of systemic insecticide, but without reducing the level of leaf miner parasitism.

Intercropping

A project continuing previous work on the effect of rows of biotic barriers (cereals, sunflowers,



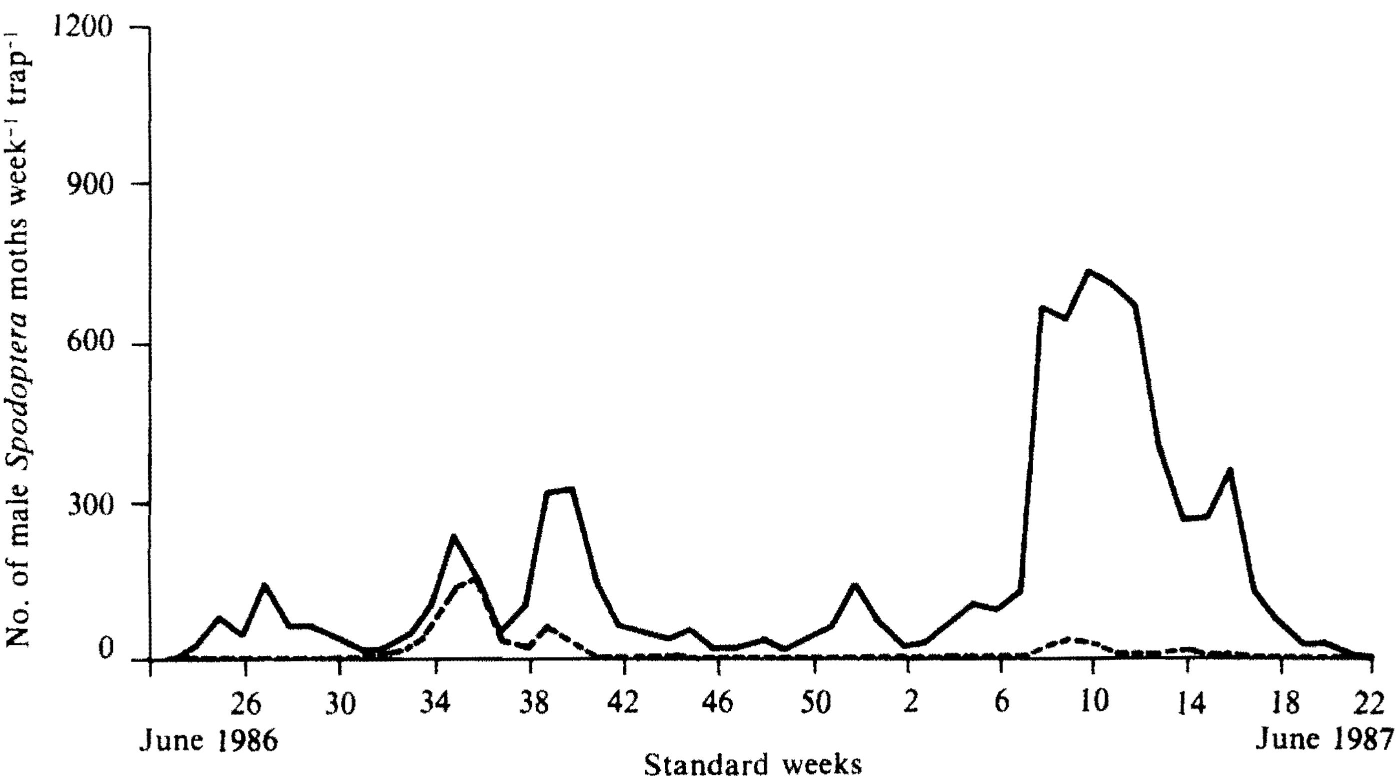


Figure 5. ***Spodoptera litura*** **flight activity monitored using pheromone and light traps, ICRISAT Center, groundnut seasons, 4 Jun 1985–3 Jun 1987.**

etc.) in groundnut crops on the incidence of pests was initiated as a joint venture between agronomists of RMP and groundnut entomologists. This project will determine why insect densities vary between the intercropping and sole cropping systems, and will make practical suggestions as to how farmers can apply the research station findings.

Storage Pests

The documentation accompanying released groundnut genotypes should include comments on the susceptibility of the stored product (in the shell or hulled) to a range of stored product pests. In 1987, we initiated procedures that will become routine in the future to provide this information.

Screening for Pest Resistance

Groundnut leaf miner (*Aproaerima modicella*). During the rainy season we were able to screen 1181 lines in three replicated trials at ICRISAT Center under high infestation pressure from the groundnut leaf miner. While no genotype showed a high degree of resistance, 35 showed sufficient resistance to this pest for this factor to be taken into consideration (Table 11), with the other attributes that include foliar diseases resistance, drought resistance, and confectionery qualities (Table 11).

Plant Improvement

During the year we made 529 new crosses (63 810 pollinations) for various breeding activities in the groundnut crop. In the 1986/87 postrainy season, where we completed 329 crosses, our average success rate was 32% in the field and 52% in the greenhouse. The lower success rate in the field was mainly due to the effect of iron chlorosis. There were, on average, 11% selfed plants during the two growing seasons.

Breeding for Adaptation to Specific Environments and Requirements

In 1987, we modified our assessment methods and we now have three levels of evaluation trials: preliminary, advanced, and elite. The preliminary trials are conducted on Alfisols and the advanced trials are on both Alfisols and Vertisols at ICRISAT Center. The elite trials are the same as the advanced ones except that they are also grown at Anantapur, Bhavanisagar, Dharwad, and Hisar, thereby testing our advanced material over a range of different environments.

We also extended the scope of this project to include multiple stress environments. We started the exercise of zonalizing groundnut-growing environments based on both biotic and abiotic stress factors to generate better adapted material. In our crossing program there has been a distinct shift towards generating material that is likely to possess relevant combinations of resistance or tolerance to multiple stress factors.

Early-Maturing Group

During 1987, we further modified the 'staggered harvesting' approach (ICRISAT Annual Report, 1984, pp. 227-229; 1986, pp. 238-239) by determining harvest date in terms of cumulative heat units (degree days) rather than the number of calendar days between sowing and harvest. This system uses the accumulated daily average temperature units above the lower threshold temperature for groundnut (10°C) over the cropping duration $[(T_{max} + T_{min})/2 - T_{base}]$. The cumulative heat units for 75- and 90-day crops in the rainy season at ICRISAT Center, starting 15 June, are 1240 and 1475 degree days (data derived from 14 years temperature records). These estimates were close to reality in the 1987 rainy season, when it took 77 days to accumulate 1240 degree days and 91 days to accumulate 1475 degree days. The equivalent periods in the 1986/87 postrainy season were 99 and 113 days.

Table 11. Groundnut genotypes with resistance to leaf miner (*Aproaerema modicella*), ICRISAT Center, rainy season 1987.

Genotype	Mean infestation rating[1]	Genotype	Mean infestation rating
ICGV 87816	5.3	ICGV 86560	5.7
ICGV 87841	5.7	ICGV 86579	6.0
ICGV 87194	5.0	ICGV 86027	5.0
ICGV 87206	5.3	ICGV 86565	6.0
ICGV 87242	5.0	ICGV 86576	5.7
ICGV 87285	5.3	ICGV 86028	5.3
ICGV 87323	5.7	ICGV 86571	6.0
ICGV 86601	5.0	ICGV 86582	5.3
ICGV 86680	5.7	ICGV 86026	5.7
ICGV 87237	4.7	ICGV 86598	4.7
ICGV 87326	5.0	ICGV 87495	5.0
ICGV 87327	5.0	ICGV 86011	4.0
ICGV 87183	5.3	ICGV 86162	4.0
ICGV 87339	5.0		
ICGV 87340	5.7	Susceptible controls	
ICGV 87341	5.0	ICG 221(TMV 2)	8.0
ICGV 86709	4.7	ICG 799(Kadiri 3)	7.3
ICGV 87165	5.0	ICG 156(M 13)	7.3
ICGV 87157	5.0	ICG 7827(JL 24)	8.0
ICGV 87160	5.0	ICGS 44	7.3
(NC Ac 1107 × EC 76446(292)	4.0	ICG 1697(NC Ac 17090)	6.3
		ICG 2271(NC Ac 343)	7.7
(NC Ac 1107 × NC Ac 17090)	5.7	ICGS 11	7.0
SE	±0.45		±0.45
CV (%)	14		14

1. Infestation rating on a 1-9 scale, where 1 = no damage, and 9 = 90-100% foliage damage.

We grew 199 and 1761 bulk selections from F_2 to F_9 generations in the 1986/87 postrainy and 1987 rainy seasons. In the postrainy season, we identified 60 new breeding lines to be tested in preliminary yield trials. In the rainy season, we identified 44 new breeding lines for yield testing and based on their apparent maturity, pod yield, and pod and seed appearance, we retained 822 bulks for further selection.

During the 1986/87 postrainy season, we also evaluated 189 germplasm lines for earliness, and pod and plant characteristics, and selected 45 for yield testing. This set of material should help us diversify sources of earliness.

Yield trials. In replicated yield trials we evaluated 142 varieties in the 1986/87 postrainy season and 49 varieties in the 1987 rainy season, at ICRISAT Center under high input conditions (60 kg P_2O_5 ha^{-1}, irrigation and protection against pests and diseases). In the 1986/87 postrainy season, 42 varieties gave significantly higher pod yields than the highest-yielding control variety in the 99-day harvest and 17 varieties gave significantly higher pod yields than the highest-yielding control variety in the 113-day harvest. Similarly, in the 1987 rainy season, two varieties outyielded the highest-yielding control variety in the 77-day harvest and one variety outyielded the highest-yielding control variety in the 91-day harvest. Selected varieties and the early-maturing control variety Chico reached acceptable levels of maturity when the crop accumulated 1240 degree days (Table 12).

Medium- and Late-Maturing Group

In the 1987 rainy season, we grew 197 populations (F_2-F_{10}) and made 243 selections for pod yield and other desirable pod and seed characteristics.

Yield trials. We evaluated 282 sequentially branching selections in three replicated yield trials for their adaptation to the postrainy season. Eleven produced significantly higher pod yields than the highest-yielding control variety (Table 13). ICGV 86236 was the only common variety among the varieties included in the EMLGVT (Alfisol) and EMLGVT (Vertisol). Several other genotypes that performed well on Alfisols were not so good on Vertisols.

In the 1987 rainy season, we evaluated 233 advanced breeding lines in seven replicated trials at ICRISAT Center and the other ICRISAT locations in India. In general, yield levels were low due to prevailing drought and other stress factors (Table 14). Only 22 varieties produced significantly higher pod yields than the highest-yielding control variety. Varieties that were commonly in the top five for yield are ICGV 86187 in the EMLGVT(SB) at 3 locations, ICGV 86347 at 3 locations, ICGV 86350 at 2 locations, ICGV 86201 at 2 locations, ICGV 86866 at 2 locations, and ICGV 86238 at 2 locations in the

Table 12. Performance of selected early-maturing groundnut varieties in staggered harvests under high-input Alfisol conditions, ICRISAT Center, postrainy season 1986/87[1].

	Pod yield (t ha^{-1})		SMK[2] yield (t ha^{-1})		Shelling %	
Genotypes	(99,1240)[3]	(113,1475)	(99,1240)	(113,1475)	(99,1240)	(113,1475)
ICGV 86016	2.62	3.52	1.55	2.55	72	74
ICGV 86065	2.15	3.11	1.33	2.27	72	76
ICGV 86038	2.06	3.05	1.36	2.17	73	76
ICGV 86061	1.99	2.90	1.34	2.10	74	75
Controls						
Chico[4]	1.25	1.57	0.88	1.19	76	79
ICGS 11[5]	1.50	2.54	0.52	1.64	54	67
SE	±0.12	±0.18	±0.13	±0.15	±2.3	±2.8
Trial mean (36 entries)	1.90	2.79	1.08	1.89	67	72
CV (%)	11	11	21	13	6	7
Efficiency over RBD (%)	100	108	98	98	101	92

1. Experimental design = Triple lattice; plot size = 6 m^2; High input = 60 kg P_2O_5 ha^{-1}, with full irrigation and insecticide sprays.
2. SMK = Sound mature kernels.
3. Figures in parentheses are the actual number of days from sowing to harvest, and the accumulated heat units over that cropping period.
4. Early-maturing source line.
5. Highest-yielding control variety in the trial.

Table 13. Performance of high-yielding medium- and late-maturing, sequentially branching groundnut varieties, ICRISAT Center, postrainy season 1986/87[1].

Trial/ Location/ Soil type/ Plot size[1]	Entry	Pod yield ($t\ ha^{-1}$)	Shelling %	100-seed mass (g)	Oil (%)	Protein (%)
EMLGVT[2]	ICGV 86259	5.66	66	69	49.2	23.8
ICRISAT Center	ICGV 86363	5.57	72	60	47.0	25.3
Alfisol	ICGV 86236	5.49	72	80	48.6	27.7
13.5 m^2	Control[3]					
	ICGS 11	4.76	69	67	48.4	25.2
	SE	±0.26				
	Trial mean (64 entries)	4.49				
	CV (%)	10				
	Efficiency over RBD (%)	100				
EMLGVT	ICGV 86236	4.64				
ICRISAT Center	ICGV 86249	4.93				
Vertisol	ICGV 86398	4.83				
13.5 m^2 (only pod	Control[3]					
yield assessed)	Kadiri 3 (Robut 33-1)	4.03				
	SE	±0.19				
	Trial mean (61 entries)	3.63				
	CV (%)	9				
AMLGVT	ICGV 86326	5.79	75	63	49.3	25.2
ICRISAT Center	ICGV 86441	5.73	62	47	47.6	26.7
Alfisol	Control[3]					
13.5 m^2	Kadiri 3 (Robut 33-1)	4.88	62	55	46.2	25.3
	SE	±0.26				
	Trial mean (81 entries)	4.55				
	CV (%)	10				
	Efficiency over RBD (%)	113				
PMLGVT	ICGV 86522	6.34	64	57	46.5	26.0
ICRISAT Center	ICGV 87382	6.12	64	57	45.8	27.6
Alfisol	ICGV 87495	6.11	69	71	51.3	29.4
6.0 m^2	Control[3]					
	Kadiri 3 (Robut 33-1)	5.24	68	62	47.5	24.7
	SE	±0.27				
	Trial mean (144 entries)	5.12				
	CV (%)	9				
	Efficiency over RBD (%)	128				

1. Triple lattice, all postrainy-season trials grown under high input conditions i.e., 60 kg P_2O_5 ha^{-1}, with full irrigation and insecticide sprays. Experimental design was triple lattice in all trials except for EMLGVT/ ICRISAT Center (Vertisol) which was grown in a randomized block design.
2. EMLGVT = Elite medium- and late-maturing groundnut varietal trial; AMLGVT = Advanced medium- and late-maturing groundnut varietal trial; PMLGVT = Preliminary medium- and late-maturing groundnut varietal trial.
3. Control = Highest-yielding control in the trial.

Table 14. Performance of selected high-yielding, medium- and late-maturing groundnut varieties in yield trials, various Indian locations, rainy season 1987.

Trial/Location/ Plot size[1]	Entry	Pod yield (t ha⁻¹)	Shelling (%)	100-seed mass (g)	Oil (%)	Protein (%)
EMLGVT(SB)	ICGV 86303	1.89	64	37	45.4	23.7
ICRISAT Center	ICGV 86310	1.75	70	33	45.5	23.7
High input	ICGV 86187	1.74	67	43	49.3	23.4
13.5 m²	Control[2]					
	ICGS 44	1.32	71	37	47.6	22.2
	SE	±0.12				
	Trial mean (49 entries)	1.32				
	CV (%)	16				
	Efficiency over RBD (%)	126				
EMLGVT(VB)	ICGV 86347	2.37	66	31	42.7	25.8
ICRISAT Center	ICGV 86350	2.02	65	30	46.4	23.7
High input	Control[2]					
6.0 m²	ICGS 65	1.57	69	36	42.7	21.9
	SE	±0.12				
	Trial mean (36 entries)	1.41				
	CV (%)	15				
	Efficiency over RBD (%)	109				
EMLGVT(VB)						
Dharwad	ICGV 86222	1.84	64	23	-	-
Rainfed	Control[2]					
4.8 m²	ICGS 65	1.49	64	27	-	-
	SE	±0.11				
	Trial mean (36 entries)	1.35				
	CV (%)	14				
	Efficiency over RBD (%)	90				
EMLGVT(VB)	ICGV 86197	4.33	65	23	-	-
Hisar	ICGV 86190	4.27	65	25	-	-
Irrigated	ICGV 86347	4.08	54	25	-	-
6.0 m²	ICGV 86866	4.03	66	27	-	-
	ICGV 86238	3.94	58	26	-	-
	Control[2]					
	ICGS 65	3.15	64	24	-	-
	SE	±0.27				
	Trial mean (36 entries)	3.41				
	CV (%)	14				
	Efficiency over RBD (%)	135				

Continued.

Table 14. *Continued.*

Trial/Location/ Plot size[1]	Entry	Pod yield (t ha^{-1})	Shelling (%)	100-seed mass (g)	Oil (%)	Protein (%)
AMLGVT(SB)	ICGV 87935	1.74	66	30	48.1	22.0
ICRISAT Center (HI)	ICGV 87143	1.66	62	33	47.6	25.9
High input	ICGV 86876	1.47	62	33	45.1	22.7
13.5 m^2	Control[2]					
	JL 24	1.20	65	36	44.9	27.0
	SE	±0.09				
	Trial mean (36 entries)	0.88				
	CV(%)	17				
	Efficiency over RBD (%)	119				
PMLGVT(SB)						
ICRISAT Center	ICGV 86928	2.17	68	44	47.5	24.4
High input	Control[2]					
6.0 m^2	JL 24	1.51	62	35	43.2	27.5
	SE	±0.15				
	Trial mean (36 entries)	1.07				
	CV (%)	24				
	Efficiency over RBD (%)	94				
PMLGVT(VB)	ICGV 86300	2.23	66	37	43.2	27.1
ICRISAT Center	ICGV 86924	1.88	55	36	45.4	26.7
High input	ICGV 86325	1.86	69	33	42.8	22.3
6.0 m^2	ICGV 86923	1.82	64	37	45.7	24.1
	ICGV 86911	1.78	68	37	47.9	22.8
	Control[2]					
	C 198	1.44	69	40	48.0	22.8
	SE	±0.10				
	Trial mean (49 entries)	1.29				
	CV (%)	14				
	Efficiency over RBD (%)	114				

1. Experimental design = Triple lattice; EMLGVT=Elite medium- and late-maturing groundnut varietal trial; AMLGVT=Advanced medium- and late-maturing groundnut varietal trial; PMLGVT=Preliminary medium- and late-maturing groundnut varietal trial; SB=spanish bunch, var *vulgaris*; VB=virginia bunch, var *hypogaea*; High input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays.
2. Control = Highest-yielding control in the trial.
3. – = Not tested.

EMLGVT(VB); ICGV 86928 and ICGV 86934 at 2 locations in the PMLGVT(SB), and ICGV 86325 at 2 locations in the PMLGVT(VB).

Of the five locations where elite trials were carried out, the highest location mean pod yield of 2.9 t ha^{-1}, was recorded at Bhavanisagar followed by Hisar, 2.8 t ha^{-1}; Dharwad, 1.5 t ha^{-1}; ICRISAT [high input (HI)], 1.4 t ha^{-1}; and ICRISAT [low input (LI)], 1.0 t ha^{-1}.

ICGV 86197 recorded the highest pod yield (4.3 t ha^{-1}) at Hisar among the entries in various trials. It was followed by ICGV 86347 (3.8 t ha^{-1})

at Bhavanisagar. Both these varieties are *Arachis* spp *hypogaea* var *hypogaea*.

Confectionery Group

We introduced 75 confectionery lines from North Carolina State University, USA. While most did not produce large pods or seeds at ICRISAT Center in the 1987 rainy season, many of them had the clean, elongate pods and seeds required by the confectionery industry. These lines have been retained for further evaluation and utilization in our crossing program.

From a total of 890 F_1-F_5 populations grown during the 1986/87 postrainy season and the 1987 rainy season, 316 selections were made for pod yield, pod shape and size, and seed shape, size, and color. Some of these selections harvested 110 DAE and had a 100-seed mass in the range of 110–150 g, whereas our best confectionery line, ICGV 86564, had a 100-seed mass of only 90 g and took 15 days longer to mature.

Yield trials. We evaluated 35 confectionery breeding lines in an advanced trial under HI conditions at ICRISAT Center during the 1986/87 postrainy season (Table 15). Several gave higher pod yields and a higher percentage of extra-large kernels than the control varieties, M 13 and Chandra. They also had higher shelling percentages than the controls.

Table 15. Performance of some high-yielding confectionery groundnut varieties under high-input conditions, ICRISAT Center, postrainy season 1986/87[1].

Variety	Branching habit[2]	Pod yield (t ha^{-1})	Shelling %	Extra-large seeds (%)[3]	100-seed mass (g)	Oil (%)	Protein (%)
ICGV 86563	A	5.97	66	40	70	46.6	26.4
ICGV 86576	S	5.78	63	75	78	49.6	25.2
ICGV 86565	S	5.66	62	71	70	49.6	26.2
ICGV 86580	S	5.49	71	90	116	43.1	29.3
ICGV 86583	S	5.17	62	72	70	49.5	26.3
ICGV 86571	S	5.05	55	84	60	47.3	24.9
ICGV 86026	S	5.03	66	72	90	49.2	29.7
ICGV 86581	S	4.79	67	88	106	45.0	28.7
ICGV 86577	S	4.76	76	87	119	46.6	28.8
ICGV 86579	S	4.04	75	93	108	46.4	29.8
ICGV 86564	A	3.69	64	53	90	51.0	26.5
Controls							
M 13	A	2.83	55	10	67	45.6	24.0
Chandra	A	2.30	52	26	76	47.3	23.6
SE		±0.30					
Trial mean (42 entries)		4.82					
CV (%)		10					
Efficiency over RBD (%)		106					

1. Plot size 13.5 m^2; high input = 60 kg P_2O_5 ha^{-1}, with full irrigation and insecticide sprays.
2. A = Alternate branching, ssp *hypogaea*; S = Sequential branching, ssp *fastigiata*.
3. One-kg bulk seed was graded and the percentage derived from the mass of seeds that could not pass through 20/64" × 3/4" mesh sieve.

ICGV 86563 produced the highest pod yield (5.97 t ha^{-1}) and had 30% more extra-large kernels than M 13 and 14% more than Chandra. It had the highest pod yield (3.36 t ha^{-1}) during the 1986 rainy season when control variety Chandra produced 2.67 t ha^{-1} (ICRISAT Annual Report 1986, p. 240).

Adaptation to Vertisols

Vertisols in India constitute about 37% of the groundnut-growing area and contribute 32% to the total groundnut production. In general, groundnut yields are reported to be lower on Vertisols than on Alfisols.

We now grow all our elite and advanced replicated yield trials at ICRISAT Center on both Vertisols and Alfisols. We found significant pod yield differences between soil types, and a significant variety × soil type interaction effect in four such yield trials. Pod yields were 11–22% lower on Vertisols, although a few entries were not affected by soil type and some even gave higher yields on Vertisols than on Alfisols.

Drought Tolerance

We advanced 113 F_2 populations to F_3 by single-pod descent. From the 26 F_4 progenies, we made 33 bulk selections under rainfed conditions for replicated yield evaluation at Anantapur and ICRISAT Center.

In our routine monitoring of advanced breeding lines, we found that nine early lines and five lines from the medium- and late-maturing group had tolerance to both mid- and end-of-season droughts. A further six lines in the medium-, and two in the late-maturing group, had tolerance to midseason and end-of-season droughts.

Yield trial. We evaluated 33 varieties for pod yield, together with one drought-tolerant breeding line and two released varieties as controls, at ICRISAT Center and Anantapur under rainfed conditions. ICGV 86600, was the best at both locations, with 6% pod yield superiority over the highest-yielding control variety at Anantapur and 22% pod yield superiority over the highest-yielding control variety at ICRISAT Center.

Tolerance to Multiple Stresses

We now monitor all our advanced breeding lines for tolerance or resistance to various stress factors in addition to assessing their yield potential.

One of our early-maturing varieties, ICGV 86054, which showed tolerance to midseason and end-of-season drought, also had tolerance to PMV disease. It did not show any yield reduction at a level of disease incidence where Kadiri 3 (Robut 33-1) suffered a yield loss of 8% and TMV 2 lost 16% of its yield. One of our insect pest-resistant lines, ICGV 86793, had tolerance to end-of-season drought and two other insect pest-resistant lines, ICGV 86798 and ICGV 86804, were tolerant to mid-season drought.

We evaluated the yields of 23 foliar diseases-resistant varieties that also have resistance to insect pests and drought. In the 1986/87 post-rainy season in stress-free environments, seven varieties were on par (5.9–6.4 t ha^{-1}) for pod yield with the highest-yielding control variety ICGS 11 (5.7 t ha^{-1}). During the 1987 rainy season, when this trial was grown at various locations, two lines at Dharwad and one line at Hisar gave significantly higher pod yield than the highest-yielding control variety in the trial (Table 16).

Nutritional and Food Quality Studies

An important characteristic of groundnut is its food quality—it contains nearly 50% lipid and 25% protein. Both are needed to supplement the high carbohydrate diet of people who live in the SAT. It is essential that we maintain existing levels of oil content, or even increase them when breeding lines destined for oil production. Germplasm lines having seed with higher-than-average oil contents have been identified, and after crossing, their progeny are being tested in multiloca-

Table 16. Performance of some elite multiple diseases- and pest-resistant groundnut selections in multilocational trials, rainy season 1987[1].

Location/Variety	Pod yield (t ha^{-1})	Disease scores[2] Rust	Disease scores[2] Late leaf spot	Groundnut leaf miner score[3]
Dharwad, rainfed				
ICGV 87165	1.77	4	5	5
ICGV 86709	1.68	4	5	5
Controls				
NC Ac 17090[4]	0.73	4	7	6
JL 24[5]	1.35	9	9	8
SE	±0.10			
Mean (25 entries)	1.06			
CV (%)	16			
Efficiency over RBD (%)	107			
Hisar, irrigated				
ICGV 87333	4.37	4	6	8
Controls				
NC Ac 17090[4]	3.34	4	7	6
ICGS 11[5]	2.75	9	9	7
SE	±0.37			
Mean (25 entries)	2.94			
CV (%)	22			
Efficiency over RBD (%)	119			

1. Experimental design = Triple lattice, plot size = 6.0 m^2.
2. Field diseases scored on a 1–9 scale, where 1 = no disease and 9 = 50–100% foliage damaged, ICRISAT Center, rainy season 1986.
3. Field insect damage scored on a 1–9 scale, where 1 = no insect damage and 9 = 90–100% foliage damaged, ICRISAT Center, rainy season 1987.
4. Rust-resistant control.
5. Highest-yielding rust- and late leaf spot-susceptible control.

tional trials. Advanced breeding lines, ICGV 86388, 86335, 86311, 86435, 86418, 86446, and 86435 had 50–52% oil content in the 1986 rainy season. The first three also had high yield potential.

We analyzed seed of several released selections, or selections close to release in India. Their oil contents were higher than those of the controls, and their protein content, and other basic seed components were comparable (Table 17). Further, the protein in these genotypes had a higher proportion of amino acids that tend to be deficient in groundnuts (Table 18). The fatty acid profile of ICGS 21 had a higher oleic/linoleic ratio (1.42) than the other varieties listed in Table 18 (0.92–0.96).

Table 17. Composition of selected groundnut genotypes, ICRISAT Center, postrainy season 1985/86.

Entry	Protein (%)	Oil (%)	Starch (%)	Soluble sugars (%)	Crude fiber (%)	Ash (%)	Moisture (%)
ICGS 1	24.9	48.3	11.8	4.6	2.2	7.3	7.3
ICGS 5	25.7	48.2	12.3	4.6	2.3	2.3	6.8
ICGS 11	25.0	48.3	11.8	4.6	2.2	2.3	6.7
ICGS 21	24.2	50.0	11.3	5.0	2.0	2.3	6.8
ICGS 44	25.4	49.1	12.2	4.4	2.1	2.2	7.1
Controls							
Kadiri 3 (Robut 33-1)	29.2	46.4	11.2	3.6	2.1	2.2	5.0
J 11	25.8	47.2	13.7	5.2	2.1	2.4	5.1
SE	±0.4	±0.2	±0.2	±0.1	±0.02	±0.01	±0.2

Table 18. Essential amino acid composition and protein contents of groundnut genotypes[1], ICRISAT Center, postrainy season 1985/86.

Component	ICGS 1	ICGS 5	ICGS 11	ICGS 21	ICGS 44	Kadiri 3[2] (Robut 33-1)	SE
Lysine	3.98	4.03	4.07	4.06	4.09	3.81	±0.04
Threonine	3.23	3.09	3.32	3.10	3.14	2.90	±0.06
Valine	4.65	4.80	4.51	4.66	4.69	4.27	±0.08
Methionine + cystine	2.95	2.65	2.38	2.55	2.65	2.18	±0.11
Isoleucine	3.73	3.86	3.76	3.66	3.64	3.49	±0.05
Leucine	6.92	7.27	6.84	7.17	7.24	6.26	±0.16
Phenylalanine + tyrosine	10.17	10.49	9.77	10.10	10.32	9.90	±0.11
Protein content (%)	49.60	49.10	49.70	49.80	49.00	52.20	±0.48

1. Means of duplicate determinations.
2. Standard control.

Utilizing Wild *Arachis* Species

In the past, our emphasis has been on the transfer of genes that confer resistance to late leaf spot and rust from the compatible species of section *Arachis* into the cultivated groundnut. We produced a wide range of interspecific derivatives from crosses between *A. hypogaea* and the only eight accessions of section *Arachis* initially available at ICRISAT, and established a number of cytologically stable, uniform, *A. hypogaea*-like, tetraploid lines resistant to these two foliar diseases.

This year we changed the emphasis. Early leaf spot and groundnut rosette virus (GRV) diseases are the major yield constraints in Africa, but we cannot screen for their resistance in India. Therefore, 21 wild *Arachis* accessions were supplied to the ICRISAT Regional Groundnut Improvement Program for Southern Africa in

Malawi to be screened for these diseases. The ICRISAT pathologist identified three accessions, *A. chacoense, Arachis* sp 30085, and *Arachis* sp 30003, resistant to early leaf spot, and another accession *Arachis* sp 30017, resistant to GRV.

We crossed the new accessions with *A. hypogaea* and with diploid species of section *Arachis* representing the A and B genomes, using *A. chacoense* as the representative of the A genome (Table 19). Except for *A. chacoense* × *Arachis* sp 30003, all the crosses attempted produced pods, but all pods produced when *Arachis* sp 30003 was a parent contained aborted or immature ovules. We transferred the immature ovules to in vitro culture. *Arachis hypogaea* was also crossed with *A. chacoense*, and produced 51 pods per 100 pollinations. We checked the plant morphology and the karyotype of these accessions, and concluded that *Arachis* sp 30017 and *Arachis* sp 30085 are in section *Arachis* and have an A genome, while *Arachis* sp 30003 is probably a member of section *Erectoides*, though the plants grown at ICRISAT Center do not have the lomentiform tuberoid roots and hypocotyl typical of that section.

We grew the triploid hybrids, *A. hypogaea* (4x) × *Arachis* sp. 30085 (2x) and they produced seeds and seedlings, as have other triploid hybrids grown at ICRISAT Center in the past. We counted chromosomes in a sample of triploid progenies, and found that 93% of plants had 60 chromosomes and were hexaploid, the remaining 7% had 40–60 chromosomes. Meiotic analysis in one of these spontaneously produced F_2 hexaploid plants revealed a high frequency of bivalents (24.9 per cell) and the pollen and pod fertility were very high, indicating that it was cytologically stable (Table 20).

We also backcrossed these triploid hybrids with *A. hypogaea*, but with little success. However, we were able to produce two backcross plants, one of which was tetraploid, and the other pentaploid. They are probably the result of fertilization between viable unreduced gametes

Table 19. Crossability of *Arachis* wild species accessions resistant to early leaf spot and groundnut rosette virus (GRV) with *Arachis hypogaea* and diploid species, ICRISAT Center, 1987.

♂ Parent / ♀ Parent	*Arachis* sp 30003			*Arachis* sp 30017			*Arachis* sp 30085		
	a[1]	b	c	a	b	c	a	b	c
2x × 2x									
A genome:									
Arachis chacoense	60	0	0	65	11	17	36	10	28
Reciprocal	47	3[2]	6	61	14	23	52	6	12
B genome:									
Arachis batizocoi	48	12[2]	25	-[3]	-	-	32	13	40
Reciprocal	59	6[2]	10	53	14	26	65	3	5
4x × 2x									
A. hypogaea ssp *hypogaea* var. virginia									
ICGMS 42	23	17[2]	74	3	1	33	34	21	62
Mani Pintar	25	6[2]	24	16	2	13	24	8	33
A. hypogaea ssp *fastigiata* var. spanish									
ICGMS 30	31	19[2]	61	-	-	-	23	13	57

1. a = Number of pollinations; b = Number of pods; c = Percentage pods pollination^{-1}.
2. In culture.
3. - = Data not available.

Table 20. Chromosome associations and pollen stainability in hybrids and backcross derivatives of *Arachis hypogaea* × *Arachis* sp 30085, ICRISAT Center, 1987.

Generation	Chromosome number	Mean chromosome association				Pollen stability (%)
		I	II	III	IV	
F_1	30[1]	8.9 (±0.39)[3]	9.2 (±0.3)	0.9 (±0.2)	-[2]	29 (±2.7)
F_2	60[1]	7.8 (±1.3)	24.9 (±0.7)	0.7 (±0.2)	0.1 (±0.1)	93 (±1.3)
BC_1F_1	40[1]	9.4 (±0.7)	13.2 (±0.4)	1.4 (±0.3)	-	27 (±2.6)
BC_1F_1	50[4]	4.9 (±1.2)	19.4 (±0.5)	1.7 (±0.3)	0.2 (±0.1)	90 (±1.7)
BC_1F_2	44-50[4]	8.6 (±0.9)	17.5 (±0.7)	0.9 (±0.2)	0.1 (±0.1)	19 (±2.0)

1. *Arachis hypogaea* cultivar Kadiri 3 (Robut 33-1).
2. - = Not available.
3. Numbers in parentheses are the standard errors (SEs).
4. *Arachis hypogaea* cultivar JL 24.

(resulting from the formation of restitution nuclei) and viable diploid gametes (resulting from genomic segregation) of the triploid hybrids, and normal gametes of *A. hypogaea.* We observed that the BC_1F_1 tetraploid backcross progeny, despite having the usually balanced chromosome number of 2n = 40, formed many univalents, and had low pollen and pod fertility. We found that the pentaploid BC_1F_1 progeny had high bivalent frequency, and high pollen fertility which indicated that there was genomic homology between the chromosomes, though pod fertility was low, and this plant only produced two seeds. One of these produced offspring which had variable chromosome numbers in the pollen mother cells, high univalent frequency, and low pollen fertility.

Although we were only able to produce a few plants in these crosses, the progeny will be carried forward by further backcrossing, and screened for resistance to early leaf spot in order to utilize *Arachis* sp 30085's resistance to this disease.

Intersectional Hybridization

Production of shoots from hybrid ovules. We crossed *A. hypogaea* cultivars MK 374 and M 13 (section *Arachis*) as female parents with *Arachis* sp 276233 (section *Rhizomatosae*), and cultured ovules on filter-paper bridges using liquid Murashige and Skoogs (MS) medium with 0.1 mg L^{-1} kinetin (Kn) and 0.075 mg L^{-1} indole acetic acid (IAA). We dissected embryos from these ovules after 60 days of culture, recorded their stage of development, and cultured them on agar slopes on MS medium at two levels of sucrose (3% and 5%) and two concentrations of naphthalene acetic acid (NAA) and benzyl amino purine (BAP), (2.0 mg L^{-1} and 0.5 mg L^{-1}).

The majority of the embryos were at the late globular stage of development when dissected from the ovules. Others were globular, and a very few were in the heart or cotyledonary stage of development (Table 21).

All heart-shaped or early cotyledonary embryos appeared normal, and grew, increasing in

Table 21. Number of hybrid (*Arachis hypogaea* MK 374 and M 13 × *Arachis* sp 276233) embryos growing when cultured at different stages of development on four different media, ICRISAT Center, 1987.

	Embryos							
	Globular		Late globular		Heart		Early cotyledonary	
Medium[1]	NC[2]	NG	NC	NG	NC	NG	NC	NG
Arachis hypogaea M 13 × *Arachis* sp 276233								
I	-[3]	-	7	0	-	-	-	-
II	-	-	2	0	1	1	-	-
III	2	0	5	2	-	-	2	2
IV	4	1	15	4	-	-	1	1
Arachis hypogaea MK 374 × *Arachis* sp 276233								
I	5	1	8	4	-	-	-	-
II	1	0	7	2	-	-	1	1
III	13	3	35	16	1	1	4	4
IV	4	0	11	7	-	-	1	1

1. I = MS+5% sucrose+2.0 mg L^{-1} NAA+0.5 mg L^{-1} BAP. II = MS+5% sucrose+0.5 mg L^{-1} NAA+0.5 mg L^{-1} BAP. III = MS+3% sucrose+2.0 mg L^{-1} NAA+0.5 mg L^{-1} BAP. IV = MS+3% sucrose+0.5 mg L^{-1} NAA+0.5 mg L^{-1} BAP.
2. NC = Number cultured, NG = Number which grew.
3. - = Not attempted.

size, becoming green, and usually forming callus on the media used. However, not all globular embryos grew, even though we varied the combinations of sucrose and hormones.

We observed that embryos of the cross MK 374 × *Arachis* sp 276233 at late globular stage were more responsive than those of the cross M 13 × *Arachis* sp 276233, and we obtained the best response on MS medium with 3% sucrose and 0.5 mg L^{-1} NAA and 0.5 mg L^{-1} BAP. Though we only obtained heart and cotyledonary embryos in low numbers, their response was very good irrespective of the medium on which they were cultured.

We tested various concentrations and combinations of NAA and BAP, and of indole butyric acid (IBA) and BAP, for their ability to induce shoot buds on hybrid callus and to promote bud elongation. With NAA and BAP, we observed bud formation on most combinations, and some embryogenesis when 5.0 mg L^{-1} BAP was added to the medium. IBA promoted callus and bud formation at low concentrations (0.1 mg L^{-1}), but was detrimental at higher concentrations (1.0 mg L^{-1}). Shoot bud development was very slow when media with kinetin at a concentration of 0.25–4.0 mg L^{-1} or gibberellic acid at 0.25–5.0 mg L^{-1} were used.

Rooting of shoots and transfer to soil. We continued our attempts to induce roots on hybrid shoots and transfer them to soil. Our previous experience in rooting cuttings indicated that stem cuttings of rhizomatous species are more difficult to root than similar cuttings from *A. hypogaea*.

We used IBA and NAA at 4 concentrations (0, 1, 2, and 4 mg L^{-1}), to give 16 hormone combinations, which were made up as solutions in water or in Hoagland's nutrient solution. We used two pots with four shoots in each for each treatment. We placed shoots in sterile sand, and watered

Table 22. Number of shoot cuttings of *Arachis hypogaea* and *Arachis* sp 276233 that produced roots when eight cuttings were planted in sand and treated with hormones in water or Hoaglands solution, ICRISAT Center, 1987.

Hormone combination		Number of rooted shoots			
		A. hypogaea		*A.* sp 276233	
NAA (mg L^{-1})	IBA (mg L^{-1})	Water	Hoag-land	Water	Hoag-land
0	0	3	7	0	2
1	0	4	7	4	2
2	0	7	8	2	3
4	0	6	7	4	2
0	1	5	7	2	2
1	1	7	7	5	2
2	1	5	8	7	2
4	1	6	8	3	0
0	2	4	7	5	0
1	2	6	8	4	0
2	2	8	8	6	0
4	2	6	7	5	1
0	4	5	8	1	0
1	4	7	8	5	1
2	4	5	8	4	2
4	4	5	8	4	0
Total		89	121	51	19

then with 100 mL of the solution at the start of the experiment and 3, 10, and 17 days later. We recorded root induction, and number, length, and branching of roots. The numbers of shoots which produced roots are shown in Table 22.

More *A. hypogaea* shoots produced roots than did *Arachis* sp 276233, both in water and Hoagland's solution. When we dissolved hormones in Hoaglands, more cuttings of *A. hypogaea* rooted than when hormones were dissolved in water, whereas in wild *Arachis* sp 276233 root formation was best with hormones in water.

The optimum concentration of NAA was 2 mg L^{-1}, with no significant effect at that concentration of IBA or of Hoaglands solution on the number of cuttings that produced roots. However, 2 mg L^{-1} NAA in combination with 1 mg L^{-1} IBA produced the maximum numbers of roots per shoot in both water and Hoagland's solution.

We took 18 cuttings of hybrid shoots that had previously been grafted onto *A. hypogaea* and had grown well. We treated them with NAA and IBA in a similar manner as in the previous experiments. Roots were induced on five shoots, one of which produced nearly 40 roots within two weeks. Four of the hybrid plants were transferred to soil, and one showed slight growth. The hybrid plants only survived for 3 to 4 months.

ICRISAT Regional Groundnut Improvement Program for Southern Africa

The ICRISAT Regional Groundnut Program is based at Chitedze Agricultural Research Station, near Lilongwe, Malawi. Our main task is to provide national groundnut research teams of the Southern African Development Coordination Conference (SADCC) countries with a continuous supply of high quality material for evaluation and utilization in their respective groundnut improvement programs. Our work is thus concerned primarily with the effective broadening of the germplasm base available to breeders in the region. Priorities are vested in breeding and selecting for increased yield, quality, and earliness, and for resistance to diseases of major importance.

Weather and Growing Conditions at Chitedze

Rainfall during the season (November 1986 to April 1987) was 1120 mm, 26% above the long term mean (888 mm). Distribution was poor, with prolonged dry spells interspersed with exceptionally heavy precipitation (638 mm of rain fell in December and January), which resulted in waterlogging. Yields were lower than expected. The pH of soils of our experimental fields varied from 4.8 to 5.6. We needed to apply P_2O_5 at 50 kg ha^{-1}. Only the hybridization block and F_1 generation plots received standard plant protection measures to control early leaf spot and aphids. Trials were sown on ridges 60 cm apart at either 10- or 15-cm spacing according to the growth form of the trial entries.

Fungal Diseases

Early Leaf Spot (*Cercospora arachidicola*)

Early leaf spot is consistently severe at Chitedze with 50 % defoliation (a score of 9 on the ICRISAT field scale) 70 DAE. We have been unable to identify any appreciable level of resistance to early leaf spot in any of the several thousand *A. hypogaea* germplasm lines or varieties assessed. We screened 113 interspecific derivatives, four of which were retained for reassessment in 1988.

Screening wild *Arachis* species. One of the 13 accessions tested, *Arachis* sp 30003, showed a high level of resistance. Reactions were similar to those recorded in 1985/86, though two species rated then as resistant (*A. chacoense* and *Arachis* sp 30085) were more severely affected. All species classified as susceptible remained so during the 1986/87 season. *Arachis stenosperma*, which was initially rated as moderately resistant now seems to be highly susceptible.

It seems that only *Arachis* sp 30003 contains resistance sufficient to warrant its use in interspecific hybridization.

Virus Diseases

Groundnut Rosette Virus (GRV) Disease

Screening for resistance. We induced a disease incidence of over 99% in susceptible lines in our GRV resistance screening nursery. Our system of selecting for resistance involves three stages. In the first stage, F_2 generations are exposed in the disease nursery. Plants that are not infected in the field, a mixture of susceptible 'escapes' and those carrying the double recessive gene for resistance, are tested during the ensuing dry season in the greenhouse. In the second stage, small samples of 3–5 seeds are taken at random from each plant. Seedlings derived from these are inoculated three times at 10-day intervals, using viruliferous aphids, and susceptible plants are discarded. In the third stage, F_3 survivors are again subjected to intensive field screening. Thus, of 9598 F_2's tested in the field in 1985/86, 1288 survived; 74 of these survived greenhouse tests during the 1986 dry season; and a final 560 F_3 plants emerged as resistant in the 1986/87 field nursery.

Variety and *Arachis* spp screening. In response to a request from the Mozambique national program, we screened 14 widely grown Mozambican lines; all were highly susceptible. The reaction of one line, Ah 138, to GRV was unusual. Its symptoms included greatly reduced, cupped green leaves, dissimilar in all respects to chlorotic rosette. We observed similar atypical reactions in two Zimbabwean lines. Similar symptoms have been reported from West Africa. We conclude that this abnormal and rare expression of GRV infection is genetically controlled.

We included seven *Arachis* spp in our disease nursery. *Arachis* sp 30003 and *Arachis* sp 30017, remained symptom-free throughout the season; the others were highly susceptible—all the plants developed severe symptoms. Samples of 11 plants of *Arachis* sp 30003 and 12 of *Arachis* sp 30017 were sent to the Scottish Crop Research Institute (SCRI) for GRV and groundnut rosette assistor virus (GRAV) assay. Neither virus was detected in any of the 23 samples. It appears these two species are immune to aphid inoculation of both GRV and GRAV. All resistant varieties of *A. hypogaea* so far tested, while apparently immune to vector inoculation of GRV, are susceptible to GRAV. The immunity of *Arachis* sp 30003 and *Arachis* sp 30017 to GRAV is thus of great relevance to future work on possible interspecific hybrid resistance to both rosette viruses.

Vector resistance. We tested the aphid-resistant variety ICG 5240 in the GRV nursery, it was susceptible to GRV, but the level of infection was considerably lower than that of the susceptible controls. Greenhouse tests in Malawi and at ICRISAT Center have revealed a number of other genotypes that are resistant to the vector and that may already be adapted to environments in southern Africa.

Early-maturing resistant accessions. One of our more important endeavors is the transfer of resistance to early-maturing lines adapted to local conditions. Our initial sources of resistance were contained exclusively in virginia types, which makes the task more difficult. During the year, we selected F_3 resistant, early-maturing lines derived from our own crosses, and in addition, purified an early-maturing West African accession (KH 241D). We are now in a position to make crosses involving early-maturing resistant × early-maturing locally adapted lines, thus accelerating this aspect of the program.

Groundnut Streak Necrosis Disease (GSND)

We made significant progress with studies on the etiology and ecology of a disease hitherto assumed to be caused by tomato spotted wilt virus (TSWV). We call this condition groundnut streak necrosis disease, after the diagnostic symptom induced in groundnut. We have shown that the causal agent of GSND is sunflower yellow blotch virus.

We found GSND at very low incidence at Chitedze during the 1982/83, 1983/84, and 1984/85 seasons. In the 1985/86 season, we recorded an increased incidence in our Chitedze experimental fields. However, in the same season, the disease assumed epidemic proportions in farmers' fields in lower-lying areas of the Southern and Central Regions of Malawi. We identified the vector, *Aphis gossypii*, and an important dry-season host of both vector and virus, *Tridax procumbens*. Peak incidence in our fields at Chitedze was closely correlated with early season migration of *A. gossypii*. All the spanish, valencia, and virginia genotypes we observed are susceptible, but there were apparent differences in susceptibility within each botanical group.

We selected two susceptible genotypes (ICGMS 55 and ICGM 197), for studies on virus-vector relationships. Vector transmission tests indicate that while the virus is readily transmissible from *T. procumbens* to groundnut, it cannot be transmitted from one groundnut plant to another. This suggests an assistor virus system similar to that of groundnut rosette, *T. procumbens* being susceptible to both viruses, but groundnut being susceptible only to the symptom-nducing component. The virus is not seedborne in groundnut. We initiated varietal screening and detected tolerance of infection with regard to symptom expression in certain lines.

Plant Improvement

Germplasm Evaluation

We completed the evaluation of 154 germplasm lines and accessions from the Zambian and Tanzanian National Programs. Thirteen of these have been entered into advanced yield trials whilst a further 26 will enter preliminary yield trials.

Hybridization

We completed a total of 100 crosses in the field. These included 12 crosses made for the Mozambique National Program between adapted Mozambique lines and high-yielding ICGMS lines (ICGMS 2, ICGMS 30, and ICGMS 42); 18 crosses for Zimbabwe for GRV and early leaf spot resistance using RG 1 and ICGMS 30; 40 crosses for GRV resistance; 20 crosses for high yield and adaptability; and 10 crosses for high yield and bold seed for the regional program.

We made a total of 12 737 pollinations which resulted in 3593 hybrid pods, a 28% success rate.

Breeding Material. We received 113 interspecific hybrid derivatives from ICRISAT Center for screening in observation plots. We retained 71 populations, from which we made 88 bulk and 14 single-plant selections. Forty-two bulk selections will be entered in preliminary yield trials. Of these, 13 were rated as good and one (2429-B_1) as very good for pod yield.

We sowed 63 F_1 crosses to confirm their hybridity and advanced them to the next generation; these included crosses between lines having good leaf retention (ICGMS 29, ICGMS 30, ICGM 285, ICGM 336, ICGM 473, and ICGM 550).

From 59 F_3-F_8 populations which included foliar diseases-resistant material, we retained 25, and made 30 bulk selections. Five F_8 selections will be included in the PYTs. Of these, two [both from (J 11 × TG 3) × NC Ac 17090)] were rated as having good yield potential.

GRV resistance screening. We screened 24 F_4 plant progenies and 21 F_4 bulks for resistance to GRV. We retained 31 populations and made 38 bulk and 4 single-plant selections. Not all selections were symptomless but were selected for their yield potential. They will be screened in progeny plots in 1987/88. We sowed 987 populations in GRV inheritance studies from which we made 972 single-plant and 40 bulk selections. These will undergo further screening.

Breeding for High Yield and Quality

Breeding material. We sowed 24 F_1 crosses made between genotypes having high yield potential and bold seed, to confirm their hybridity and advance them to the next generation. From 75 F_2 populations we retained 42 and made 84 bulk and 19 single-plant selections. A number of these were rated visually as good for pod yield and confectionery quality and three were rated as very good. These were (ICGMS 45 × Chalimbana)-P1, (ICGMS 42 × Chalimbana)-P1, and (ICGMS 2 × Egret)-P1.

From 118 F_3-F_6 populations, we retained 94 and made 142 bulk and 15 single-plant selections. We selected 24 F_5 and F_6 selections for inclusion in yield trials. Eight selections from the crosses ICGMS 1 × Makulu Red, F334A-B-1 × Makulu Red, ICGS 5 × Makulu Red, Robut 33-1 × Chitembana, and NC Ac 171352 × Ah 114 were rated as good for yield potential.

Yield trials. We evaluated 46 sequentially branching and 73 alternately branching breeding lines in three yield trials. These entries included selections made for disease resistance and for high yield and quality. A number of these lines performed well and will be advanced in 1987/88.

Sixty sequentially branching and 31 alternately branching breeding lines were included in the two AYTs. Several performed well and showed potential for high yield and good quality (Table 23). We selected eight alternately branching lines and 10 sequentially branching spanish lines for inclusion in regional yield trials.

We evaluated 12 confectionery groundnut lines in a yield trial where each entry was grown with and without fungicide protection. Yield response to fungicide application ranged from 59 to 142%. M 13, SP 1, and Egret responded least to fungicide but were the highest-yielding entries (Table 24). It is apparent that confectionery groundnut lines received from ICRISAT Center are extremely susceptible to early leaf spot but respond markedly to fungicide application. However, seed quality and boldness, even under protected conditions, do not reach such high levels at Chitedze as at ICRISAT Center.

Regional Yield Trials

The virginia cultivar trial was grown at 6 locations in 4 countries, the spanish cultivar trial at 7 locations in 5 countries, and the valencia cultivar trial at 1 location in each of 3 countries.

The virginia trial in Mozambique was adversely affected by the lack of rainfall. ICGMS 42 was ranked high at the remaining five locations and was significantly superior to the local varieties at most sites. ICGMS 42 is now at the prerelease testing stage in eastern Zambia.

Spanish cultivar trials in Botswana, Mozambique, Malawi (Ngabu), and Zambia (Magoye)

Table 23. Performance of some groundnut breeding populations in advanced yield trials (AYTs), Chitedze, Malawi, 1986/87.

Entry	Pedigree	Time to maturity (d)	Pod yield (t ha^{-1})	Shelling %	100-seed mass (g)	Seed color	Mean early leaf spot score[1]
Alternate branching[2]							
ICGV-SM 86722	(P84/6/20)P_1-B_1× NC Ac 2821)	144	3.24	70	47	Red	8
ICGV-SM 86725	(USA 20 × TMV 10)F_3-B_1-B_2B_1	123	2.52	79	56	Red	7
Local control							
Mawanga		138	2.86	72	59	Variegated	7
SE			±0.12				
Trial mean (36 entries)			2.14				
CV (%)			12				
Sequential branching[3]							
ICGV-SM 86053	(ICGM 291)P_1-B_1-B_2	111	2.49	69	39	Tan	8
ICGV-SM 86057	(J 11 × TG 3 × NC Ac 17090) F_5-P_2-B_1	130	2.48	74	48	Tan	7
ICGV-SM 86068	(Goldin 1 × Faizpur 1-5) × (Manfredi × M 13)F_3-B_1-B_2-B_1	126	2.36	69	35	Red	8
ICGV-SM 86051	(2328)B_1-B_1-B_1	118	2.19	74	41	Red	8
Local control							
Malimba		105	1.69	77	27	Tan	8
SE			±0.056				
Trial mean (64 entries)			1.71				
CV (%)			6.6				

1. Scored at 90 DAE on a 1-9 scale, where 1 = no disease and 9 = 50-100% of foliage destroyed.
2. 6 × 6 lattice, plot size 14.4 m^2.
3. 8 × 8 lattice, plot size 14.4 m^2.

were adversely affected by the lack of rainfall. However, certain entries showed promise in the surviving trials and ICGMS 55, ICGMS 56, and ICGMS 58 gave consistently high yields across locations.

Insect Pests

An entomologist was transferred from ICRISAT Center to the Regional Program for the 1986/1987 season to follow up requests from the SADCC national programs for more input into solving the groundnut pest problems of the region. The objectives were to survey farmers' fields to find out which insects were likely to be causing problems and to work with the national programs to carry out experiments to determine the effects of these insects on groundnut yields.

Surveys

Detailed surveys were carried out in Malawi, Tanzania, Zambia, and Zimbabwe. Botswana was visited but not surveyed in detail. Previous

Table 24. Response of selected confectionery groundnut lines to early leaf spot (*Cercospora arachidicola*) control[1], Chitedze, Malawi, 1986/87.

Entry	Pod yield (t ha^{-1}) - spray	Pod yield (t ha^{-1}) + spray[2]	Response to spray (%)	100-seed mass (g) - spray	100-seed mass (g) + spray	Seed color
M 13	3.38	5.37	58.9	65	64	Tan
SP 1	3.34	6.16	84.4	51	53	Tan
Egret	3.75	6.12	63.2	51	54	Tan
HYQ(CG)S-62	3.07	6.29	104.2	58	64	Red
HYQ(CG)S-5	2.44	5.90	141.8	47	59	Tan
Local control						
Chalimbana	2.17	4.27	96.7			
SE	±0.23					
Trial mean (15 entries)	2.71	5.54				
CV (%)	9					

1. Split-plot in randomized complete blocks, sub-plot size 14.4 m^2.
2. Chlorothalonil as Daconil 2787® applied nine times (at the rate of 1.2 kg a.i. ha^{-1}) at 10-day intervals beginning 42 DAS.

Table 25. Summary of survey data on insects associated with groundnut plants in three countries of southern Africa, 1987.

	Malawi Central	Zimbabwe	Zambia	
	(early season)	Central and North (early/midseason)	East	South Central (midseason)
Number of fields	18	29	13	11
Mean field size (ha)	0.54	0.44	0.48	0.77
Mean plants/field (×10^{-3})	223	664	228	650
Mean plants ha^{-1} (×10^{-3})	41	150	48	84
White grubs (100 plants)$^{-1}$	533 (±77)[3]	394 (±64)	107 (±25)	154 (±59)
Millepedes (100 plants)$^{-1}$	254 (±63)	14 (±05)	17 (±79)	35 (±15)
Wireworms[1] (100 plants)$^{-1}$	238 (±56)	35 (±08)	39 (±07)	66 (±22)
Dorylus[2] sp (100 plants)$^{-1}$	2 (±12)	45 (±21)	45 (±19)	56 (±22)
Microtermes[2] (100 plants)$^{-1}$	232 (±28)	13 (±07)	58 (±17)	214 (±49)
Mean pods plant^{-1}	0	104 (±19)	140 (±14)	44 (±15)
Damaged plants (%)	-	33 (±07)	61 (±16)	112 (±23)
Roots damage (%)	-	276 (±45)	191 (±37)	377 (±51)

1. Wireworms (Elateridae) + false wireworms (Tenebrionidae).
2. Data are plants affected by these taxa.
3. Numbers in parentheses are standard errors (SEs).

experience directed us to search the root and pod zone for the insects most likely to cause problems. Severe foliage damage caused by defoliation was found only at two sites, both of which were research stations where insecticides had been applied as a prophylactic measure.

The survey summary (Table 25) shows that white grubs (larvae of scarabaeid beetles) were the most frequently encountered soil insects. They were particularly numerous in Malawi and Zimbabwe. *Microtermes* were most abundant in southern Zambia in midseason. In Botswana, estimates from field stations indicate that members of this genus can cause a 50% crop loss by killing plants and damaging pods. Pod borers had caused up to 11% damage by midseason. Observations in farmers fields at harvest time indicate that this level had been exceeded by a further 10%. Damaged pods increase the risk of aflatoxin contamination. It should be noted that, before this survey, doryline ants *Dorylus* spp had not been recognized as groundnut pests.

Field Trials

An indication of the effect of soil insects on yield was obtained by applying an insecticide to the soil in half the plots of a field trial and leaving the other half untreated. This procedure was done at five research stations in Malawi. The treated plots in these trials had 0, 5.0 (no effect), 23.8, 53.1, and 60.2% greater yields than the nontreated controls. Regular insect sampling implicated white grubs, termites, and wireworms as the cause of these yield differences.

- soil insects, as a whole, are a major constraint to groundnut production in southern Africa.
- termites (*Microtermes* spp) attack groundnut plants in drought conditions because there is little else left for them to eat.
- termites destroy approximately 20% of the pods during postharvest drying.
- killing some species of ants with insecticides can result in an increase in termite attack.
- the amount of damage caused by soil insects is related to the intensity of cultivation. Insects were less of a problem in fields coming out of fallow and in shifting agriculture than in the intensive agricultural scene of central Malawi and the Zimbabwe communal lands.
- the diversity of these soil insect species is wide, especially that of white grubs and termites.

Regional Groundnut Improvement Program for West Africa

The Groundnut Improvement Program was established at the ICRISAT Sahelian Center (ISC), Niamey, Niger, in September 1986, with the appointment of an agronomist. A breeder and a pathologist joined the Program in January 1987. We formulated and prepared research projects to cover all the major aspects of the proposed program.

Our activities were concentrated at three locations in Niger: ISC at Sadoré (13° 18'N; 568 mm mean annual rainfall), the Institut national de la recherche agronomique de Niger (INRAN) station at Bengou (11° 59'N; 839 mm mean annual rainfall), and the INRAN station at Maradi (13° 28'N; 642 mm mean annual rainfall).

We continued to establish contacts for cooperative research with national programs in Burkina Faso, Guinea, Mali, Niger, and Senegal. We also initiated collaborative research with the Peanut Collaborative Research Support Program (Peanut-CRSP), Institut français de recherche scientifique pour le développement en coopération (ORSTOM), Institut de recherches pour les huiles et oléagineux (IRHO), and Centre régional de formation et d'application en agrométéorologie et hydrologie operationnelle (AGRHYMET).

Physical Stresses

Drought

Screening of germplasm for drought tolerance. Some of the lines in the 1987 international drought trial from ICRISAT Center gave higher haulm yields than the control cultivar, but none of them gave pod yields as high as the control, TS 32-1, which gave 0.91 ± 0.10 t pods ha^{-1}. Field screening methods to evaluate genotypes for resistance to drought are being developed using cultivars with known levels of tolerance.

Soil and Water Management

We evaluated the performance of two groundnut cultivars (28-206 and ICGS(E) 30) under three cultivation methods at Bengou. Tied ridging (1.29 t ha^{-1} dried pods) was significantly superior to both broadbed (1.17 t ha^{-1} dried pods) and flat cultivation (1.10 t ha^{-1}dried pods).

Plant Nutrition

Soils in the Sahel are sandy, poor in nutrients, low in organic matter, and have a low buffering capacity. We initiated studies to examine the importance of various mineral nutrients in groundnut production.

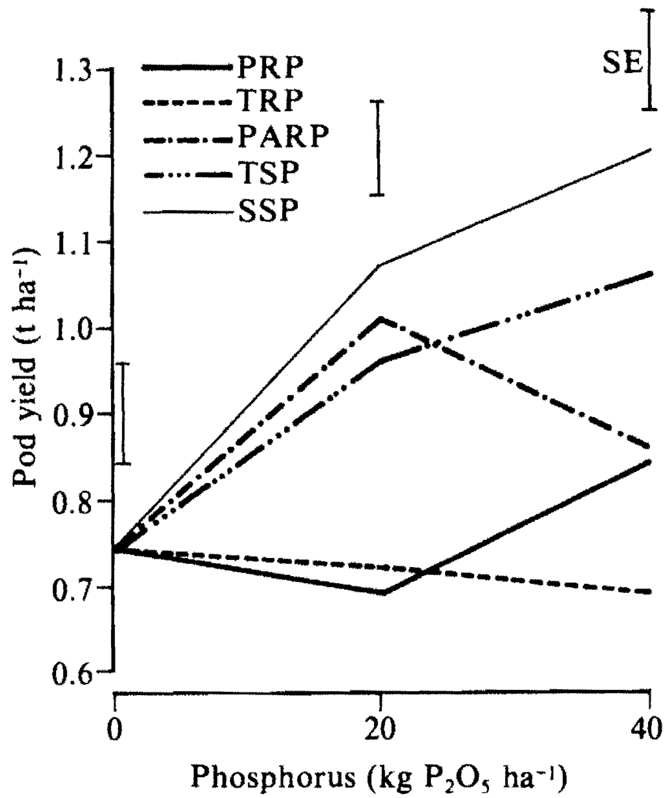


Figure 6. Effect of various sources of phosphorus and rates on pod yield of groundnut varieties 55437 and ICGS(E) 30, ISC, Sadoré, Niger, rainy season 1987.

Phosphorus. At ISC, Sadoré, we compared three sources of rock phosphates; Parc-W rock phosphate (PRP), Tahoua rock phosphate (TRP) and Parc-W partially acidulated rock phosphate (PARP), with single superphosphate (SSP) and triple superphosphate (TSP) at 20 and 40 kg ha^{-1} P_2O_5 on two genotypes 55-437 and ICGS(E) 30. Increasing the rate of P application from 0 to 40 kg P_2O_5 ha^{-1} did not result in an increase in pod yield when P was applied as TRP or PRP. However, when SSP, TSP, or PARP were applied at a rate of 20 kg P_2O_5 ha^{-1}, there was an increase in pod yield (Fig. 6). The effects of different P treatments on haulm yield were similar to those observed on pod yield.

Biotic Stresses

Disease Surveys

We surveyed groundnut diseases in September 1987 to assess their distribution and relative importance in major groundnut-producing areas of Burkina Faso and Niger, in collaboration with such national groundnut programs as the University of Ouagadougou, Burkina Faso, and INRAN, Niger, and international groundnut programs such as IRHO and Peanut-CRSP.

Burkina Faso. We examined 64 groundnut fields in the eastern, central, southcentral, and southern provinces of the country. Early leaf spot (*Cercospora arachidicola*) was severe in nearly all fields in the eastern, central, and southcentral provinces. Late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*) were serious only in the southern provinces, especially on spanish types. We noted a high incidence of peanut clump in some fields in the southern province. The incidence of GRV was low during the 1987 season. Other diseases observed during the survey included pod rot (probably *Rhizoctonia solani* from our field observation), Phyllosticta leaf spot (*Phyllosticta arachidis*), collar rot (*Aspergillus niger*), aflaroot (*A. flavus*), leaf scorch (*Leptosphaerulina crassiasca*), zonate spot (causal agent unknown), witches' broom (mycoplasma-like organism), bud necrosis (TSWV), and peanut mottle (PMV). *Alectra* sp (family : Scrophulariaceae), a parasitic flowering plant, was observed on groundnut in the south.

Niger. We examined 57 fields in Dosso, Gaya, Maradi, Matameye, Say, and Zinder areas of Niger. There were severe epidemics of GRV (predominantly green) between Maradi and Zinder (up to 100% incidence). Leaf spots (predominantly late leaf spot) were observed in almost all fields but were only important in Gaya. Pod rot was severe in many locations, especially in drought-affected areas. Seeds were extensively colonized by *Aspergillus flavus*. Variability in crop growth (etiology unknown) was severe in many fields near Birni N'Konni, Dosso, Madaoua, Maradi, and Zinder. Other diseases observed during the survey included rust, phyllosticta leaf spot, leaf scorch, zonate spot, collar rot, aflaroot, peanut clump, peanut mottle, and witches' broom.

Table 26. Effect of fungicidal control of foliar diseases on pod yield (t ha^{-1}) of six groundnut cultivars in trials[1] at three locations in Niger, rainy season 1987.

	Sadoré		Bengou		Maradi	
Cultivar	WS[2]	FS[2]	WS	FS	WS	FS
55-437	0.65	0.72	3.66	5.44	0.75	0.77
28-206	0.43	0.46	3.07	4.02	0.10	0.11
796	0.53	0.53	3.63	4.93	1.11	1.17
TS 32-1	0.88	0.93	3.84	5.05	0.81	0.85
ICGS 11	0.70	0.71	4.49	6.18	0.50	0.53
47-16	0.53	0.53	2.57	2.85	0.24	0.25
SE	±0.09		±0.26		±0.05	
Mean	0.62	0.65	3.54	4.74	0.58	0.61
SE	±0.03		±0.15		±0.02	
CV (%)	29		11		19	

1. Split-plot design with spray treatments as main plots and cultivars as subplots, 4 replicates, main plot size 48 m^2, subplot size 8 m^2.
2. Water spray (WS) and fungicide spray (FS) at 15-day intervals. Five sprays applied, three of carbendazim followed by of chlorothalonil.

Yield Losses from Diseases

We conducted field trials at Bengou, Maradi, and Sadoré in Niger during the 1987 rainy season to assess yield losses from foliar, seed, and seedling diseases of groundnut.

Foliar diseases. Five West African groundnut cultivars (55-437, 28-206, 796, TS 32-1, and 47-16) and one ICRISAT-bred cultivar ICGS 11 were given two spray treatments: water (500 L ha^{-1}) and fungicides (carbendazim at 500 g a.i. in 500 L of water ha^{-1} and chlorothalonil at the rate of 1.6 kg in 800 L water ha^{-1}) (Table 26).

Both early and late leaf spots were severe at Bengou, but only late leaf spot was evident at Sadoré and Maradi, and the disease severity was low. The mean percentage leaf area affected for all genotypes in the water treatment was 10.5% at Sadoré and 12.2% at Maradi. However, at Bengou it was 96.5% and resulted in a mean yield loss of 24%. There was no yield response to fungicide at Sadoré or Maradi.

Seed and seedling diseases. Seeds of the cultivar 55-437, treated with four protectant chemicals and untreated seeds were sown in replicated field trials at Bengou, Maradi, and Sadoré. There was reduction in plant stand at Bengou (23%), Maradi (26%), and Sadoré (27%), which was largely due to *Aspergillus niger, A. flavus, Rhizopus* spp, and *Fusarium* spp. The loss in pod yield was considerable at Sadoré (24%) and Maradi (19%), (Table 27).

Epidemiology of Leaf Spots

Sources of primary inoculum. We observed late leaf spot development on off-season (March-

Table 27. Effect of seed treatment on plant stand and pod yield of groundnut 55-437 in trials[1] at three locations in Niger, rainy season 1987.

	Sadoré		Bengou		Maradi	
Treatment[2]	Plant stand (m^{-2})[3]	Pod yield ($t\ ha^{-1}$)	Plant stand (m^{-2})	Pod yield ($t\ ha^{-1}$)	Plant stand (m^{-2})	Pod yield ($t\ ha^{-1}$)
Thiram 75% WP[4]	23	0.58	21	3.54	15	0.71
Thioral®[5]	22	0.56	22	3.45	12	0.66
Apron® plus 50 DS[6]	21	0.57	19	3.38	14	0.57
Bavistin® 50% WP[7]	21	0.51	22	3.35	14	0.70
Control	17	0.45	17	3.32	11	0.57
SE	±1	±0.06	±1	±0.22	±1	±0.04
CV (%)	8	23	8	13	21	11

1. Randomized block design with 4 replicates, plot size 8 m^2.
2. Seed treated with seed-protectant chemicals at the rate of 3 g kg^{-1} seed just before sowing.
3. Measured 20 DAS.
4. Tetramethylthiuram disulphide.
5. Tetramethylthiuram disulphide (25%) + heptachlor (20%).
6. Furathiocarb (34%) + metalaxyl (10%) + carboxin (6%).
7. Carbendazim.

June) groundnut crops at Maradi and early leaf spot on volunteer groundnut plants at Bengou. This suggests that the two pathogens can perpetuate on off-season crops and on volunteer plants. Inoculation of field plots with infected crop debris collected during the previous season resulted in an earlier appearance of the disease than in noninoculated plots, indicating that crop debris can provide an inoculum source for subsequent crops.

Insect Pests

We established a groundnut pest-monitoring plot at Bengou on 28 June 1987 to identify pests and to determine their population density and seasonal abundance. We monitored the populations of aphids and leaf hoppers (jassids) with yellow sticky traps. Their density remained below damaging levels throughout the season. The millepede population began increasing with pod formation (14 July) and increased dramatically until pods hardened (9 October), when 39% of pods had been damaged. The millepede population then declined.

We monitored the termite population using wooden baits (25 cm × 25 cm × 50 mm) throughout the season. All baits were attacked by termites by the second week after emergence. However, there was no crop damage until 11 August, after which it increased until 45% of the pods were damaged by 2 October.

Thus, in 1987, millepedes were the major pest constraint to groundnut production and termite scarification was recognized as being important and likely to be conducive to aflatoxin contamination.

Plant Improvement

Genotype Evaluations

Groundnut Cultivar Trial at ISC. We grew our yield trial at three sites: Sadoré (with light supplementary irrigation), Sadoré (under rainfed conditions), and at the INRAN station, Maradi.

Table 28. Performance of selected lines in the ICRISAT Sahelian Center Groundnut Cultivar Trial, Sadoré, Niger, rainy season 1987.[1]

	Rainfed				Irrigated			
Genotype	Pod yield (t ha^{-1})	Haulm yield (t ha^{-1})	Shelling (%)	100-seed mass (g)	Pod yield (t ha^{-1})	Haulm yield (t ha^{-1})	Shelling (%)	100-seed mass (g)
ICGS 11	0.73	1.14	59	37	1.77	2.36	66	38
ICGS 26	0.84	1.13	55	42	1.59	3.04	64	44
ICGS 56	0.74	1.13	60	34	1.94	2.34	68	41
ICGS 76	0.54	1.35	55	43	2.18	2.91	66	53
ICGS 82	0.87	1.65	51	45	1.95	3.20	56	46
ICGV 86529 (ICG(PRS)1)	1.24	1.59	63	39	1.91	3.23	58	35
ICG(CGS) 6	0.79	1.54	45	42	1.89	3.46	57	46
ICG(CGS) 57	0.63	1.20	54	44	1.53	2.67	55	46
ICG 1697	0.62	1.43	38	24	1.21	3.97	36	27
Controls								
55-437	0.57	0.62	63	26	1.50	2.41	67	32
T 177-83	0.62	0.58	58	29	1.65	1.92	66	33
TS 32-1	0.87	1.01	57	32	2.78	1.75	67	35
J 11	1.06	1.24	63	29				
JL 24					1.52	3.64	57	36
WB 9	0.61	0.58	61	31	1.54	1.97	66	34
SE	±0.10	±0.13	±2	±2	±0.16	±0.25	±2	±2
Trial mean (25 entries)	0.72	1.22	53	34	1.57	2.88	58	37
CV (%)	33	26	10	14	26	21	8	15

1. 5 × 5 lattice square with 6 replicates, plot size 8 m^2.

When no data is reported, it indicates that the rainfall was unsatisfactory. ICGV 86529 (ICG (PRS) 1) gave a higher pod yield than any other line except J 11 in the rainfed trial, and performed quite well in the irrigated trial (Table 28). ICGS 76, ICGS 82, ICG(CGS) 6, and ICG(CGS) 57 had relatively large seeds, compared with the control cultivars. ICG 1697, which has drought tolerance, gave high haulm yields, but its pod yields and shelling percentage were low.

Material from the ICRISAT Regional Groundnut Program for Southern Africa. In the spanish cultivars trial, ICGMS 5 and ICGMS 13 performed particularly well, giving significantly higher pod yields than the control 55-437. The seeds of these two lines were also larger than the control cultivars. ICGMS 2 and ICGMS 21 had good pod yields and high shelling percentages.

In the alternate-branching cultivar trial, ICGMS 38, ICGMS 39, and ICGMS 42, gave pod yields equal to or better than the higher-yielding control, 55-437 (Table 29). The haulm yields and seed size of ICGMS 38 and ICGMS 42 were larger than the controls. The performance of these lines during a 105-day season at Bengou (shorter than the 150–160 days in Malawi) is remarkable.

Yield of interspecific hybrid derivatives. We evaluated 25 stable interspecific hybrid (*A. hypogaea* × *A. cardenasii*) derivatives for pod and

Table 29. Performance of selected lines in the SADCC Regional Groundnut Cultivar Trials[1] 1986/87, Institut national de recherches agronomiques du Niger (INRAN), Bengou, Niger, rainy season 1987.

Genotype	Pod yield (t ha^{-1})	Haulm yield (t ha^{-1})	Shelling (%)	100-seed mass (g)
Spanish				
ICGMS 2	2.20	3.05	69	36
ICGMS 5	2.52	3.49	63	59
ICGMS 13	2.44	3.18	66	50
ICGMS 21	2.34	3.40	69	37
Controls				
55-437	2.00	3.17	67	34
28-206	1.47	3.49	61	36
SE	±0.15	±0.44	±3	±2
Trial mean (36 entries)	1.69	3.84	63	45
CV (%)	15	20	10	7
Alternate branching				
ICGMS 38	2.71	5.24	69	57
ICGMS 39	2.50	3.49	61	50
ICGMS 42	2.60	5.61	54	61
Controls				
437	2.50	3.34	67	41
28-206	1.85	4.56	60	36
SE	±0.21	±0.50	±4	±3
Trial mean (25 entries)	1.82	6.18	57	48
CV (%)	20	14	11	11

1. 6 × 6 and 5 × 5 triple lattice, plot size 6 m^2.

haulm yields in a replicated trial during the 1987 rainy season at Bengou. The entries significantly outyielded the control cultivars in both pod and haulm yields (Table 30).

Screening of germplasm for adaptation. We received a sample of 500 lines representing 75 groundnut-growing countries from the Genetic Resources Unit (GRU), ICRISAT Center. We received about 40 seeds of each line; the samples were divided in two parts, and a 2-m row of each line was grown at Sadoré and Bengou. Because of the small sample size and the known soil variability, we sowed every alternate line in the germplasm trial with a control variety (55-437 at Sadoré and 28-206 at Bengou). We compared the yield of the germplasm lines with that of the control rows on each side. We established stringent selection criteria to identify lines that performed better than the controls. At Sadoré, we selected lines with a minimum pod yield of 2.0 t ha^{-1}, a minimum shelling percentage of 65%, and a minimum of 120% of the yield of the two neighboring rows of the control variety (55-437). At Bengou, we selected lines with a minimum pod yield of 2.5 t ha^{-1}, a minimum shelling percentage of 67%, and a minimum of 150% of the yield of the control variety (28-206).

Table 30. Performance of three groundnut interspecific hybrid derivatives[1] Bengou, Niger, rainy season 1987.

Genotypes	Yield (t ha^{-1}) Pods	Haulms	Shelling (%)
CS 11 (82 × 34-115M)[2]	5.60	6.96	71
799 (82 × 34-9B)[2]	5.16	6.14	67
CS 52 (82 × 34-9B)[2]	4.81	6.53	69
Controls			
28-206	3.81	4.69	73
55-437	4.23	4.56	73
SE	±0.31	±0.61	±2
Trial mean (25 entries)	3.09	4.33	68
CV (%)	18	24	6

1. Randomized block design with 3 replicates, plot size 1 m^2.
2. *Arachis hypogaea* and *Arachis cardenasii* derivatives.

We selected 64 lines that performed relatively well at Sadoré and 28 lines that performed relatively well at Bengou. Most of these lines came from only 19 of the 75 countries of origin. Of the three lines from Swaziland, all performed well at Sadoré and one performed well at Bengou. A good proportion of the lines from Australia, and a reasonable number of lines from India, USA, and Zaire also performed well at Sadoré. We will test these lines and other germplasm from selected countries of origin in the 1988 season.

Investigations on Crop Growth Variability

During our surveys in Niger in 1986 and 1987, we observed large variations in growth within fields, especially in sandy soils. The affected plants usually occurred in patches, intermixed at random with apparently healthy plants. We observed three distinct types of symptoms on affected plants :

1. Plants were severely stunted, and chlorotic, with poor shoot and root development. Necrosis of roots was severe, with shredding of cortex tissue. Pods were few in number with necrotic lesions on their surfaces. Mortality was evident in many cases.

2. Plants were severely stunted, bushy, and dark green, with mild mosaic symptoms on young leaves.

3. Plants severely stunted, as in category 1, but older leaves showed black necrotic lesions on their margins.

We did not know what caused these symptoms, but suspected lack of organic matter, soil-nutrient imbalance, and biotic stress factors in the soil, to be possible causes. We initiated a multidisciplinary research project that will identify and hopefully eliminate the constraints involved.

Occurrence of peanut clump virus. Peanut clump virus (PCV) was detected in bushy, dark green, stunted plants by electron-microscopy, ELISA tests, and the inoculation of indicator hosts. This indicates that PCV is one of the factors contributing to the variation in crop growth (see 2 above).

Plant parasitic nematodes. Soil samples collected from the rhizosphere and geocarposphere of affected plants contained *Tylenchorhynchus, Helicotylenchus, Longidorus,* and *Meloidogyne* species. The pathogenic role of these nematodes in the current context has not been established.

Effect of farmyard manure and carbofuran. Farmyard manure (FYM) at 0, 2.5, 5.0, 7.5, and 10.0 t ha^{-1} had no significant effect on crop growth and yield.

We investigated the effects of soil treatment with carbofuran, a broad-spectrum pesticide, on crop growth variability at Sadoré. Crop growth in plots treated with carbofuran at 2, 4, 6, 8, and 10 kg a.i. ha^{-1} just before sowing was more than in nontreated controls.

In a further trial at Sadoré, soil treatment with 10 kg carbofuran a.i. ha^{-1} and 10 t FYM ha^{-1} resulted in three times the pod yield and twice the haulm yield of the control plots (Table 31), but treatment with FYM alone was not effective.

Table 31. Effect of carbofuran and farmyard manure (FYM) on plant height and yield of groundnut 55-437, Sadoré, Niger, rainy season 1987.[1]

			Yield (t ha^{-1})			
	Plant height (cm)[3]		Irrigated		Rainfed	
Treatment[2]	Irrigated	Rainfed	Pods	Haulms	Pods	Haulms
Carbofuran + Farmyard manure	25	16	3.04	2.55	1.75	1.23
Carbofuran	21	15	2.14	1.30	1.67	1.05
Farmyard manure	14	10	1.10	1.03	0.78	0.70
Control	11	8	0.84	0.80	0.66	0.61
SE	±2	±1	±0.20	±0.14	±0.10	±0.06
CV (%)	24	22	27	25	16	14

1. Randomized block design with 6 replicates under irrigation and 4 replicates under rainfed conditions, plot size 16 m^2.
2. 10 kg a.i. carbofuran ha^{-1} and 10 t ha^{-1} FYM.
3. Mean of five plants per replication.

Screening of pesticides. We evaluated the efficacy of four pesticides: dibromochloropropane (nematicide), dazomet (general purpose soil fumigant), carbofuran (insecticide and nematicide) and aldicarb (biocide) in controlling the variation in crop growth, under rainfed and irrigated conditions at Sadoré. Dibromochloropropane was most effective in reducing the variation in crop growth and increasing the pod and haulm yields under irrigation. Aldicarb was most effective under rainfed conditions (Table 32). Plots treated with dibromochloropropane

Table 32. Effect of four pesticides on plant height and yield of groundnut, 55-437, Sadoré, Niger, rainy season 1987[1].

			Yield (t ha^{-1})			
	Plant height (cm)[3]		Irrigated		Rainfed	
Treatment[2]	Irrigated	Rainfed	Pods	Haulms	Pods	Haulms
Dibromochloropropane	32	15	3.85	3.41	1.86	1.78
Dazomet	25	12	2.89	2.59	1.10	1.00
Carbofuran	17	14	2.50	1.98	1.66	
Aldicarb	18	18	1.97	1.71	2.55	0.96
Controls	12	11	1.19	1.09	1.09	0.92
SE	±2	±1	±0.33	±0.33	±0.12	±0.20
CV (%)	23	12	27	30	17	30

1. Randomized block design with 4 replicates under irrigation and 5 replicates under rainfed conditions, plot size 8 m^2.
2. Dibromochloropropane (at the rate of 20 L in 85 L of water ha^{-1}), carbofuran (at 6 kg a.i. ha^{-1}) and aldicarb (at 4 kg a.i. ha^{-1}) were applied to the field plots on the day of sowing. Dazomet (at 300 kg ha^{-1}) was applied 15 days before sowing.
3. Mean of five plants per replication.

(irrigated conditions) and aldicarb (rainfed conditions) showed vigorous plant growth, as assessed by the plant height, root length, and number of leaves on the main stem and pods $plant^{-1}$. Nodulation was good. Plants in control plots were stunted and chlorotic with severely necrosed root systems.

Most of the pesticides used in this study are general biocides and are also known to influence the physiological processes of the plant. The reasons for the positive effects on crop growth variability may not be simple to elucidate.

Effect of soil solarization. There were no significant differences in crop growth and pods and haulms yields between solarized and nonsolarized plots.

Cooperative Activities

Asian Grain Legumes Network (AGLN)

The AGLN was established in 1986 as a result of the recommendation made by the Consultative Group Meeting for Asian Regional Research on Grain Legumes in 1983 (ICRISAT Annual Report 1983, p.148), and subsequently ratified by the Review and Planning Meeting on Grain Legumes in 1985 (ICRISAT Annual Report 1985, p.173). Its broad objective is to facilitate testing and dissemination of appropriate varieties and technologies to increase production of groundnut, chickpea, and pigeonpea in the Asian region, including the host country, India with which ICRISAT has a special relationship involving many collaborative studies with ICAR scientists.

The AGLN coordinator had discussions with donor agencies and Institutions in the region, notably the ACIAR, Economic and Social Commission for Asia and the Pacific (ESCAP) Regional Coordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber Crops in the Humid Tropics of Asia and the Pacific (CGPRT Centre), the Canadian International Development Agency (CIDA), the European Economic Community (EEC), FAO, the International Development Research Centre (IDRC), the United States Agency for International Development (USAID), and Winrock International. The discussions centered around coordinating and strengthening relationships between donor agencies and ICRISAT to avoid duplication of efforts.

Memoranda of Understanding

Although ICRISAT has been collaborating with many Asian countries in the past, Memoranda of Understanding (MOUs) were signed to facilitate the movement of material and scientists for collaborative research activities. During April, the Director General signed an MOU with the Minister for Agricultural Development and Research, Sri Lanka; and in December, another with the Secretary of Agriculture, His Majesty's Government of Nepal. The MOU's with Indonesia and the People's Republic of China were revised, and are expected to be signed early in 1988. There are already MOU's with Bangladesh, Burma, Pakistan, the Philippines, and Thailand. During the year initial contacts were established with Afghanistan, the Democratic People's Republic of Korea, and Vietnam.

Work Plans

Meetings were held in Bangladesh, Burma, Nepal, and Sri Lanka to develop detailed yearly Work Plans bearing in mind constraints to yield, and research needs in each country, and their capabilities. Requirements for training and special research projects have also been identified. The Asian Development Bank (ADB) has agreed to provide financial support to these four south Asian countries to enable the implementation of their Work Plans and each country has identified coordinator(s) who will liaise with AGLN. A special Work Plan for Pakistan with emphasis on pigeonpea, and tentative Work Plans for Indonesia, People's Republic of China, the Philippines, and Thailand have been developed.

Other Activities

ICRISAT scientists undertook crop surveys, monitored international and national trials, and participated in germplasm collection as part of agreed Work Plans.

A groundnut breeder, a pathologist, and a nematologist monitored groundnut trials and surveyed diseases and nematodes in Nepal during September. Bud necrosis disease (BND) was widespread. Rust and late leaf spot were observed at Rampur. Early leaf spot incidence was high at Nawalpur, and this location could be used for disease resistance screening. Although root-knot nematode was abundant on other crops, groundnut was not infected. Suspected damage by lesion nematode was observed on groundnut grown on river banks. Among insects, jassids and termites appeared important.

A Burma-AGLN joint mission was undertaken in Burma in October-November to train local scientists in collection, preservation, and evaluation of germplasm. Groundnut germplasm collection was undertaken as a part of the training program, and 41 local landraces were collected.

Considering the importance and the extent of damage caused by PStV, 6500 groundnut germplasm lines were screened at two locations in Indonesia (Baru in Sulawesi and Muneng in Java). This screening was funded by an ADAB/ACIAR/ICRISAT joint project. Germplasm lines free from PStV infection will be re-tested under controlled greenhouse conditions to confirm resistance.

AGLN staff attended the review and planning meetings of ACIAR on pigeonpea and groundnut in Indonesia and Thailand to develop joint programs on these crops. Some of these activities are supported by funds from ADAB and ACIAR.

The first issue of an AGLN Cooperators Report was distributed, it covers the activities of the AGLN since its inception and summarizes the Work Plans developed for each country. The report also gives details of trials available from ICRISAT; and a list of future workshops and meetings to be organized by ICRISAT.

As a part of an exchange of visits, two scientists each from Sri Lanka and Nepal and one from Bangladesh visited ICRISAT to familiarize themselves with ongoing research and to discuss collaborative research with the concerned ICRISAT scientists.

AGLN was also involved in various workshops and meetings. These are dealt with under 'Workshops, Conferences, and Seminars' below.

Legumes On-Farm Testing and Nursery Unit (LEGOFTEN)

ICRISAT responded to a request from the Government of India for the rapid transfer of legumes technology by forming a new unit, 'Legumes On-Farm Testing and Nursery Unit' (LEGOFTEN). This is a multidisciplinary unit that is working with state scientists to compare the state-recommended, local farmers', and ICRISAT methods of growing legumes. The unit was formed in May 1987 and concentrated on the groundnut crop during the following rainy season.

The ICRISAT method involved sowing cultivars with high yield potential. Varieties with no foliar diseases resistance were protected with fungicides. Seeds were hand sown at 120–140 kg ha^{-1} into a broadbed-and-furrow system. The fertilizer treatments included phosphorus as single super phosphate, and supplementary calcium, zinc, and iron. Insecticides were applied as required.

Yield maximization trials were conducted in 5 states (Table 33). Pod and haulm yields were markedly higher under ICRISAT's high-input regime under both rainfed and irrigated conditions. Growing groundnut by the ICRISAT method cost Rs.9000 ha^{-1} compared to Rs.6000–7000 ha^{-1} by the state-recommended practices, but the higher yields more than compensated for the increased investment (Table 34).

In a further set of trials in Maharashtra state, we grew the cultivars JL 24 or SB XI in farmers' fields according to the state and ICRISAT practices. Overall, ICRISAT's methods gave 0.5 t ha^{-1} more than the state methods, including a 2.5% increase in shelling percentage. A farmer

Table 33. Pod and haulm yields of groundnut crops grown according to ICRISAT, state, and local practices under irrigated and rainfed conditions, rainy season 1987.

	Pod (t ha⁻¹)			Haulm (t ha⁻¹)		
Trial/Location	ICRISAT	State	Local	ICRISAT	State	Local
Irrigated						
Garikapadu (AP)[1]	1.92	1.22	0.70	7.30	5.00	4.50
Gadwal (AP)	3.05	1.90	0.82	6.00	2.70	1.01
R.K. Shala (K)	3.66	1.12	1.18	5.80	3.00	2.70
Guladhalli (K)	3.36	0.88	1.02	3.00	1.80	2.00
Retare (MS)	4.80	4.30	-[2]	-	-	-
Wai (MS)	4.15	3.16	-	7.44	6.62	-
Kadegaon (MS)	2.70	1.85	1.72	3.20	3.30	2.90
Dhule (MS)	1.86	1.08	0.52	3.10	2.60	1.87
Neyveli (TN)	4.14	2.27	2.27	5.60	5.80	4.72
Musaravakkam (TN)	2.97	2.72	1.69	5.42	4.50	4.67
Sukinda (O)	4.26	1.44	1.16	7.80	5.90	5.30
Mean	3.35	2.00	1.24	5.47	4.12	3.30
Rainfed						
Teosa (MS)	2.50	1.05	0.40	4.94	3.06	2.40
Kadegaon (MS)	1.85	1.15	0.70	5.40	4.40	3.00
Mean	2.17	1.11	0.55	5.17	3.73	2.70
Average	3.17	1.85	1.11	5.41	4.05	3.18

1. AP = Andhra Pradesh, K = Karnataka, MS = Maharashtra, TN = Tamil Nadu, O = Orissa.
2. - = Data not available.

Table 34. Average cost of cultivation, income, and profit in different methods of groundnut cultivation, rainy season 1987[1].

Method of cultivation	Income[2] from pods + haulm (Rs ha⁻¹)	Cost of cultivation (Rs ha⁻¹)	Profit (Rs ha⁻¹)
ICRISAT	27 050	9 000	18 780
	(17 300-37 980)[3]	(4 518-16 071)	(9 050-31 500)
State	15 230	6 771	8 430
	(7 980-28 590)	(4 775-10 330)	(-230-23 293)
Local	10 370	5 565	4 800
	(4 200-15 880)	(3 075-10 070)	(-870-14 140)

1. Average for 13 locations in five states of India.
2. Selling price of pods Rs.8 000 t^{-1} and that of fodder Rs.500 t^{-1}.
3. Numbers in parentheses describe the range.

adopting ICRISAT's methods would have increased his net profit by more than Rs.4000 ha^{-1}.

Cooperation with AICORPO and other National Programs in India

During the 1987 rainy season our proposal to include 12 new varieties in the All India Coordinated Research Project on Oilseeds (AICORPO) trials was accepted. These included nine sequentially and three alternate-branching varieties. Three other ICRISAT varieties, ICGS 44-1, ICG(FDRS) 10, and ICG 2271 were identified by AICORPO for rainy-season adaptive trials in farmers' fields (Table 35).

We contributed three new varieties to the postrainy-season (rabi/summer) AICORPO

Table 35. Current status of ICRISAT groundnut varieties in AICORPO rainy season trials, 1987.

Trial[1]	Variety	Zone[2]	Remarks
IET(SB)	ICGV 86124, 86127, 86236, 86309, 86315, 86600, 86635, 86598, 86590	All six zones	New entries
	ICG(FDRS) 34, ICGV 86020, 86022		Retained from FDRVT
	ICGV 86029, 86031		Retained from BNDRVT
CVT(SB)	ICGV 86014, 86015	Northern	Promoted from IET (Early)
	ICGV 86010, 86011, 86012, 86013	Peninsular	Promoted from IET(SB)
NET(SB)	ICG(FDRS) 43	Peninsular	Promoted from CVT(SB)
	ICGS 44-1	Southeastern	Promoted from CVT(SB)
IET(VB)	ICGV 87779, 87780, 86699	All except Central zone	New entries
	ICGV 86033, 86034		Retained from BNDRVT
CVT(SB)	ICGV 86030, 86032	All six zones	Promoted from BNDRVT
	ICGV 86005,	Northern, Southern	Promoted from IET(VB)
	86004	Southern	Promoted from IET(VB)
NET(VB)	ICGS 65	Southeastern	Promoted from CVT(VB)
	76	Peninsular	Promoted from CVT(VB)
HPSVT	ICG(CG)S 10,11,13,14, 15,19,21,49 ICG(AF)S 28, ICGV 86024, 86027, 86028	13 locations in different zones	Retained
Adaptive Trials[3]	ICGS 44-1	Peninsular	Promoted from NET(SB),
	ICG(FDRS) 10		Proposal submitted
	ICG 2271	Southern	Promoted from NET(VR), Proposal submitted.

1. SB = Spanish bunch, VB = virginia bunch, VR = virginia runner; IET = Initial Evaluation Trial, CVT = Coordinated Varietal Trial; NET = National Elite Trial; BNDRVT = Bud Necrosis Disease Resistant Varietal Trial; FDRVT = Foliar Diseases Resistant Varietal Trial; HPSVT = Hand Picked Selection Varietal Trial.
2. Northern zone = Uttar Pradesh, parts of Haryana, Punjab, Rajasthan, and Bihar; Western zone = Gujarat; Central zone = parts of Maharashtra and Madhya Pradesh; Southeastern zone = Orissa and West Bengal; Peninsular zone = Andhra Pradesh, Karnataka, and parts of Maharashtra; Southern zone = Tamil Nadu.
3. Results from adaptive trials of ICGS 1, ICGS 5, and ICGS 11, in the northern zone and ICG(FDRS) 4 in the peninsular zone, identified during the 1986 rainy-season AICORPO Workshop, are awaited.

Table 36. Current status of ICRISAT groundnut entries in AICORPO postrainy (rabi/summer) season trials, 1987/88.

Trial[1]	Entry	Zone[2]	Remarks
IET (normal duration)	ICGV 86187, 86236, 86315	Northern and Southern	New entries
CVT (normal duration)	ICGS 103, 105, 87	Northern	Promoted from IET (Old)
			Promoted from IET (New)
	ICGS 84, 103, 105	Southern	Promoted from IET (Old)
	ICGS 87, 109, ICG(FDRS) 68		Promoted from IET (New)
CVT (short duration)	ICGS(E) 21	Northern	Promoted from IET (Early)
Adaptive trial	ICGS 37	Northern	Proposal submitted

1. All postrainy-season entries are sequential branching subsp *fastigiata*; IET = Initial Evaluation Trial, CVT = Coordinated Varietal Trial.
2. Northern zone = Punjab, Uttar Pradesh, Rajasthan, Haryana, Gujarat, Madhya Pradesh, and parts of Maharashtra; Southern zone = Orissa, parts of Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu.

trials. Another ICRISAT variety ICGS 37 was recommended for inclusion in the postrainy-season adaptive trials in the northern zone (Table 36). Many other ICRISAT varieties were promoted to the next level of trials in both seasons.

Our influence on AICORPO trials remains significant; 40% of the entries in the rainy-season trials, and 32% of the entries in the postrainy-season trials are from ICRISAT.

Both ICGS 11 and ICGS 44 have become popular for postrainy-season cultivation in India. ICGS 11 was formally released by the Central Varietal Release Committee of the Government of India in 1986. We now await a formal release of ICGS 44 for postrainy-season cultivation in the western zone. In the 1986/87 postrainy season adaptive trials in Gujarat, this variety produced 36.6% higher pod yields than the local cultivar GG 2 and is being proposed for release.

A total of 8.3 t of the seed of ICGS 1, ICGS 5, ICGS 11, ICGS 21, and ICGS 44, and ICG(FDRS) 4 and ICG (FDRS) 10 was supplied to a range of organizations in India. We supplied seed for increase and adaptive trials. One hundred and ten farmers were also provided with small quantities of ICGS 11 and ICGS 44. We also supplied 400 seed samples to 59 scientists in India in addition to the seed requirements of the AICORPO trials throughout the country.

International Trials and Observation Nurseries

We reorganized our various international trials into five trials. These trials are named as III in the series and are listed in Table 37.

We intend to run these trials at least twice at each location before revising them.

So far we have sent IEGVT to 20 locations, IMLGVT to 16 locations, ICGVT to 13 locations, IFDRGVT to 10 locations, IPRGVT to 5 locations, and IDN to 2 locations. These locations include 14 countries in Africa (Republic of Benin, Botswana, Burundi, Cameroon, Egypt, Ghana, Kenya, Liberia, Malawi, Niger, Republic of Guinea, Somalia, Sudan, and Uganda), 6 in Asia (Burma, Nepal, People's Republic of China, the Philippines, Sri Lanka, and Thailand), 2 in the Caribbean (the Dominican Republic and Honduras), and Australia. In

Table 37. ICRISAT international groundnut trials and nurseries and number of entries in each.

Trial name	No. of entries
International Early Groundnut Varietal Trial (IEGVT)	24(+1)[1]
International Medium and Late Groundnut Varietal Trial (IMLGVT)	34(+2)
International Confectionery Groundnut Varietal Trial (ICGVT)	23(+2)
International Foliar Diseases Resistant Groundnut Varietal Trial (IFDRGVT)	35(+1)
International Pest Resistant Groundnut Varietal Trial (IPRGVT)	14(+2)
International Drought Nursery (IDN)	16(+2)

1. Numbers in parentheses are local controls.

addition to complete trial sets, we also supplied 1419 seed samples of lines included in these trials, and other breeding lines, to scientists in 28 countries.

The results of international groundnut varietal trials, received from our cooperators in 1987, are encouraging.

Early-Maturing Groundnut Varietal Trial

At Saria in Burkina Faso, eight of the early-maturing lines significantly outyielded the local variety TS 32-1. ICGV 86065 produced a pod yield of 3.0 t ha^{-1}, ICGV 86071 and ICGV 86061 produced pod yields of 2.9 t ha^{-1} each, while TS 32-1 produced a pod yield of 2.3 t ha^{-1}.

In Thailand, in trials grown under 'before-rice conditions', ICGV 86015 produced 3.7 t pods ha^{-1} and significantly outyielded the local variety Tainan 9, which produced 2.7 t pods ha^{-1}. Under 'after-rice conditions', ICGV 86070 significantly outyielded Tainan 9 by 69% and ICGV 87938 significantly outyielded Tainan 9 by 37%. In the preliminary trials, ICGV 86101, produced 65% higher pod yields than Tainan 9, ICGV 86111 produced 33% higher pod yields than Tainan 9, and ICGV 87602 produced 52% higher pod yields than Tainan 9 in three different trials.

In Pakistan, several ICRISAT-bred early-maturing lines in a national early-maturing cultivar trial outyielded the local variety, Banki. ICGV 86077 produced 1.7 t pods ha^{-1} at Islamabad compared to 0.79 t of Banki and ICGV 86068 produced 0.99 t pods ha^{-1} at Chakwal compared to 0.15 t ha^{-1} of Banki.

At their request, for use in multilocational testing, we supplied Burma with 5 kg bulk seed of ICGV 86065 for multiplication.

North Carolina State University selected ICRISAT-bred, early-maturing lines as gene-donors to contribute earliness to virginia types.

Groundnut Varietal Trial for Adaptation

ICGS 61 gave the highest pod yield (3.1 t ha^{-1}) in Burundi producing significantly more than the local variety, G 18 (2.3 t ha^{-1}). Similarly, five ICRISAT groundnut varieties ICGS 50 (1.9 t ha^{-1}), ICGS 76 (1.4 t ha^{-1}), ICGS 18 (1.4 t ha^{-1}), ICGS 51 (1.3 t ha^{-1}), and ICGS 63 (1.2 t ha^{-1}) showed 24–39% fresh pod yield advantage in the wet season over the local variety Ilcos Red (0.5 t ha^{-1}) in the Philippines. In another test, conducted during the dry season at the same location, ICGS 76 produced the highest fresh pod yield of 6.2 t ha^{-1}.

In trials in Ethiopia and Ghana, differences between entries were nonsignificant, but the highest-yielding selections had 24% and 35% pod yield superiority over the local varieties. ICGS 26 gave the highest pod yield in Ghana (3.9 t ha^{-1}) and ICGS 49 in Ethiopia (5.8 t ha^{-1}).

Confectionery Groundnut Varietal Trial

We received data on trial sets sent in 1986 from eight locations. Seven confectionery groundnut selections in Korea, six in Zambia, four each in Sudan and People's Republic of China, two in Nepal, and one in Burundi gave significantly higher pod yields than the local control varieties. ICGV 86979 with 3.3–4.0 t pods ha^{-1} significantly outyielded local control varieties (1.8–3.2

t ha^{-1}) in Sudan, People's Republic of China, Korea, and Zambia.

We analyzed data on 100-seed mass from ten locations. All the lines had a regression coefficient greater than 0.72 indicating the strong influence of environment on the expression and stability of seed size.

Foliar Diseases Resistance Trial

Results from the 1985/86 and 1986 internaticnal trials conducted in Thailand indicated the superior performance of resistant ICRISAT lines. In the trial conducted after rice (December 1985-April 1986), the yield advantage of resistant ICRISAT lines ranged from 6 to 46%. The best resistant entry, ICGV 87179 gave 3.6 t dried pods ha^{-1} compared to 2.4 t ha^{-1} by the local cultivar Tainan 9. In the rainy-season (May-October 1986) trial, the yield superiority of the ICRISAT entries ranged from 18 to 46%.

Jamaica released one of our improved germplasm lines, Tifrust 2 (ICG 7886), developed jointly by the United States Department of Agricuture—Agricultural Research Station (USDA-ARS), Coastal Plain Research Station, University of Georgia, Tifton, Georgia, USA and ICRISAT, as Cardi-Payne. This variety has a high degree of resistance to rust and moderate resistance to late leaf spot. On average, it gave 1.6 t pods ha^{-1} in farmers' fields, 75% more than the local variety. It has been cited as ideal for Jamaican conditions because it meets farmers' requirements and is useful for roasting, canning, butter making, oil extraction, and confectionery purposes.

Workshops, Conferences, and Seminars

Workshop on Aflatoxin Contamination of Groundnut

An International Workshop on 'Aflatoxin Contamination of Groundnut' was held at ICRISAT Center, India, 6-9 October. Fifty scientists from 26 countries joined ICRISAT scientists to present research findings, discuss recent advances in understanding of the groundnut aflatoxin problem, and consider research and extension approaches to evaluate, monitor, and control contamination of groundnuts at national and international levels. The meeting recommended the production of an Information Bulletin to provide, in a convenient form, useful advice on how to evaluate and monitor the contamination problem and how to control the invasion of groundnuts by aflatoxin-producing fungi and the production of aflatoxins. The need to inform the public in general, and policy makers in particular, about the hazards posed by aflatoxin contamination of groundnut and some other agricultural commodities was highlighted.

ICRISAT has published a short 'Summary and Recommendations' document providing the gist of the Workshop deliberations. This will be translated into French and Spanish and distributed as widely as possible to increase awareness of the problem. Copies are available from ICRISAT Center. The full proceedings are in preparation.

Peanut Stripe Virus Coordinators' Meet

A Peanut Stripe Virus Coordinators' Meeting was held 9-12 June 1987 at Malang, East Java, Indonesia. Nineteen scientists from Australia, Indonesia, Japan, the Philippines, Thailand, USA, and from ICRISAT and FAO participated. The meeting was sponsored by ACIAR, Australian Development Assistance Bureau (ADAB), Peanut-CRSP, and ICRISAT. The participants discussed this newly identified but widespread virus in southeast Asia, the People's Republic of China, and the USA. The recommendations of the meeting were:

- for AGLN-ICRISAT to coordinate future research on PStV.
- to organize a training course in 1988 on identification of groundnut viruses with special reference to PStV.
- to undertake surveys for PStV in south and southeast Asia.

- to produce an Information Bulletin on PStV.
- to organize a second PStV coordinators meeting in Thailand in 1989.
- to inform the Inter-governmental Plant Protection Commission regarding the dangers of PStV.
- that countries having a record of PStV should assay seed for presence of the seedborne virus before exporting.
- to identify country coordinators for collaborative work on PStV.
- to publish "Letters to Editors" in International Journals to emphasize that PStV is the accepted name of the virus, and names such as 'mild mottle' and 'blotch', describing disease symptoms, are names of the disease caused by PStV.

First Regional Plant Protection Workshop in Southern Africa

Sixteen groundnut pathologists and entomologists representing the national programs of Malawi, Mozambique, Swaziland, Tanzania, Zambia and Zimbabwe, and ICRISAT Regional and Center Programs, toured centers of groundnut research in Malawi, Zambia, and Zimbabwe, 16–20 February. The current status of pathogens and pests in the SADCC region was reviewed in informal sessions at the University of Zimbabwe, Harare, and discussions of the tour and the subsequent recommendations were made at the closing session in Lilongwe. ICRISAT Center scientists presented special topic papers on aflatoxins and the ICRISAT pest survey of southern Africa.

Third Consultative Group Meeting on Collaborative Research on Groundnut Rosette Virus Disease

Seventeen groundnut scientists and plant virologists from France, Federal Republic of Germany, Malawi, Nigeria, UK, USA, and from ICRISAT Center and Regional Programs met in Lilongwe, Malawi, 8-10 March, to discuss collaborative research on GRV disease. The scientists studied the disease in the field, and examined research currently in progress at ICRISAT's Regional Groundnut Program at Chitedze Research Station.

ACIAR/AGLN Workshop on Management of Legume Pests

A Workshop on the Management of Legume Pests was cosponsored by ACIAR and AGLN. The workshop was held 31 August to 3 September 1987 at Khon Kaen, Thailand; and 7-10 September 1987 at Malang, Indonesia. Considering the importance of other legumes in both countries, mung bean, soybean, and cowpea were included along with groundnut and pigeonpea. ACIAR sent a professional pest manager and ICRISAT deputed one entomologist to help in conducting the workshop with help from local entomologists. Twelve participants were involved in each country to discuss the various aspects of pest management including: pests and their distribution; biology, ecology, and damage by major pests; sampling and survey procedures and yield loss assessment; insects as disease vectors; insecticides; biological control; host-plant resistance, and integrated pest management principles. The participants were asked to evaluate the usefulness of the course. All were appreciative, and requested more information/literature on pest management principles.

Publications

Institute Publications

Information Bulletin

Dick, K.M. 1987. Pest management in stored groundnuts. Information Bulletin no. 22. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp. 46 ref. ISBN 92-9066-124-0. (IBE 022)

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 210 pp. ISBN 92-9066-109-7. (CPE 032)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Coordination of grain legumes research in Asia: summary proceedings of the Review and Planning Meeting for Asian Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 16-18 Dec 1985, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 96 pp. ISBN 92-9066-120-8. (CPE 040)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Proceedings of the Second Regional Groundnut Workshop for Southern Africa. 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: ICRISAT. 164 pp. ISBN 92-9066-125-9. (CPE 041)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Research on grain legumes in eastern and central Africa: summary proceedings of the Consultative Group Meeting for Eastern and Central African Regional Research on Grain Legumes (Groundnut, Chickpea, and Pigeonpea), 8-10 Dec 1986, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. Patancheru, A.P. 502 324, India: ICRISAT. 128 pp. ISBN 92-9066-129-1. (CPE 042)

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. International Arachis Newsletter no. 1. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 1010-5824. (NAE)

Journal Articles

Dick, K.M. 1987. Losses caused by insects to groundnuts stored in a warehouse in India. Tropical Science 27(2):65-75. (JA 585)

Giller, K.E., Nambiar, P.T.C., Srinivasa Rao, B., Dart, P.T., and **Day, J.M.** 1987. A comparison of nitrogen fixation in genotypes of groundnut (*Arachis hypogaea* L.) using ^{15}N-isotope dilution. Biology and Fertility of Soils 5:23-25. (JA 600)

Hobbs, H.A., Reddy, D.V.R., Rajeshwari, R., and **Reddy, A.S.** 1987. Use of direct antigen coating and protein A coating ELISA procedures for detection of three peanut viruses. Plant Disease 71:747-749. (JA 569)

Hobbs, H.A., Reddy, D.V.R., and **Reddy, A.S.** 1987. Detection of a mycoplasma-like organism in peanut plants with witches' broom using indirect enzyme-linked immunosorbent assay (ELISA). Plant Pathology 36(2):164-167. (JA 613)

Mehan, V.K., McDonald, D., and **Rajagopalan, K.** 1987. Resistance of peanut genotypes to seed infection by *Aspergillus flavus* in field trials in India. Peanut Science 14:17-21. (JA 602)

Nambiar, P.T.C., Anjaiah, V., and **Srinivasa Rao, B.** 1987. Factors affecting competition of three strains of rhizobia nodulating groundnut *Arachis hypogaea*. Annals of Applied Biology 110:527-533. (JA 589)

Nambiar, P.T.C., Rego, T.J., and **Srinivas Rao, B.** 1987. Comparison of the requirements and utilization of nitrogen by genotypes of sorghum (*Sorghum bicolor* (L.) Moench), and nodulating and non-nodulating groundnut (*Arachis hypogaea* L.). Field Crops Research 15(2):165-179. (JA 535)

Nambiar, P.T.C., and **Sivaramakrishnan, S.** 1987. Detection and assay of siderophores in cowpea rhizobia (*Bradyrhizobium*) using radioactive Fe (^{59}Fe). Letters in Applied Microbiology 4(2):37-40. (JA 633)

Nambiar, P.T.C., and **Srinivasa Rao, B.** 1987. Effect of sowing depth on nodulation, nitrogen fixation, root and hypocotyl growth, and yield in groundnut (*Arachis hypogaea*). Experimental Agriculture 23:283-291. (JA 561)

Rajendrudu, G., and **Williams, J.H.** 1987. Effect of gypsum and drought on pod initiation and crop yield in early maturing groundnut (*Arachis hypogaea*) genotypes. Experimental Agriculture 23:259-271. (JA 384)

Rao, J.K., Sahrawat, K.L., and **Burford, J.R.** 1987. Diagnosis of iron deficiency in groundnut, *Arachis hypogaea* L. Plant and Soil 97(3):353-359. (JA 307)

Stalker, H.T., and **Moss, J.P.** 1987. Speciation, cytogenetics, and utilization of *Arachis* species. Advances in Agronomy 41:1-40. (JA 635)

Subrahmanyam, P., and **Smith, D.H.** 1987. Effect of host genotype on incubation period, receptivity, lesion diameter, and leaf area damage of *Didymella arachidicola* on peanut. Peanut Science 14:90-94. (JA 621)

Subrahmanyam, P., Smith, D.H., Taber, R.A., and **Shepherd, E.** 1987. An outbreak of yellow mold of peanut seedlings in Texas. Mycopathologia 100:97-102. (JA 614)

Vasudeva Rao, M.J. 1987. Host specificity in *Striga* spp and physiological "strains". Pages 14-25 *in* Parasitic weeds in agriculture (Musselman, L.J., ed.). vol. 1. *Striga*. Boca Raton, FL, USA: CRC Press. (JA 468)

Vasudeva Rao, M.J. 1987. Techniques for screening sorghums for resistance to *Striga*. Pages 282-304 *in* Parasitic weeds in agriculture (Musselman, L.J., ed.). vol. 1. *Striga*. Boca Raton, FL, USA: CRC Press. (JA 467)

Wadia, K.D.R., Nageswara Rao, R.C., and **Williams, J.H.** 1987. An improved method for identification of dormant sequentially branched progenies from populations derived from crosses between non-dormant (subspecies *fastigiata*) and dormant (subspecies *fastigiata*) groundnut (*Arachis hypogaea* L.). Ole'agineux 42(2):75-82. (JA 616)

Conference Papers

Amin, P.W. 1987. Insect pests of groundnut in India and their management. Pages 219-233 *in* Plant protection in field crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, CPPTI, Hyderabad, India (Veerabhadra Rao, M., and Sithanantham, S., eds.). Hyderabad, A.P., India: Plant Protection Association of India. (CP 298)

Bock, K.R. 1987. Rosette and early leaf spot diseases: a review of research progress, 1984/85. Pages 5-14 *in* Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 318)

Gibbons, R.W. 1987. The role of wild species in the improvement of the cultivated groundnut (*Arachis hypogaea* L.). Pages 33-42 *in* Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 320)

Hennen, J.F., Subrahmanyam, P., and **Figueiredo, M.B.** 1987. The taxonomy, life history, and evolution of *Puccinia arachidis* Speg. Pages 145-155 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 409)

Krishna, K.R., and **Williams, J.H.** 1987. Vesicular arbuscular mycorrhiza and genotype effect on peanut symbiosis and growth. Page 48 *in* Mycorrhiza in the next decade: practical applications and research priorities: proceedings of the Seventh North American Conference on Mycorrhiza, 3-8 May 1987, Gainesville, FL, USA (Sylvia, D.M., Hung, L.L., and Graham, J.H., eds.). Gainesville, FL, USA: Institute of Food and Agricultural Sciences, University of Florida. (CP 351)

Lawn, R.J., and **Williams, J.H.** 1987. Limits imposed by climatological factors. Pages 83-98 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 312)

Nigam, S.N. 1987. A review of the present status of the genetic resources of the ICRISAT Regional Groundnut Program, of the Southern African Cooperative Regional Yield Trials, and of rosette virus resistance breeding. Pages 15-30 *in* Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 319)

Reddy, L.J., Nigam, S.N., Dwivedi, S.L., and **Gibbons, R.W.** 1987. Breeding groundnut cultivars resistant to rust (*Puccinia arachidis* Speg.). Pages 17-25 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 404)

Singh, A.K. 1986. Alien gene transfer in groundnut by ploidy and genome manipulations. Pages 207-209 *in* Genetic Manipulations in Plant Breeding (Horn, Jensen, Odenbach, Schieder, eds.). Berlin, West Germany: Walter de Gruyter and Co. (CP 227)

Singh, A.K., Moss, J.P., and **Rao, B.G.** 1987. Incorporation of rust resistance from wild *Arachis* species into the cultivated groundnut. Pages 41-48 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 406)

Subrahmanyam, P., and **McDonald, D.** 1987. Groundnut rust disease: epidemiology and control. Pages 27-39 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 405)

Varma, B.K., and **McDonald, D.** 1987. Groundnut rust disease and plant quarantine. Pages 55-58 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 408)

Wightman, J.A., Amin, P.W., Ranga Rao, G.V., and **Dick, K.M.** 1987. Research on groundnut pests at ICRISAT. Pages 103-114 *in* Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 313)

Williams, J.H., Ramraj, V.M., and **Pal, M.** 1987. Physiological studies on foliar diseases: varietal differences in response to use of fungicides. Pages 49-53 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 407)

Thesis

Witzenberger, A. 1987. Influence of different photoperiod and "Kylar" treatments on the vegetative and reproductive growth of several groundnut genotypes (*A. hypogaea* L.). Einfluss unterschiedlich gestalteter Photoperiode- und "Kylar"-behandlungen auf das vegetative und reproduktive Wachstum mehrerer Erdnuss-genotypen (*A. hypogaea* L.). Ph.D. thesis, Rheinische Friedrich-Wilhelms-Universitat Zu Bonn, Bonn, Federal Republic of Germany. 202 pp.

RESOURCE MANAGEMENT

Contents

Cover photo: Measuring the strength of a Vertic Inceptisol with a vane shear during a study on root penetration.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. 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, A.P. 502 324, India.

RESOURCE MANAGEMENT

The Resource Management Program (RMP) aims to increase the productivity and income of farm households in the semi-arid tropics (SAT) by developing better farming systems. In designing these systems, the Program seeks ways of using scarce resources that are both more efficient and, in the long term, more sustainable.

Research in Resource Management is divided between several sites in India (mainly on Alfisols, Vertisols, and Vertic Soils) and in Niger (mainly on sandy soils of the Sahel). Programs in the two regions are complementary; they have been fully integrated in the following report. Division of the material follows broad themes that progress logically from the definition of resources in the SAT, through the development of better methods for managing these resources, to the evaluation of technology on an operational scale, either on research stations or in farmers' fields. Within each theme, contributions from physical scientists, biologists, and economists can be distinguished but there is an increasing trend towards interdisciplinary projects where these distinctions will be less pronounced.

Emphasis has been given to a number of major projects that were completed in 1987, e.g., the collection of village records in Burkina Faso, primary tillage on Alfisols, a system for the limited irrigation of dryland crops (LID), the design of an ultra-low-volume sprayer for insecticide application, and the potassium balance of soil in relation to cropping.

During the year, RMP scientists continued to develop active research links with national services, notably through the Central Research Institute for Dryland Agriculture (CRIDA) in Hyderabad and through the Institut national de recherche agronomique du Niger (INRAN). Other significant links, both personal and institutional, are recorded at the end of this report.

Characterizing Resources

Climate

Climate Variability in the SAT

The Sahelian countries have recently suffered from extreme droughts and persistent crop failures. In India, there is a widespread belief that rainfall is becoming more variable. A study was therefore conducted to evaluate changes in rainfall variability at about 40 locations in India and the Sahel. Long-term records for two typical locations, Niamey in Niger, and Hyderabad in India, were analyzed for evidence of recent climatic changes.

Figure 1 shows the variability in annual rainfall at Hyderabad from 1901 to 1987. In these 87 years, rainfall exceeded 991 mm (mean + 1 SD) in 10 years and fell below 579 mm (mean – 1 SD) in 9 years. The time series shows no significant trend and the rainfall in a given year is not correlated with that of the preceding or the following year. Based on this analysis, annual rainfall at Hyderabad, although variable from year to year, has not changed greatly during recent years.

Figure 2 shows the variability of annual rainfall at Niamey from 1905 to 1987. The rainfall was less than average in 40 years, with a high frequency of dry years toward the end of the record. For example, in the last 17 years, only 4 years have recorded annual rainfall greater than the long-term mean, and rainfall in all years after 1979 was below the long-term mean. Serious drought (annual rainfall $<75\%$ of the long-term mean) has occurred in 5 of the last 10 years. The major implication of this persistently low rainfall in recent years is a serious shortening of the growing season in this already marginal zone. As a consequence, the suitability of entire agroecological regions for some agricultural crops has

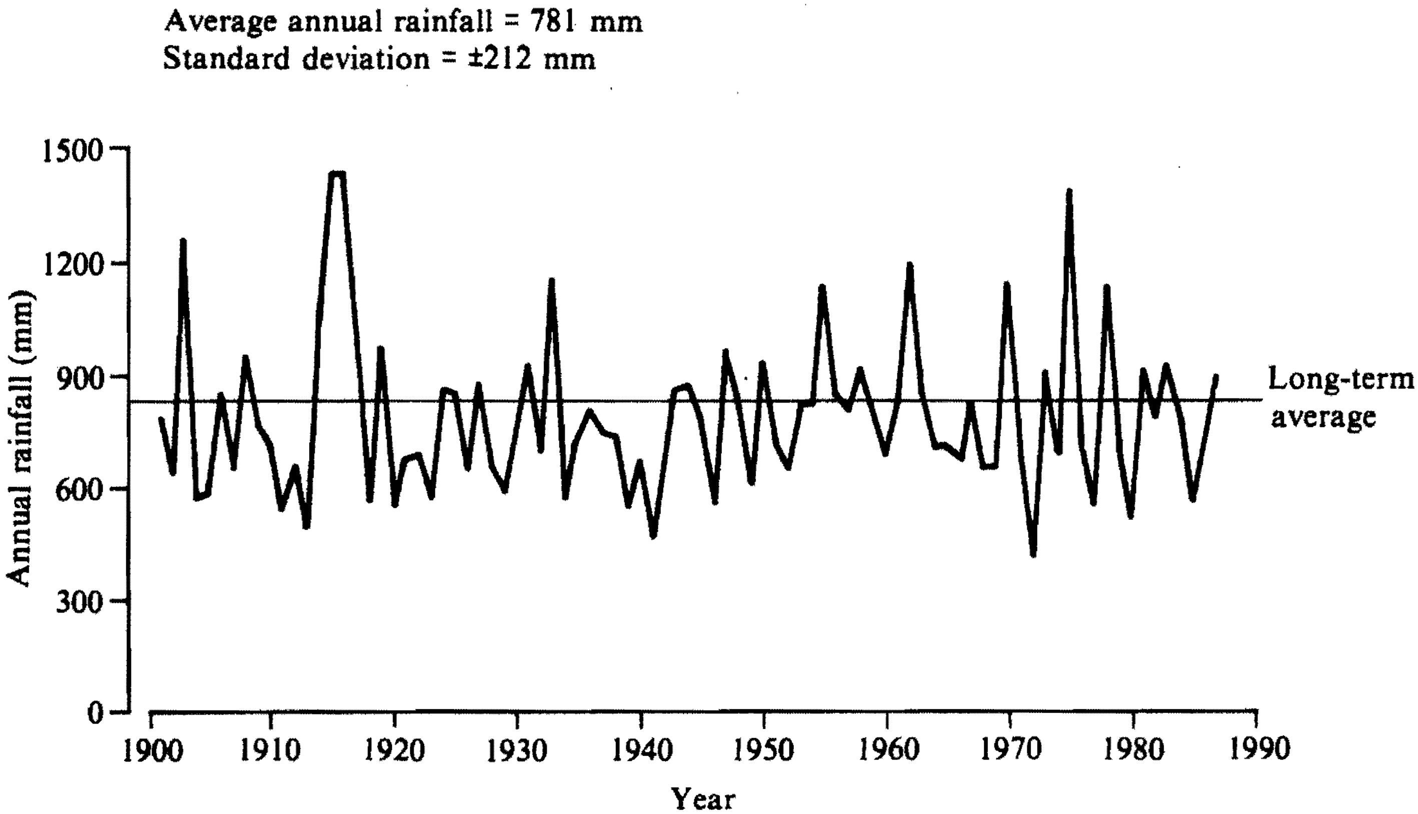


Figure 1. Annual rainfall at Hyderabad, India, 1901-1987.

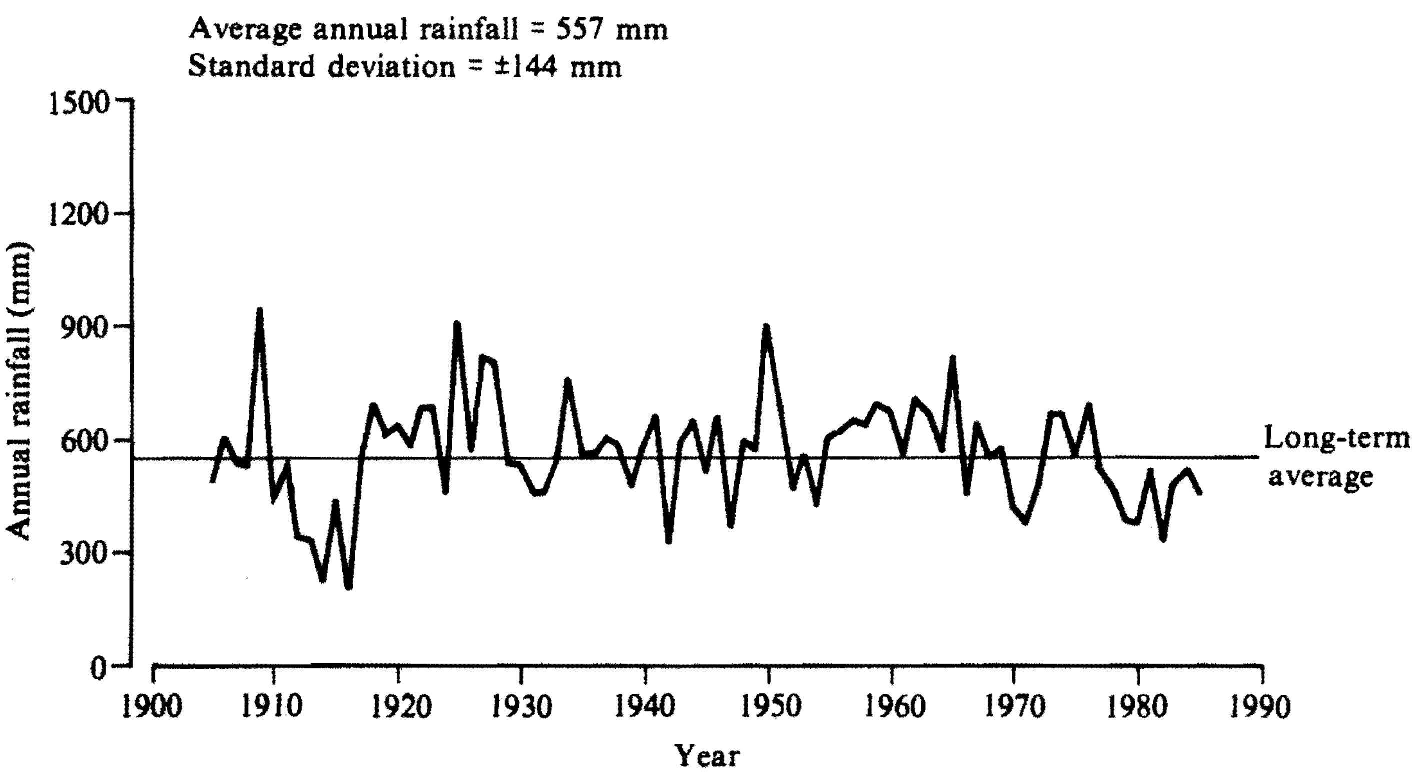


Figure 2. Annual rainfall at Niamey, Niger, 1905-1987.

changed. An example is the extent of change after 1970 in the northern limit of the area suitable for groundnut cultivation. In effect, this limit moved south by 3-5° of latitude (Fig. 3). Groundnut production in the Sahel, which had considerably expanded in the 1950s and 1960s, when a series of good rainfall years occurred, has since declined. A vast stretch of the Sahelian zone has recently suffered repeated crop failures due to drought.

Compared with Hyderabad, Niamey has longer sequences of consecutive 'dry' years with below-average rainfall, and much fewer 'wet' years interspersed among the dry years. These results show that droughts are longer in the Sahelian zone and the agricultural consequences would be more severe than those in the Indian SAT. The development of innovative technologies to increase and stabilize food production in the Sahel is a formidable challenge.

Agroclimatology of African Vertisols

Because several countries in Africa wish to improve the productivity of Vertisols, we analyzed the agroclimatic environment of Vertisol areas covering about 43 million ha in 28 African states. There are two general climatic types in the SAT: dry and wet/dry (Fig. 4). In the dry SAT, the rainy period ranges between 2 and 5 months and the annual rainfall between 400 and 800 mm.

As an example of the water balance in the dry SAT, Figure 5 shows the distribution of monthly rainfall and potential evapotranspiration (PE) at Bulawayo, Zimbabwe, where annual rainfall satisfies only 40% of the annual PE demand. In the rainy season (Nov-Mar), rainfall exceeds PE during December, January, and February. In this period, about 100 mm of surplus water is available for storage in the soil profile and could sustain crops in March and April. Thus we con-

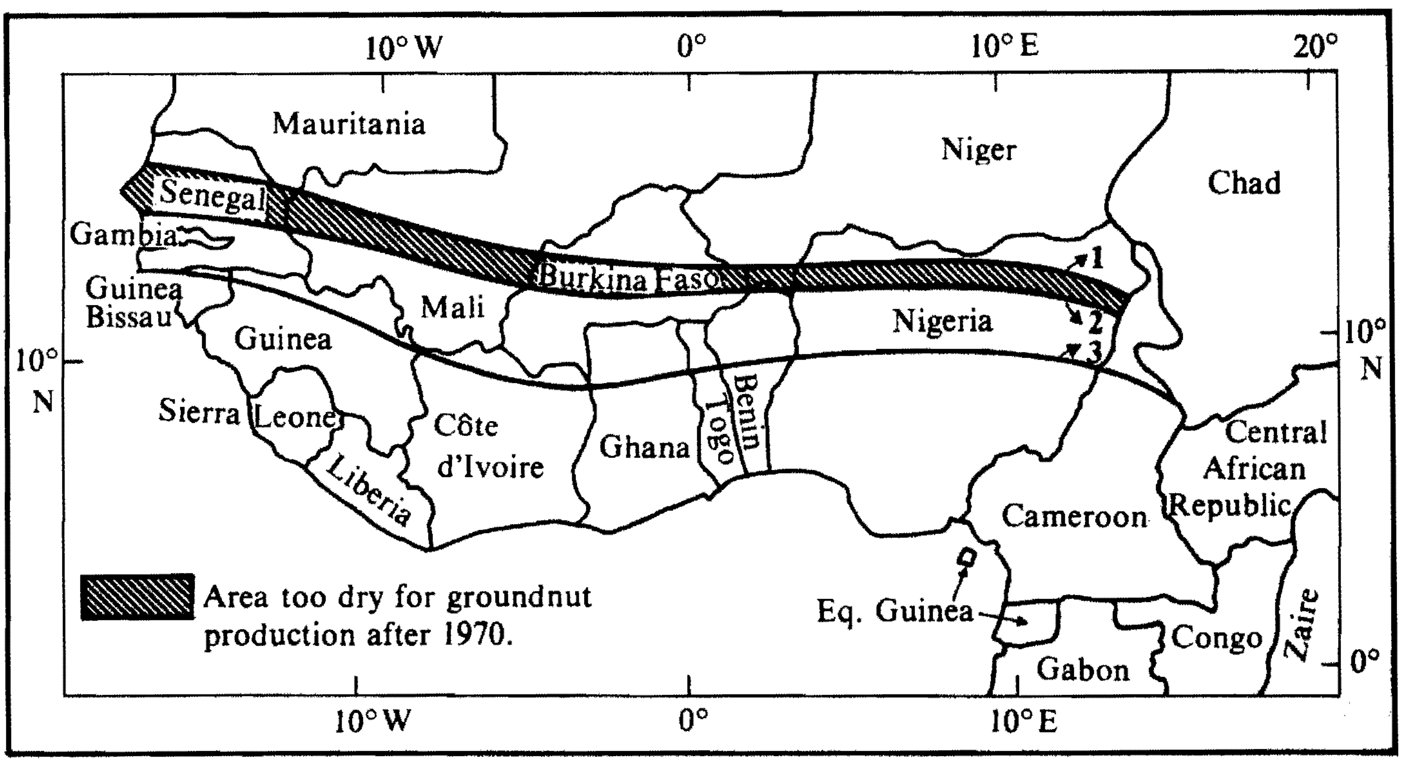


Figure 3. Delineation of the approximate groundnut-growing area of West Africa that has been affected by drought since 1970. (1 = Northern limit of groundnut-producing area before 1970; 2 = Northern limit of groundnut-producing area after 1970; and 3 = Southern limit of groundnut-producing area that has not shown any significant change).

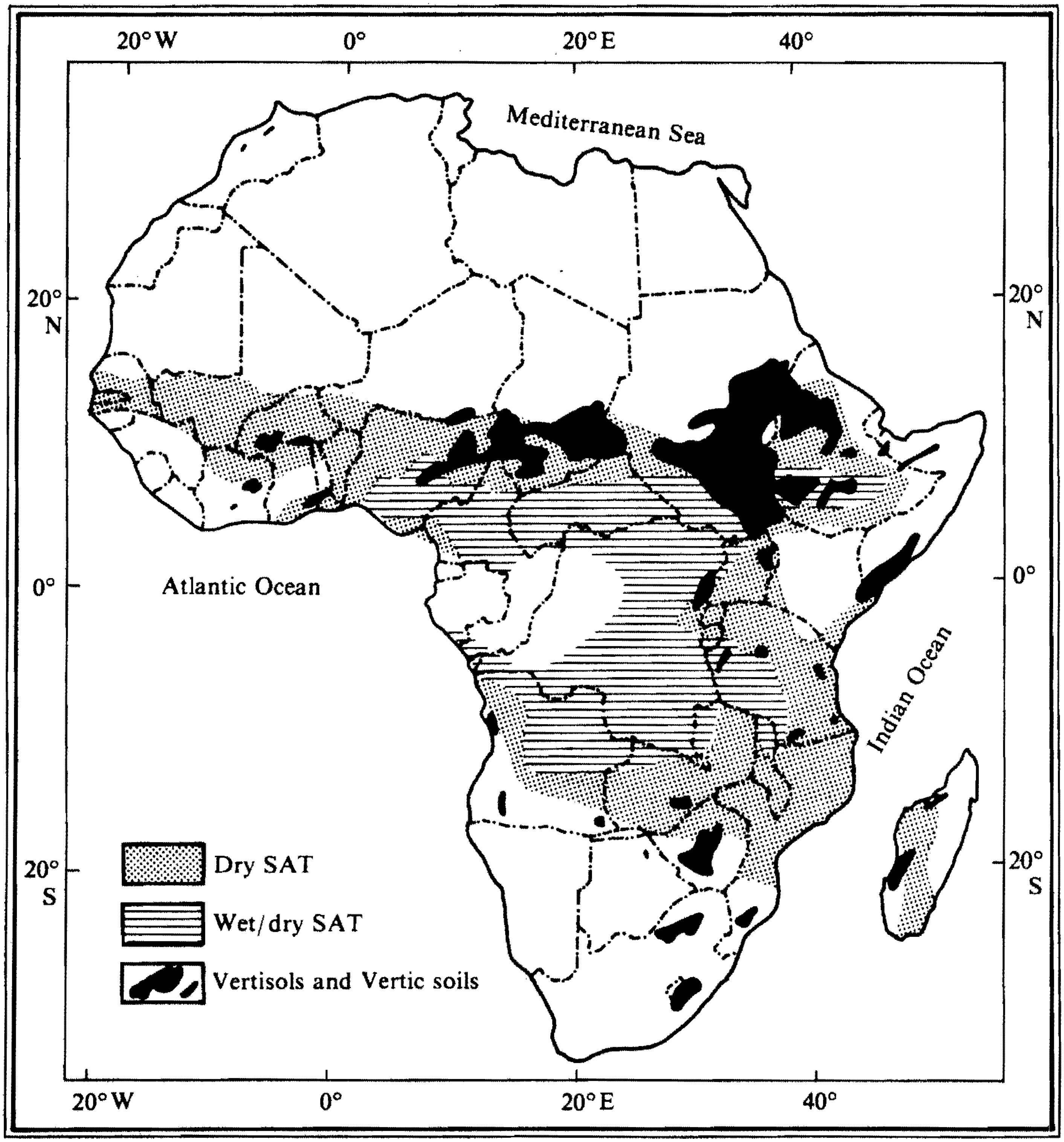


Figure 4. Distribution of Vertisols and Vertic soils in dry and wet/dry semi-arid tropical regions of Africa.

sider that the growing season at Bulawayo extends from December to March/April (120-150 days), so that at least one and possibly two rainfed crops could be grown. About 20 million ha of Vertisols and associated soils of Africa are in areas with a dry SAT climate. This region is suitable for arable farming, and several components of ICRISAT's improved Vertisol management technology could be adapted to increase agricultural production there.

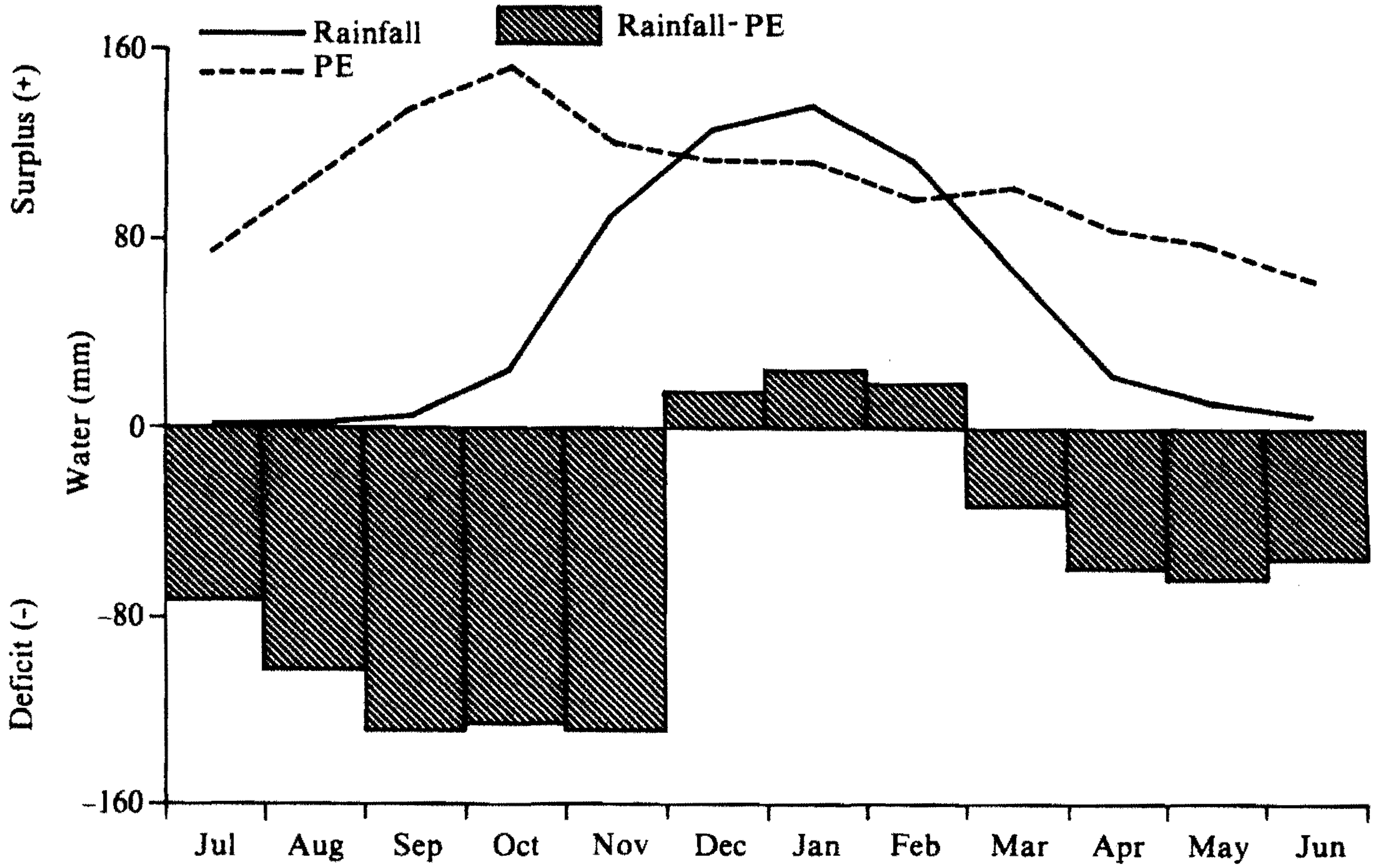


Figure 5. An example of the water balance for a dry SAT climate (mean annual rainfall 594 mm, mean annual PE 1516 mm), Bulawayo, Zimbabwe (20° 09′S, 28° 37′E).

In the wet/dry SAT, rainfall exceeds PE for 4.5-7 months during the year (Fig. 4). The annual rainfall generally exceeds 800 mm and the growing season ranges between 180 and 300 days. Twenty-five percent of the Vertisols and Vertic soils of Africa are in this region. Figure 6 shows the water balance for Debre-Zeit, Ethiopia. Rainfall exceeds PE for 4 successive months—June through September, and surplus water exceeds 300 mm during the rainy season. Most of the wet/dry SAT area of Africa is underutilized for crop production; waterlogging and soil erosion are the main constraints. The cropping intensity of this region could be increased by the introduction of watershed-based land and water management techniques. The International Board for Soils Research and Management (IBSRAM), the International Livestock Centre for Africa (ILCA), and ICRISAT are currently cooperating with the national research programs of some African nations to test and validate several options for improved management of Vertisols. The results obtained with improved technology in Ethiopia are encouraging.

Spatial Variability of Rainfall

Rainfall in West Africa is low, variable, and undependable. Although the spatial variability of rainfall had been studied extensively over broad regions in West Africa, comparable reports for small areas are limited because systematic networks of monitoring gauges do not exist. We installed 18 rain gauges on a 400-m grid over 500 ha centered on the ICRISAT Sahelian Center

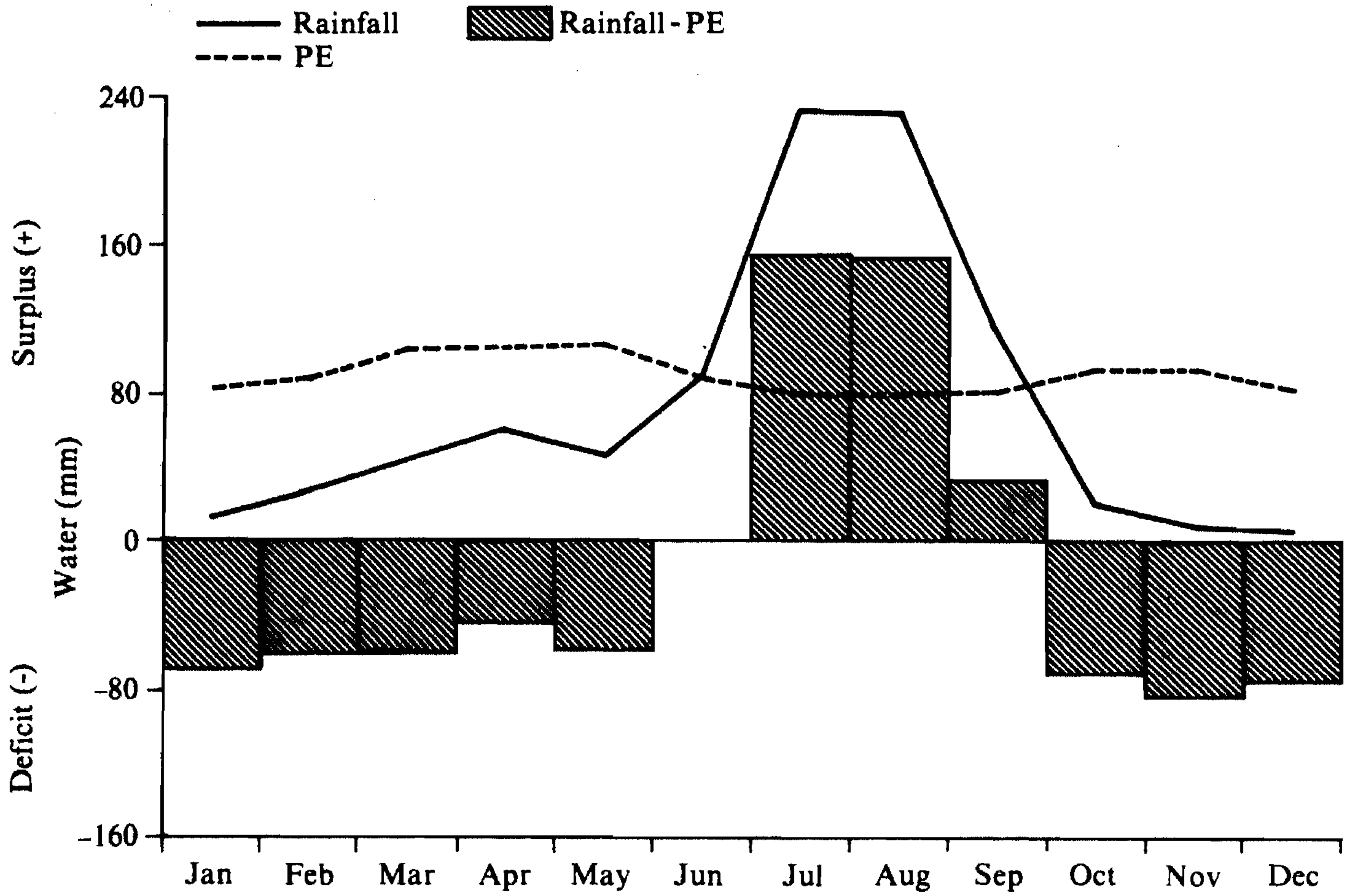


Figure 6. An example of the water balance for a wet/dry SAT climate (mean annual rainfall 866 mm, mean annual PE 1319 mm), Debre Zeit, Ethiopia (8° 44′N, 39° 02′E).

(ISC) meteorological observatory. Figure 7 shows rainfall isohyets prepared from the recordings on 22 July, 1986. Over 3.2 h, rainfall ranged from 8.9 mm to 34 mm and was 22.1 mm at the observatory. For each rainstorm the recording at the observatory was within the SE of the mean rainfall recorded by the 18 rain gauges. Geostatistical techniques were used to estimate the distance over which rainfall recordings could be expected to be independent. For most of the storms in 1986 this distance was 1 km. Figure 8 shows that the mean rainfall for each storm over the 18 gauges along with the variance for 1986 and 1987. In 1986, most of the storms at the beginning of the rainy season exhibited a large variance, while in 1987, the pattern was different with early-season storms showing the lowest variance. In general, storms depositing more than 20 mm showed larger variance.

Soils

Physical Characteristics of Vertic Inceptisols

About 35 million ha of black soils in India and about 30 million ha of black soils in Africa are classified as Vertic Inceptisols. These soils are generally characterized by the shallow depth of the weathered parent material (murrum) and the presence of many stones on the surface and within the soil profile (Fig. 9). They do not swell and shrink as much as Vertisols. In India they are mainly used to grow such rainy-season crops as castor (*Ricinus communis*) and sunflower (*Helianthus annuus*). As part of our studies on the water balance of a Vertic Inceptisol at ICRISAT Center, we determined the main soil physical properties for two profiles.

The variability within this soil group is shown by the contrast between the two profiles in terms of texture trends with depth. The sand content in profile I shows an increase with depth, from 41% at the surface to 73% at 115 cm (Table 1); in profile II it fluctuates between 32 and 44%. Generally, the silt content is uniform with depth. The clay content at the surface is 40% in both profiles but the trend with depth tends to complement the sand trend, i.e., it declines with depth in profile I. Consequently, the textural class ranges from clay at the surface to sandy loam at 1.45-m depth in profile I while it is clayey for almost all the horizons in profile II. For accurate interpretation of agronomic experiments on these soils, soil heterogeneity should be characterized and taken into consideration.

We used core samples (30-cm diameter) to study the bulk density and the distribution of stones in the profiles. The peak in the stone

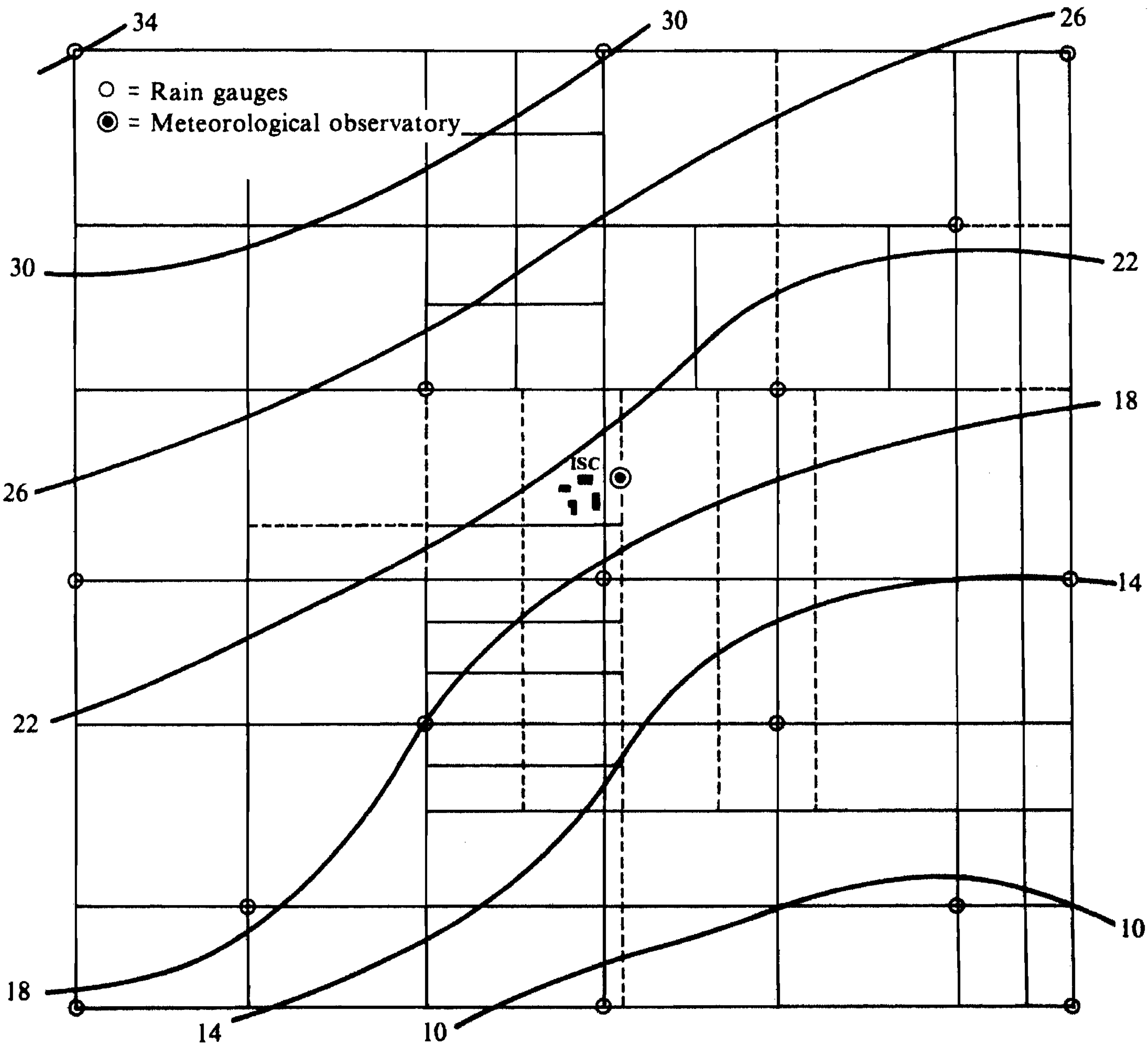
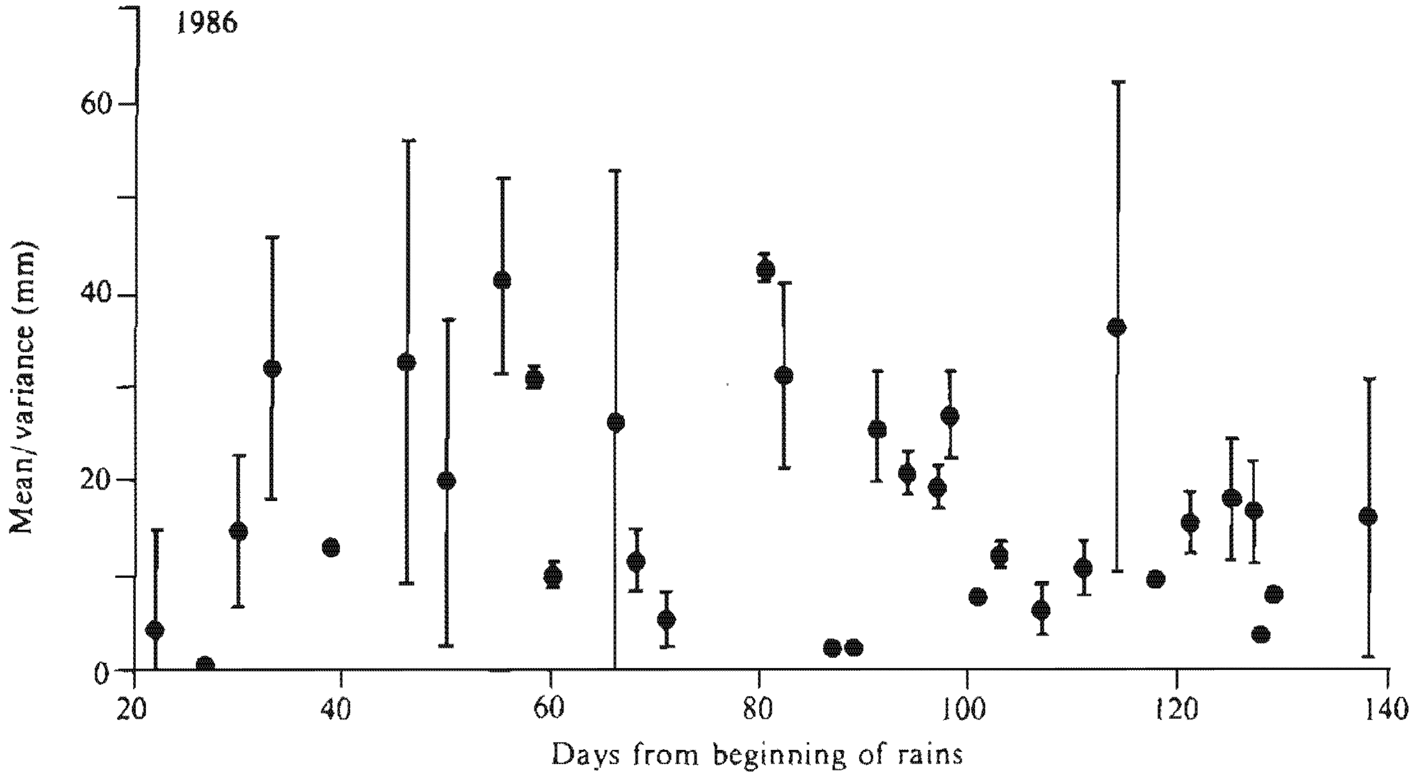


Figure 7. Spatial variability of rainfall shown as isohyets measured on a 400 m grid over 500 ha, ISC, Sadoré, Niger, 22 July 1986.



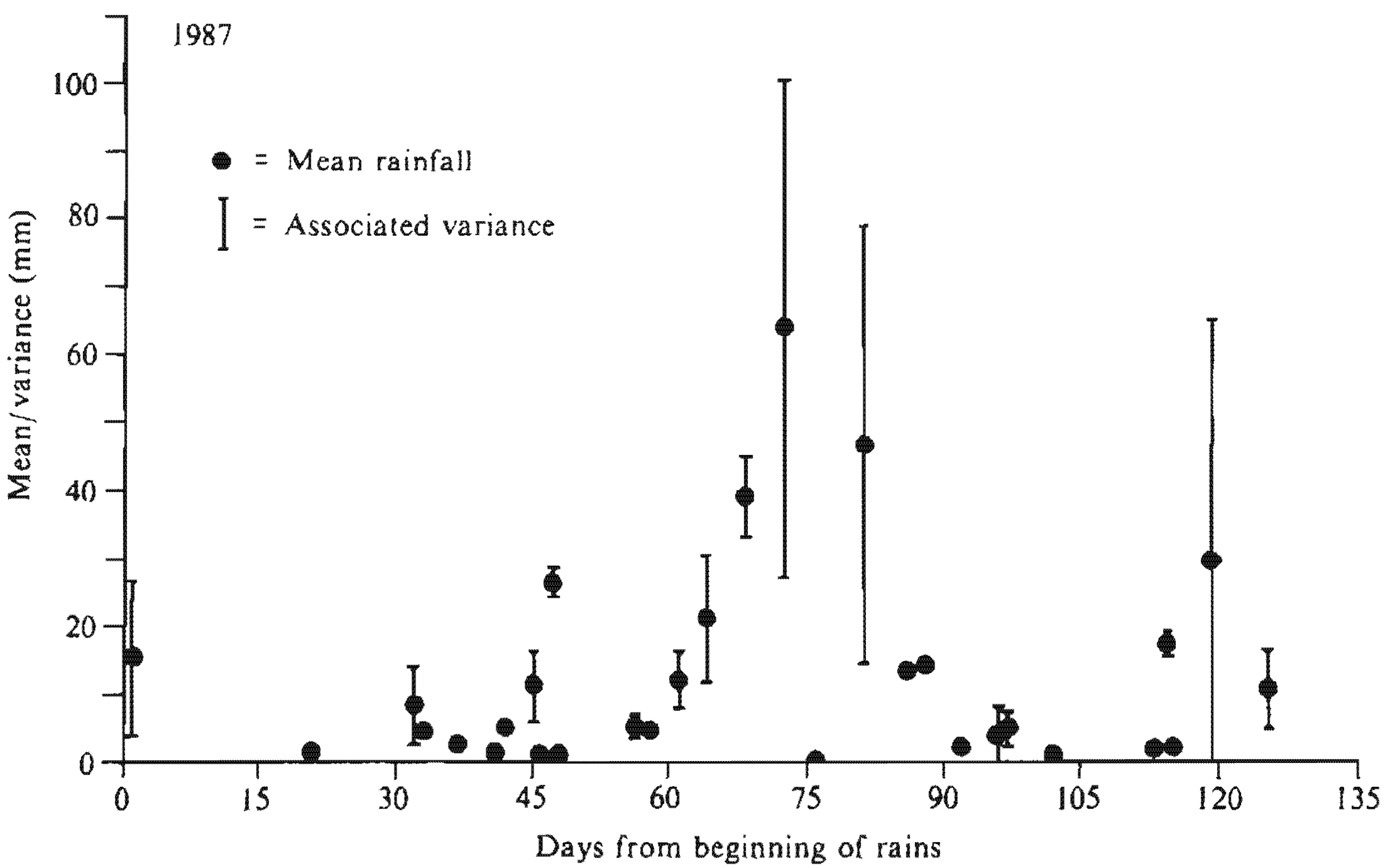


Figure 8. Mean rainfall and associated variance for different rain storms at ISC, Niger, rainy seasons 1986 and 1987.

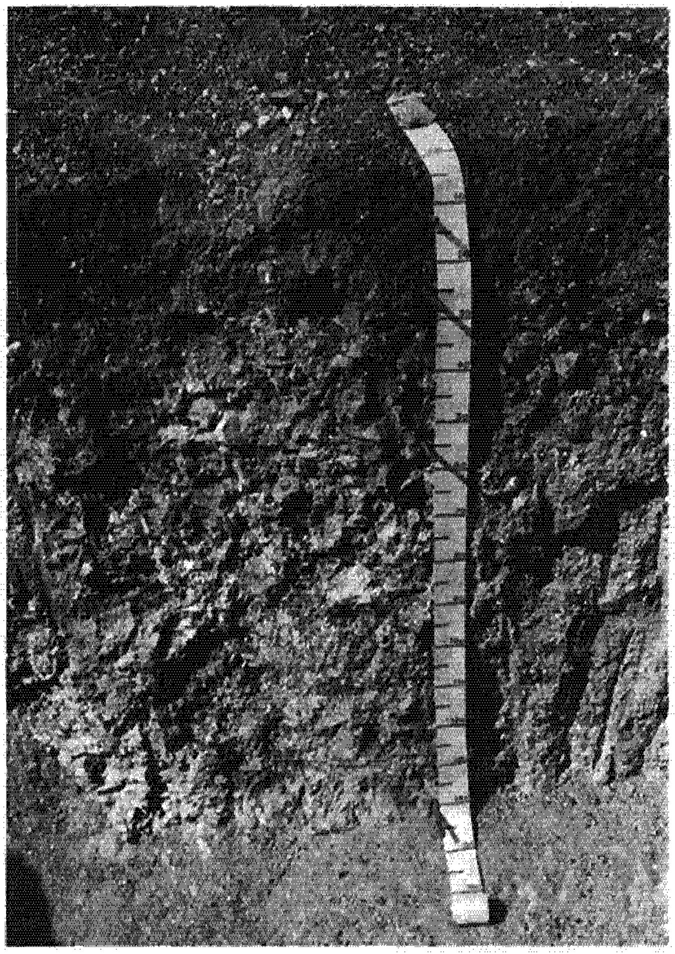


Figure 9. Profile of Vertic Inceptisol (Pit I) showing shallow soil depth, ICRISAT Center, 1987.

content of the profile is at a depth of 25-70 cm (Fig. 10). The field bulk density and the density and volume of stones were used to calculate the bulk density of the soil between the stones. The presence of stones reduces the bulk density and hence increases the porosity of the stone-free soil between the stones. The calculated porosity of 52-60% for the soil between the stones 25-70 cm deep suggests that it is a loosely packed, porous matrix.

Two hydraulic functions, the soil moisture characteristic and the unsaturated hydraulic conductivity are necessary to describe water movement in soils. We determined the unsaturated hydraulic conductivity function using the instantaneous profile method. Figure 11 shows that the unsaturated hydraulic conductivity at 15 cm, 30 cm, 75 cm, and 120 cm depths ranges from 10^{-5} to 10^{-8} ms^{-1}. For comparison, the unsaturated hydraulic conductivity of a coarse sandy soil is 10^{-4} to 10^{-5}. These results confirm our field observations over several years that Vertic Inceptisols have good internal drainage. The unsaturated hydraulic conductivities are greater in the subsoil than in the surface soil and therefore the zone of restriction to water movement is the topsoil.

Table 1. Sand, silt, and clay content and texture distribution in two Vertic Inceptisol profiles, ICRISAT Center, 1986.

	Profile I				Profile II			
Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture/class	Sand (%)	Silt (%)	Clay (%)	Texture/class
0- 10	41	19	40	Clay	38	22	40	Clay
10- 25	50	14	36	Sandy clay	42	16	42	Clay
25- 40	57	12	31	Sandy clay loam	33	19	48	Clay
40- 55	58	12	30	Sandy clay loam	44	27	29	Sandy clay loam
55- 70	58	13	29	Sandy clay loam	33	25	42	Clay
70- 85	64	10	26	Sandy clay loam	32	25	43	Clay
85-100	66	13	21	Sandy clay loam	32	26	42	Clay
100-115	70	12	18	Sandy loam	-[1]	-	-	-
115-130	73	13	14	Sandy loam	-	-	-	-
130-145	69	17	14	Sandy loam	-	-	-	-

1. - = samples not taken.

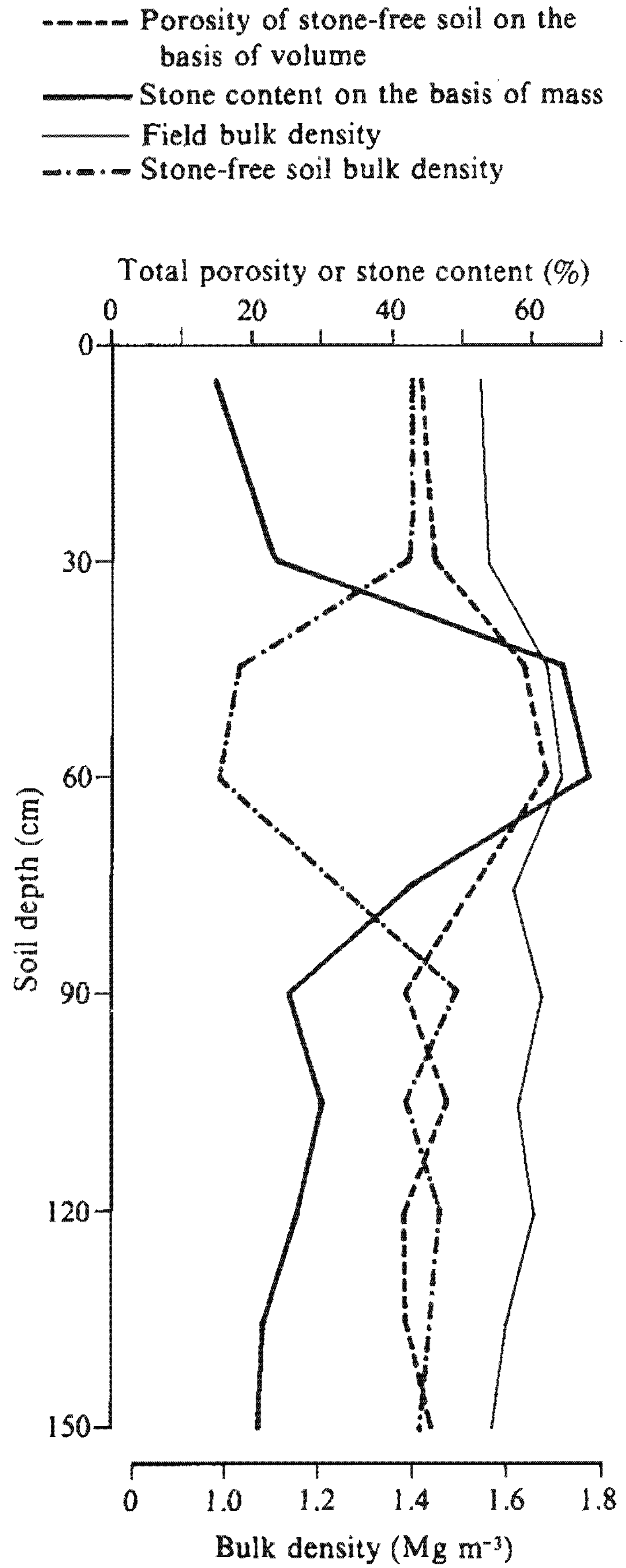
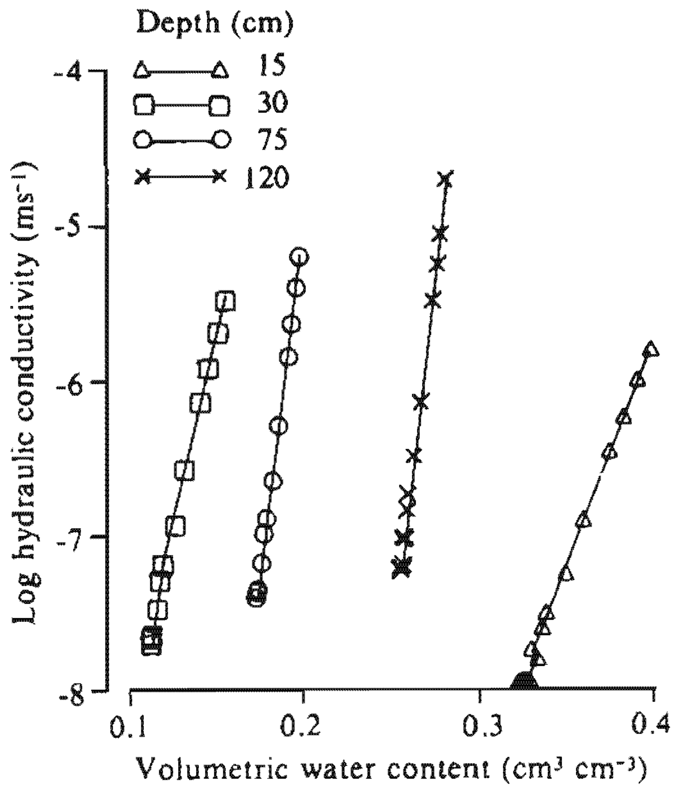


Figure 10. Porosity, stone content, field bulk density (wet profile) and stone-free soil bulk density in a Vertic Inceptisol, ICRISAT Center, 1986.



$\text{Log } K_{15} = 29.2\ WC_{15} - 17.5\quad r^2 = 0.997\quad rse = 0.048$

$\text{Log } K_{30} = 50.2\ WC_{30} - 13.3\quad r^2 = 0.996\quad rse = 0.049$

$\text{Log } K_{75} = 87.8\ WC_{75} - 22.7\quad r^2 = 0.997\quad rse = 0.050$

$\text{Log } K_{120} = 98.0\ WC_{120} - 32.3\quad r^2 = 0.915\quad rse = 0.274$

Figure 11. Logarithm (base 10) of unsaturated hydraulic conductivity, as a function of water content K(O) at four depths in a Vertic Inceptisol, ICRISAT Center, 1986.

Animal Power

Constraints to Animal Traction Adoption in West Africa

Limited adoption of animal traction technology in the West African SAT has long puzzled development officials and researchers. Because non-availability of labor for land preparation and weeding are often cited as major production constraints, animal traction should, in principle, save labor in these operations, making it attractive to limited-resource farmers. Nevertheless, traction systems are employed on less than 15% of the area sown in the region, despite public and private efforts to promote adoption spanning more than half a century. Although a number of farm-level studies have diagnosed low adoption through comparisons of manual and traction systems in particular locations, their results have generally been inconclusive and often contradictory. Most of these studies were time- and place-specific and could not support analyses of broad factors such as climatic, edaphic, and household characteristics that condition profitability and adoption.

In collaboration with a student from Stanford University, USA, working under the auspices of Purdue University and the Semi-Arid Food Grains Research and Development Organization (SAFGRAD) we analyzed production data for the 1981 and 1982 cropping seasons, collected from four ICRISAT study villages representing the Sahelian and Northern Guinean zones of Burkina Faso, and from two study villages representing the Sudanian zone monitored by the SAFGRAD program. We used comparative budget analyses, econometric techniques, and whole-farm modeling to measure the response of productivity to various animal-drawn plowing and weeding systems under differing rainfall and land-pressure situations.

We found that particular components of draft animal tillage systems can be profitably used but only under well-defined conditions that permit high utilization of animals and equipment. Our comparisons of use rates and factor productivity across agroclimatic zones showed that ox-drawn plows can substantially increase yields in farmers' fields, primarily in areas where the preparatory rainfall period is long enough to permit land preparation without significantly delaying sowing. Soils and crops that respond well to plowing—such as maize, groundnuts, and cotton—further favored adoption of mechanized plowing. These conditions were mostly present in the Northern Guinean zone and to a more limited extent in the Sudan Savanna, but were largely absent from the Sahelian zone.

Even under these favorable conditions, the magnitude of yield gains from plowing were generally too small to make adoption profitable without expansion of the cultivated area. Because labor supplies for weeding restrict farm size, labor saving through mechanized weeding was a necessary complement to plowing where surplus land was available for expansion. We measured the labor-saving effects of using animal traction for tillage by fitting farm-level production functions to estimated rates of technical substitution of manual for animal traction labor. In each village, the regressions indicated that the marginal rate of technical substitution between draft animal power and human labor exceeded five. This means that even with three persons required to guide a team of oxen–as is common in the region–human labor is substantially more productive when working with draft animals than when following traditional practices.

Our analyses also showed that the potential benefits of area expansion from such labor savings were not realized by most households immediately upon adoption, but required several years for farmers to develop the skills to use the equipment efficiently. In separate regressions, we estimated the effect of years after adoption (i.e., experience with the animal traction package) on hours of equipment use and on cultivated area. At all study sites we found highly significant positive relationships which suggested that maximum potential benefits were not realized until between 6 and 12 years after adoption. Before this point, early adopters who obtained animals and equipment on credit faced cash-flow imbalances associated with debt repayment which, when accompanied by unfavorable weather and poor harvests, often forced the most asset-poor adopters into financial loss and divestment.

Satisfying the climatic and edaphic conditions for a given equipment package did not assure high utilization for all types of production units, in part because animal traction systems display important economies of size. Opportunities to rent equipment are tightly constrained by the synchronous nature of tillage operations, with the result that the large investment costs of animals and equipment must be spread over a large cultivated area to achieve profitable levels of use.

We constructed a linear programming model of a small farm to trace the effects of farm size, restricted access to land, and limited utilization of draft animals on profitability. Because the analysis compared manual, donkey, and oxen systems, the model's technical coefficients were based on survey data from one Sudanian-zone study village, the only site where observations were adequate to specify all three systems.

Animal traction was introduced into the model as an integer variable, making it available for use while imposing the annual cash and labor costs of animal maintenance. The extent to which draft animals are used, was however determined endogenously at levels consistent with the seasonal availability of household labor.

In three separate runs we assumed discrete adoption of (1) the plow alone, (2) the weeder alone, and (3) the plow and weeder together. Ox-plow adoption alone was not profitable as the model predicted no area expansion and draft-team use for only 60 h during the growing season. In contrast, the model predicted that the adoption of weeding implements alone resulted in farm expansion by 4 ha, with the increased area going into high-value groundnuts. The draft animals were used for 300 h and gross farm income was predicted to increase by more than 30%.

With adoption of both plowing and weeding equipment, gross farm income increased by 60-75% over manual tillage. These gains were largely the result of expanding groundnut cultivation. Annual equipment use was predicted to increase to more than 400 h.

In order to simulate the effect of underutilization, we restricted usage to varying levels and the model's results traced a curve relating utilization to potential benefits. By parametrically altering the number of family workers, we also observed that, because of economies of size for animal traction systems, farm revenues were positively associated with family size. Smaller farms, in terms of cultivated area and household labor force are disadvantaged. The labor required to maintain the draft animals demands a larger share of their total farm labor supply, and the small area sown limits use of draft animals for both weeding and plowing to uneconomically low levels.

Finally, we computed the return on investment of animal traction by taking into account initial purchase and annual maintenance costs, and the time lags in achieving benefits. Based on the survey data, the risk of losses from the death of draft animals was also included. The model predicted that the initial investment in the full oxen package was not recouped until the 5th year when full benefits were also achieved. When we assumed benefit streams that reflect those observed in the surveys, the estimated internal rates of return were 26% for oxen traction and 35% for donkey traction, reflecting the lower investment costs and comparable benefits for donkey versus oxen traction. Using the income gains predicted by the model, but restricting utilization and learning to a level consistent with that observed in the field gave a rate of return of 25% for oxen traction and 41% for donkey traction. When the learning period was cut by half, or levels of utilization were increased by 50%, rates of return were more than 40% for oxen traction and more than 60% for donkey traction. Although these returns compare favorably with commercial banking rates, in regions where rural capital markets impose high risk premiums, informal interest rates can substantially exceed these levels. In particular, these rates of return may well be insufficient for near-subsistence farmers who use their few assets as insurance substitutes to cover production risks and family emergencies.

These results carry several implications for mechanization policy. Given the wide diversity of West Africa, equipment packages should be designed and targeted only to areas where rainfall patterns, soil types, and land availability permit high and profitable utilization of each relevant component. Targeting within those areas to larger and better-endowed farmers would make adoption even more successful. Poor targeting on both counts underlies many of the past failures. It is evident that such a policy would favor already privileged producers, those located in higher-potential zones, and those more favorably endowed with farm-level resources. But to promote adoption among farmers in marginal areas and among those who lack the complementary resources needed to fully utilize the equipment and animals, will only burden them with untenable investments. In terms of equity, the ultimate consequences of policies to promote adoption of traction systems among very poor farmers would almost certainly be even more deleterious than an approach that favors the better-endowed farmers.

Food

Income and Consumption under Drought Conditions in West Africa

Poor rainfall in 1984 severely reduced crop yields in the Sahelian and Sudanian zones of Burkina Faso. Our farm-level studies were able to monitor the strategies that drought-affected farmers employed to maintain household consumption. Our resources during 1984 and 1985 were complemented by a collaborative project with the International Food Policy Research Institute (IFPRI), which enabled us to include a 24-h recall survey of food consumption conducted at biweekly intervals. This study compared a village in the Sudanian zone with a village in the Sahelian zone. The villages were selected to be representative of each zone.

Because of the drought, household crop production from the 1984 harvest met only 29% of annual energy requirements in each zone, using the World Health Organization (WHO) Standard of 11.9 kilojoules (2850 Calories) per day for an adult male. Despite this production shortfall, the average Sahelian zone household succeeded in meeting consumption requirements and achieved a daily intake of more than 12.2 kilojoules per adult male equivalent. In contrast, actual consumption among Sudanian zone households was on average 18% below the WHO standard.

Our analysis of the distribution of consumption across households and seasons revealed several additional patterns that distinguished the Sahelian and Sudanian zone situations (Table 2). Firstly, consumption levels were not only substantially lower but were more equally distributed between households in the Sudanian zone village. When grouped by the value of assets (animal and cereal stocks immediately before the 1984 harvest) per adult equivalent, nearly all groups were short of food in most seasons. The Sahelian zone provides a striking contrast as inadequate consumption was confined mainly to asset-poor households.

Secondly, the degree of cross-seasonal variation of consumption [represented by the coefficient of variation (CV)] was also substantially greater in the Sudanian zone than in the Sahelian zone. Sahelian zone farmers were better able to avoid large seasonal reductions in consumption by supplementing crop stocks through cereal purchases.

Thirdly, the potential consequences of energy deficits in the Sudanian zone were magnified by the fact that seasonal consumption and activity

Table 2. Average daily energy (kilojoules) consumption per adult-equivalent, by season, for households stratified by wealth in the Sahelian and Sudanian zones of Burkina Faso, 1984/85.

Region	Household wealth status	Sep-Nov 1984	Dec-Feb 1985	Mar-Aug 1985	Jun-Aug 1985	Sep-Nov 1985	Total	CV (%)
Sahel	Poor	*10.9*[1]	*9.8*	*9.5*	*10.0*	*10.9*	*10.5*	25
	Middle	16.4	13.3	*11.7*	12.2	12.8	13.6	28
	Rich	13.3	12.2	*10.7*	12.0	13.6	12.5	22
Sudan	Poor	*8.5*	*9.2*	*9.4*	*9.0*	*12.0*	*9.7*	37
	Middle	*8.7*	*8.3*	*8.3*	*7.8*	*9.5*	*8.5*	36
	Rich	*11.0*	*10.7*	*11.7*	*10.0*	13.0	*11.3*	34

1. Energy levels in italics are below WHO standards of 11.9 kilojoules (2850 Calories) d^{-1} per adult-equivalent.

levels were contra-cyclical. Energy intake was least in each stratum during the cropping season, when demands for energy expenditure were greatest. This contrasted with the Sahelian zone where consumption was consistently lowest during the hot season when labor demands were least. These comparisons suggest that the 'hungry season' hypothesis frequently found in literature may hold true only in situations of extreme deprivation when households are unable to ration consumption during the cold and hot seasons in order to meet rainy-season food requirements.

Fourthly, when we examined food consumption by source, we found that the asset-poor households in both zones consumed a higher percentage of purchased food and thus were more vulnerable to market imperfections. Such vulnerability was particularly acute during the immediate preharvest period when 60-70% of the energy consumed in the poor strata was purchased. This means that because grain prices normally peak during this period, the effects of seasonal price swings on real income were felt particularly by poorer households.

To determine the factors that explained these significantly different consumption patterns in our two study zones, we analyzed the employment and income profiles of sample households. We found that Sahelian zone farmers pursued income strategies that were substantially more diverse across sectors and regions than Sudanian zone farmers. For example, the agricultural sector (crop production plus farm wage labor) accounted for only 23% of income in the Sahelian zone but fully 55% in the Sudanian zone. Major alternative sources of income included livestock trading and migration labor which, when combined, provided nearly two and a half times the absolute income for households in the Sahelian zone compared to those in the Sudanian zone (CFA 17100 vs. CFA 7100 per household). Since income from both sectors is largely determined by economic conditions in the urban centers of Burkina Faso as well as in the coastal countries of West Africa, earning levels from these sources have relatively low covariation with local crop incomes. As supplemental income sources, they therefore tend to stabilize aggregate household incomes from the effects of variation in local crop production.

Although we did not attempt to rigorously examine the structural determinants of these differences in income strategies, background evidence suggests several contributing factors. Pastoralism has long constituted a central element in production strategies and cultural identity of the ethnic groups who inhabit the Sahelian zone. This reflects not only low population pressure and thus greater access to noncultivated land available for forage production, but also a response to the higher production risks that characterize cropping in that zone. These risks create incentives to invest in movable assets, such as livestock, as a form of insurance. Their past investment of time to establish links with regular seasonal employment outside the region was probably also a response to traditionally high interannual variation in crop income.

In contrast, farming households in the higher, and less variable rainfall conditions of the Sudanian zone have traditionally emphasized crop production with somewhat smaller investments in livestock. Increasing land pressure and ecological decline in this zone have progressively eliminated much of the grazing potential, further reducing the importance of livestock. Land pressure has simultaneously reduced the capacity of farmers in the Sudanian zone to produce and stock large grain surpluses to buffer them from annual production shocks. Because these changes have occurred rapidly and relatively recently, migration and the establishment of links with external employment have not yet been adequately developed to replace the insurance role formerly played by animal and cereal stocks.

Our findings have several implications. Firstly, disaggregation not only by region, but also by household wealth and season is essential to determine the magnitude, location, and welfare consequences of crop failures. Overall averages can grossly underestimate the food problem depending upon the underlying distribution of consumption across households and seasons.

Secondly, to assess the relative need for relief assistance between regions, indirect measures such as yield or rainfall deficits may poorly reflect the degree of actual food insecurity where there are important differences in the structure of production and in farm-level purchasing power. Due to regional variation in income strategies, areas of greatest risk are not necessarily in the low-rainfall Sahelian zone as is commonly assumed. When comparable shortfalls in production occur, there may be greater risk of severe food shortages in the Sudanian zone.

Thirdly, following a poor harvest, dependence on the market and thus vulnerability to market imperfections was high across study sites and wealth strata. The particularly high market dependence of poorer households in both zones, and the fact that the purchased share of their total consumption was largest during the preharvest seasons when cereal prices normally peak, indicate that improvements in market infrastructure to reduce interregional and interseasonal price margins could have major benefits for both efficiency and equity. Where purchasing power is lacking, generation of seasonal employment, such as public works projects financed by food-for-work programs, may be a highly effective and complementary policy instrument.

Improving Technology

Land and Water Management

Primary Tillage on Alfisols

The inherent structural instability of Alfisols is not restricted to their immediate surface but extends to the lower layers. Consequently, their profiles are often prone to structural deterioration leading to hardening. Bulk density as high as 1.67 t m^{-3} has been recorded for the lower horizons. Compaction of the soil at depth affects water storage and crop root growth. Primary tillage aims, among other things, at loosening the compact layer but its effects are often transient. We therefore initiated an experiment to measure the long-term effects of different tillage practices and soil amendments primarily designed to alleviate soil physical constraints.

Eleven tillage treatments, described in Table 3, were first applied during the 1983 rainy season and the experiment continued till 1987. However, after 2 years, seven of the tillage treatments T_1, T_2, T_3, T_7, T_8, T_{10}, and T_{11} were stopped because of their poor performance. Sorghum (CSH 6) was grown in all years except in 1985 when, as a result of severe shoot fly attack on sorghum, the experiment was resown with castor (*Ricinus communis*). Fertilizer was applied at the rate of 60 kg N ha^{-1} and 13 kg P ha^{-1}. Bullocks were used for all tillage operations except for the 25-cm deep tillage, which was done with a 60-hp tractor.

Treatments that include the incorporation of either phosphogypsum or dry crop residue, (i.e., T_2, T_3 T_7, T_8, T_{10}, and T_{11}) significantly reduced the sorghum yield compared to their respective controls T_1, T_6, and T_9 (Table 3). Incorporation of dry crop residues resulted in severe nitrogen deficiency and other problems related to sowing and intercultivation. Where phosphogypsum was applied, the general crop growth was very poor and several nutritional deficiencies were observed in sorghum. Penetration resistance showed no significant improvement following the application of phosphogypsum.

There was significant ($P < 0.01$) difference between grain yields on the traditionally tilled (T_4, 10-cm deep) and deep-plowed (T_9, 25-cm deep) treatments (Table 3). Compared with traditional plowing, deep plowing increased average sorghum yield by 28%, and this increase in sorghum yields was observed in both high-(1983) and low-rainfall years (1984 and 1986). Penetration resistance was lowest in the deep-plowed plots throughout the crop-growing season.

In the first 4 years there was no significant ($P < 0.5$) difference between grain yields with inverting tillage (T_6, 15-cm deep moldboard plowing) and noninverting tillage (T_5 15-cm deep). A significant increase in grain yield was observed only in the 5th year of the experiment implying that the beneficial effect of noninverting tillage may only become apparent after several years.

In 1986, photographs of roots were taken 75 days after emergence (DAE) from the tillage

Table 3. Effect of different tillage and amendment treatments on sorghum grain yield, runoff, and soil loss, Alfisol, ICRISAT Center, 1983–87.

Treatment		Sorghum grain yield[1] ($t\ ha^{-1}$) Average of 2 years	Average of 4 years	Runoff[2] (mm)	Soil loss[2] ($t\ ha^{-1}$)
BBF Configuration					
T_1	Split-strip plowing	1.88		-[3]	-
T_2	15-cm deep primary tillage + application of phosphogypsum at 10 $t\ ha^{-1}$	1.76		-	-
T_3	15-cm deep primary tillage + incorporation of crop residue at 5 $t\ ha^{-1}$ [4]	1.02		-	-
Flat Configuration					
T_4	10-cm deep traditional plowing		2.52	128	1.66
T_5	15-cm noninverting primary tillage		2.83	102	1.62
T_6	15-cm deep moldboard plowing		2.76	106	1.70
T_7	15-cm deep moldboard plowing + application of phosphogypsum at 10 $t\ ha^{-1}$	1.67		-	-
T_8	15-cm deep moldboard plowing + incorporation of crop residue[4] at 5 $t\ ha^{-1}$	1.44		-	-
T_9	25-cm deep moldboard plowing		3.22	85	1.41
T_{10}	25-cm deep moldboard plowing + application of phosphogypsum	2.14		-	-
T_{11}	25-cm deep moldboard plowing + incorporation of crop residue[4] at 5 $t\ ha^{-1}$	1.65		-	-
	SE	±0.13	±0.07	±4.9	±0.279

1. Grain yield values of treatments T_4, T_5, T_6, and T_9 are averages of 4 years (1983, 1984, 1986, and 1987) and those of treatment nos. T_1, T_2, T_3, T_7, T_8, T_{10}, and T_{11} are averages of 2 years (1983 and 1984).
2. Average values of 1986 and 1987.
3. - = Data not collected.
4. Chopped dry rice straw incorporated in 1983, chopped dry sorghum stalks incorporated in 1984.

treatments (Fig. 12). Root penetration as well as total root mass increased with depth of tillage.

Significant differences in runoff were observed between T_4, T_6, and T_9 (Table 3). Runoff was highest in the traditional plowing treatment (T_4) but was significantly reduced by both types of 15-cm tillage treatments (T_5 and T_6) and further reduced significantly by plowing to 25 cm (T_9) (Table 3). Tillage treatments had no significant effect on soil loss.

Soil and Water Conservation on Vertic and Inceptisols

Shallow Vertic soils cover extensive areas in the SAT. They are often erosion-prone and provide limited amounts of water to plants. The critical importance of the topsoil of such soils is illustrated by a soil profile with crop roots (Fig. 13). Deep-rooted crops like castor (*Ricinus communis*) and sunflower (*Helianthus annuus*) and

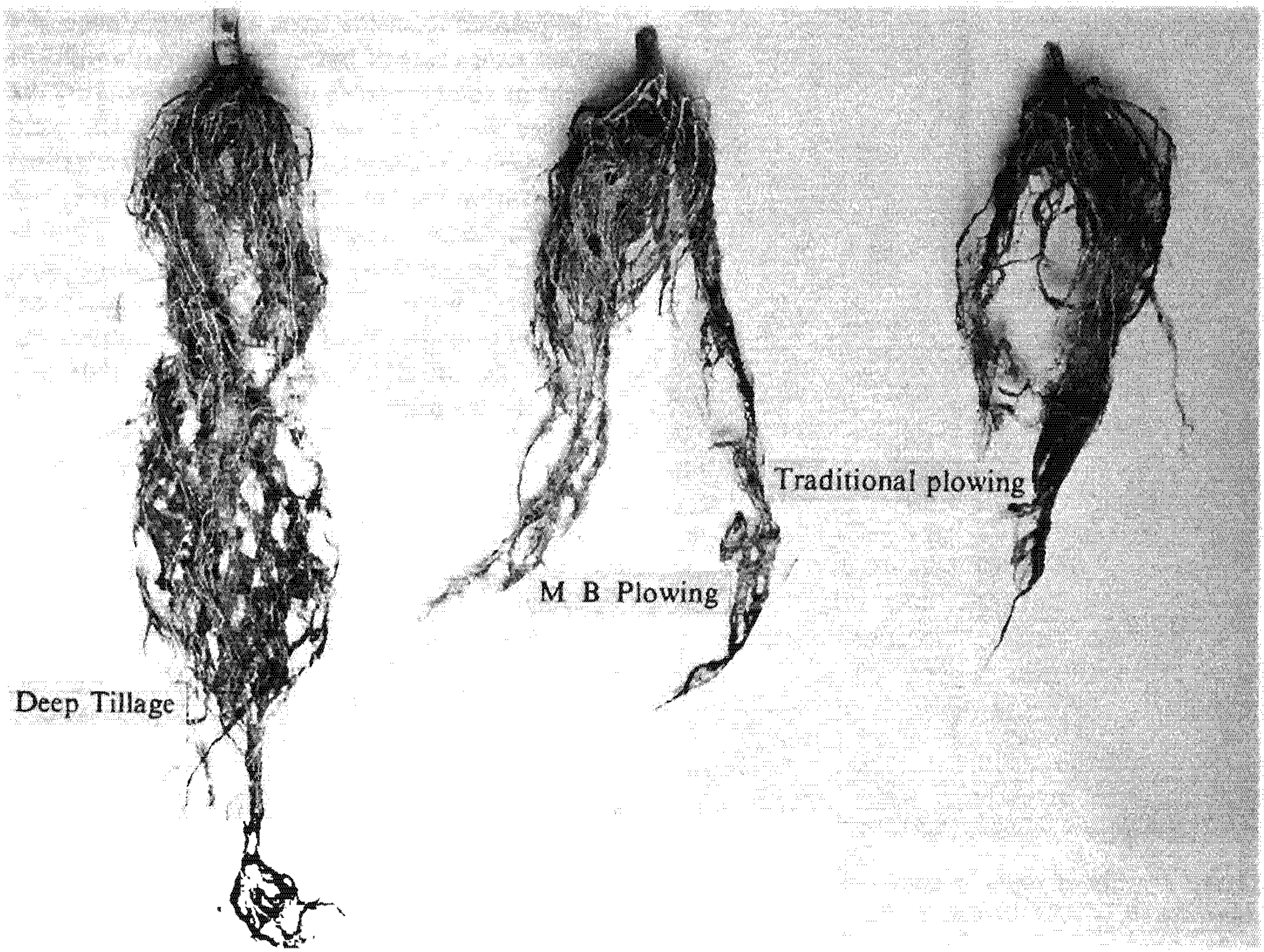


Figure 12. Roots of sorghum plants grown on an Alfisol under three tillage systems (left to right: deep tillage, moldboard plowing, and traditional plowing) sampled 75 days after emergence, ICRISAT Center, 1986.

trees, established in the topsoil, can extract moisture and (some) nutrients from the substrata. But if the top 20-30 cm of soil is eroded, crop establishment and early growth in the gravelly and calcareous substrata is difficult.

In 1985, we applied the following treatments on a contour layout with annual cropping in 0.2-ha plots;

T_1. Trenching with leucaena (*Leucaena leucocephala*). Trenches (0.3-m cross-sectional area) with bunds (Fig. 14) at 20-m horizontal intervals and leucaena at 2-m spacing.

T_2. Trenching with acacia (*Acacia nilotica* var *cupressiformis*). As for T_1, but with acacia at 2-m spacing.

T_3. Leucaena hedgerows. Hedges (each of four rows, 50-cm apart) with a 20-m horizontal interval.

T_4. Flat-planted leucaena rows. 20-m tree-to-tree spacing, 20-m row-to-row horizontal interval.

T_5. Control. Cultivation of annual crops on contours.

The trenches could store 15 mm runoff water. Castor (cv Aruna) was grown as the annual crop in 1986, and sunflower (cv Morden) in 1987.

In 1986/87, hedgerows and flat-planted leucaena trees caused a small reduction in the yield of the first few rows of castor but trenching with acacia or leucaena had a generally positive effect on castor yield (Fig 15). In 1987 (rainy season), sunflower yields were substantially reduced by

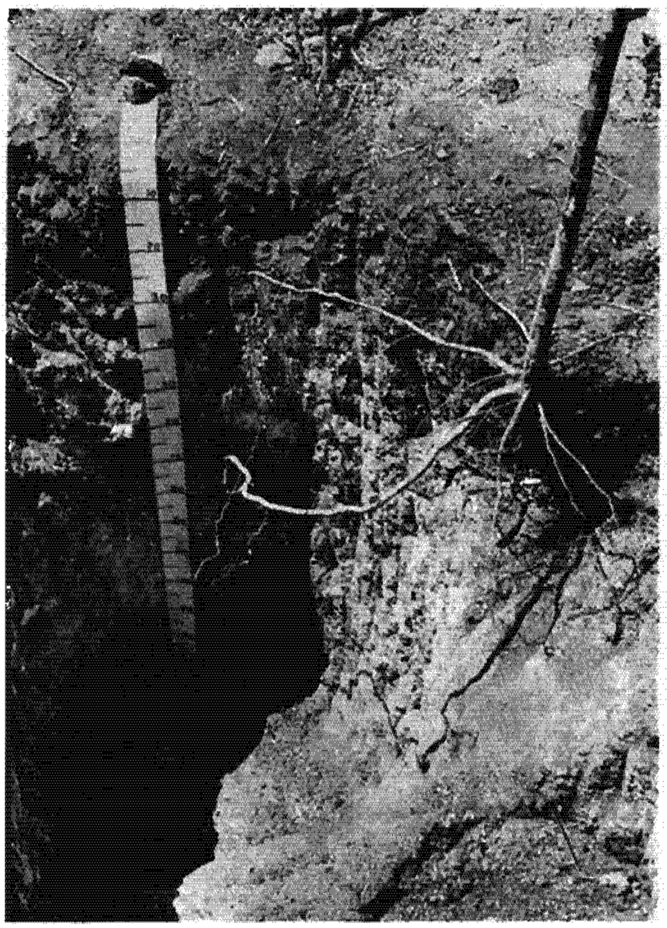


Figure 13. Castor roots in calcareous and gravelly substrata, ICRISAT Center, 1987.

flat-planted leucaena trees up to a distance of 4 m on either side of trees (Fig 16). Although the yield of the two rows of sunflower nearest the hedges was also drastically reduced, the yield elsewhere was almost uniform. Sunflower grown in plots that had trenches alongside trees (T_1 and T_2) had almost uniform yields (Fig 16). Trenching and hedgerows were effective in controlling runoff and erosion (Table 4). However, comparisons of total productivity and economic evaluation of the different treatments can be made only after the trees are harvested.

Table 4. Effect of treatments on runoff and soil erosion from a Vertic Inceptisol, ICRISAT Center, mean of 1986 and 1987.

Treatment	Seasonal rainfall (mm)	Runoff (mm)	Soil erosion (t ha^{-1})
Trenching	550	3	0
Hedgerows	550	21	0.8
Control	550	64	4.7

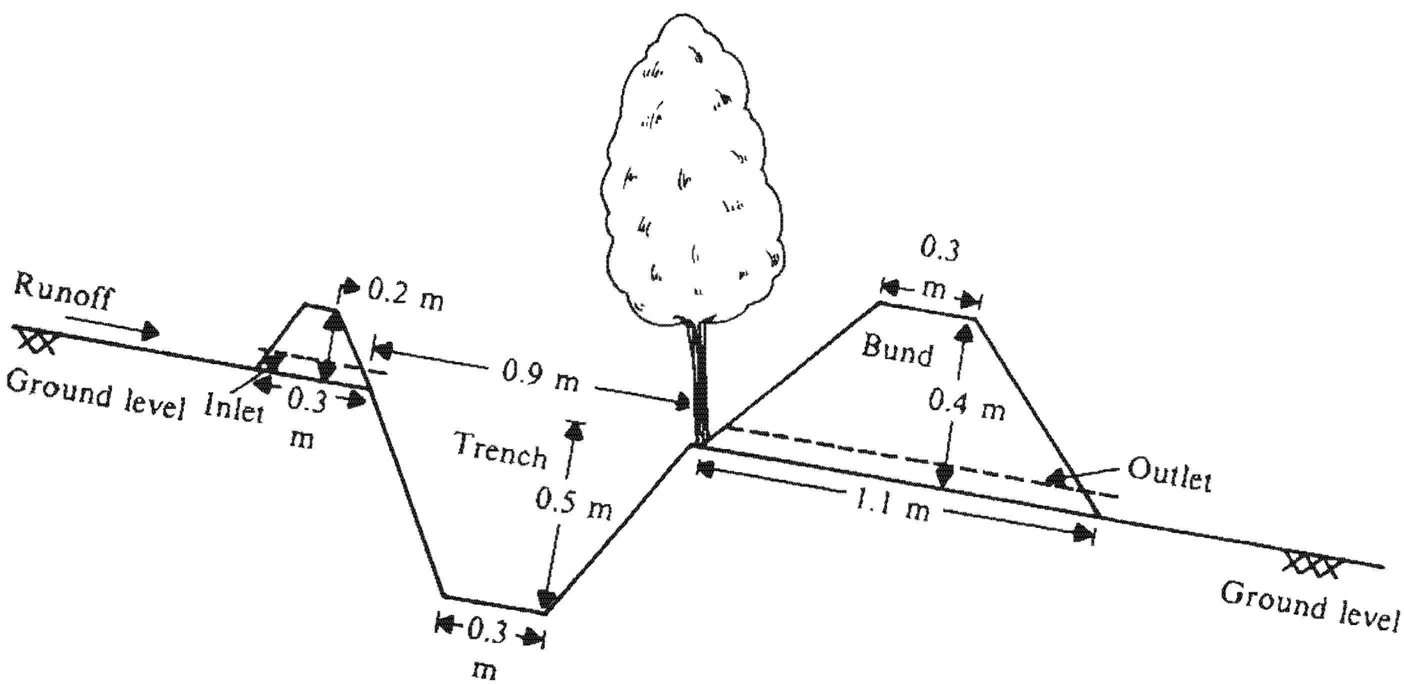


Figure 14. Diagrammatic cross-section showing the scale of components in the trench-bund system and the position of trees (slope exaggerated).

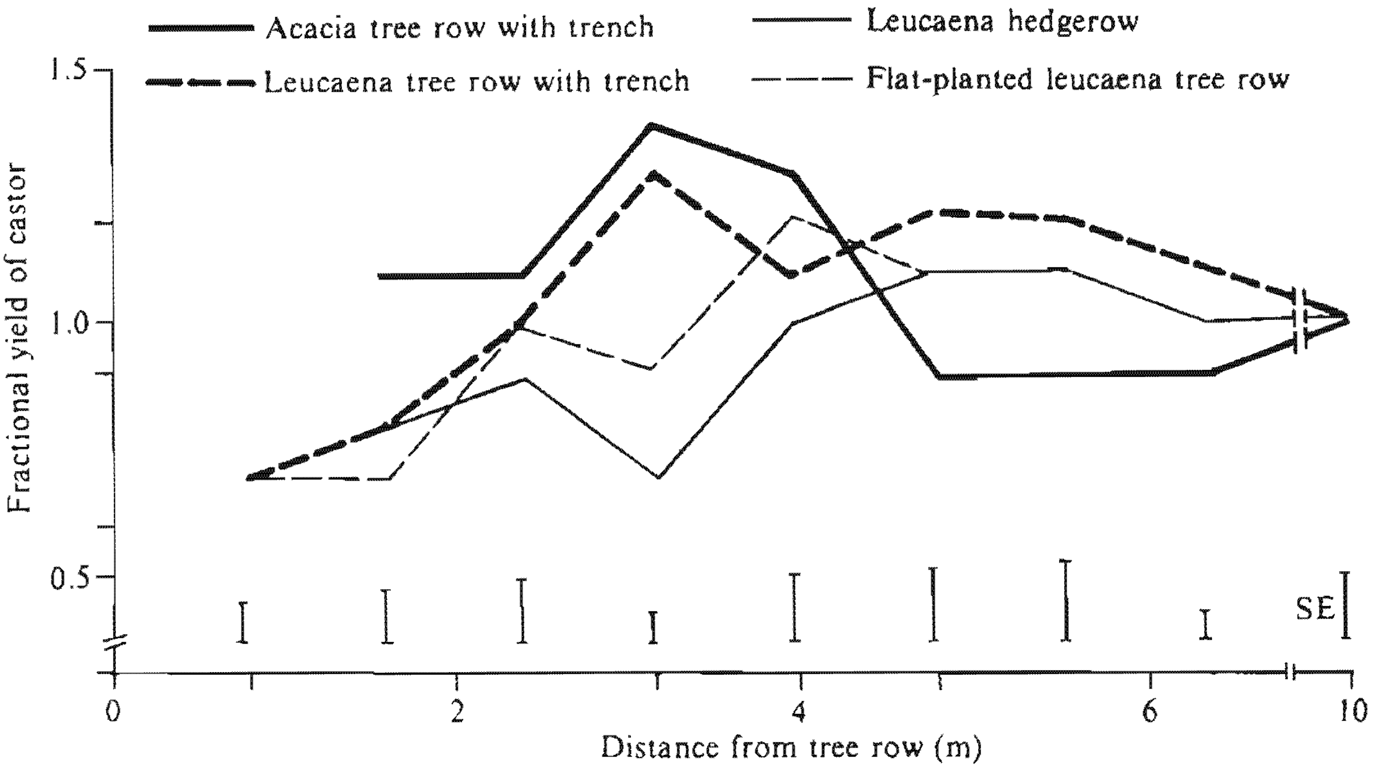


Figure 15. Yield of castor as fraction of yield midway between rows of trees, Vertic Inceptisol, ICRISAT Center, 1986/87.

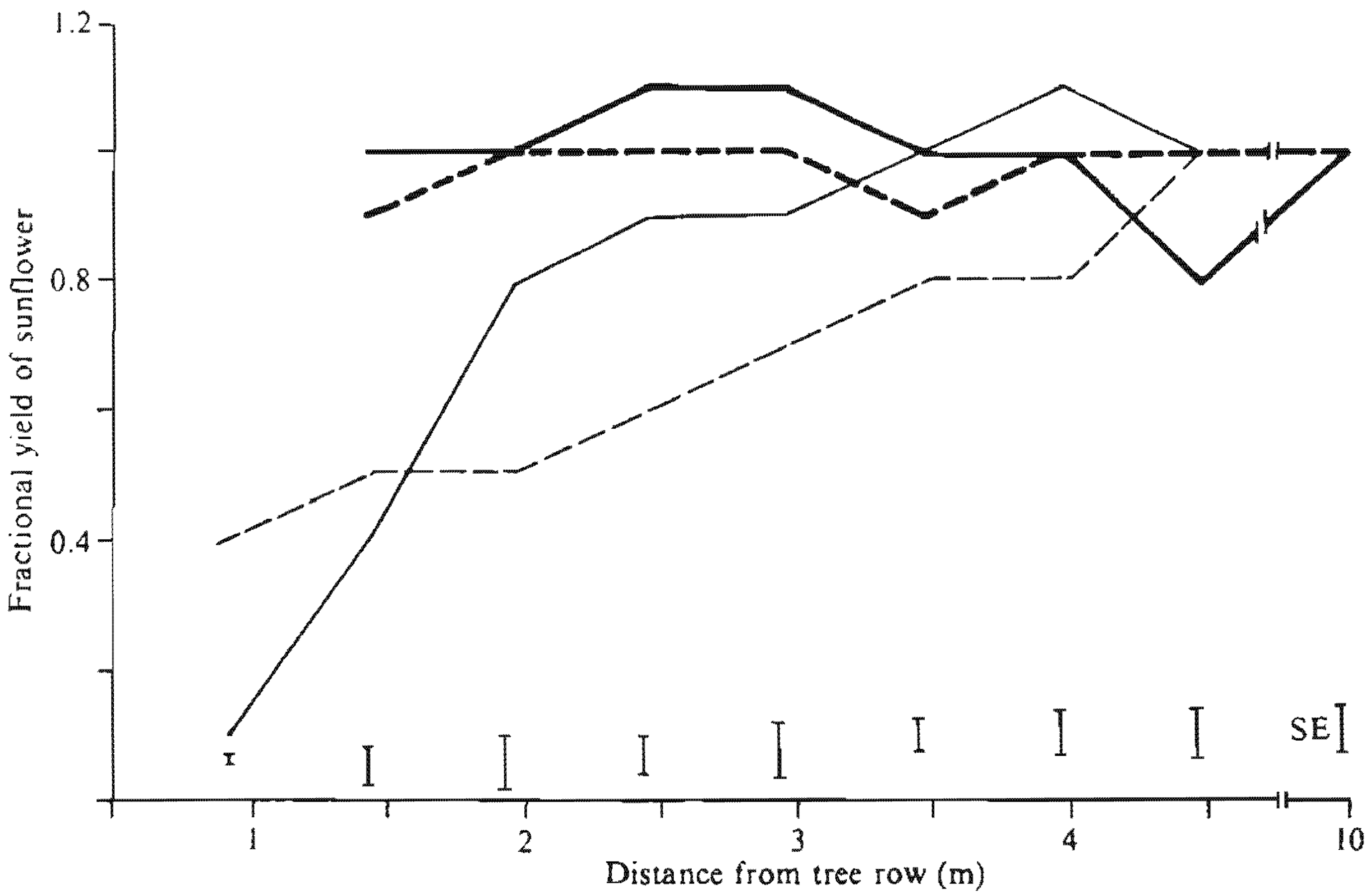


Figure 16. Yield of sunflower as a fraction of yield midway between rows of trees, Vertic Inceptisol, ICRISAT Center, rainy season 1987.

Limited Irrigation of Dryland Crops (LID)

Research was initiated in 1984 (Annual Report 1984 pp 268-270) on the evaluation of the LID concept. In the LID system, developed by Texas A&M University to optimize use of rain and limited amounts of irrigation water, fields are divided into three sections. The uppermost section is conventionally irrigated; the middle section is partially irrigated by excess water from the uppermost section; and the lowest section is managed as dryland, but receives normal rainfall runoff, and sometimes irrigation runoff from the upper sections. Different plant populations and fertilizer rates can be used on each slope section.

In the 1985 rainy season, we grew sorghum (CSH 6) on an Alfisol using a ridge and furrow system. Each main plot consisted of three 20-m long subplots in sequence down the slope. Fertilizer rates and plant populations were varied in each slope section as shown in Table 5. Total rainfall between sowing (late June) and harvest was 408 mm. Rainfall during August was 50 mm, and 27 mm fell in the first fortnight of September. Five applications of water totalling 250 mm were applied to the fully irrigated treatment and to the upper section of the LID and LID alternate furrows (LID-AF) treatments. Total runoff (as a fraction of seasonal rainfall plus applied water) was 30.7% for the fully irrigated treatment compared with 17.7%. for the LID treatment and 12.5% for the LID-AF treatment. Runoff from dryland with tied ridges was 3.3% compared to 12.0% from the dryland treatment (control).

Sorghum grain yield was significantly higher for the fully irrigated treatment compared with all other treatments (Table 5). The poor grain yield on the middle and lower sections of the fully irrigated, low fertility, low plant population (LFP) treatment was due to stem borer damage and slight waterlogging. The water application efficiency (WAE) [defined as treatment yield minus control yield per unit depth of irrigation water, (kg mm^{-1})], was highest for the LID treatment [12.1 kg mm^{-1} (calculated for the whole area)] followed by LID-AF, fully irrigated, high fertility high population (HFP), and fully irrigated (LFP) treatments.

The LID concept was further evaluated in

Table 5. Effect of five water-application treatments on grain yield (t ha^{-1}) of sorghum (CSH 6), Alfisol, ICRISAT Center, rainy season 1985.

Slope section (distance from top, m)	Dryland		Dryland, tied ridges		Full irrigation		LID[3] each furrow	LID alternate furrow
	LFP[1]	HFP[2]	LFP	HFP	LFP	HFP		
Upper (0-20)	1.06	1.60	1.31	1.81	2.16	3.72	3.41 (HFP)	3.05 (HFP)
Middle (20-40)	1.62	1.78	1.84	2.01	1.84	3.52	2.60 (LFP)	2.25 (LFP)
Lower (40-60)	2.30	2.28	2.42	2.36	1.75	2.95	2.00 (LFP)	2.07 (LFP)
SE			±0.17				±0.12[4]	
Mean	1.66	1.89	1.86	2.06	1.92	3.39	2.67	2.46
WAE[5] (t m^{-1})					1.04	6.92	12.17	9.40

1. LFP = Low fertility, low plant population; 58 kg N ha^{-1}, 20 kg P ha^{-1}, 9 plants m^{-2}.
2. HFP = High fertility, high plant population; 138 kg N ha^{-1}, 20 kg P ha^{-1}, 18 plants m^{-2}.
3. LID = Limited irrigation-dryland.
4. Refers to LID treatments.
5. Water application efficiency (WAE) = $\frac{\text{Treatment yield} - \text{Control yield (kg)}}{\text{Depth of irrigation (mm)}}$

experiments with sorghum (CSH 6) sown on an Alfisol in late June 1986 and early July 1987.

Rainfall between sowing and harvest of the sorghum was 257 mm in 1986 and 375 mm in 1987. In both years, September was the driest month, with only 27 mm in 1986 and 63 mm in 1987. To the fully irrigated treatment and to the upper section of the LID treatment, we applied four irrigations totaling 120 mm in 1986 and five (220 mm) in 1987. A supplementary irrigation treatment received one irrigation of 30 mm in 1986 and two of 50 mm in 1987.

In both years, total runoff water from the fully irrigated treatment was 29% of the seasonal irrigation plus rain compared with 14% in 1986 and 10% in 1987 for the LID treatment. The total runoff from supplementary irrigated and from dryland treatments was 15% of the seasonal rainfall.

The highest yields in 1986 were from HFP under full irrigation (Table 6). Under full irrigation with HFP, WAE was 7.5 kg mm^{-1} compared with 1.88 kg mm^{-1} for LFP. One supplementary irrigation (30 mm) gave a WAE of 7.5 kg mm^{-1}. The LID treatment received 40 mm (on a whole-area basis) and gave the highest WAE (9.19 kg mm^{-1}).

The sorghum yields in 1987 were generally poor, possibly because this was the 4th consecutive crop of sorghum. The grain yield for the dryland treatment (control) was 1.2 t ha^{-1} compared with 1.6 t-ha^{-1} for fully irrigated LFP, 2.2 t ha^{-1} for fully irrigated HFP, 1.34 t ha^{-1} for the supplementary irrigated treatment, and 1.6 t ha^{-1} for the LID treatment. The LID treatment gave the highest WAE—7.5 kg mm^{-1} compared with 2.5 kg mm^{-1} for fully irrigated LFP, 6.25 kg mm^{-1} for fully irrigated HEP, and 2.8 kg mm^{-1} for the supplementary irrigated treatment.

Observations during these three seasons with relatively low rainfall show that the LID concept can provide a strategy for the effective use (high WAE) of a small amount of water in areas of unpredictable rainfall. The LID concept could be further improved by the use of tied ridges to trap irrigation or rainfall runoff. Plant population density and fertility should be matched to the expected moisture regime in each section.

Agronomy

Crop Establishment

Plant establishment problems on the sandy soils at ISC are usually caused by a combination of soil, weather, and environmental factors. Soil

Table 6. Effect of four water application treatments on sorghum (CSH 6) grain yield (t ha^{-1}), Alfisol, ICRISAT Center, rainy season 1986.

Slope section	Dryland, LFP[1]	Supplemental irrigation, LFP	Full irrigation LID[3]	Full irrigation LFP	Full irrigation HFP[2]
Upper	2.20	2.48	3.09 (HFP)	2.63	3.40
Middle	2.11	2.40	2.71 (LFP)	2.38	3.2
Lower	2.14	2.20	2.11 (LFP)	2.35	3.46
WAE[4]		5.25	9.19	1.88	7.5
SE[5]		±0.013		±0.09	
Mean	2.15	2.36	2.64	2.45	3.35

1–4. (see Table 5).
5. Second SE refers to full irrigation treatments.

bulk densities range from 1.40-1.70 Mg m^{-3} with porosities of 43-36%. The higher densities may hamper root development. Strong easterly winds usually precede rainstorms, causing wind erosion on unprotected fields; seedlings are also sandblasted and buried. In 1984, we started to study the effects of seed size, sowing depth, sowing method, presowing cultivation, and fertilizer application on the establishment and yield of pearl millet.

Seed Size and Sowing Depth

Using a factorial design, we studied the effects of sowing depth and seed size on the establishment of two improved pearl millet cultivars, 3/4 HK, and CIVT, and Sadoré Local, the local cultivar at ISC. Sowing depths were 1 cm, 3 cm, 5 cm, and 7 cm. Seeds were graded into 'small', 'medium', and 'large' categories, and sown in hills at 40 seeds $hill^{-1}$.

We evaluated crop establishment by percentage emergence, seedling dry matter mass, and the number of secondary roots per seedling. Crop establishment was generally best where seeds were sown between 3 and 5 cm deep. Seed size was also important. Of the seeds sown, field emergence was 40% from small seeds, 51% from medium seeds, and 54% from large seeds (SE= ±1.2). Shoot dry mass (average of 5 hills) measured 24 DAS was 1.8 g for small, 3.2 g for medium, and 5.1 g for large seeds (SE= ±0.21). Maximum soil temperatures were 47°C at 1 cm, 43.8°C at 3 cm, 42.3°C at 5 cm, and 41°C when measured 7 cm deep 3 DAS on a typical clear day after rainfall. The maximum soil temperature at 1 cm was close to the limit at which pearl millet ceases to germinate.

Sowing Method

In 1984 we compared two sowing methods: sowing in hills (comparable to the traditional method) and drilling seeds. We sowed pearl millet (cv Sadoré Local) using a precision planter capable of sowing into hills or continuous row drilling, thus ensuring consistent seed placement and rate for both methods tested.

Initial populations were higher in rows than in hills, but seedling survival and growth was better in hills. Between 3 and 13 DAS, average pearl millet seedling stands in rows dropped from 20 to 13 m^{-2}. The average total number of seedlings in hills was 11, with an average of 1 hill m^{-2}. Maximum seedling heights were significantly greater in hills (16.9 cm) than in rows (10.2 cm SE= ±0.86), probably because the mutual protection provided by the cluster of seedlings favored the innermost seedlings. Yields were low because of an exceptionally poor rainy season—the average crop evapotranspiration amounted to only 190 mm. However, grain yield from hills was higher—0.34 t ha^{-1}—whereas with rows it was 0.27 t ha^{-1}(SE= ±0.03). Fertilizer increased yield from 0.25 t ha^{-1} to 0.36 t ha^{-1}) (SE= ±0.03).

Presowing Tillage and Fertilizer Use

We evaluated four presowing tillage treatments at ISC; plowing to a depth of 15 cm, ridging (ridges formed without any pre-tillage, spacing 75 cm, height 15 cm), sandfighting (small depressions and clods), and zero-tilled (control). Treatments were applied after the first rain. Plowing and ridging with the soil at field capacity (8%-10% water by volume) reduced the mean bulk density of the surface (0-15 cm) to 1.22 Mg m^{-3}, increasing porosity to 54%. Recompaction due to raindrop impact was slow, and penetrometer measurements confirmed the persistence of reduced soil strength. Two months after plowing, soil resistance was still 50% lower than in zero-tilled soil. Each year we applied 7.5 kg P ha^{-1} before cultivation and 40 kg N ha^{-1} in a split application 2-3 and 4-6 weeks after sowing. Rows were spaced at 75 cm, perpendicular to the prevailing direction of erosive winds. Two improved pearl millet cultivars 3/4 HK and CIVT were compared to Sadoré Local in the experiment, and we sowed 1.33 hills m^{-2}. Tillage and fertilizer treatments were constant throughout the experiment.

The average crop evapotranspiration for the local pearl millet was 320 mm in 1985 and 330 mm in 1986. Erosive winds killed some seedlings. Survival rates between sowing date and harvest were similar for presowing tillage treatments and use of fertilizer (Table 7). Plowing, ridging, and the use of fertilizers increased crop establishment and yield in both years compared to sand-fighting and zero-tilled treatments.

Our results show the usefulness of presowing tillage in establishing a better crop on fields susceptible to wind erosion. Although plowing allowed more plants to survive compared with the other treatments, ridging seems the most suitable method as it required considerably less energy and time. In addition, it helps reduce wind erosion because it increases soil roughness. Our results also show that the application of fertilizers can play an important role in improving crop establishment.

Table 7. Effect of presowing tillage treatment, pearl millet cultivar, and fertilizer application on hills surviving at harvest as percentage of sown hills, ISC, rainy seasons 1985 and 1986.

	Hill survival (%)[1]	
Treatment	1985	1986
Tillage		
Plowing	77	79
Ridging	63	61
Sandfighting	47	47
Zero tillage	46	59
SE	±4	±3
Cultivar		
3/4 HK	55	53
CIVT	69	64
Sadoré Local	51	67
SE	±2	±3
Fertilizer application[2]		
– Fertilizer	43	49
+ Fertilizer	74	74
SE	±1.9	±2.2
CV (%)	33	36

1. Split-split-plot design replicated 4 times, plot size 30 m^2.
2. 7.5 kg P ha^{-1} at sowing and 20 kg N ha^{-1} at 14-21 and 21-28 DAS.

Pearl Millet Genotypes for Intercropping

We have evaluated pearl millet cultivars that could be sown late in the rainy season as a contingent intercrop. Cultivars with high tillering ability were chosen as this has been identified as an important trait in intercropping (ICRISAT Annual Report 1981, p.264-265). Pearl millet/groundnut intercrops were sown in a 1:2 row arrangement on an Alfisol at ICRISAT Center on 26 August 1986 and on 15 July in 1987 (Table 8). The pearl millet genotypes were ICMH 423 and ICMV 83117 with BK 560 as a control; the groundnut was ICGS E21, a 90-day cultivar. In 1987, ICMH 423 was replaced by ICMH 451, (MH 179), and groundnut JL 24 was included as a control for ICGS E21.

In 1987, the pearl millet test cultivars (ICMH 451 and ICMV 83117) in the intercrop gave lower grain yields but higher biomass than BK 560. In contrast to 1986, sole crops of the test cultivars gave lower grain yields and biomass than BK 560. The observations on relative sole crop and intercrop yields are at variance with previous indications that intercrop yield could be predicted from sole crop yield (ICRISAT Annual Report 1981, p.266). However, these results are consistent with the findings in earlier wet years (ICRISAT Annual Report 1979/80, p.206) that good rainfall distribution (as occurred in 1987) tends to reduce differences in yield between pearl millet cultivars. Biomass production in 1987 was 2.0-2.5 t ha^{-1} higher than in 1986 and Land Equivalent Ratios (LER) of test cultivars were above unity and similar to values reported in seasons with normal rainfall (LER = 1.2-1.3). The average radiation for July-August 1987 was unusually low (about 15 MJ m^{-2} d^{-1} compared with 18 MJ m^{-2} d^{-1} in 1986), which partly explains the generally poorer growth of the test cultivars relative to BK 560. The pod

Table 8. Grain yield and total biomass ($t\ ha^{-1}$) of four pearl millet cultivars and a groundnut cultivar in sole and intercrops grown on an Alfisol, ICRISAT Center, rainy seasons 1986 and 1987.

Genotype	Sole crop	Intercrop: Pearl millet	Intercrop: Groundnut
	Grain yield 1986 ($t\ ha^{-1}$)		
Pearl millet			
ICMH 423	1.80	0.94	0.22
ICMV 83117	1.70	1.03	0.25
Control			
BK 560	1.70	0.80	0.27
SE	±0.14	±0.20	±0.02
Groundnut			
ICGS E21	0.60		
SE	±0.14		
	Biomass ($t\ ha^{-1}$)		
Pearl millet			
ICMH 423	5.01	2.25	0.93
ICMV 83117	5.47	3.44	0.83
Control			
BK 560	4.22	1.57	1.00
SE	±0.27	±0.70	±0.08
Groundnut			
ICGS E21	1.81		
SE	±0.06		
	Grain yield 1987 ($t\ ha^{-1}$)		
Pearl millet			
ICMH 451 (MH 179)	2.31	1.64	0.43
ICMV 83117	1.86	1.46	0.43
Control			
BK 560	2.60	1.81	0.49
SE	±0.49	±0.18	±0.04
Groundnut			
ICGS E21	1.15		
Control			
JL 24	1.15		
SE	±0.49		
	Biomass ($t\ ha^{-1}$)		
Pearl millet			
ICMH 451 (MH 179)	7.05	4.49	1.82
ICMV 83117	7.62	4.24	1.75
Control			
BK 560	7.78	3.90	1.87
SE	±0.47	±0.25	±0.17
Groundnut			
ICGS E21	3.85		
Control			
JL 24	3.85		
SE	±0.47		

yields and biomass of both groundnut cultivars were similar and unaffected by the change in pearl millet cultivars. In these trials, groundnut ICGS E21 had no yield advantage over the control JL 24.

Cowpea-based Cropping Systems at ISC

Cowpea is an important food legume in semi-arid regions West Africa where the bulk of the world crop is produced. The greatest constraint to production is insect attack at all growth stages. Varieties are largely photoperiod-sensitive and their growing cycle is longer than the average length of the rainy season, particularly in the Sahel. They are mostly grown at very low densities in association with cereals; insecticides and fertilizers are seldom used. As a result, cowpea yields are extremely low and average only 0.2 $t\ ha^{-1}$.

The International Institute of Tropical Agriculture (IITA) has developed short-duration cultivars requiring 55-75 days to mature, with multiple disease resistance and tolerance to important insect pests. In cooperation with IITA, we have tested and selected varieties suited to various cropping systems with low inputs. We also aim to improve management practices to further enhance varietal performance and evolve improved pearl millet-based cropping systems.

Improved Cultivars

Since 1984, we have evaluated a large number of breeding lines and local varieties grown as sole crops or intercropped with pearl millet. Short-duration cultivars can be relatively high-yielding when grown as a sole crop and protected from insect pests. Grain yields of up to 1.6 $t\ ha^{-1}$ of rainy-season cowpea have been recorded in the absence of added nitrogen fertilizer and with only moderate levels of phosphorus (< 10 kg P ha^{-1}).

In an intercrop, cowpea yield depends on sowing date, population, plant type, and rainfall. For example, yields are reduced by more than

50% in early-maturing types and by about 30% in prostrate, indeterminate types when intercropped with pearl millet. Analysis of the system × genotype interaction showed a strong correlation between the performance of cultivars in sole and intercrop systems. This suggests that selection and testing of cowpea cultivars can be done in either system. Our trials have shown that early-maturing, erect cultivars have less influence on pearl millet yield than late-maturing, prostrate cultivars.

Dual-purpose Cultivars

The local cowpea varieties show considerable variation but are generally spreading, indeterminate types adapted to low plant density. Farmers prefer these types to improved varieties for their general adaptability and fodder quality. Fodder demand far exceeds production and there is a ready market for cowpea hay, which commands the same price as cowpea grain. One of our principal objectives is therefore to select short-duration cultivars that yield both grain and hay.

We earlier identified cultivars that produce acceptable grain and fodder yields and are resistant to bacterial blight (*Xanthomonas campestris*), an important foliar disease of cowpea (ICRISAT Annual Report 1985, p. 270).

In 1985, we evaluated 15 dual-purpose cultivars intercropped with pearl millet in two villages (Gobery and Sadeize Koira) in southwest Niger in a researcher-managed farm trial. We sowed cowpea in hills spaced 0.75 m × 1.5 m in alternate rows with pearl millet. In both villages, rains stopped early and yields were variable. We repeated the trial in 1986 at Gobery alone and in 1987, we used six cultivars at Gobery and Sadoré (off-station). In both years, the insect pressure was high and the cowpea did not yield any grain. At both locations, fertilizer application significantly increased pearl millet yield but had no consistent effect on cowpea hay yield (Table 9). These results indicate that cowpea at low plant densities might not respond to fertilizer and that improved cultivars are not suited to low densities.

Insecticides

In 1985, we tested two spraying regimes (2 and 4 sprayings during the season) on 16 cowpea cultivars. We used a new electrodyne sprayer that applied a concentrated insecticide (Cymbush Super®) and does not require water for mixing. Spraying twice was as effective as spraying four times (Table 10). In our evaluation trials, we adopted a 2-spray regime and achieved effective insect control. We are testing the profitability of this technology with farmers in two villages in operational-scale experiments at ISC and Birni N'Konni.

Table 10. Grain yield of cowpea cultivars evaluated with minimum insecticide spray, application, ISC, rainy season 1985[1].

	Grain yield (t ha^{-1})	
Cultivars	2 sprays	4 sprays
IT82D 716	0.75	0.67
IT835 724-4	0.79	0.74
IT82D 703	1.27	0.99
IT82E 18	0.64	0.72
TVX 3236	0.85	1.02
Local Sadoré	0.37	0.49
SE	±0.14	
Mean (18 entries)	0.59	0.64
SE (Mean)	±0.06	
CV (%)	32	

1. Split-plot, 3 replications, plot size 12 m^2.

Vegetable Cowpea

During 1985-1987, we evaluated the potential of vegetable cowpea at ISC. On the sandy soils at ISC and under moderate fertility, fresh pod yields of up to 5 t ha^{-1} are possible from four harvests in less than 70 DAS (Table 11). Most of

Table 9. Effect of fertilizer on dual-purpose cowpea cultivars intercropped with pearl millet at Gobery, and Sadoré, Niger, rainy seasons 1986 and 1987.

Trial location/ Cowpea cultivar	Cowpea hay (t ha^{-1})			Pearl Millet grain (t ha^{-1})		
	F1[2]	F2	F3	F1	F2	F3
Gobery 1986						
VITA 3	0.25	0.47	-	0.16	0.94	-
VITA 5	0.30	0.14	-	0.32	0.63	-
TVX4659-03E	0.10	0.62	-	0.32	0.59	-
TN88-63	0.40	0.70	-	0.30	0.67	-
TN3-78	0.31	0.35	-	0.32	0.64	-
Local Sadoré	0.31	0.33	-	0.36	0.51	-
SE	±0.07			±0.13		
Mean	0.29	0.44	-	0.39	0.70	
SE	±0.04			±0.09		
CV (%)	36			37		
Gobery 1987						
VITA 3	0.12	0.07	0.13	0.16	1.19	1.00
TVX4659-03E	0.11	0.15	0.17	0.44	1.14	1.28
TN88-63	0.21	0.26	0.26	0.32	1.06	1.60
TN3-78	0.13	0.10	0.05	0.30	1.03	1.01
Local Sadoré	0.64	0.47	0.46	0.14	0.88	1.52
Sole pearl millet	-	-	-	0.29	0.96	1.36
SE	±0.03			±0.15		
Mean	0.18	0.15	0.16	0.33	1.04	1.35
SE	±0.01			±0.06		
CV (%)	41			33		
Sadoré (off-station) 1987						
VITA 3	0.07	0.09	0.12	0.04	0.11	0.22
TVX4659-03E	0.16	0.14	0.19	0.05	0.24	0.33
TN88-63	0.37	0.43	0.24	0.09	0.18	0.31
TN3-78	0.05	0.06	0.17	0.04	0.21	0.31
Local Sadoré	0.22	0.15	0.21	0.07	0.15	0.17
Sole pearl millet	-	-	-	0.05	0.18	0.28
SE	±0.02			±0.03		
Mean	0.12	0.12	0.13	0.06	0.18	0.27
SE	±0.01			±0.01		
CV (%)	33			40		

1. Plot size, 36 m^2, 4 replications.
2. F1 = No fertilizer; F2 = 8.7 kg P ha^{-1}; 22.5 kg N ha^{-1}; F3 = 17.5 P ha^{-1}; 45 kg N ha^{-1}.

Table 11. Yield of fresh pods ($t\ ha^{-1}$) of vegetable cowpeas, ISC, rainy seasons, 1985, 1986, and 1987[1].

Cultivar	1985 (430 mm)[2]	1986 (447 mm)	1987[3] (280 mm)	Mean
IT81D 1228-14	6.19	5.96	1.58	4.58
IT81D 1228-13	8.16	4.33	1.29	4.59
IT81D 1228-10	8.53	3.87	1.75	4.72
IT835 899	7.64	5.01	1.14	4.60
IT835 898	9.84	4.45	1.04	5.11
IT835 911	7.40	4.35	1.61	4.45
TVX 21	3.07	1.26	1.43	1.92
SE	±0.58	±0.60	±0.18	
Trial mean (10 entries)	6.75	3.72	1.14	
CV (%)	15	23	38	

1. RBD, plot size 12 m^2.
2. Rainfall received between sowing and last harvest.
3. Low pod yields due to drought and heat stress during flowering.

the vegetable cowpeas are highly resistant to foliar diseases and remain green until the last harvest. While moisture is available in the soil, they continue flowering and producing pods. They are ideal both as a garden and a fodder crop.

Cowpea as an Off-season Crop

In Niger, there is increasing interest in growing off-season crops with irrigation. The dry season in Niger lasts from October to the end of May. Between November and February, water is abundant in the Niger River but night temperatures often average less than 20°C so that cowpea growth is very slow. We have screened a large number of breeding lines for such desirable characteristics as rapid emergence from cool soils, vigorous growth, earliness, and the ability to produce many pods.

In a trial involving 10 cultivars during the cool months, the major field pests of cowpea were not encountered. With only one insecticide spray treatment against aphids, it was possible to obtain 1 $t\ ha^{-1}$ of grain and 2 $t\ ha^{-1}$ of hay. To obtain such yields during the rainy season requires two to three insecticide sprays. We have started a joint trial with INRAN at four locations to further explore the potential of cowpea under different irrigation treatments.

Cropping Systems in Mali

The development of improved techniques for pearl millet/maize, sorghum/groundnut, and sorghum/cowpea intercropping systems was a major focus in 1987.

Pearl millet/maize. We continued our studies to 'fine-tune' earlier innovations in technology by improving the pearl millet component of the system. Using a factorial design, we evaluated the performance of two cultivars, two sowing arrangements, and three different methods of sowing intercropped pearl millet. All other factors including crop density (5 plants m^{-2} of maize and 3 plants m^{-2} of pearl millet) remained constant.

The intercropped pearl millet, which is slightly taller and later-maturing than NKK, performed better in terms of yield and total LER (Table 12). However, this cultivar exerted greater competition on maize resulting in lower maize grain yields. A sowing arrangement of one row of pearl millet with one row of maize favored maize, which smothered the sparsely populated and later-sown pearl millet. In the sowing arrangement of one row of pearl millet with two rows of maize (pearl millet sowing density was doubled in the row to maintain the overall population density), the competition balance favored pearl millet, resulting in higher pearl millet grain yields and lower maize grain yields. The combined LER was also higher in the one row pearl millet to two rows maize sowing arrangement. As transplanting is becoming popular in southern Mali, we included transplanting treatments in the experiment. Transplanting 3-week old pearl millet seedlings when maize had attained

Table 12. Effect of cultivar, sowing arrangement, and method and time of pearl millet sowing on performance of pearl millet/maize intercrops, Sotuba, Mali, rainy season 1987.

Treatment	Intercrop pearl millet[1] Grain yield (t ha^{-1})	LER[2]	Intercrop maize 1 Grain yield (t ha^{-1})	LER	Combined LER
Pearl millet cultivar					
NKK	0.51	0.34	2.84	0.81	1.15
M9D3	0.64	0.45	2.69	0.77	1.22
SE	±0.02		±0.09		
Row arrangement					
1 pearl millet : 1 maize	0.46	0.31	2.90	0.83	1.14
1 pearl millet : 2 maize	0.76	0.52	2.63	0.77	1.27
SE	±0.02		±0.09		
Method and time of pearl millet sowing					
Direct seeding, maize at 4-leaf stage	0.63	0.43	2.65	0.76	1.19
Transplanting, maize at 4-leaf stage	0.83	0.56	2.39	0.68	1.24
Transplanting, maize at flowering	0.26	0.18	3.25	0.93	1.11
SE	±0.04		±0.11		
CV (%)	18	16			

1. Sole crop yields: NKK = 1.5 t ha^{-1}, M9D3 = 1.44 t ha^{-1}, and maize = 3.5 t ha^{-1}.
2. LER = Land Equivalent Ratio, calculated using trial means for respective sole crop.

the 3-4 leaf stage resulted in better pearl millet growth and yields when compared to direct seeding both crops at the same time. However, maize suffered due to enhanced competition from pearl millet and produced lower grain yields. Transplanting late in the season when maize was flowering did not have any significant competitive effect on maize, resulting in the highest maize grain yields. Pearl millet, however,when transplanted late could produce only 0.26 to grain ha^{-1}. The total LER was highest in the treatment where pearl millet was transplanted early (when maize had attained the 4-leaf stage).

These results support our earlier recommendation of sowing one row of late pearl millet to two rows of maize.

Sorghum/groundnut. During 1987, we examined sorghum sowing date, the fertilizer N applied to sorghum, and sorghum and groundnut cultivars. Delaying sorghum sowing resulted in a significant reduction in sorghum grain yield because of poor crop establishment under the already established groundnut (Table 13). However, when groundnut and sorghum were sown at the same time, groundnut suffered severe competition and significant reduction in pod yield. The total LER was higher when both the crops were sown together. In terms of economic yield, however, delayed sowing of sorghum would have given a better economic result as groundnut is about three times more valuable than sorghum. Sorghum responded significantly to added N fertilizer and the increased competition significantly lowered groundnut yields. The LER was greater when fertilizer N was added.

Table 13. Relationship between yield, sowing date of sorghum, and fertilizer N for sorghum/groundnut intercrops, Sotuba, Mali, rainy season 1987.

	Intercrop sorghum		Intercrop groundnut		
Treatment	Grain yield (t ha^{-1})	LER[1]	Grain yield (t ha^{-1})	LER	Combined LER
Sorghum sown					
At GSD[2]	2.15	0.88	1.20	0.59	1.47
GSD + 4 weeks	1.00	0.41	1.69	0.83	1.23
SE	±0.09		±0.06		
Fertilizer N (kg ha^{-1})					
0	1.39	0.57	1.50	0.74	1.31
46	1.76	0.72	1.39	0.68	1.40
SE	±0.09		±0.06		
CV (%)	30		19		

1. LER = Land Equivalent Ratio.
2. GSD = Groundnut Sowing Date.

The effect of sorghum cultivars on groundnut yield was also evaluated. In general, early-flowering and short-statured sorghums offered less competition to intercropped groundnuts compared to late-flowering and taller cultivars. Shorter-duration groundnut cultivars performed better than longer-duration cultivars when intercropped with sorghum.

Sorghum/cowpea. With the introduction of improved cultivars, cowpea is being increasingly grown as a commercial grain crop. During 1987, we examined the effect of different densities of cowpea (improved cv KN1) on the performance of a sorghum (improved cv Malisor 84-1)/cowpea intercropping system. Recommended pest control measures were followed.

Increasing cowpea density from 0.8 plants m^{-2} (traditional cowpea density) to 10 plants m^{-2} did not have any significant effect on the grain yields of sorghum, although there was a trend towards lower yields (Table 14). However, increasing the cowpea density resulted in a significant increase in cowpea grain yields. The results show that grain yields of 3 t ha^{-1} of sorghum and 0.5 t ha^{-1} of cowpea are achievable.

Table 14. Yields of sorghum/cowpea intercrops grown with different cowpea densities, Sotuba, Mali, rainy season 1987.

Cowpea density (plants m^{-2})	Grain yield (t ha^{-1})	
	Sorghum	Cowpea
0.8	3.38	0.20
2.5	3.27	0.36
5.0	3.12	0.46
10.0	3.15	0.51
SE	±0.43	±0.08
CV (%)	21	27

Perennial Pigeonpea as an Agroforestry Species

At ICRISAT Center in 1985/1986, we studied the suitability of perennial pigeonpea for agroforestry on Alfisols. Indeterminate pigeonpea varieties resistant to wilt and to sterility mosaic disease (ICPL 6443, ICPL 11289, ICPL 8094, and ICPL 8860) were grown under irrigation at spacings ranging from 0.5 to 9.5 plants m^{-2} with four replications. Varieties (main plots) were randomized within blocks, but spacings (subplots) were arrayed from low to high within each varietal plot. Grain was harvested in October 1985, and January and April 1986.

Grain yield was reduced at a spacing of 0.5 plants m^{-2} but was unaffected by spacings in the range of 1.5-9.5 plants m^{-2} (Fig. 17). Average yield for each genotype was 2.10 t ha^{-1} for ICPL 8094, 1.83 t ha^{-1} for ICPL 6443, 1.83 t ha^{-1} for ICPL 8860, and 1.67 t ha^{-1} for ICPL 11289 (SE = ±0.124).

ICPL 8094 consistently outyielded other geno-

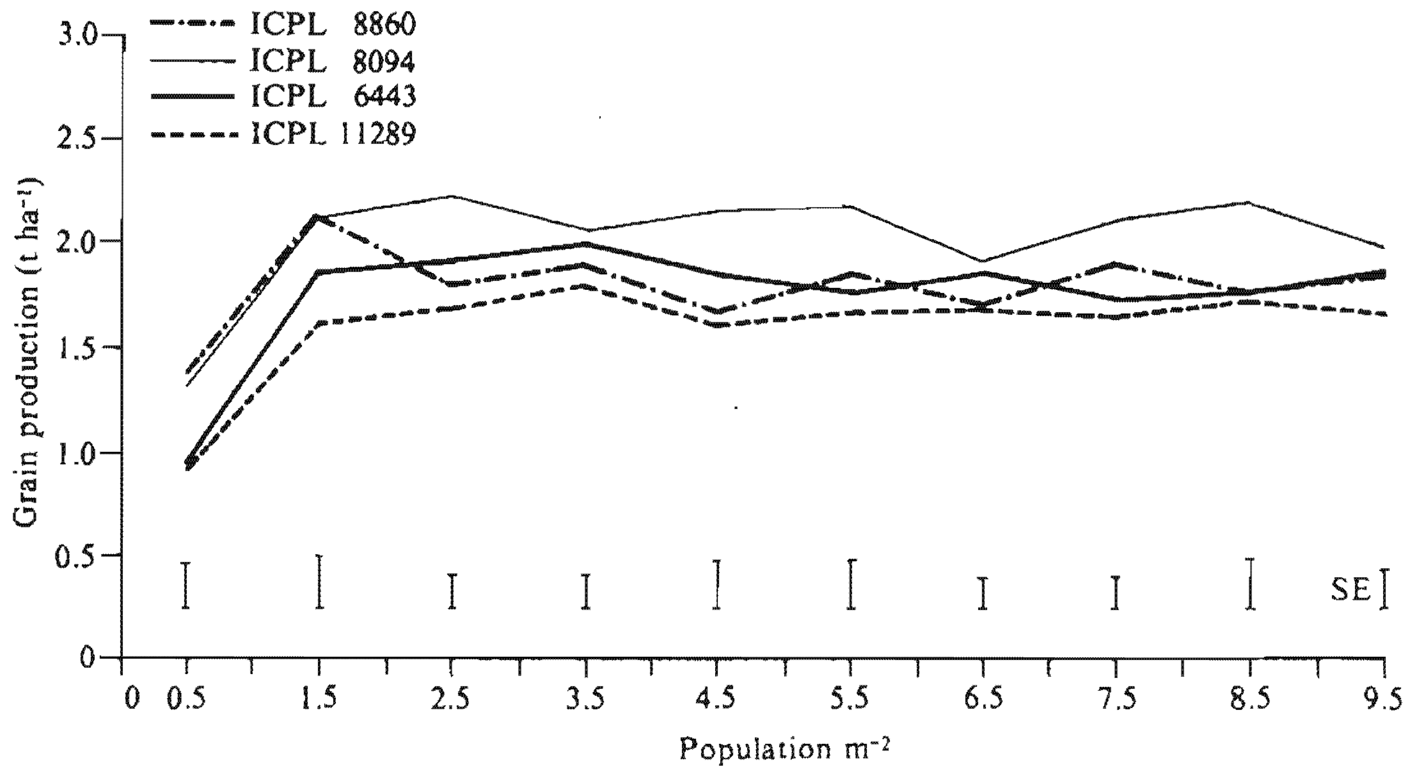


Figure 17. Grain production of four perennial pigeonpea varieties on a shallow Alfisol, ICRISAT Center, 1985/1986.

types at spacings exceeding 0.5 plants m^{-2}, whereas ICPL 11289 was generally the poorest grain producer. Our results suggest that plant morphology influences grain yield. ICPL 11289 is tall and erect, while ICPL 8094 and ICPL 8860 have bushy, spreading habits. Pigeonpeas with a spreading growth habit produce more pods and appear better able to exploit greater growing space at lower populations.

Fuelwood production in the first year of this 2-year trial was estimated using allometric formulae to convert average basal stem diameter into average stem dry mass, based on 160 felled sample plants. These averages were then adjusted by accounting for mortality and population, to obtain estimates of dry-mass fuelwood yield. In contrast to grain, the production of fuelwood decreased with increasing plant population because stem diameter decreased. Because of its plasticity with respect to grain yield, high fuelwood production, and particularly its perenniality, pigeonpea offers an attractive and manageable source of useful products. Yet it is shorter-lived than arboreal species, and farmers can easily remove it from their fields should they wish to.

Biomass Production in Agroforestry

A major objective of our agroforestry research is to manage leucaena hedgerows to maximize leucaena fodder production during the dry season (Jan-Jun), and yield of the associated crop during the rainy season (Jun-Oct). Production from leucaena is encouraged during the dry season when atmospheric conditions are least favorable for crop growth. In 1986 and 1987, we examined the relative efficiency of biomass production in the two seasons by measuring the total amount of solar radiation intercepted by leucaena hedgerows and by three cropping systems, i.e., sole sorghum, sole pigeonpea, and a sorghum/pigeonpea intercrop. Measurements were made in a two-way systematic design experiment on a Vertic Inceptisol (ICRISAT Annual Report 1986, p.308).

Solar radiation interception by leucaena in sole and hedgerow systems was between 1000 and 1700 MJ m^{-2} during the dry season but only 850-900 MJ m^{-2} during the rainy season (Fig. 18). Despite the greater interception of radiation in the dry season, the radiation use efficiency (RUE) was low (0.21 ± 0.06 g MJ^{-1}) and production ranged from 3.6 to 3.8 t ha^{-1}. In contrast, during the rainy season, the radiation use efficiency was three times higher (0.61 ± 0.03 g MJ^{-1}) and biomass production ranged from 5.2 to 5.5 t ha^{-1}. Our results also show that the RUE can be increased by including C4 cereals like sorghum within leucaena hedgerow systems. Rainy-season values for these systems reached 1.0 g MJ^{-1} in both 1986 and 1987, which is close to reported values for sole pearl millet and sorghum (ICRISAT Annual Report 1984, p.255).

Can fodder production from leucaena be further increased without sacrificing crop yield, given that RUE is greatest in the rainy season? One possibility would be to grow leucaena and cereal crops in separate areas as sole crops so that both canopies could be separately managed. Although none of our trials have been designed to test this system, we can estimate its potential productivity. In our trials, sole leucaena cut at

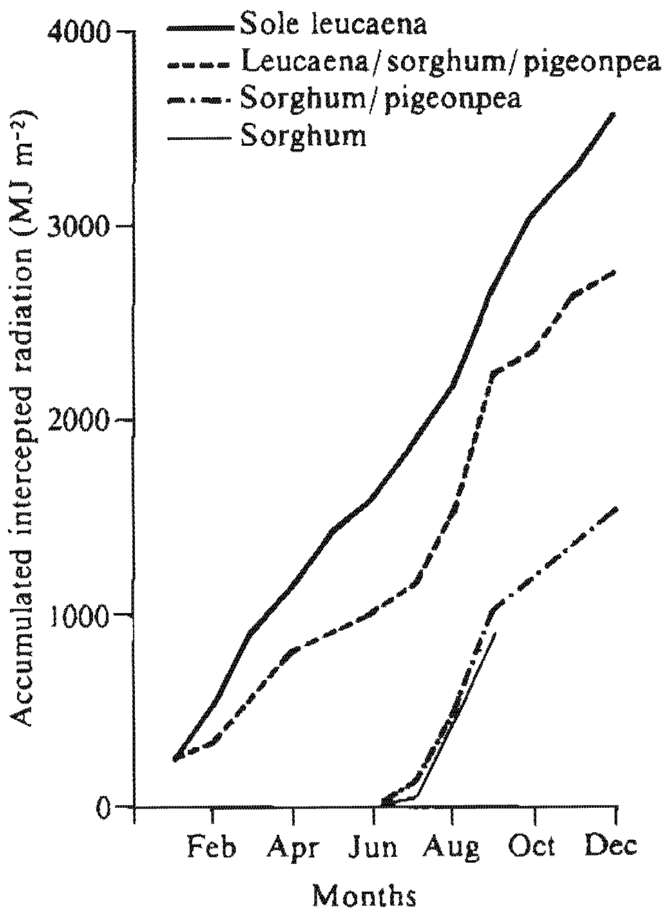


Figure 18. Accumulated intercepted solar radiation for agroforestry and cropping systems on Vertic Inceptisols, ICRISAT Center, 1986.

Table 15. Biomass production, intercepted radiation, and radiation use efficiency (RUE) for leucaena, sorghum, and agroforestry combinations, Vertic Inceptisol, ICRISAT Center, 1986.

Crop system	Biomass (t ha^{-1})	Total intercepted radiation (MJ m^{-2})	Radiation use efficiency (g MJ^{-1})
Sole leucaena			
Pruned	12.3 (±0.97)[1]	3 844	0.32
Unpruned[2]	25.2	4 960	0.51
Alley cropping			
3.8 m	9.4 (±0.50)	2 238	0.42
4.7 m	9.0 (±0.38)	2 000	0.45
5.6 m	9.3 (±0.77)	2 385	0.39
Sole sorghum	7.4 (±0.67)	740	1.00

1. Figures in parentheses are SEs.
2. Based on calculation of potential radiation interception and a RUE of 0.61 g MJ^{-1} in the rainy season.

the onset of the rainy season and once during the rainy season to reduce competition with crops, intercepted 3844 MJ m^{-2} and produced 12.3 t ha^{-1} of biomass in one year. We calculated that, by allowing the leucaena to grow until late February when fodder demand is high, biomass produced could reach 25 t ha^{-1} (Table 15). Thus, by growing and managing leucaena and cereal crops separately, we could expect to produce more fodder. For example, if half the land were under leucaena and the remainder under sorghum, the combined yield should be 17 t ha^{-1} compared with 9 t ha^{-1} in alley cropping. Currently this hypothesis is being tested on an operational scale with perennial pigeonpea in place of leucaena, because perennial pigeonpea is considered to have better prospects for agroforestry than leucaena in India.

Mechanization

Twin Spinning-Disc Knapsack Sprayer

Some of the insect pests and diseases of crops in the SAT can be controlled by pesticides. Farmers using conventional knapsack sprayers to apply pesticides usually need large volumes of clean water, but this is often scarce. An alternative to the conventional sprayer is the portable, battery-operated, spinning-disc, controlled droplet applicator (CDA). These applicators have the

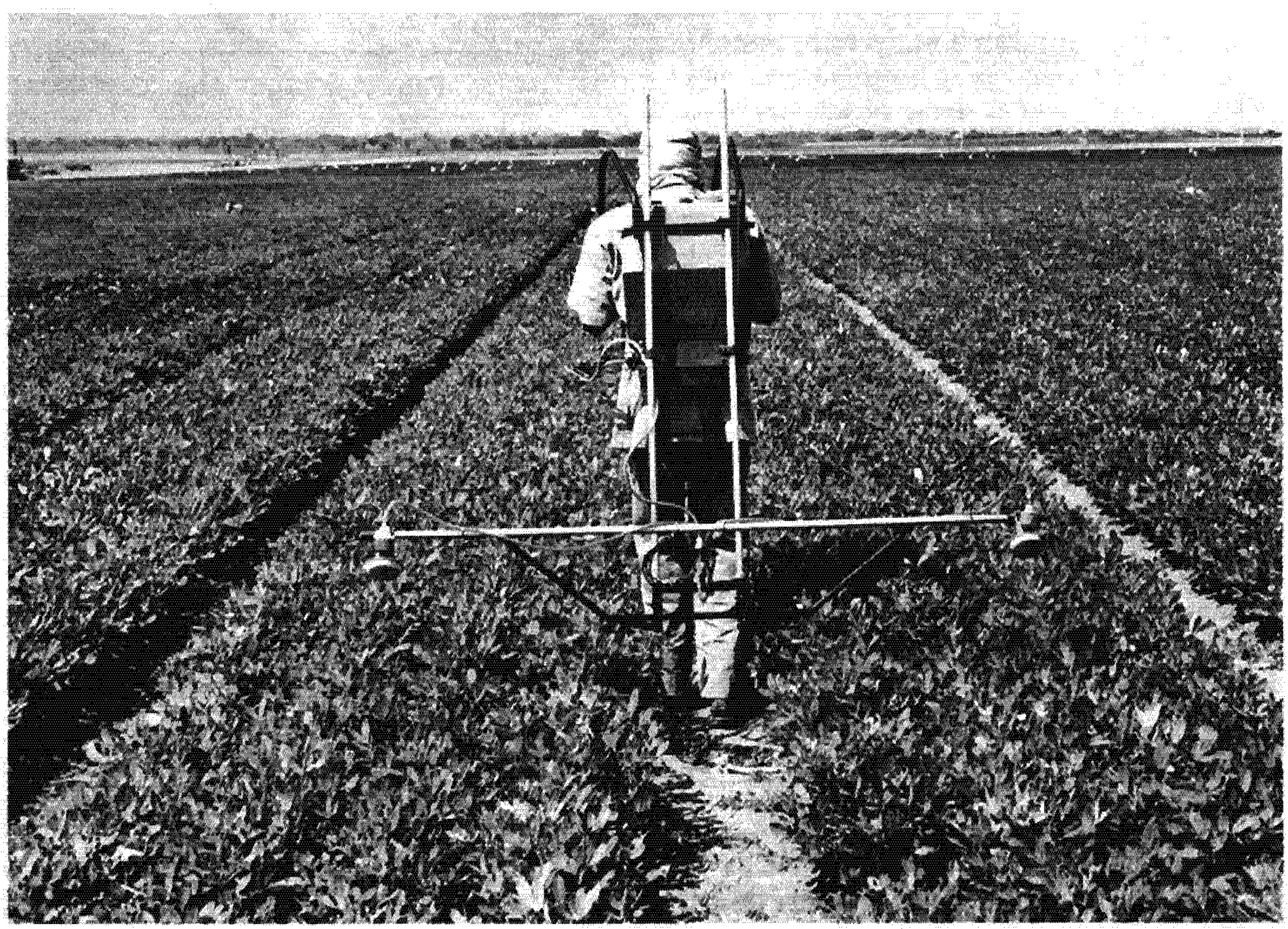


Figure 19. Twin spinning-disc knapsack sprayer used to apply pesticides to groundnut and other low-growing crops.

advantage of being light and needing only a small volume of water.

We have developed a twin spinning-disc knapsack sprayer (Fig. 19) for groundnut and such low-growing crops as chickpea and mungbean. Combining the best features of both the conventional knapsack sprayer and the CDA, this consists of a 10-L tank fitted onto a tubular frame. A 1.5-m wide boom is an integral part of the frame. Two spinning-disc applicators mounted on the boom are energized by a 6-volt rechargeable battery placed under the tank. The chemical solution flows from the tank to the discs through a cutoff valve and a flow-regulating disc. The constant flow of solution is facilitated by an air vent in the container cap. The sprayer is carried on the back of the operator and the position of the boom can be adjusted to obtain the correct height of the boom above the crop. The sprayer weighs approximately 9 kg and costs about Rs. 900 (US $ 70).

We evaluated the performance of the twin spinning-disc sprayer for application of wettable powder and emulsifiable concentrate formulations, in two groundnut trials jointly conducted with the Legumes Program at ICRISAT Center. In both trials, the twin spinning-disc sprayer performed as well as the conventional knapsack sprayer (Table 16) in controlling early leaf spot (*Cercospora arachidicola*), and late leaf spot (*Phaeoisanopsis personata*), leafminer (*Aproaerema modicella*), thrips (*Frankliniella schultzei, Scirtothrips dorsalis*), and jassids (*Empoasca kerri*). The twin spinning-disc sprayer covered a 3-m wide swath, required only 15 L of water, and about 1.5 man-h to cover 1 ha whereas the conventional knapsack sprayer required more than 400 L of water and 200 man-h to spray 1 ha.

In another experiment, the twin spinning-disc sprayer was compared with a portable single spinning-disc sprayer to assess the risk to the operator from exposure to spray chemicals. The amount of chemical solution falling on an operator spraying groundnut was measured when the wind direction was at 30° or more across the operator's direction of travel and windspeed was less than 10 km h^{-1}. There was no significant difference in the rate at which the spray was deposited on the operator from the two sprayers (Table 17). However, on a unit sprayed area basis, the operator exposure with the twin spinning-disc sprayer (which has double the work rate) would be only half of that with the single spinning-disc sprayer. The spray boom on the twin spinning-disc sprayer is designed to allow the operator to walk ahead of the spray. Despite this, the legs of the operator receive a relatively high proportion of spray droplets. Contamination can be further reduced if the polythene sheet that protects the legs of the operator is suspended from the sprayer frame or is worn on the operator's back. In addition, the operator should follow the normal rules for safe handling of agricultural chemicals, i.e., wear protective clothing, including a face mask and gloves when handling and mixing the concentrated insecticide. Spraying should only be done when there is little or no wind, and the operator

Table 16. Insects per groundnut plant, 36 h after insecticide application using two types of spraying equipment, ICRISAT Center, postrainy and rainy seasons 1987.

	Postrainy season		Rainy season		
Sprayer type	Leaf miner	Thrips	Leaf miner	Thrips	Jassids
Conventional knapsack sprayer	0.63	2.00	12.4	0.10	0.02
Twin spinning-disc sprayer	0.25	1.72	14.0	0.24	0.02
Control (no spray)	2.48	4.57	43.2	4.20	0.40
SE	±0.24	±0.26	±0.91	±0.068	±0.011

Table 17. Deposit of spray (drops cm^{-2}) on the feet, legs, and waist of an operator spraying groundnut, ICRISAT Center, postrainy season 1986.

Type of spinning-disc sprayer	Drops cm^{-2}				FA (%)[1]			
	Feet	Legs	Waist	Total	Feet	Legs	Waist	Total
Single	1.13	0.34	0.10	1.57	16.4	6.4	5.6	28.4
Twin	0.50	0.84	0.04	1.18	11.8	21.2	6.0	31.4
Mean	0.81	0.59	0.07		14.1	13.8	5.8	
SE	±0.454		±0.019		±9.41		±2.99	

1. FA = area exposed to chemical as a function of the area of sample paper used for measurement.

should walk such that the wind is always at least 30° across his path. Even with these precautions, very toxic chemicals must not be used in twin spinning-disc sprayers.

Computerization

Microcomputers and Agricultural Economists

Proficient use of microcomputers can substantially enhance the productivity of both researchers and research institutions organized to accommodate these tools. Microcomputers have been widely adopted and accommodated in developed countries where they soon affected methodology research. Although microcomputers and commercial software packages can be bought in India, their use by researchers remains very limited. Unless agricultural researchers and the Indian research system begin to use microcomputers, a technology gap will develop, impeding communication between scientists in India and their peers abroad.

In order to ascertain researchers' awareness of, and access to microcomputers and software, we interviewed agricultural economists during the Annual Conference of the Indian Society of Agricultural Economics in December 1986 and mailed questionnaires to agricultural economics research institutions. We obtained 48 responses from 37 organizations (24 universities, 10 research institutes, and 3 government departments) from 14 states and New Delhi.

Nearly one third of the respondents had access to a mainframe computer, and about one quarter had access both to a mainframe computer and a microcomputer. Most of the respondents (69%) who already have, or will soon have access to a microcomputer, do not have access to a mainframe computer, indicating that microcomputers are used as substitutes for mainframes. One third of the respondents had access to neither microcomputers nor mainframes and one out of seven respondents did not have the prospect of obtaining access to any computer in the foreseeable future. Reasons given for the nonavailability were lack of funds, indifference of senior personnel, and lack of personnel able to operate computers.

Less than half of the respondents provided information on the software used. Of these, most used commercially available software designed for business applications, mainly for statistical and economic analyses, tabulation of data, and data management. Very few respondents used more specialized software designed for scientific applications. Despite reliance on purchased software, most respondents felt that they would have better control over software quality and reliability if it were written in-house rather than purchased. The majority of respondents were unfamiliar with the technical specifications of the microcomputers available in their research organizations.

Nearly two-thirds of the respondents reported that no administrative changes had been necessary to accommodate microcomputers. Where such changes had been necessary, they comprised recruiting new staff, or retraining available staff. Several responses indicated that the potential provided by microcomputers to decentralize computing and allow immediate computer access is not fully realized.

To prevent a widening microcomputer technology gap between research organizations in India and the more highly developed countries, it will be necessary to increase awareness among research administrators and researchers to the potential that microcomputers offer for augmenting research productivity, and to establish avenues for the exchange of software between research organizations.

Assessing Sustainability

Potassium Fertility

High-yielding cropping systems on Alfisols do not usually need potassium (K) fertilizers. An experiment at ICRISAT Center to examine the long-term sustainability of such systems was started in 1979 and concluded in 1986 on an Alfisol (Patancheru series). We have previously presented interim results for the first 4 years (ICRISAT Annual Report 1983 pp.260-262). The following is the final report for this experiment.

The nutrient treatments in the experiment were designed to show: the onset of K deficiency; and the role of various amendments in promoting or alleviating the exploitive removal of K from the soil. The nutrient treatments were: N fertilizer to promote cereal growth, and thus K uptake and K removal from the soil; residues (cereal stalks) from the previous year's crop, or farmyard manure (FYM); and four rates of applied K (0, 30, 60, and 120 kg K ha^{-1} a^{-1}). A sorghum/pigeonpea intercrop (2:1 row arrangement) was alternated annually with a pearl millet/groundnut intercrop (1:3) to minimize the buildup of pests and diseases. Each of the three replicates contained duplicate mainplots of each cropping system. Responses to nutrient treatments, applied to split plots within the main plots, could therefore be assessed on each cropping system in each year. The soil on each plot was sampled after harvest in 1978, 1983, and 1987, and the above-ground crop material was analyzed each year.

Crop yields. Over the 8-year period, K fertilizer caused small but statistically significant ($P < 0.05$) increases in average yields of sorghum straw and grain, pigeonpea stalks and grain, pearl millet straw and grain, and groundnut haulms and pods (Fig. 20). The annual yield responses for sorghum (Fig. 21) provide a good example of the interseasonal variation. Sorghum responded little in the first 2 years; subsequent yield responses did not increase with time but fluctuated around a general mean. Further, the fact that there was a response to K only after the first 2 years does not necessarily imply the onset of deficiency resulting from the depletion of soil-exchangeable K, but rather an increasing demand for K. Yields of sorghum increased over the first 4 years, but then stayed the same.

We conclude that:

- For all four crops, this soil is marginally deficient in available K;
- the occurrence and severity of K deficiency differed between crops and between years; sorghum was the most responsive crop; and
- groundnut responded to K only in years when grain yields (and rainfall) were low.

Nutrient uptake. Potassium removed in harvested crops ranged from 49 kg ha^{-1} a^{-1} for the N_0 K_0 treatment (control) to 90 kg ha^{-1} a^{-1} for the N_{120}, K_{120} treatment (Table 18). Application of fertilizer-N alone (120 kg N ha^{-1} a^{-1}) increased the removal of K in crops by 6 kg ha^{-1} a^{-1}. The apparent recovery of K fertilizer by the crop decreased from 50% for the first 30 kg ha^{-1} increment of fertilizer-K to 17% for the 60–120 kg K ha^{-1} increment. Annual removal of other nutrients by harvested crops was 77–108 kg N ha^{-1} a^{-1} and 10.0–13.2 kg P ha^{-1} a^{-1}.

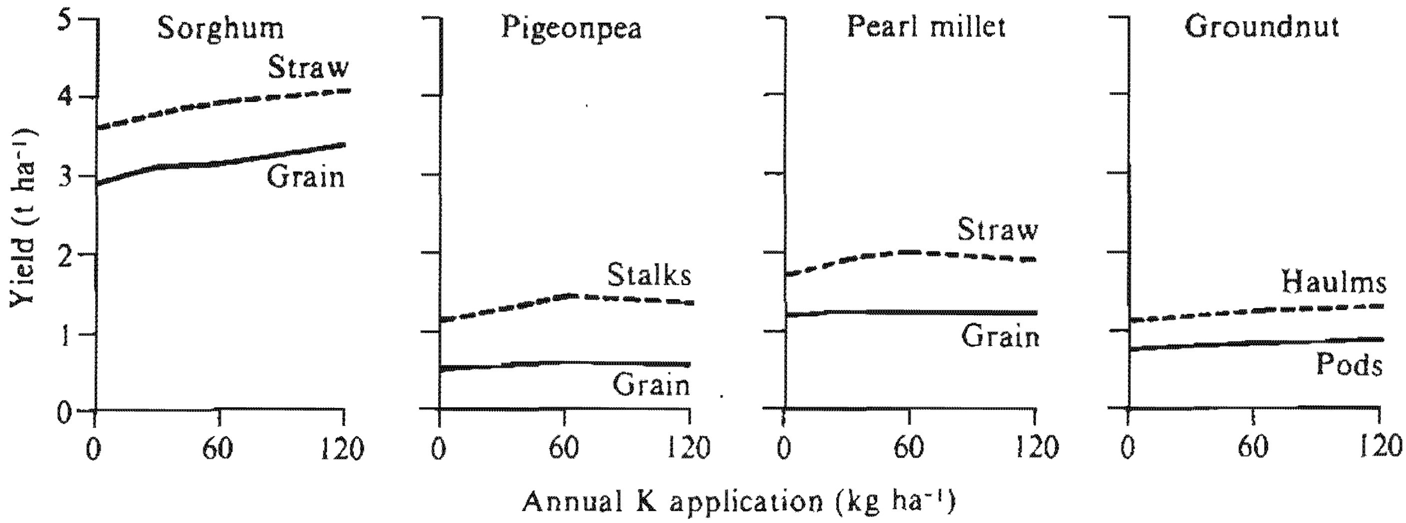


Figure 20. Effect of fertilizer K on average grain (or pod) and straw, stalk or haulm yield of sorghum, pigeonpea, pearl millet, and groundnut grown on an Alfisol (Patancheru series), ICRISAT Center, 1976-86.

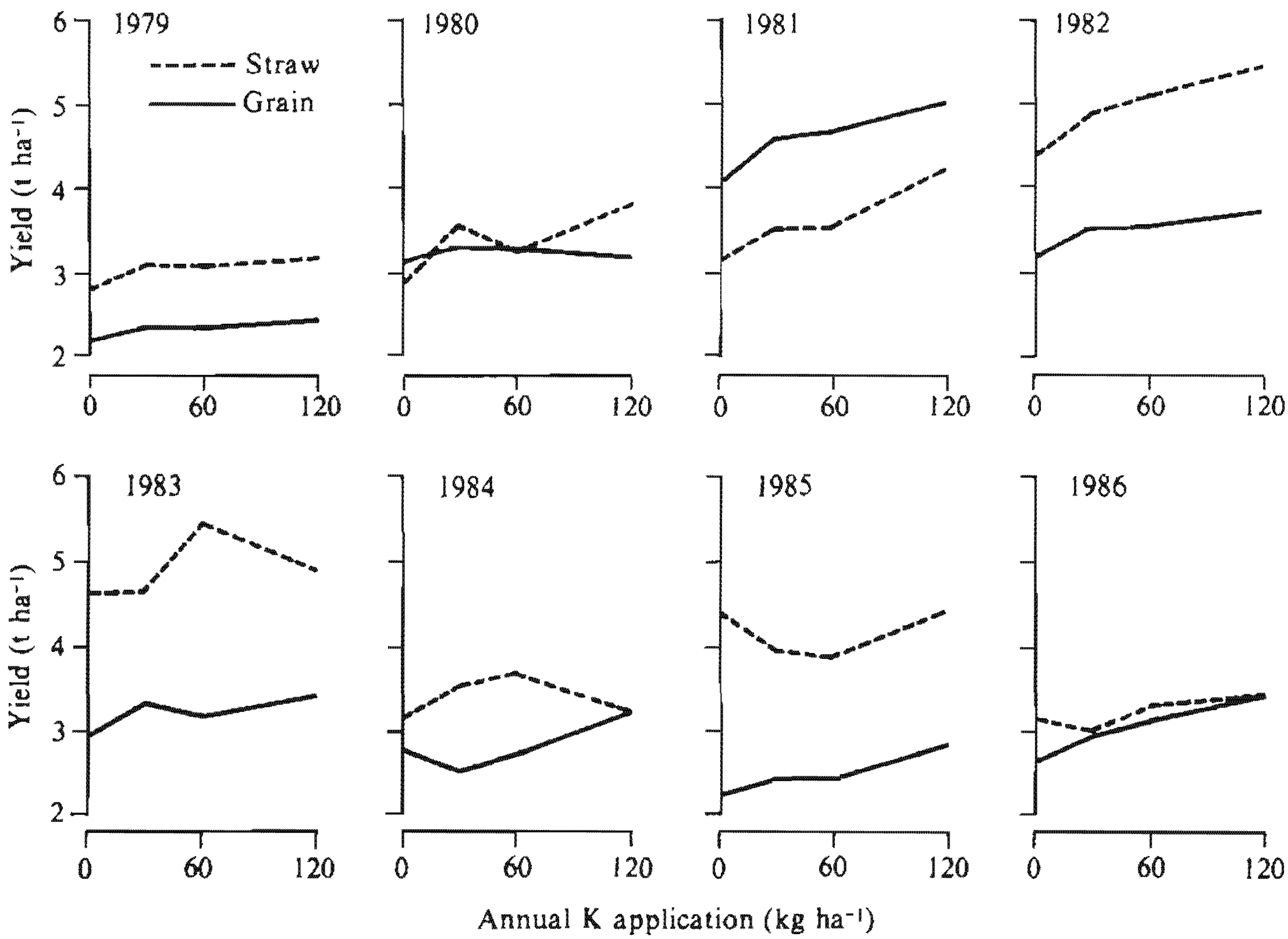


Figure 21. Effect of fertilizer K on annual yield of sorghum (straw and grain) grown on an Alfisol (Patancheru series), ICRISAT Center, 1979-86.

Table 18. Effect of nutrient treatments on the potassium balance of an Alfisol, ICRISAT Center, 1979-1987.

	Treatment[1]									
	Control	N_{60}	N_{120}	K_{30}	K_{60}	K_{120}	RR[2]	FYM[3]-N_{120}	FYM	SE
Additions (kg ha^{-1} a^{-1})										
Fertilizer N	0	60	120	120	120	120	120	120	0	
Fertilizer K	0	0	0	30	60	120	0	0	0	
Organic matter	0	0	0	0	0	0	2700	5000	5000	
K inputs and outputs (kg ha^{-1}) 1979-87										
Removed	394	410	440	559	643	724	528	585	580	±10.5
Added	0	0	0	240	480	960	345	735	735	
Net input	-394	-410	-440	-319	-163	166	-183	150	155	
Exchangeable K (mg K kg^{-1} soil)										
1979	65	53	54	60	62	61	58	59	56	± 5.8
1983	49	49	48	57	72	84	56	52	56	± 4.0
1987	44	39	44	46	59	76	48	40	45	± 6.6
Change (1979-87)	-21	-14	-10	-14	-3	15	-10	-19	-11	
Changes in soil K 'pools' (kg K ha^{-1}) 1979-87										
Exchangeable K[4]	-88	-55	-46	-59	13	63	-42	-80	-46	
Nonexchangeable K[5]	-306	-355	-394	-260	-150	173	-141	230	201	

1. Basal application of 15 kg P ha^{-1} to all treatments.
2. Return of residues (cereal straw).
3. FYM = Farmyard manure.
4. Calculated from exchangeable K concentration by assuming soil bulk density = 1.40 t m^{-3}.
5. Calculated from nonexchangeable K i.e., calculated net input -exchangeable K

Soil nutrient status. Over the 8 years of the experiment, the nutrient treatments did not cause detectable changes in soil pH, total N, available-P, exchangeable-Ca, and exchangeable-Mg. Exchangeable-K increased under the highest rate of fertilizer application (120 kg K ha^{-1} a^{-1} but decreased under all other treatments, including FYM (92 kg K ha^{-1} a^{-1}) (Table 18). For reasons that are not yet understood, exchangeable-Ca increased markedly in all treatments over the first 4 years, but not subsequently.

Nutrient balances. The 2-year rotation of improved cropping systems with 120 kg N ha^{-1} a^{-1} removed 55 kg K ha^{-1} a^{-1} from the soil in the absence of fertilizer-K inputs; on the other hand, about 21 kg K ha^{-1} a^{-1} of the 120 kg K ha^{-1} a^{-1} added was not removed in crops (Table 18). Figure 22 shows that an input of about 80 kg K ha^{-1} a^{-1} is needed to maintain the potassium status of this soil at its initial level; this was achieved by only 3 treatments: fertilizer at 120 kg K ha^{-1} a^{-1} and FYM (with or without fertilizer-N).

The exchangeable-K content of the soil decreased from an average initial level of about 60 ppm (260 kg ha^{-1}) to about 40 mg kg^{-1} where K was not applied; it increased to 76 mg kg^{-1} with the highest K input (120 kg ha^{-1} a^{-1}). Because these changes were small in relation to the amounts of K added to or removed from the soil,

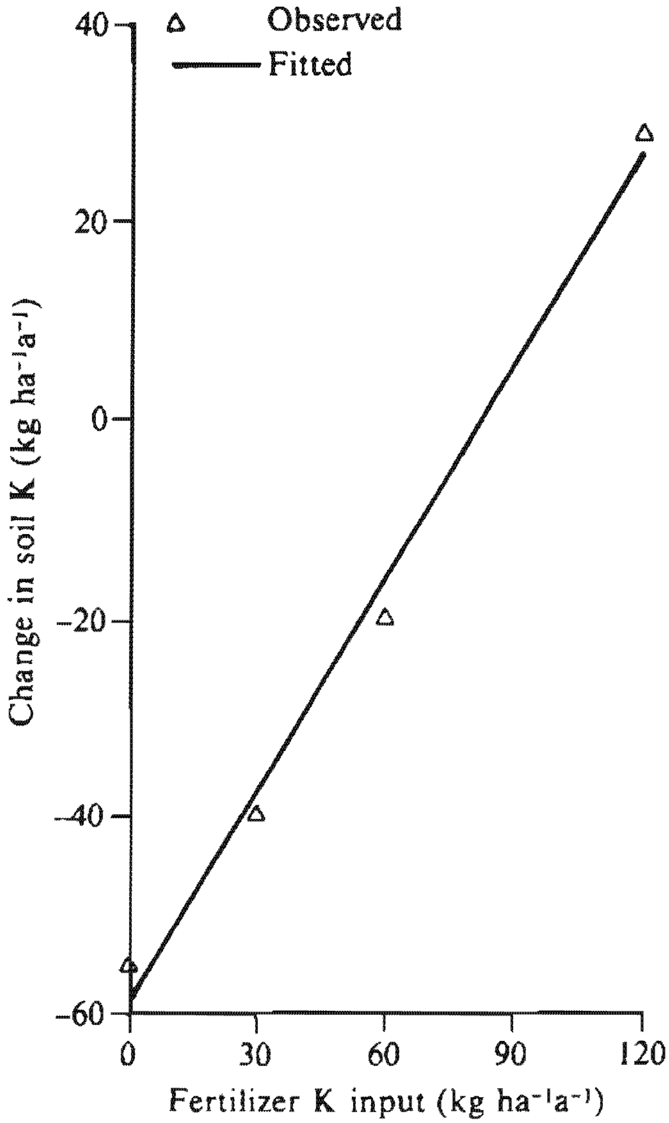


Figure 22. Relationship between average K inputs and removal of K by improved cropping systems on an Alfisol (Patancheru series), ICRISAT Center, 1979-86.

we assume that unaccounted-for K was absorbed by or released from the nonexchangeable sites in the soil.

The calculated amounts involved in such transfers (Table 18) are usually several times greater than those in exchangeable-K. We conclude that K rapidly interchanges between the solution and the nonexchangeable pools in the soil, and that measurements of exchangeable-K alone do not provide a satisfactory basis for assessing gains or losses of K from this soil.

Soil N content (0-30 cm) did not change significantly over the 8-year period. We assume that the legume components of the intercrops maintain the soil N status; the annual input of N, by biological N fixation, is therefore probably similar to the total N removal of 77 kg ha^{-1} (without fertilizer-N inputs). The estimated fixation rates for each treatment are given in Table 19. Nitrogen addition by biological N fixation is probably one of the causes of increased yields over the first 4 years and illustrates the role to be played by legumes in sustaining soil fertility.

Conclusions

Soil can readily supply 55 kg K ha^{-1} a^{-1} from reserves (80 t K ha^{-1} 30 cm^{-1}) and this process could continue for many years, as the reserves are extremely large. Nevertheless, in the very long term, continuous removal of K from the soil will result in deficiencies unless K is added, either as fertilizer or by the return of K to the soil in the form of crop residues or FYM. Soil N status is maintained by the legume component of intercrops, and the only nutrients required are an annual application of about 15 kg P h^{-1} and an occasional application of zinc.

Vertisol Technology

The sustainability of improved Vertisol technology can be judged by comparing it with the traditional system as we now have a record of 11 successive years. Improved technology was applied on an operational scale on 17 watersheds at ICRISAT Center in 1976. Major benefits are better drainage, capacity for double cropping, lower runoff, and reduced soil loss. Full details of the technical components of the Vertisol technology and the complete layout of the watersheds were described earlier (ICRISAT Annual Report 1975/76, p.190).

Improved technology clearly reduces runoff and soil loss (Table 20). A simple index of the stability of production is the standard deviation

Table 19. Effect of nutrient treatments on the nitrogen balance of an Alfisol, ICRISAT Center, 1979-1987.

	Treatments									
	Control	N_{60}	N_{120}	K_{30}	K_{60}	K_{120}	RR[1]	FYM[2]+N_{120}	FYM	SE
Additions (kg ha^{-1} a^{-1})										
Fertilizer N	0	60	120	120	120	120	120	120	0	
Fertilizer K	0	0	0	30	60	120	0	0	0	
Organic matter	0	0	0	0	0	0	2700	5000	5000	
Total soil N (mg kg^{-1})										
1979	458	495	483	500	487	513	545	505	477	± 6.8
1983	474	493	498	489	522	531	548	524	517	±15.1
1987	483	497	486	456	479	525	532	548	544	±20.7
Inputs and outputs, 1979-1987										
Change in soil N										
mg kg^{-1}	25	2	3	-44	-8	12	-13	43	67	±25.8
kg ha^{-1}[3]	105	8	13	-181	-34	50	-55	176	281	
Additions as										
Fertilizer N (kg ha^{-1})	0	300	600	600	600	600	600	600	0	
Organic N (kg ha^{-1})	-	-	-	-	-	-	127	634	634	
Removals of crop N	620	685	747	797	816	836	771	865	755	
Estimated N fixation[4]										
Total (kg N ha^{-1})	725	393	160	16	182	286	-11	-193	402	
Average (kg N ha^{-1} a^{-1})	91	49	20	2	23	35	-1	-24	50	

1. RR = return of residues (cereal straw).
2. FYM = farmyard manure.
3. Bulk density assumed at 1.40 t m^{-3}.
4. Estimate of fixation ignores N inputs in rainfall, and losses by leaching and volatilization.

of the 11-year mean. The double-cropping system shows much less variation (CV=13%) compared to the traditional practice of a single crop (CV=40%) (Table 20). The stability of the traditional system appears to be more susceptible to the vagaries of the weather as the CVs for yield and rainfall are similar (40% vs. 30%). Annual rainfall totals can be misleading because they do not indicate seasonal distribution and the timing of rainfall or stress can be critical to crop yield. However, crops grown under the improved technology are evidently less affected by drought.

There is no indication that productivity has declined under either system during the 11 years. This is expected as the soil is very deep (> 2 m) and fertility is maintained either by regular input of fertilizer or by natural mineralization. Nevertheless, the watershed concept has clearly demonstrated the efficiency of the soil-and-water-conservation practice and has increased the stability of crop production in an erratic rainfall regime typical of many parts of the SAT.

Table 20. Grain yield, runoff, and soil loss under improved and traditional technologies on deep Vertisols in 11 successive years, ICRISAT Center 1976–1987.

Year	Cropping period rainfall (mm)[1]	Improved system (double cropping) Total yield[2] ($t\ ha^{-1}$)	Runoff (mm)	Soil loss ($t\ ha^{-1}$)	Traditional system (single crop) Chickpea ($t\ ha^{-1}$)	Runoff (mm)	Soil loss ($t\ ha^{-1}$)
1976/77	708	3.92	73	0.98	0.54	238	9.20
1977/78	616	4.29	1	0.07	0.86	53	1.68
1978/79	1089	3.40	273	2.93	0.53	410	9.69
1979/80	715	3.49	73	0.70	0.45	202	9.47
1980/81	751	4.50	116	0.97	0.56	166	4.58
1981/82	1073	4.24	332	5.04	1.04	435	11.01
1982/83	667	4.36	10	0.20	1.23	20	0.70
1983/84	1045	4.81	154	0.80	0.47	289	4.70
1984/85	546	4.36	11	N[3]	1.23	75	N
1985/86	477	3.42	4	N	0.84	18	N
1986/87	538	4.83	35	N	1.27	114	N
Mean	748	4.15	98.4	1.46	0.82	183	6.38
SE	±223	±.52	±113	±1.69	±0.32	±147	±3.97
CV (%)	30	13	114	116	40	80	62

1. Average rainfall for Hyderabad (29 km from ICRISAT Center) based on 1901-1984 data is 784 mm with a CV of 27%.
2. Total yield of sorghum and pigeonpea.
3. N = Measurements were not taken.

Testing Technology

Fertilizer Practices

Soil Fertility

We have been collaborating with the International Fertilizer Development Center (IFDC) since 1982 in a research program designed to find ways of improving fertilizer use and efficiency that will increase agricultural production in the Sahel.

In 1987, we conducted on-station experiments at ISC and the INRAN research station at Bengou, and off-station trials at Gobery and Gaya, Niger.

Phosphorus. Phosphate rock from deposits at Tahoua (PRT) and at Parc-W (PRW) were tested for use as pearl millet fertilizers in collaborative studies with IFDC during 1985-87. In trials at Gobery, we compared partially acidulated rock phosphate PARP (50% converted to monocalcium phosphate) from these Nigerien deposits with triple superphosphate (TSP) and single superphosphate (SSP) from commercial sources. Parc-W PAPR, SSP, and TSP were equally effective but Tahoua PAPR was no more effective than finely ground PRT. This was probably because the iron content of PRT (10% Fe_2O_3) reacted to make P insoluble as the PAPR aged after acidulation.

For the different P sources, we determined soil P available at 50% flowering of pearl millet in soil to which a total of 40 kg P ha^{-1} or 70 kg P ha^{-1} had been applied over 3 years. Where 40 kg P ha^{-1} had been added, only commercial sources of P gave a Bray P1 value significantly higher than the control (Table 21). The relatively low residual level of available P in the Tahoua PARP treatment is attributed to immobilization by iron and is consistent with the poor response by pearl millet.

An advantage of the low P absorption capacity of these sandy Sahelian soils is the high residual effect of P fertilizers. In a long-term trial conducted at Gobery, we applied fertilizers during the 1984 cropping season and followed residual effects in 1985, 1986, and 1987. Four years after the application of 40 kg P ha^{-1} as SSP pearl millet grain yield still increased four-fold over the control. At the level of 13 and 26 kg P ha^{-1}, there were no differences between SSP, TSP, Parc-W PR, and Parc-W PARP (40% acidulated). The critical level of available P necessary for 90% of maximum yield was 10 mg kg^{-1} as determined by the Bray P1 method.

Nitrogen. Owing to the wide spacing of pearl millet crops in Niger, plant roots must explore a

Table 21. Cumulative effect of phosphorus source and rate of application of available P [Bray P1 (mg^{-1})] at pearl millet flowering in the 3rd year, Gobery, Niger, rainy season 1987[1].

	Total P applied 1985-1987 (kg P ha^{-1})	
Phosphorus source	40	70
Tahoua rock phosphate (PRT)	3.66	5.35
Tahoua rock phosphate partially acidulated (Tahoua PARP)	3.62	3.91
Parc-W rock phosphate (PRW)	3.33	4.57
Parc-W rock phosphate partially acidulated (Parc-W PARP)	4.62	8.05
Single superphosphate (SSP)	5.64	11.11
Triple superphosphate (TSP)	5.29	10.28
Control	2.24	2.24
SE	±0.81	±0.72
CV (%)	45	25

1. Randomized complete block, plot size 50 m^2.

Table 22. Recovery of ^{15}N from pearl millet grain, above-ground plant tissue, soil profile, and total recovery for different sources and methods of nitrogen application, Sadoré, Niger, rainy season 1985[1].

Treatment	Grain (%)	Plant tissue (%)	Soil profile (%)	Total ^{15}N recovery (%)
Urea placed on hill surface (USHP)	5.3	14.1	11.2	25.6
Urea placed deep (UG)	5.0	10.3	24.8	32.2
Urea broadcast and incorporated (UBI)	8.9	15.4	33.4	48.9
Calcium ammonium nitrate placed deep (CANG)	12.3	37.7	29.8	67.6
Calcium ammonium nitrate broadcast and incorporated (CANBI)	10.9	21.8	31.6	53.3
Ammonium nitrate placed deep (ANG)	13.4	28.9	31.9	60.8
Ammonium nitrate broadcast and incorporated (ANBI)	14.6	27.9	39.6	67.5
SE	±1.2	±2.0	±1.9	±2.4
CV (%)	26	22	17	12

1. Randomized complete block, plot size 50 m^2.

large volume of soil if they are to receive maximum benefits from broadcast fertilizer. Volatilization of broadcast urea also causes losses. Our previous attempts to improve N uptake by deep placement of N as urea (U) near the plant were unsuccesful because of loss by volatilization. At Sadoré in 1985, we attempted to improve the spatial availability of N while avoiding N volatilization. Calcium ammonium nitrate (CAN) and ammonium nitrate (AN) (which do not readily volatilize) were used in a deep-placement treatment (CANG and ANG) and compared to CAN, AN, and U broadcast and incorporated (CANBI, ANBI and UBI). Urea drilled in hills, i.e., placed deep (UG) and urea placed on the hill surface (USHP), as practiced by farmers in Niger, were also introduced as treatments. The percentage ^{15}N recovery is reported in Table 22. Nitrogen losses were up to 75% when these practices were used compared to only 32% when nitrogen was applied as CAN placed deep.

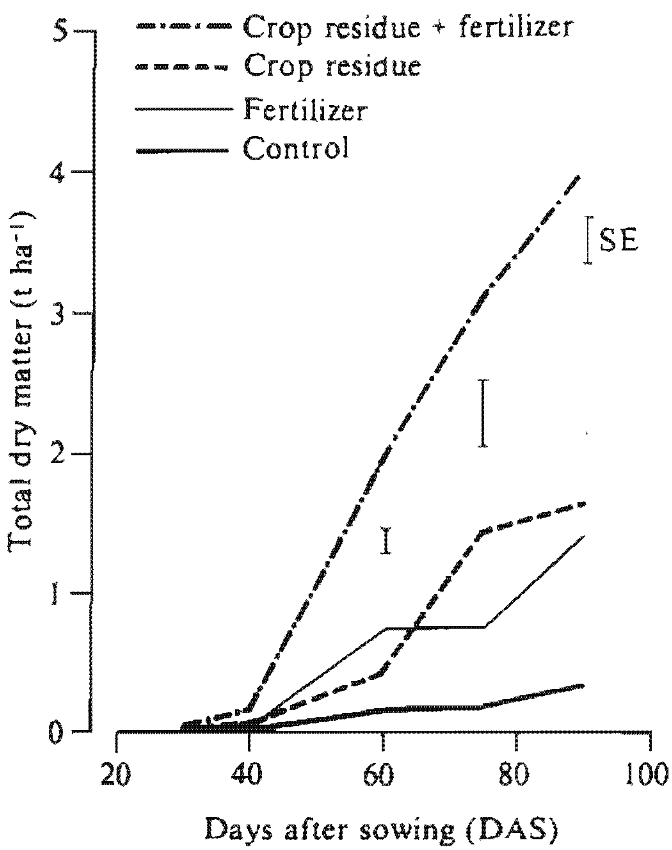


Figure 23. Effect of application of pearl millet residue over a five-year period (1983-1987) on total dry matter of pearl millet at various growth stages, Gobery, Niger, rainy season 1987 .

Crop residues. In 1983, we set up a trial at Sadoré to study the effect of crop residue and fertilizer on pearl millet. Crop residues (4 t ha^{-1} pearl millet stover) were added in the first year to the treated plots. In subsequent years, residues produced were simply placed on the plot surface. Addition of crop residues alone gave the same dry matter yield as fertilizers alone (Fig. 23). Highest dry matter yields were obtained when crop residues were supplemented with mineral fertilizers.

Fertilizer Use on Sorghum

We continued collaborative IFDC/ICRISAT on-farm research to identify the constraints to farmers' use of fertilizer on dryland crops in India (ICRISAT Annual Report 1986, pp. 315-316). A farmer-managed experiment to determine how manuring history and soil types affect the economics of sorghum grain yield response to nitrogen was carried out in Kanzara village in the Vidharbha region of Maharashtra. This region is characterized by medium-deep Vertisols and an annual rainfall of 800–1200 mm. Improved sorghum cultivars have been widely adopted in this region during the past decade but yields remain below potential, in part because farmers use less than the recommended rate of 50-80 kg N ha^{-1}.

In the 1986 rainy-season experiment, basal urea was applied at four nitrogen levels—28, 57, 85, and 114 kg N ha^{-1}—replicated twice on 100 m^2 subplots in each of seven fields. Farmers managed the crops with researchers being present at sowing and harvesting. Plots had been selected to represent three major soil groups distinguished by farmers using the local soils taxonomy. This taxonomy, identified through interviews with farmers, included three major and four secondary soil types distinguished primarily by depth and percentage of black soils.

Yield response to N varied widely. Based on prevailing N and grain sorghum prices, optimal fertilizer levels ranged from 0-113 kg N ha^{-1}. Moreover, in nearly all the cases, optimal fertilizer levels were consistently grouped by farmer soil type and were inversely related to soil quality. Neither organic carbon nor mineralizable N tests were as good as the farmer classification for grouping the response results. The data support the hypothesis that this classification is an efficient and accurate basis for fertilizer recommendations.

The actual use of N by farmers in Kanzara is less than the levels derived from experimental results. Through farmer interviews we determined that this is largely due to the relative newness of the cultivars and the inadequate time for farmers to evaluate fertilizer responses over a range of seasonal conditions. In addition, calculation from one season's experiment does not reflect the year-to-year uncertainty faced by farmers when making decisions about fertilizer use.

These results suggest that the major constraints on N-fertilizer use may be learning-related and the situation could be expected to improve as farmers gain experience in using fertilizer on improved sorghum cultivars. Recommendations, tailored to farmers soil groups, would expedite the adjustment process. Owing to uncertain rainfall patterns, the current extension recommendations may be too high for all but the best quality fields. Longer-term experimental data and/or crop modeling will be necessary to make a more conclusive assessment.

Adoption of Vertisol Technology

In 1987, we studied farmer assessment of the Vertisol technology options tested at Begumganj

Table 23. Farmer adoption of improved Vertisol technology options by 18 watershed and 7 non-watershed farmers in Begumgunj, Madhya Pradesh, India, 1986/87.

	18 Watershed farmers			7 Nonwatershed farmers
Practice	No.using before 1982[1]	No. adopting during field trials	No. using in 1986/87	No. using in 1986/87
Rainy-season cropping of soybean	4[2]	14[2]	13[3]	4[3]
Dryland double cropping	Probably none	17	9+4[4]	1+3[4]
Summer plowing	18	0	18	6
Improved drainage furrows	0	18	2	0
Broadbeds	0	18	0	0
Dry sowing	0	8	1	0
Improved seed	3	13	16	4
Use of chemical fertilizer	4	11	15	5
Using recommended dose of fertilizer[5]	0	0	4	1
Row-seeding rainy-season crop	1	14	14	5
Chemical plant protection	1	6	7	6
Use of wheeled tool carrier	0	18	0	0

1. ICRISAT field trials began in 1982/83.
2. Includes wet and dryland.
3. Includes those growing soybeans on land that can be irrigated; 23 of 25 farmers grew soybeans in 1986/87.
4. The second number indicates the number of farmers who planned to double crop but had to fallow in the postrainy season because of moisture deficit in 1986/87.
5. All who apply fertilizer at sowing mix it with the seed.

in Madhya Pradesh from 1982/83 to 1984/85 (ICRISAT Annual Report 1985, pp. 280-282). Twenty-five farmers were interviewed, 18 with land in the watershed, and 7 with neighboring land.

In general, seed-centered, agronomic recommendations were accepted more readily than resource-based, land- and water-management practices (Table 23). Dry sowing before the rainy season, small watershed management, and use of the wheeled tool carrier were new to farmers in 1982. One farmer continues to dry sow but others who had unfavorable experiences reverted to their traditional practice of sowing after the onset of the monsoon. Several farmers with middle-elevation watershed land continue to use furrows (but not broadbeds) and to maintain field drains, but those uphill from them are indifferent and those downhill are negative to the watershed-management plan. The wheeled tool carrier is no longer in use, but several farmers liked its sowing performance.

Some components, such as cropping soybeans in the rainy season and the use of inorganic fertilizer and improved seed, were being tried by a few farmers before the start of the verification trial. Their adoption has expanded dramatically since 1982/83. Farmers are now keenly aware of the potential benefits from double cropping and this consequence of the verification trial will probably be its major lasting contribution.

Table 24. Planned treatment combinations under evaluation in INRAN/ICRISAT operational-scale research, Birni N'Konni, Niger, 1987-1989.

Treatment combinations	Crop rotation and year		
	1987	1988	1989
Traditional[1]	M/C	M/C	M/C
Improved[2]			
F + AT + RO	M	M	M
F + AT + RI	M	C	M
F + AT + RI	C	M	C
F + HC + RI	M	C	M
F + HC + RI	C	M	C
F + AT + RO	C	C	C

1. No chemical fertilizer, mixed cropping of pearl millet and cowpea (M/C), hand cultivation.
2. Improved varieties of pearl millet (M) or cowpea (C). Thirteen kg P ha^{-1} before sowing. Sowing in parallel rows. F = fertilizer; AT = animal traction for presowing direct ridging and interrow weeding; RO = without crop rotation; RI = with crop rotation; and HC = hand cultivation (no presowing ridging).

Operational Scale Studies

West Africa

In 1987, INRAN and ICRISAT began collaborating on an operational scale experiment at Birni N'Konni, Niger, an INRAN substation 340 km east of Niamey. Soils in this area are characterized by a higher clay content than those at Sadoré.

We compared combinations of innovative technologies including; application of phosphorus (13 kg P ha^{-1}), improved varieties of pearl millet (CIVT) and cowpea (TN 578) in sole crop systems, rotation of sole crops, and animal traction for presowing, ridging, and weeding. These components were combined in 7 treatments (Table 24). The experimental design was similar to the one used at ISC, Sadoré (ICRISAT Annual Report 1986, p. 310), with four replications.

The onset of the rainy season at Birni N'Konni was late by 5 weeks, and subsequent total rainfall was only 240 mm. Nevertheless, sole pearl millet with 13 kg P ha^{-1} yielded 0.85 t ha^{-1} of grain (SE = ±0.07) and 1.55 t ha^{-1} of stover (SE = ±0.16), compared with 0.26 t ha^{-1} of grain and 1.08 t ha^{-1} stover in the traditional system of mixed cropping pearl millet and cowpea without fertilizer. Sole-crop cowpea with addition of fertilizer yielded 0.60 t ha^{-1} of grain (SE = ±0.04) and 1.23 t ha^{-1} of hay (SE = ±0.13) compared with the 0.11 t ha^{-1} of grain and 0.71 t ha^{-1} of hay under the traditional system.

Sowing on ridges and mechanized interrow weeding using animal traction gave increases of 0.16 t ha^{-1} of pearl millet grain, 1.00 t ha^{-1} of pearl millet stover, and 0.34 t ha^{-1} of cowpea hay, but cowpea grain was reduced by 0.13 t ha^{-1} in the improved sole rop system.

Mechanization of interrow weeding reduced the time spent on the first weeding by 42% from 56 man-h ha^{-1} (including manual thinning) and the second weeding by 37%, from 36 man-h ha^{-1}. Total labor requirements were 292 man-h ha^{-1} for the traditional system, 240 man-h ha^{-1} for hand-cultivated pearl millet, and 231 man-h ha^{-1} for animal-traction cultivated pearl millet. Hand-cultivated improved cowpea had a total labor requirement of 386 man-h ha^{-1} compared with 423 man-h ha^{-1} when cultivated by animal traction. These high figures are primarily due to the labor-intensive hand-picking of the cowpeas, which required 175 man-h ha^{-1}.

India

Last year we described joint ICAR/ICRISAT projects on two watersheds; Mittimari in the Kolar district of Karnataka, and Chevella in Medak district of Andhra Pradesh (ICRISAT Annual Report 1986, p 317). These collaborative studies continued in 1987.

In the Mittimari watershed, in cooperation with the University of Agricultural Sciences, Bangalore, we studied responses of a groundnut/pigeonpea intercrop to land-management practices on Alfisols over 10 farms. Table 25 shows that mean yields of both groundnut and pigeonpea were significantly increased by better management. Rainfall in the cropping season was 464 mm in 1986 and 443 mm in 1987. Improved land management also reduced runoff. Seasonal runoff values in 1986 were: farmers practice, 39 mm; contour cultivation, 32 mm; contour cultivation and furrows, 25 mm; and contour cultivation and trenches, 22 mm.

We also compared the effects of primary tillage using three implements: 1. animal-drawn country plow (8-10 cm deep), as commonly used in this area; 2. animal-drawn Kolar moldboard plow (12-15 cm deep), and 3. tractor-drawn disc plow (20-25 cm deep). As there were no significant yield differences between the three practices, the existing tillage practice appears to be adequate for groundnut/pigeonpea intercropping on this soil.

In the Chevella watershed, we collaborated with CRIDA to evaluate land-management practices on Vertic Inceptisols in two farmers' fields and to compare animal-drawn seed and fertilizer drills in another farmers' field. In 1987, sunflower (Fig. 24) yield was 1.41 t ha^{-1} with contour

Table 25. Grain yield (t ha^{-1}) of groundnut (JL 24) and pigeonpea (HY 3) under different land treatments, Mittimari, India, rainy seasons 1986 and 1987.

	1986		1987	
Treatment	Groundnut	Pigeonpea	Groundnut	Pigeonpea
Farmers practice (control)	0.86	0.74	1.14	0.42
Contour cultivation	1.00	0.82	1.20	0.56
Contour cultivation and furrows at 3.3-m intervals	1.09	0.91	1.27	0.54
Contour cultivation and trenches at 15-m intervals	1.17	0.89	1.35	0.65
SE	±0.06	±0.07	±0.06	±0.03

Figure 24. A farmer with his prolific sunflower crop in an ICAR/ICRISAT Cooperative land management study, Chevella watershed, rainy season 1987.

Table 26. Performance of seed and fertilizer drills used to sow sunflower at Chevella, India, rainy season 1987.

Drill type	Metering system	Pull force (N)	Work rate (ha h^{-1})	No. of plants m^{-2}	CU[1]
Fertiplanter[2]	Mechanical (Inclined plate)	893	0.36	9.3	52.0
Agribar[2]	Hand	1020	0.35	8.2	51.9
CRIDA[3]	Hand	402	0.47	11.4	42.4
CIAE[4]	Mechanical (Fluted roller)	775	0.34	12.1	38.2
Rayala gorru[5]	Hand	579	0.33	8.2	39.3
Local practice[6]	Hand	765	0.17	11.1	50.2
Mean		736	0.34	10.1	45.7
SE		±25.5	±0.044	±1.5	±4.16

1. CU = Coefficient of uniformity in plant spacing.
2. The Ferti-planter and Agribar, developed by ICRISAT, include covering and pressing devices; for other drills, seed and fertilizer were covered by dragging shrub branches behind them (normal farmer practice).
3. Developed by Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.
4. Developed by Central Institute of Agricultural Engineering (CIAE), Bhopal.
5. Local improved seed/fertilizer drill.
6. Dropping fertilizer and seed by hand behind country plow.

cultivation compared with 1.23 t ha^{-1} (SE = ± 0.04) in the control (farmers practice). Tied ridges (1.33 t ha^{-1}) gave no yield advantage over contour cultivation. However, tied ridges did reduce runoff; from a seasonal rainfall of 744 mm, runoff values were: control, 118 mm; contour cultivation, 95 mm; and contour cultivation with tied ridges, 69 mm.

The evaluation of seed and fertilizer drills showed that hand metering of seed could be as effective in obtaining uniform crop stand as mechanical metering (Table 26). A major factor in this result is that farmers in the Chevella area are highly skilled in hand metering. Among the drills tested the one developed by CRIDA was the best as it has a very low draft (0.4 kN) and is easy to construct and operate.

Modeling

Chickpea

In order to provide information needed to model the growth of chickpea, we measured biomass production, light interception, and transpiration by this crop grown on a Vertisol during the postrainy seasons of 1984, 1985, and 1986.

In 1984, we compared three cultivars (subtreatments) with irrigated and nonirrigated main treatments using a split-plot design. In 1985 and 1986, a line-source irrigation system that applied water each week was used to create a range of water deficits at various growth stages.

Dry-matter production was correlated with cumulative solar radiation interception in both irrigated and nonirrigated treatments (Fig. 25). The slopes of these lines representing the radiation use efficiency (RUE) of chickpea are not significantly different. In the irrigated treatments the RUE for both seasons and cultivars ranged from 0.49 to 0.67 g MJ^{-1} of solar radiation with a mean of 0.58 g MJ^{-1} (Table 27). In the nonirrigated treatments, it ranged from 0.39 to 0.57 g MJ^{-1} with a mean of 0.48 g MJ^{-1}. Radiation use efficiency showed a quadratic decrease with transpiration ratio (actual to poten-

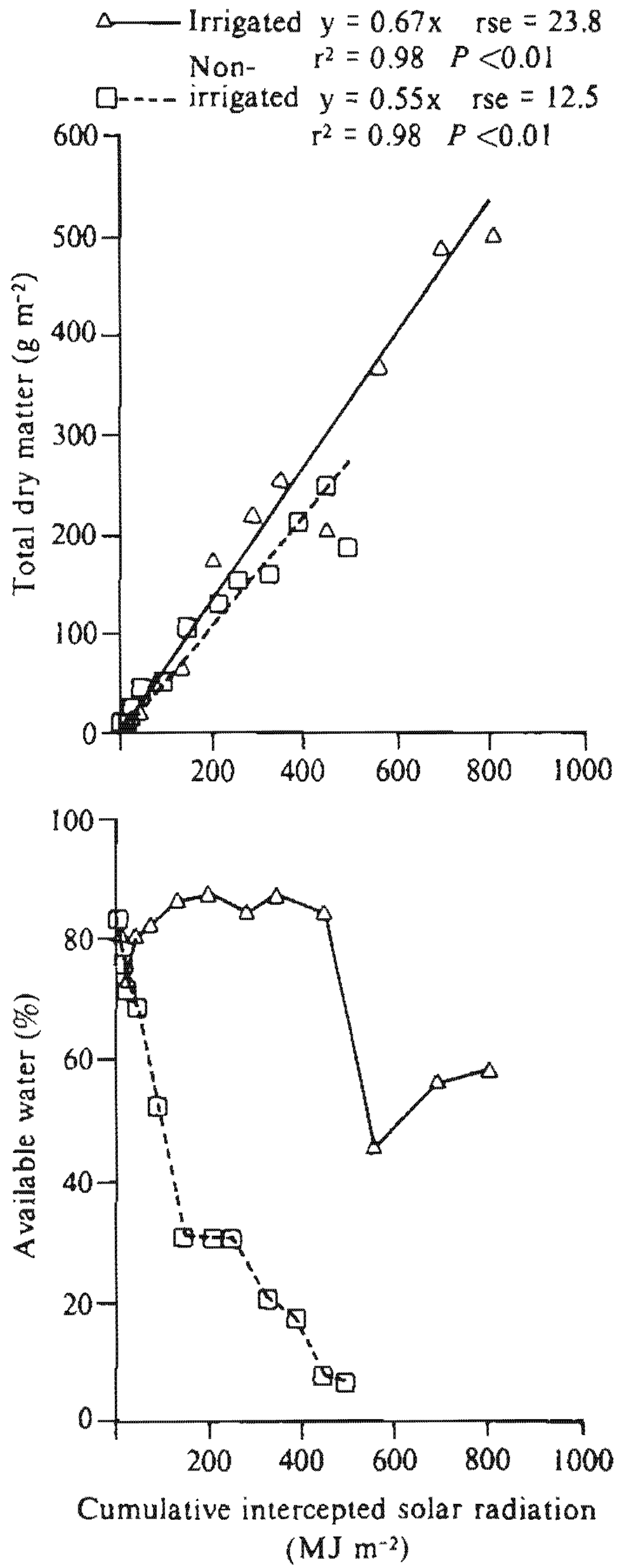


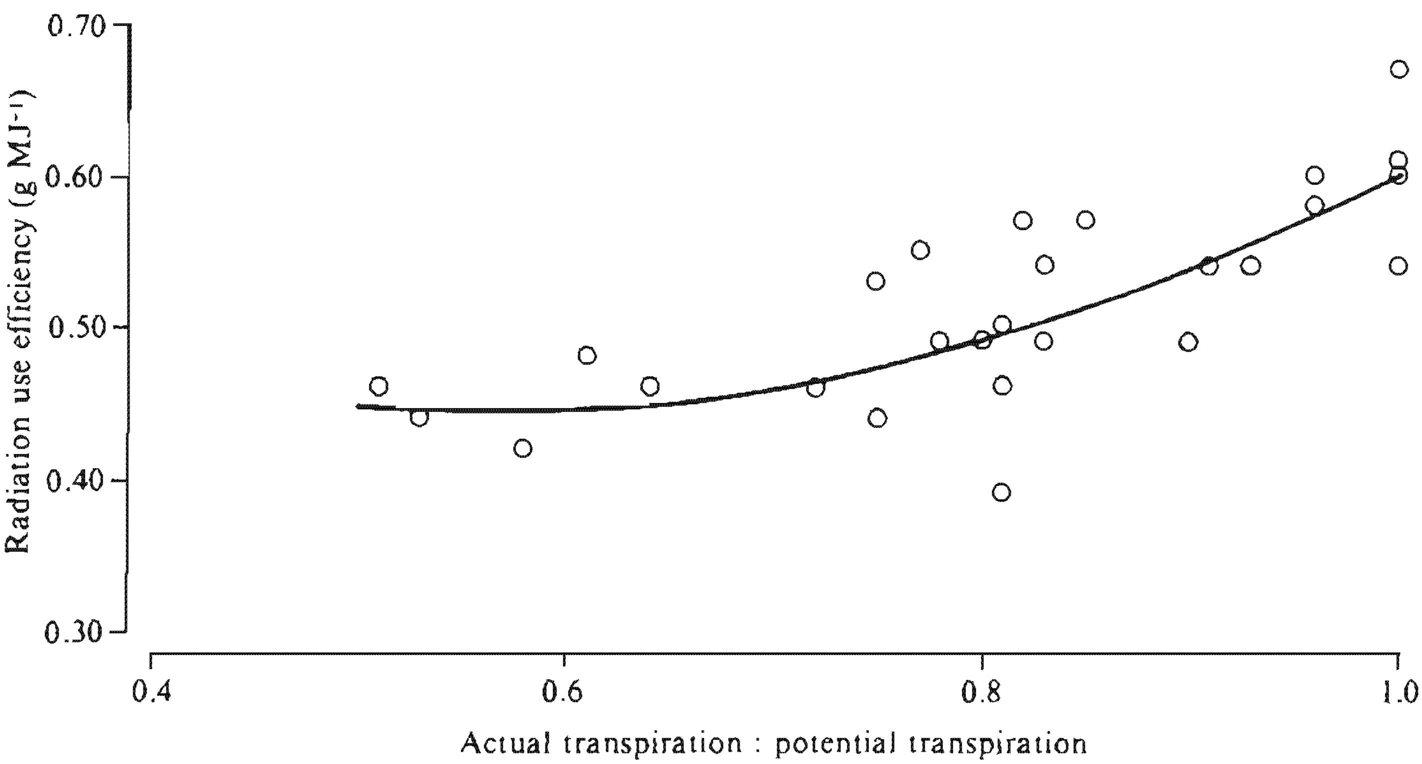
Figure 25. Relationship between total dry matter production, percentage of available water, and cumulative solar radiation interception by chickpea (cv Annigeri), ICRISAT Center, postrainy season 1984.

Table 27. Effect of drought on radiation-use efficiency (RUE) of different chickpea cultivars grown on irrigated and dryland, ICRISAT Center, postrainy seasons 1984, 1985, and 1986.

	Irrigated		Dry	
Season/ Cultivar	RUE ($g\ MJ^{-1}$)	SE	RUE ($g\ MJ^{-1}$)	SE
1984				
Annigeri	0.67	±0.018	0.55	±0.016
K 850	0.61	±0.029	0.57	±0.014
G 130	0.60	±0.015	0.44	±0.012
1985				
Annigeri	0.49	±0.016	0.46	±0.018
1986				
JG 74	0.54	±0.026	0.39	±0.011
Mean	0.58		0.48	

tial) observed during the season up to maximum dry-matter production (Fig. 26), but was not correlated with the saturation deficit of the air.

Dry matter production was linearly related to transpiration (Fig. 27) in both irrigated and nonirrigated treatments, the irrigated treatment producing 2.54 g of dry matter kg^{-1} of water transpired and the nonirrigated treatment 1.66 g. The dry matter-transpiration (DM-T) ratio in the irrigated treatment ranged from 1.94 to 2.54 g kg^{-1} over the three seasons, with a mean of 2.18 g kg^{-1} (Table 28). In the nonirrigated treatment it ranged from 1.42 to 2.16 g kg^{-1} with a mean of 1.76 g kg^{-1}. The DM-T ratio of chickpea decreased with increase in air saturation deficit. These ratios were multiplied by the corresponding values of saturation deficit to get quantities expressed as g kPa kg^{-1} of transpiration. This reduced the CV from 10.1 to 4.4% in the irrigated treatment indicating that the DM-T depends on atmospheric demand. In the nonirrigated treat-



$$y = 0.69 - 0.88x + 0.79x^2 \quad rse = 0.043$$
$$r^2 = 0.61 \quad P < 0.01$$

Figure 26. Relationship between radiation use efficiency of chickpea, and the ratio of actual to potential transpiration, ICRISAT Center, postrainy seasons 1984, 1985, and 1986.

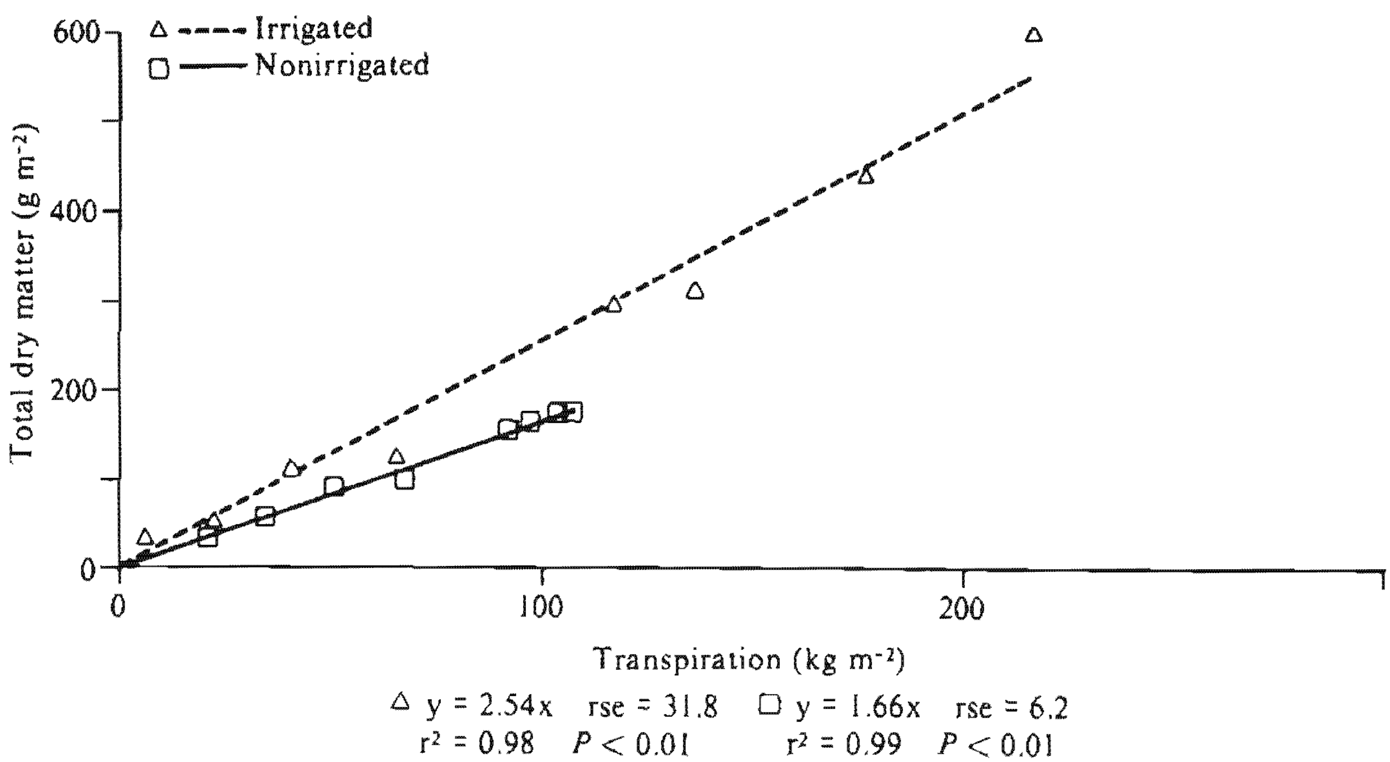


Figure 27. Relationship between total dry matter production and transpiration of chickpea (cv JG 74), ICRISAT Center, postrainy season 1986.

Table 28. Effect of moisture deficit on dry matter-transpiration (DM-T) ratio of chickpea and its normalization with saturation deficit of air, ICRISAT Center, postrainy seasons 1984, 1985, and 1986.

	DM-T ratio ($g\ kg^{-1}$)				Saturation deficit (kPa)				Normalized DM-T ratio ($g\ kPa\ kg^{-1}$)	
Season/Cultivar	Irrigated	SE	Dry	SE	Irrigated	SE	Dry	SE	Irrigated	Dry
1984										
Annigeri	2.16	±0.001	1.77	±0.008	2.46	±0.210	2.81	±0.218	5.3	5.0
K 850	2.11	±0.012	1.79	±0.010	2.46	±0.210	2.81	±0.218	5.2	5.0
G 130	1.94	±0.017	1.42	±0.007	2.46	±0.210	2.81	±0.218	4.8	4.0
1985										
Annigeri	2.16	±0.013	2.16	±0.013	2.26	±0.119	2.32	±0.122	4.9	5.0
1986										
JG 74	2.54	±0.015	1.66	±0.010	1.96	±0.090	2.19	±0.098	5.0	3.6
Mean	2.18		1.76						5.0	4.5
CV (%)	10.1		15.2						4.4	14.7
Grand mean		1.97							4.8	
CV (%)		16.3							11.2	

ment normalization of DM-T value did not significantly reduce the CV (from 15.2 to 14.7%). When DM-T ratios were pooled for all treatments, the CV decreased from 16.3 to 11.2% when saturation deficit was accounted for. A relatively conservative value of 4.8 g kPa kg^{-1} was obtained, which could be used to estimate biomass production in different water regimes.

Pearl Millet

The framework for a pearl millet simulation model was described earlier (ICRISAT Annual Reports 1983, pp.242-243; and 1984, p.255). We revised the phenology and growth subroutines of the model based on information generated by the Resource Management and Cereals Programs at ICRISAT Center, and by the Department of Physiology and Environmental Science of the University of Nottingham, UK. The durations (t) of three growth stages: emergence to panicle initiation (GS_1); panicle initiation to anthesis (GS_2), and anthesis to physiological maturity (GS_3) were simulated by:

$$\frac{1}{t} = (T - T_b)/\theta_1, \text{ when } T < T_o, \text{ or}$$

$$\frac{1}{t} = [(T_m - T)\ \theta_1/\theta_2]/\theta_1, \text{ when } T_o < T < T_m$$

where,

θ_1/θ_2 = $(T_o - T_b)/(T_m - T_o)$,
T = average air temperature,
T_b = base temperature (10°C),
T_m = maximum temperature (45°C),
T_o = optimum air temperature (30°C),
θ = thermal time for a developmental stage.

Daily potential dry-matter production was calculated based on light use efficiency and light interception (2.2 g of dry matter per MJ l of Photosynthetically Active Radiation intercepted). Daily net dry-matter gain is calculated by accounting for soil water deficits. The water deficit coefficients (WATDCO) were derived from field experiments conducted at ICRISAT Center, and the algorithms used in the model are as follows:

$$\text{WATDCO} = 1.0, \text{ when } (1 - \frac{SW}{UL}) < 0.25, \text{ or}$$

$$= 1.48 - 1.97\,(1 - \frac{SW}{UL}),$$

$$\text{when } 0.25 < (1 - \frac{SW}{UL}) < 0.75, \text{ or}$$

$$= 0, \text{ when } (1 - \frac{SW}{UL}) > 0.75$$

where,

SW = Simulated available soil water on any day, and
UL = Available water-holding capacity of the root zone.

The model was tested with independent data. Simulated total dry matter (TDM) was compared with observed TDM of two pearl millet cultivars (BJ 104 and ICMH 412) grown under five drought treatments in 2 years (1983 and 1984 dry seasons) at ICRISAT Center (Fig. 28). The pearl millet model explained 70% variation in the observed TDM. The root mean square error was 17% of the mean observed TDM. On average, simulated TDM was 7% greater than that observed. However, the intercept for the regression between observed and simulated values was not significantly different from zero and the slope for the regression between observed and simulated values was not significantly different from 1.0. The model therefore accounted for water deficit effects reasonably well in terms of calculating TDM. It will be improved to account for the effects of water deficits on phenology, dry-matter accumulation rates in different growth stages, and yield components (grain mass, and grain numbers) in pearl millet.

The probability of successful crop establishment, and of various levels of biomass production for different sowing dates at Anantapur, computed with the model, is shown in Figure 29. Cultivars with a duration of 60 days were used for the simulation because the Cereal Improvement Program has been developing early-maturing pearl millet cultivars for short growing sea-

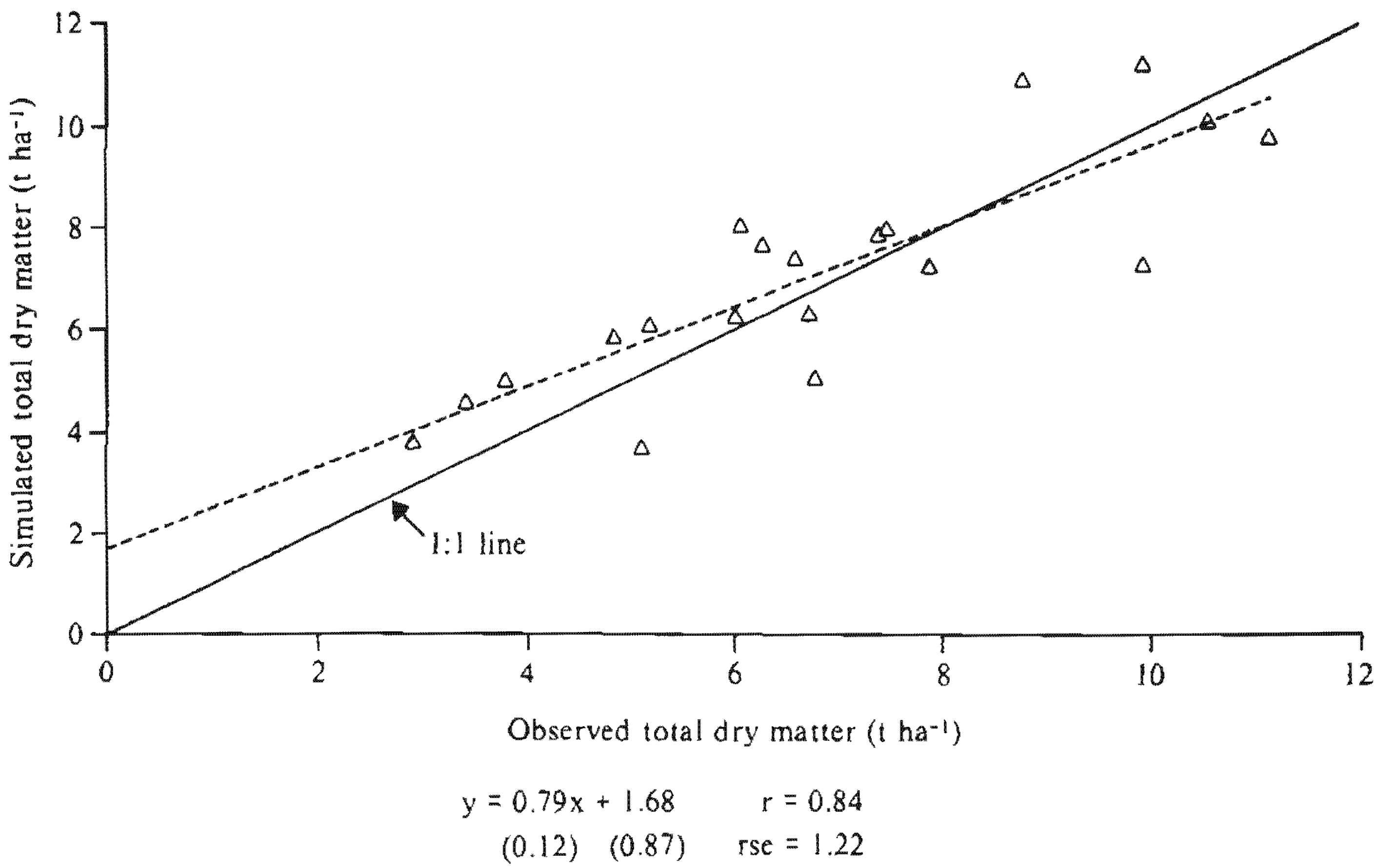


Figure 28. Relationship between simulated and observed total dry matter of pearl millet. Data (n = 20) pooled over two cultivars, five drought treatments, ICRISAT Center, postrainy seasons 1984 and 1985.

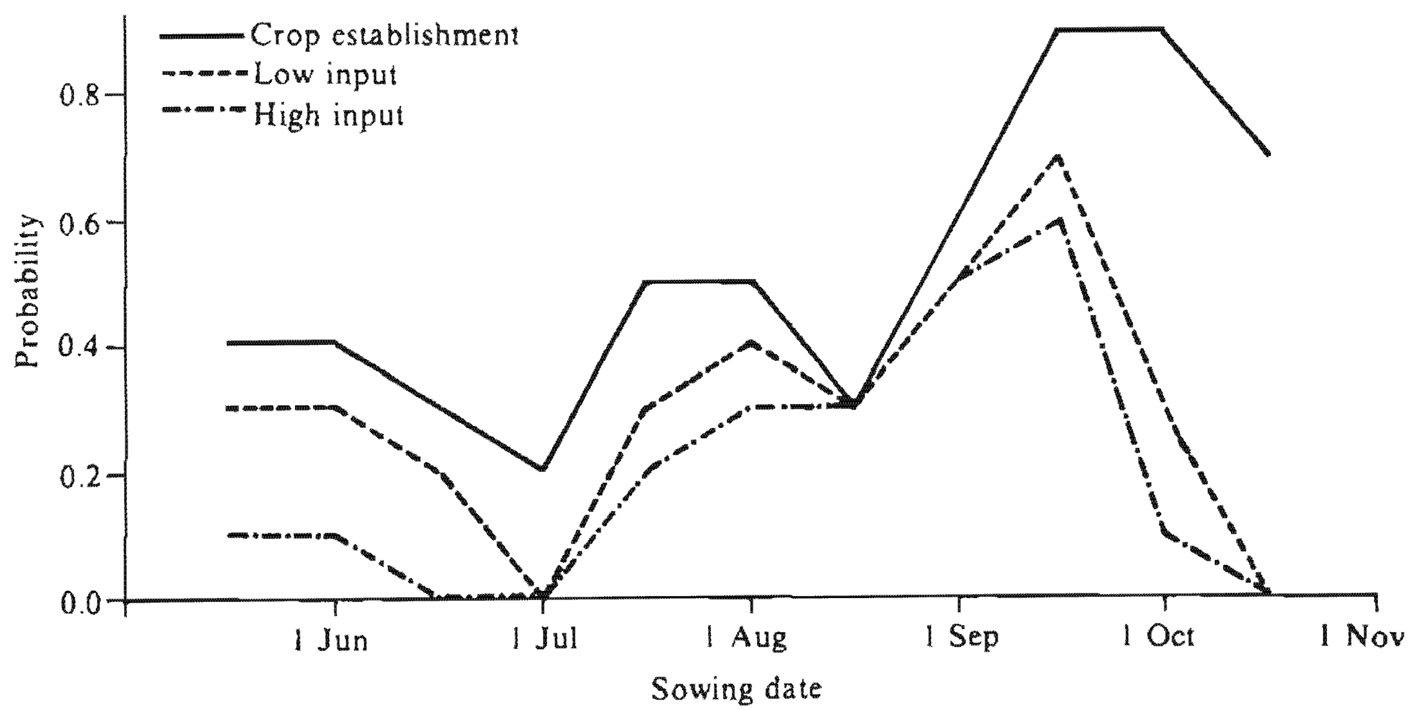


Figure 29. Probability of establishing a rainfed pearl millet crop and achieving at least 1.5 t ha^{-1} total dry matter under low input (assuming LAI = 1.0 at anthesis) and at least 3.0 t ha^{-1} total dry matter under high input (LAI = 3.0 at anthesis) for different sowing dates at Anantapur, India, 1977-1986.

sons. We modified the thermal time requirements of BJ 104 to simulate a crop with a duration of 60 days.

Daily climatic data from 1977 to 1986 were used. It was assumed that crops germinated when soil water exceeded 20 mm within 15 DAS and that plants emerged when 50 thermal time units accumulated after germination. Using this criterion, it is found that the probabilities of establishing a crop at Anantapur range from 30 to 90% across different dates of sowing with the best sowing date in September.

The probabilities of achieving TDM of more than 1.5 t ha^{-1} under low input (assuming LAI = 1.0 at anthesis) and at least 3.0 t ha^{-1} under high input (assuming LAI = 3.0 at anthesis) are 50% or less at all sowing dates except for 15 September. Results showed that crops sown between 15 August and 15 September have similar probabilities of achieving at least 1.5 t ha^{-1} TDM under high input and 3.0 t ha^{-1} TDM under low input.

Cooperative Activities

Collaborative Projects with National Programs

West Africa

Niger. We continued two joint pearl millet trials with INRAN, Niger, consisting of early- and medium-maturing cultivars at six locations in Niger. These trials are coordinated by INRAN and we contributed five entries for each trial. We also conducted a joint trial in pearl millet/cowpea intercropping. We participated in the recently formed SAFGRAD cowpea network, and conducted trials to which we contributed five entries.

At the invitation of INRAN we evaluated the type of rain-gauge network needed to monitor spatial variability of rainfall at five principal INRAN research stations in Niger, – Kolo, Ndunga, Bengou, Birni N'Konni, and Maradi. A network of rain gauges was installed at each station on a 200 × 200 m grid. During the 1987 rainy season we assisted INRAN staff in the collection of records.

In cooperation with INRAN, we also installed automatic weather stations at Bengou and Maradi. Rainfall, temperature, wind speed and direction, relative humidity, solar radiation, and soil temperature data were collected on an hourly basis and were automatically recorded. Computer programs were then used to generate monthly weather summaries which were regularly supplied to INRAN.

Mali. We continued to support three research stations in Mali—Sotuba, Cinzana, and Koporo—by providing financial aid (through USAID), as well as technical assistance on station management. We also collaborated with scientists on crop protection, breeding, and soil science problems.

India

Collaboration with CRIDA. Alley cropping agroforestry trials in the SAT have consistently shown that yields of many upland crops, e.g., sorghum and pigeonpea, are greatly reduced (30-90%) when hedgerow spacings are less than 5 m (ICRISAT Annual Report 1986, p.309). When rainfall is low (< 400 mm), crop yield is reduced even at 10-m spacing. This year, we conducted a joint experiment with CRIDA at Gunegal farm to determine the relative importance of competition for light and moisture in alley cropping of leucaena hedgerows, 10 m apart, with three crops (sorghum, castor, and cowpea). The hedgerows were arranged in an east-west orientation. The soil on this site is a medium-deep gravelly Alfisol. Our trials have shown that sorghum is the most tolerant crop, while castor is least able to tolerate competition (Fig. 30). Competition for moisture was examined by installing a polythene sheet in the soil on one side of each hedgerow, to a depth of 0.5 m, to act as a root barrier. Soil-moisture content was measured at several distances from the hedgerow. A control

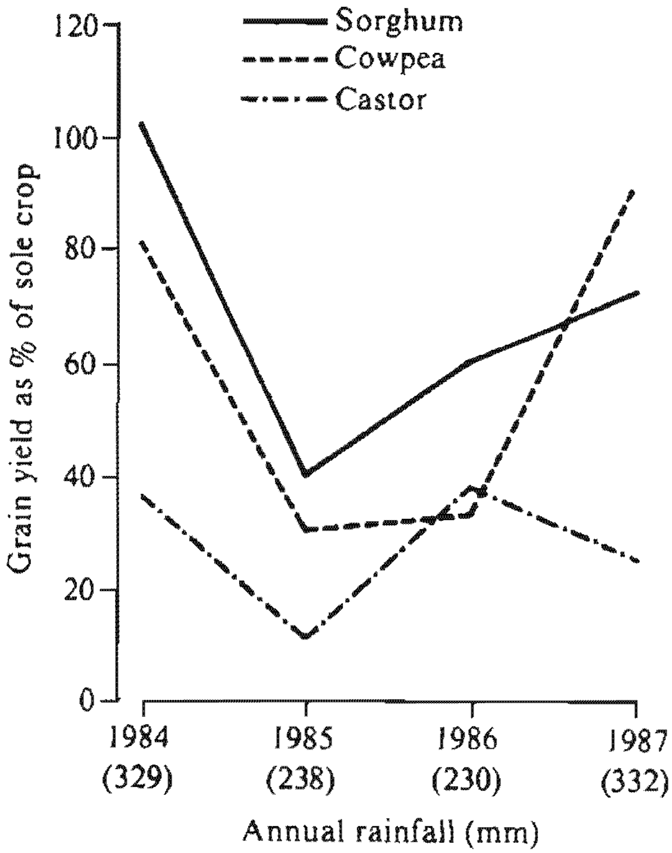


Figure 30. Grain yield of crops grown in a 10-m wide spacing of leucaena hedgerows on an Alfisol, Gunegal Farm, rainy seasons 1984–1987.

had no root barrier. Radiation, temperature, humidity, and windspeed were regularly monitored under the trees, at the middle, and at the edges of the alleys (Fig. 31).

The amount and distribution of rainfall were ideal for crop growth at this site in 1987. Yields of sole crops were 3.3 t ha^{-1} for sorghum, 0.79 t ha^{-1} for cowpea, and 0.73 t ha^{-1} for castor. The effect of hedgerow competition on yield of intercropped sorghum and cowpea was less than if the year had been dry. However, growth adjacent to the trees was greatly reduced where there was no root barrier. Because of the greater growth of crops in the middle of the alleys total yields for the barrier treatment were 20% greater than in sole sorghum, and 9% greater than in cowpea (Fig. 32). This improvement in yield is probably associated with the modification in microclimate within the alleys. Windspeed and saturation deficit were lower in the alleys compared to sole crops but the analysis is still incomplete. Crop rows adjacent to the trees intercepted 25–40% less radiation than sole crops. During this season the total solar radiation was rarely above 20 MJ m^{-2} d^{-1} because of cloudy weather; the average value was about 15 MJ m^{-2} d^{-1}.

It is clear that the main loss of yield in this agroforestry system is caused by competition for moisture rather than for light, even in a season when the mean radiation level was subnormal. Legumes such as cowpea benefit from shading, which reduces total transpiration and promotes plant growth. Excavation of the root system of leucaena showed extensive spread of the roots 10-30 cm below the soil surface, which explains the severe competition for moisture with adjacent crops.

In another collaborative project on Nitrogen Management in Drylands, parallel experiments

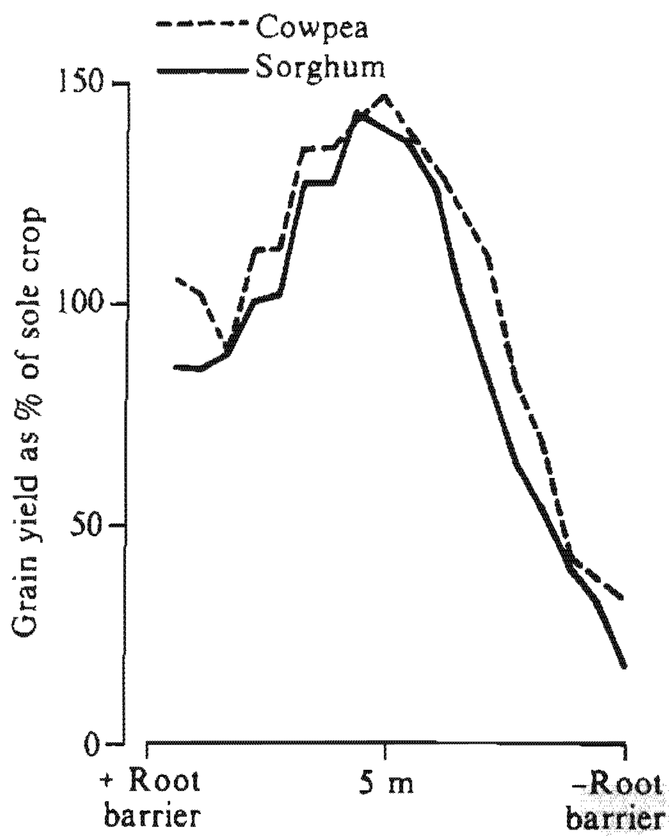


Figure 32. Relative grain yield of sorghum and cowpea between leucaena hedgerows, with and without a root barrier, Gunegal Farm, rainy season 1987.

Figure 31.a. Agroforestry trial location showing root barrier installation along one hedgerow (right) in May, and b. crops growing at the same location in September, Gunegal Farm, Andhra Pradesh, 1987.

on Alfisols at CRIDA's Hayatnagar Research Farm and ICRISAT Center assess the residual effects of legumes in simple rotations based on castor. (See also under Operational Scale Studies p.324).

Workshops, Conferences and Seminars

ICRISAT Center

ICAR/ICRISAT Working Group Meeting on Agrometeorology

The second ICAR/ICRISAT working group meeting on agrometeorology was held from 3-6 February 1987 at ICRISAT Center. The objectives were to review the research progress of various sub-centers of the All India Coordinated Agrometeorology Project (AICAP), to identify research thrusts in agrometeorology, and to formulate a time-bound technical program. The meeting was attended by 34 participants representing different centers of the AICAP project, CRIDA, ICAR, and IARI. Participants from Anand, Anantapur, Bangalore, Hisar, Jabalpur, Ludhiana, Mohanpur, Ranchi, and Solapur, reviewed progress in climate data analysis, microclimatological studies, and crop-weather relationships. The group emphasized the need to develop a detailed program of research for each of the centers on base-data analysis for the transfer of agrotechnology. The workshop recommended the adoption of a common methodology for minimum data collection on weather, soil, and crops, and for agronomic and crop-weather modeling experiments to be conducted at the various centers.

Groundnut Modeling Training Workshop

The first International Training Workshop on Groundnut Modeling was organized from 23 March-3 April, at ICRISAT Center. It was cosponsored by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and ICRISAT as part of the cooperative groundnut modeling experiments in progress at several locations in India (ICRISAT Annual Report 1986, p.317). Scientists from Australia, Sri Lanka, Thailand, USA, and India attended the workshop. Topics included phenology, photosynthesis and growth; testing and validation of the University of Florida PNUTGRO model; model adaptation and system analysis; data-base management; risk analysis and applications for crop improvement; and the use of expert systems. Field visits gave modelers a practical perspective. The participants brought 13 data sets of groundnut experiments conducted in areas ranging from 11°N to 32°N latitude to test the PNUTGRO model. These data sets provided excellent material for practical training in the use of the model. Deficiencies in the model were highlighted for future improvement.

West Africa

Soil, Crop, and Water Management for Rainfed Agriculture in the Sudano-Sahelian Zone

This workshop was conducted by INRAN, and the United States Agency for International Development (USAID), TROPSOILS, and ICRISAT, from 11 to 16 January in Niamey, Niger, for nearly 100 participants from different backgrounds. Countries represented included Burkina Faso, Cameroon, Cape Verde, Chad, Côte d'Ivoire, Ethiopia, France, Ghana, India, Italy, Mali, the Netherlands, Niger, Norway, Senegal, Sudan, UK, USA, and Zaire.

Thirty-seven technical presentations focused on rainfed agriculture, soil and water management, residue management and agroforestry, cropping systems, cultural practices, modeling, and economic considerations.

Working groups studied agroecological constraints and production systems, soil and crop management for efficient use of water, soil-fertility management, crop-residue management in relation to livestock and soil and water conservation, and the socioeconomic impact of new farming technologies.

Les Cultures Associés au Mali (Intercropping Systems in Mali)

In collaboration with the Institut d'économie rurale (IER), we organized a workshop on Intercropping Systems in Mali from 15 to 17 September in Bamako. About 50 scientists and extension workers from Mali reviewed past cropping systems research in Mali and developed a set of recommendations for future research. A number of papers related to agroclimatology, agronomy, breeding, crop protection, and on-farm verification were presented and discussed. Packages of technologies for cereal/cereal and cereal/legume systems were also developed for extension to farmers. The proceedings of this workshop are being jointly published by IER and the ICRISAT Mali program.

Publications

Institute Publications

Research Bulletin

von Oppen, M., and **Subba Rao, K.V.** 1987. Tank irrigation in semi-arid tropical India. Economic evaluation and alternatives for improvement. Research Bulletin no. 10. 1987. Patancheru, A.P. 502 324, India: ICRISAT. 38 pp. 29 ref. ISBN 92-9066-121-6. (RBE 010)

Information Bulletins

Sivakumar, M.V.K., and **Gnoumou, Faustin.** 1987. Agroclimatology of West Africa: Burkina Faso. Information Bulletin no. 23. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 198 pp. 20 ref. ISBN 92-9066-122-4. (IBE 023)

Sivakumar, M.V.K. et **Gnoumou, Faustin.** 1987. Agroclimatologie de l'Afrique de l'Ouest : le Burkina Faso. Bulletin d'information no. 23. 1987. Patancheru, A.P. 502 324, India: ICRISAT. 198 pp. 20 ref. ISBN 92-9066-123-2. (IBF 023)

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 196 pp. ISBN 92-9066-103-8. (CPE 030)

IARCs (International Agricultural Research Centers). 1987. Proceedings of the Workshop on Farming Systems Research, 17-21 Feb 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 160 pp. ISBN 92-9066-119-4. (CPE 039)

Journal Articles

Awadhwal, N.K., Takenaga, T., and **Bansal, R.K.** 1987. Development of improved agricultural implements at ICRISAT. Agricultural Mechanization in Asia, Africa and Latin America 18(3):21-25. (JA 593)

Bansal, R.K., and **Leeuwestein, R.** 1987. Performance evaluation of an oscillating trough-type fertilizer applicator. Journal of Agricultural Engineering Research 36(2):101-114. (JA 528)

Huda, A.K.S., Seetharama, N., and **Virmani, S.M.** 1986. Management of agricultural drought with special reference to soil water availability and water requirements of dryland crops in India. Jal Vigyan Sameeksha 1(1):153-171. (JA 666)

Huda, A.K.S., Virmani, S.M., and **Sekaran, J.G.** 1986. Simulation model for sorghum crop and its application. Indian Journal of Plant Physiology 29(4):317-330. (JA 362)

Huda, A.K.S. 1987. Simulating yields of sorghum and pearl millet in the semi-arid tropics. Field Crops Research 15(3,4):309-325. (JA 665)

Huda, A.K.S., Sivakumar, M.V.K., Sri Rama, Y.V., Sekaran, J.G., and **Virmani, S.M.** 1987. Observed and simulated responses of two sorghum cultivars to different water regimes. Field Crops Research 16(4):323-335. (JA 497)

Huda, A.K.S., and **Virmani, S.M.** 1987. Effects of variations in climate and soil water on agricultural productivity. Pages 36-55 *in* The impact of climatic variations on agriculture. vol. 2. Assessments in semi-arid regions (Parry, M.L., Carter, T.R., and Konijn, N.T., eds.). Dordrecht, Netherlands: Reidel. (JA 673)

Jodha, N.S. 1987. Introduction. Pages 1-20 *in* The impact of climatic variations on agriculture. vol. 2. Assessments in semi-arid regions (Parry, M.L., Carter, T.R., and Konijn, N.T., eds.). Dordrecht, Netherlands: Reidel. (JA 685)

Jodha, N.S., and **Singh, R.P.** 1987. Village level farm adjustment to rainfall variability. Pages 56-67 *in* The impact of climatic variations on agriculture. vol. 2. Assessments in semi-arid regions (Parry, M.L., Carter, T.R., and Konijn, N.T., eds.). Dordrecht, Netherlands: Reidel. (JA 686)

Jodha, N.S., and **Subba Rao, K.V.** 1987. Chickpea: world importance and distribution. Pages 1-10 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 503)

Jodha, N.S., and **Virmani, S.M.** 1987. Conclusions and implications. Pages 68-74 *in* The impact of climatic variations on agriculture. vol. 2. Assessments in semi-arid regions (Parry, M.L., Carter, T.R., and Konijn, N.T., eds.). Dordrecht, Netherlands: Reidel. (JA 687)

Rao, M.R., Rego, T.J., and **Willey, R.W.** 1987. Response of cereals to nitrogen in sole cropping and intercropping with different legumes. Plant and Soil 101(2):167-177. (JA 587)

Sahrawat, K.L. 1987. Determination of calcium, magnesium, zinc and manganese in plant tissue using a dilute HCl extraction method. Communications in Soil Science and Plant Analysis 18(9):947-962. (JA 618)

Sahrawat, K.L., Rao, J.K., and **Burford, J.R.** 1987. Elemental composition of groundnut leaves as affected by age and iron chlorosis. Journal of Plant Nutrition 10(9-16): 1041-1049. (CP 304)

Sivakumar, M.V.K., and **Piara Singh.** 1987. Response of chickpea cultivars to water stress in a semi-arid environment. Experimental Agriculture 23(1):53-61. (JA 363)

Sivakumar, M.V.K., and **Virmani, S.M.** 1987. Climate and production in the semi-arid and the humid tropics. Pages 129-169 *in* Global aspects of food production (Swaminathan, M.S., and Sinha, S.K., eds.). London, UK: Tycooly Publishing Ltd. (JA 320)

Stoop, W.A. 1987. Adaptation of sorghum/maize and sorghum/pearl millet intercrop systems to the toposequence land types in the North Sudanian Zone of the West African savanna. Field Crops Research 16(3):255-272. (JA 576)

Stoop, W.A. 1987. Variations in soil properties along three toposequences in Burkina Faso and implications for the development of improved cropping systems. Agriculture, Ecosystems, and Environment 19(3):241-264. (JA 714)

von Oppen, M., and **Parthasarathy Rao, P.** 1987. Chickpea marketing, trade and prices. Pages 383-397 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International. (JA 483)

Conference Papers

Bansal, R.K., Awadhwal, N.K., and **Mayande, V.M.** 1987. Implement development of SAT Alfisols. Pages 97-107 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 361)

El-Swaify, S.A., Singh, S., and **Pathak, P.** 1987. Physical and conservation constraints and management components for SAT Alfisols. Pages 33-48 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 357)

Engelhardt, T. 1987. Water supply optimization with discrete stochastic linear programming. Pages 79-87 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 360)

Huda, A.K.S., and **Virmani, S.M.** 1987. Agroclimatic environment of chickpea and pigeonpea. Pages 15-31 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 382)

Kanwar, J.S., and **Virmani, S.M.** 1987. Management of Vertisols for improved crop production in the semi-arid tropics: a plan for a technology transfer network in Africa. Pages 157-172 *in* Proceedings of the First Regional Seminar on Management of Vertisols under Semi-Arid Conditions, 1-6 Dec 1986, Nairobi, Kenya. Bangkok, Thailand: International Board for Soil Research and Management (CP 354)

Matlon, P.J. 1987. The West African semiarid tropics. Pages 59-77 *in* Accelerating food production in sub-Saharan Africa (Miller, J.L., Delgado, C.L., and Blackie, M.J., eds.). Baltimore, MD, USA: Johns Hopkins University Press (for the International Food Policy Research Institute). (CP 193)

Matlon, P.J. 1987. Making millet improvement objectives fit client needs: improved genotypes and traditional management systems in Burkina Faso. Pages 233-245 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 374)

Parthasarathy Rao, P., and **von Oppen, M.** 1987. Food legume production in Asia: past trends and future prospects. Pages 54-63 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 331)

Pathak, P., Singh, S., and **Sudi, R.** 1987. Soil and water management alternatives for increased productivity on SAT Alfisols. Pages 533-550 *in* Soil conservation and productivity: proceedings of the Fourth International Conference on Soil Conversation, 3-9 Nov 1985, Maracay, Venezuela. Caracas, Venezuela: University of Venezuela. (CP 262)

Patanothai, A., and **Ong, C.K.** 1987. Limits imposed by management in rainfed farming systems. Pages 72-82 *in* Food legume improvement for Asian farming systems: proceedings of an International Workshop, 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 335)

Sahrawat, K.L., and **Burford, J.R.** 1987. Salt in the soil environment, and its consequences for the management of chickpea and pigeonpea. Pages 105-108 *in* Adaptation of chickpea and pigeonpea to abiotic stresses: proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 386)

Seetharama, N., Krishna, K.R., Rego, T.J., and **Burford, J.R.** 1987. Prospects for sorghum improvement for phosphorus efficiency. Pages 229-249 *in* Sorghum for acid soils: proceedings of a Workshop on Evaluating Sorghum for Tolerance to Al-toxic Tropical Soils in Latin America, 28 May-2 Jun 1984, Cali, Colombia. Cali, Colombia: Centro Internacional de Agricultura Tropical. (CP 196)

Sivakumar, M.V.K., Piara Singh, and **Williams, J.H.** 1987. Agroclimatic aspects in planning for improved productivity of Alfisols. Pages 15-30 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 358)

Spencer, D.S.C., and **Sivakumar, M.V.K.** 1987. Pearl millet in African agriculture. Pages 19-31 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 380)

Squire, G.R., Ong, C.K., and **Monteith, J.L.** 1987. Crop growth in semi-arid environments. Pages 219-231 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 375)

Swindale, L.D. 1987. Farming systems and the international agricultural research centers: an interpretative summary. Pages 132-139 *in* Proceedings of the Workshop on Farming Systems Research, 17-21 Feb 1986, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 355)

Takenaga, T., and **Awadhwal, N.K.** 1987. Prospects for mechanization in developing countries of the semi-arid tropics. Pages 515-522 *in* Proceedings of the International Symposium on Agricultural Mechanization and International Cooperation in High Technology Era, 2-7 Apr 1987, University of Tokyo, Japan. Tokyo, Japan: Japanese Society of Agricultural Machinery. (CP 347)

von Oppen, M. 1987. Tank irrigation in southern India: adapting a traditional technology to modern socioeconomic conditions. Pages 89-93 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 359)

Willey, R.W., Reddy, M.S., and **Natarajan, M.** 1987. Conventional cropping systems for Alfisols and some implications for agroforestry systems. Pages 155-163 *in* Alfisols in the semi-arid tropics: proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 Dec 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 356)

Theses

Freire, M.J.V.C.A. 1987. Effect of staggered sowing dates and plant proportions in intercropping groundnut/maize. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 130 pp.

Mao, Mohamed Ahemed. 1987. The effect of planting dates and irrigation on the yield of two rainy season sorghum cultivars. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 110 pp.

TRAINING

Contents

Cover photo: In-service trainees learn to operate a JD Cone planter while sowing groundnuts on a broadbed-and-furrow system, ICRISAT Center, 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Training Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India.

TRAINING

The Training Programs at ICRISAT Center were coordinated by the Training Advisory Committee. Training officers and research scientists supervised the individualized programs for Postdoctoral Fellows, In-service Fellows, Research Scholars (MSc and PhD), In-service Trainees, and Apprentices. Participants were selected from nominations by national Ministries of Agriculture, Universities, or SAT research and development programs. This year, 210 individuals representing 46 countries received 4499 weeks of skill-development training at ICRISAT Center (Tables 1 and 2).

Table 1. Participants in longterm training programs, ICRISAT Center, 1987.

Category	Number	Weeks	Countries
Postdoctoral Fellows	5+11[1]	412	10
In-service Fellows	34+ 1	114	11
Research Scholars	10+15	815	11
In-service Trainees	124+ 3	2990	35
Apprentices	5+ 2	168	4
Total present	178+32	4499	46[2]

1. Number continuing into 1988.
2. Different countries.

Table 2. Participants by region, country, and category in training, ICRISAT Center, 1987.

Region/country	IS[1]	ISF	RSc	PDF	App	Total
Western Africa						
Benin	3					3
Chad	4			1		5
Ghana	1			0+1[2]		1+1
Guinea	4					4
Mali	5					5
Mauritania	1					1
Morocco		1				1
Niger	3					3
Nigeria	6					6
Senegal	1					1
The Gambia	4					4
Tunisia		1				1
Eastern Africa						
Burundi	1					1
Ethiopia	8+2		1+1			9+3
Kenya	3		0+2			3+2
Rwanda	2					2
Somalia	7		1			8
Sudan	6	3				9

Continued.

Table 2. *continued*

Region/country	IS	ISF	RSc	PDF	App	Total
Southern Africa						
Lesotho	1					1
Malawi	3					3
Mozambique	2		1			3
Swaziland	1					1
Tanzania	5					5
Zambia	8					8
Zimbabwe	5					5
Asia						
India	8	15	2+6	1+5		26+11
Nepal	1					1
Malaysia		1				1
Pakistan	5	1				6
People's Republic of China	4	2				6
Republic of Korea		1				1
Sri Lanka	3+1	5		0+1		8+2
Thailand	2					2
The Philippines	3	3				6
Vietnam	4					4
Yemen (PDR)	2					2
Yemen (AR)	3					3
Latin America and the Caribbean						
Mexico	3	1+1				4+1
Nicaragua	2					2
Trinidad				0+1		0+1
Others						
Australia			1	1		2
Federal Republic of Germany			1+3	0+1	1	2+4
Japan			0+1	0+1		0+2
The Netherlands			2		3+1	5+1
UK			0+1	1	1	2+1
USA			1+1	1+1	0+1	2+3
Total	124+3	34+1	10+15	5+11	5+2	178+32

1. IS: In-service Trainees, ISF = In-service Fellows,
   RSc = Research Scholars, PDF = Postdoctoral Fellows, App = Apprentices.
2. Number continuing into 1988.

International, regional, and national training activities involved more than 692 SAT national scientists, technicians, and students from 59 countries in over 947 man-weeks of transferring research technology (Tables 3 and 4). Their training opportunities included research skill development, research station management, thesis research, field study programs, field days, travelling seminars, and training workshops at ICRISAT Center and other locations.

Table 3. International, regional, and national workshop/training activities, 1987.[1]

Activity (sponsors/leadership)	Location	Participants	Countries represented
11-16 Jan. Water and crop management systems for rainfed agriculture in the Sudano-Sahelian Zone (INRAN, ICRISAT, USAID, TROPSOILS)	Niger	100	Burkina Faso, Cameroon, Cape Verde, Chad, Côte d'Ivoire, Ethiopia, Ghana, France, India, Italy, Mali, Netherlands, Niger, Norway, Senegal, Sudan, UK, USA, Zaire
11-31 Jan. Chickpea, pigeonpea, and groundnut pathology course (ICRISAT)	India	10	China, India, Malaysia, Morocco, Pakistan, Philippines, Sri Lanka, Tunisia
2 Feb-13 Mar. Farm superintendents training course (SADCC/ICRISAT, ICRISAT)	Zimbabwe	16	Botswana, Burundi, Lesotho, Malawi, Swaziland, Tanzania, Zambia, Zimbabwe
9-11 Feb. Chickpea scientists meeting (ICRISAT-India, Syria, Pakistan)	India	40	Ethiopia, India, Nepal, Pakistan
15-21 Feb. Regional groundnut plant protection study tour (ICRISAT, ICRISAT/Malawi)	Malawi, Zambia, Zimbabwe	22	Malawi, Mozambique, Swaziland, Tanzania, Zambia, Zimbabwe
16 Mar-16 Apr. Technicians' training course (SADCC/ICRISAT, ICRISAT)	Zimbabwe	7	Lesotho, Malawi, Zambia, Zimbabwe
20-29 Mar. Millet monitoring tour (SADCC/ICRISAT)	Zimbabwe	6	Botswana, Tanzania, Zambia, Zimbabwe
20-31 Mar. Sorghum monitoring tour workshop (SADCC/ICRISAT, INTSORMIL)	Zambia Zimbabwe	19	Malawi, Mozambique, Swaziland, Tanzania, Zimbabwe
23 Mar-3 Apr. International training workshop on groundnut modeling (IBSNAT, ICRISAT)	India	22	Australia, India, Niger, Sri Lanka, Thailand, USA
30 Mar-3 Apr. Thirty-third annual meeting of PCCMCA (CLAISA, INTSORMIL, ICRISAT)	Guatemala	16	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Mexico, Panama

Contd...

Table 3 *continued*

Activity (sponsors/leadership)	Location	Participants	Countries represented
2-5 Jun. Pigeonpea scientists meeting (ICRISAT)	Kenya	30	Ethiopia, Kenya, Malawi, Nigeria, Tanzania, Zimbabwe
8-9 Sep. Pearl millet field day (ICRISAT)	India	45	Botswana, India, Mali, Malawi, Pakistan
13-18 Sep. Short course on seed production (EARSAM, ICRISAT/SADCC, INTSORMIL, FAO, ICIPE, CIMMYT, Uganda Seed Scheme and seed companies)	Kenya	50	Botswana, Burundi, Ethiopia, Kenya, Lesotho, Malawi, Rwanda, Somalia, Sudan, Tanzania, Uganda, Zambia, Zimbabwe
21-24 Sep. Annual regional pearl millet improvement workshop (ISRA ISC, IC)	Senegal	40	Benin, Burkina Faso, Cote d' Ivoire, Guinea, Ghana, Mali, Niger, Nigeria, Senegal
21-24 Sep. Fourth regional workshop of the Southern Africa Sorghum and Millet Network (SADCC/ICRISAT)	Zimbabwe	47	Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, Zimbabwe
30 Sep-3 Oct. Third sorghum monitoring tour (WCASRN)	Burkina Faso	11	Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, The Gambia, Ghana, Niger, Nigeria, Senegal, Togo, Mali
5-15 Oct. Training workshop on *Striga* control and screening (ICRISAT, IRAT, Sudan, USA)	Burkina Faso	12	Burkina Faso, Cameroon, The Gambia, Ghana, Kenya, Mali, Niger, Nigeria, Sudan, Togo, Uganda
17-20 Nov. International workshop on sorghum stem borers (ICRISAT)	India	35	Burkina Faso, Cameroon, El Salvador, France, India, Kenya, Nigeria, Somalia, Sudan, UK, USA , Zimbabwe.

1. This is not intended to be a comprehensive list of workshops and conferences held at or sponsored by ICRISAT. Only those events that included a training component are listed.

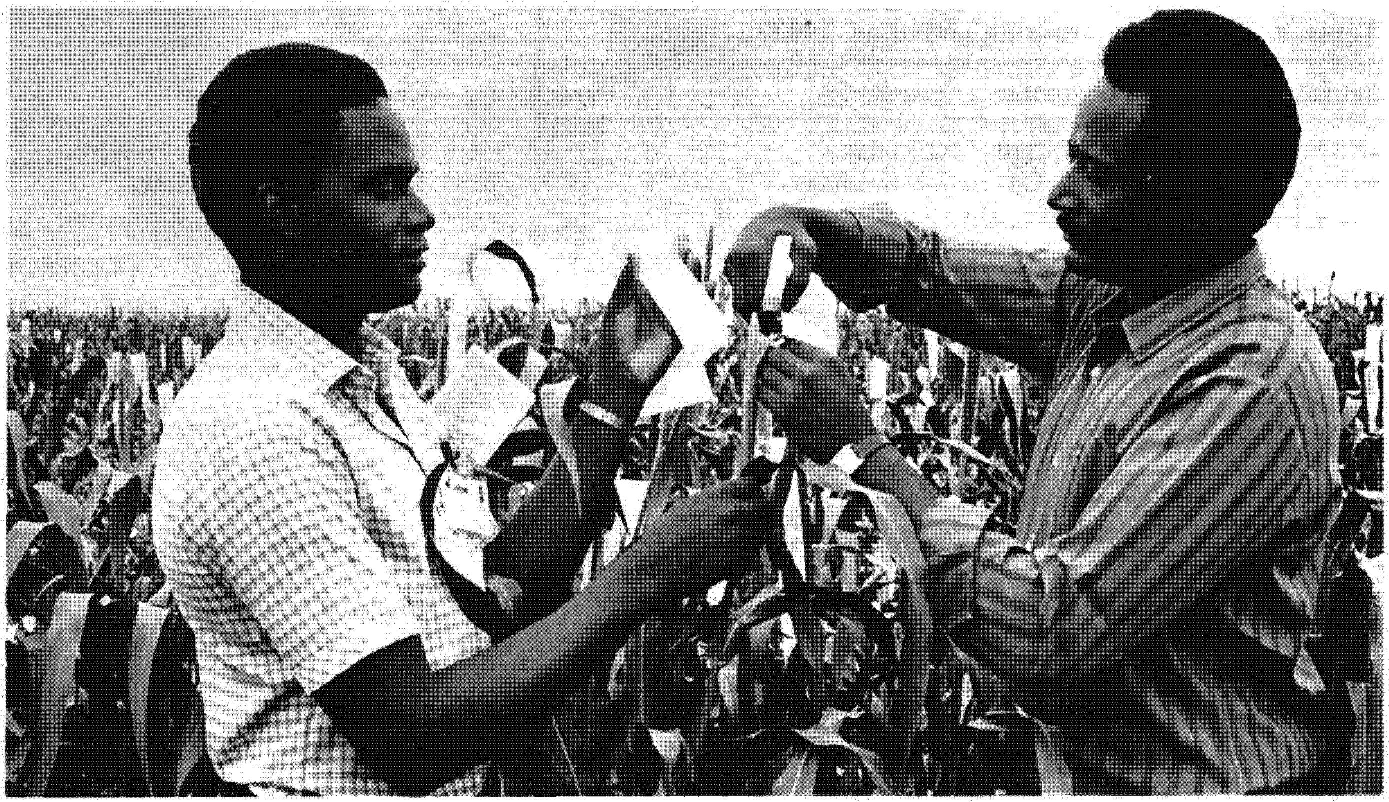
Table 4. In-country training activities, 1987.

Location	Activity (sponsors/leadership)	Participants	Countries or groups
Zimbabwe, participant countries	Disease resistance screening techniques. On-the-job training (SADCC/ICRISAT)	17	Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, Zimbabwe
Rwanda, Ethiopia	Training in screening techniques for sorghum ergot and downy mildew resistance (SAFGRAD, ICRISAT)	2 3	Technicians Scientists and technicians
India	5-7 Apr. Computer-based training program for NABARD/AFC officials on resource characterization (ICRISAT)	10	Development officers and managers from NABARD/AFC
India	11-15 May. Groundnut production technology course (ICRISAT)	35	Department of Agriculture scientists (6 states)
Thailand	31 Aug-3 Sep. Workshop on management of legume pests (ACIAR, AGLN/ICRISAT)	12	Legumes scientists/ technicians
Indonesia	7-10 Sep. Workshop on management of legume pests (ACIAR, AGLN/ICRISAT)	12	Legumes scientists/ technicians
Mali	15-17 Sep. Intercropping systems workshop (IER, ICRISAT)	50	Scientists and extension staff
India	11-15 Oct. Hybrid pigeonpea training course (ICRISAT)	12	University, ICAR, national seed corporations and private seed company scientists
Zimbabwe	Dec 87. Practical field experience in sorghum breeding, millet breeding, agronomy, pathology, and entomology (SADCC/ICRISAT)	9	University students (3 months)

In-service Training Programs at ICRISAT Center

An intensive 8-week English course was conducted by Osmania University, Hyderabad for 32 technicians and scientists from Benin, Burundi, Chad, the People's Republic of China, Guinea, Mali, Mauritania, Mexico, Mozambique, Nicaragua, Niger, Rwanda, and Sudan. The course stressed the acquisition of a scientific vocabulary with speaking, reading, and writing skill development.

During the 6-month rainy season program, 89 trainees planned, conducted, and summarized 212 experiments, trials or demonstrations for their individual studies (Table 5 and 6).



In-service trainees bagging pearl millet, ICRISAT Center, 1987.

Table 5. Experiments, trials and demonstrations planned and conducted by rainy-season in-service trainees, ICRISAT Center, 1987.

Experiment or trial involving	Crop					
	Sorghum	Pearl millet	Groundnut	Pigeonpea	Intercropping	Total
Varieties	21	5	18	5		49
Hybrids	4	1				5
Fertilizers	23	6	5	1		35
Weed control	1	2	1			4
Plant density	11	1	5	1		18
Sowing dates	2	1				3
Rhizobium trials			2			2
Pathology	3	3	11			17
Entomology	9		2			11
Intercropping					26	26
Sowing methods	2					2
Grain quality	3		1			4
Physiology	2					2
International trials	11	4	6	2		23
Demonstrations	1					1
'B' lines	1					1
Population cycles		1				1
Crossing blocks			8			8
Total	94	24	59	9	26	212

Table 6. Practical in-service training activities guided by program scientists, ICRISAT Center, Jun-Oct, 1987.

	Participants and length of study			
Discipline	1 week	2 weeks	3 weeks	6 weeks
Genetic Resources				
Sorghum	12			
Pearl millet	4			
Pigeonpea	2			
Groundnut	12			
Cereals				
Sorghum				
Physiology	2			
Pathology	13	1	2	
Striga resistance screening	1	2		
Entomology	5		10	
Breeding	4	14	1	
Grain quality	6			
Pearl millet				
Physiology	1			
Pathology	4	3	1	
Breeding	1	3		
Legumes				
Pigeonpea				
Agronomy	2			
Breeding			2	
Entomology	2	1	3	
Pathology/nematodes	4			
Quality	1			
Groundnut				
Breeding	2	10	1	
Cytogenetics	2			
Entomology	15			
Microbiology	2			
Pathology	4	3	10	
Physiology	4			
Quality	1	1		
Virology	14	1		
Resource Management				
Agroclimatology	4	1		1
Cropping systems	9	13		
Farm power and machinery	14		1	1
Land and water management	16	2	2	

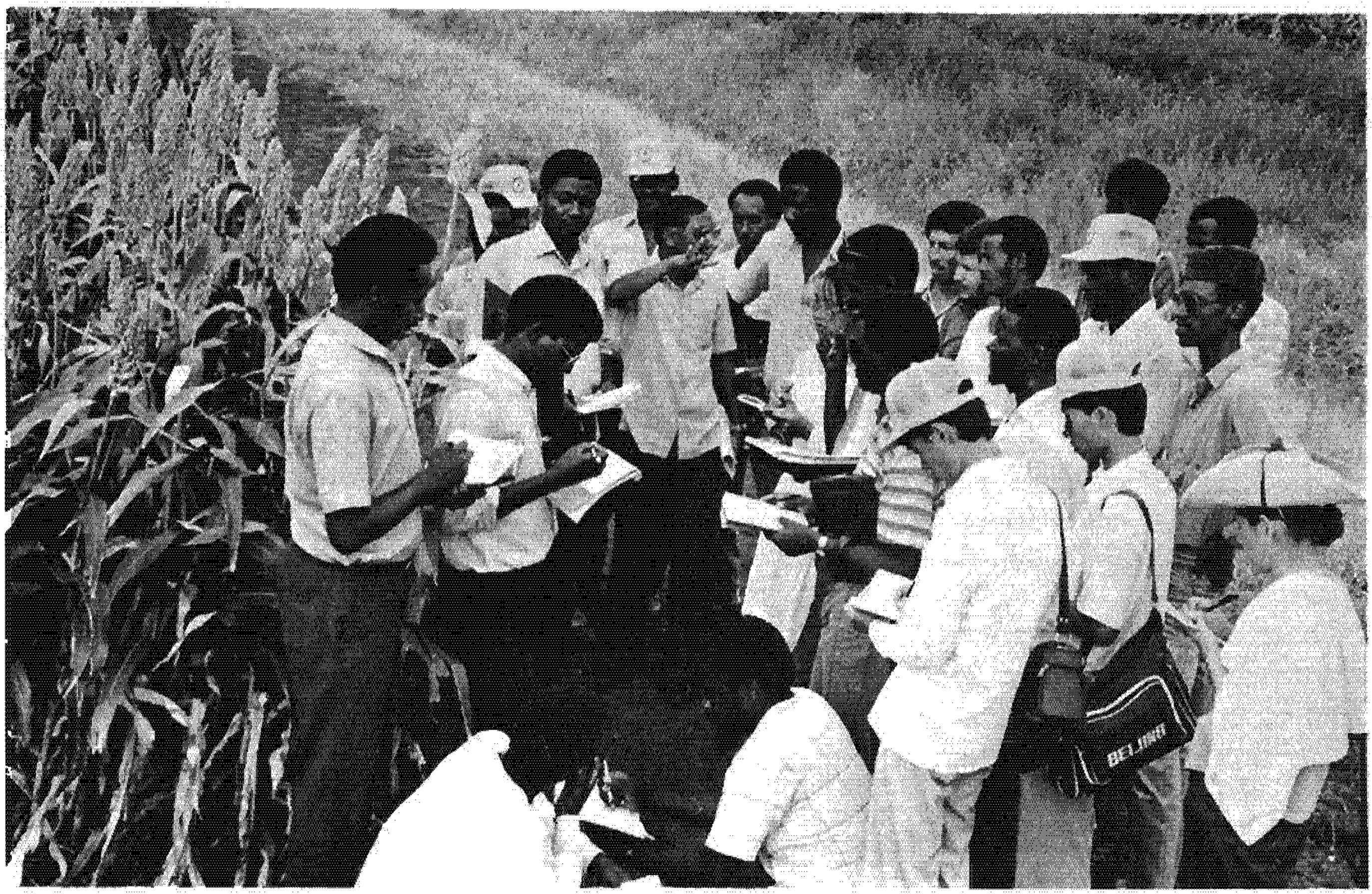
contd...

Table 6. *continued.*

Discipline	Participants and length of study			
	1 week	2 weeks	3 weeks	6 weeks
Soil fertility	25			3
Soil physics and conservation	8			
Weed science	6			
General				
Experimental statistics	20	1		
Microcomputer uses	26			
Plant protection	24			
Plant quarantine	1			
Research station management	12	8		
Technology transfer	3			

- Twenty six participants worked on cereals improvement with reference to plant breeding, pathology, entomology, physiology, grain quality, experimental design, data interpretation, and data presentation.
- Fifteen participants studied legumes improvement with special skill development in plant breeding, pathology, virology, entomology, physiology, experimental design, data interpretation and data presentation.
- Twenty eight participants studied crop production with emphasis on agronomy for increased yield, plant nutrition, weed management, experimental design, data handling,

In-service trainees preparing a plot for a sowing experiment, ICRISAT Center, 1987.



In-service trainees take notes as a scientist describes a sorghum yield trial, ICRISAT Center, 1987.

interpretation and presentation, and methods of technology transfer to scientists and farmers.

- Twenty participants worked on resource management in relation to land and water management, cropping systems, agroclimatology, research farm management, economics of crop production systems, data processing, interpretation, and presentation, and animal-drawn equipment utilization.

Economists from Ethiopia, The Gambia, Lesotho, Senegal, Somalia, Sri Lanka, The Philippines, Tanzania, and Zambia participated in a 5-week course at ICRISAT Center. They studied ways to identify and understand constraints to agricultural development in the SAT and the means of alleviating them through technological and institutional change, and interdisciplinary agricultural research.

The postrainy-season groups studied chickpea, pigeonpea, and groundnut improvement techniques which were established in plots with supplemental irrigation (Table 7).

Table 7. Experiments and trials initiated by postrainy season in-service trainees, ICRISAT Center, 1987.

	Crops			
Type of trial	Chick-pea	Pigeon-pea	Ground-nut	Total
Variety	2	2	1	5
'B' line	1	1		
Breeding nursery	1			1
Pathology	2			2
Physiology (drought)	2			2
Total	8	2	1	11

In-service Regional and National Activities

A 3-month course in sorghum breeding and production was guided by ICRISAT staff based at the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) for participants from Costa Rica, Nicaragua, Mexico, and El Salvador. These participants were associated with the CIMMYT training courses.

A 6-week course for research station managers was held in Zimbabwe. The 14 participants from 8 SADCC countries studied agronomic and management skills for accurate and timely experimentation.

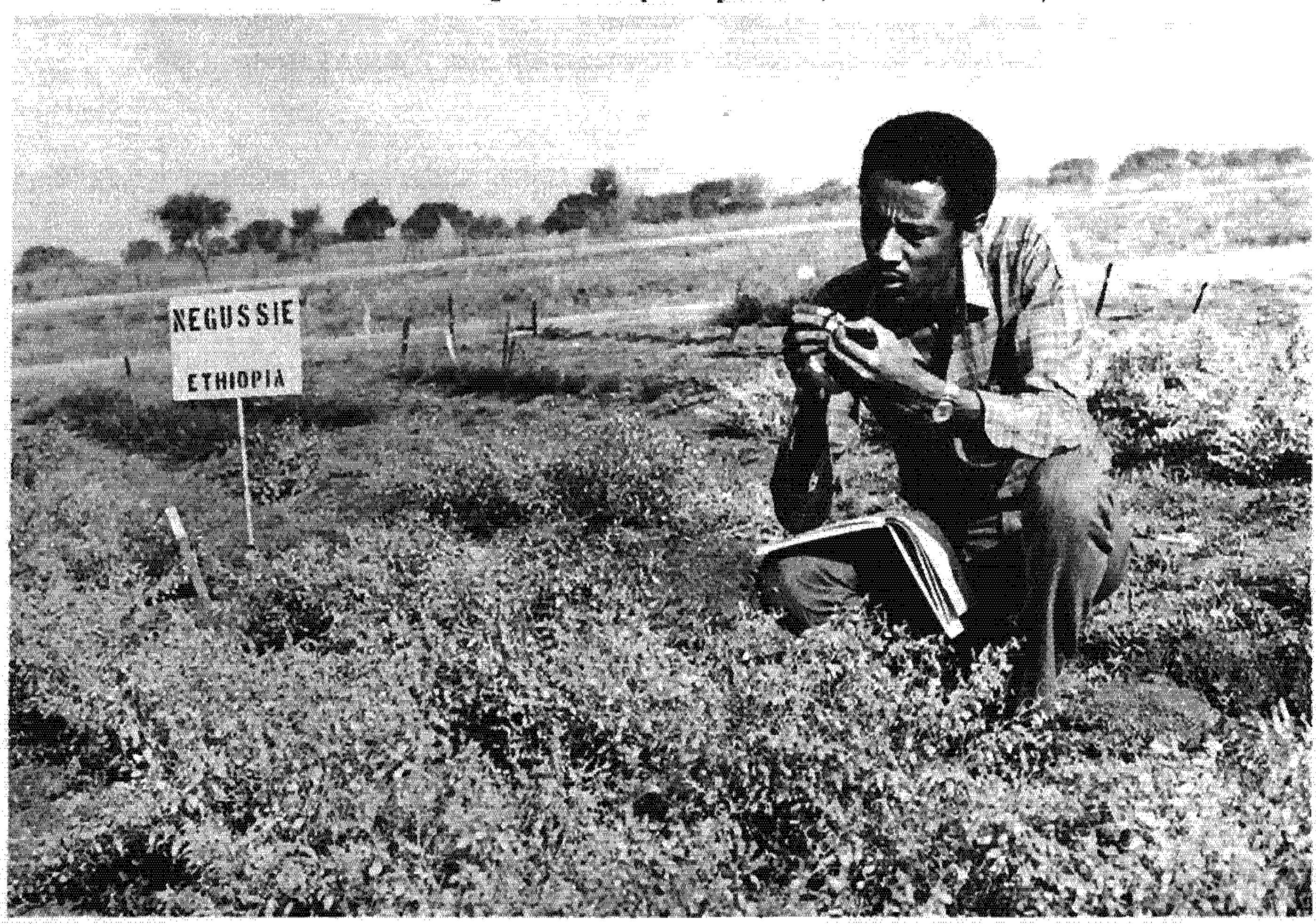
The second 4-week cereal improvement course was conducted in Zimbabwe for 7 technicians from 4 SADCC countries. Emphasis was placed on crop improvement technologies, experimental design, disease and pest resistance screening techniques, and data processing.

On-the-job training in sorghum ergot and downy mildew screening techniques were provided for two scientists in Rwanda and three scientists in Ethiopia.

A short-term course to study ways to improve seed production was held in Kenya for eastern and southern African scientists. The techniques for quality seed production, seed processing, and seed handling in tropical environments were studied by scientists, seed technologists and seed production agency staff.

A 1- to 5-week study of sorghum breeding and agronomy in Mexico, Central America, and the Caribbean was guided by ICRISAT/CIMMYT staff for visiting scientists from Mexico and Chad at CIMMYT.

An in-service trainee studies insect damage to a chickpea experiment, ICRISAT Center, 1987.



In-service fellows on a legumes pathology course, ICRISAT Center, 1987.

A 5-month cereal quality evaluation course was conducted for workers from Ethiopia, Kenya and Sudan. The course provided an opportunity to develop skills to determine grain quality and the influences of processing and food preparation on food quality and acceptability.

Five Indian scientists from the National Bureau of Plant Genetic Resources (NBPGR) received training at ICRISAT Center in the description and evaluation of germplasm, gene bank facilities, and techniques for long-term preservation.

An intensive 4-day pigeonpea hybridization course at ICRISAT Center emphasized the techniques required for hybrid pigeonpea seed production. The 12 participants were from Indian universities, the Indian Council for Agricultural Research, government seed corporations, and private seed companies.

A 5-day groundnut production technology course was held at ICRISAT Center for 35 Indian scientists from 6 State Departments of Agriculture. The objectives were to maximize seed production of new and adapted varieties for rainfed conditions with supplemental irrigation and improved technology.

In-service Fellowships

Senior scientist fellowships were provided for short-term intensive study within a research discipline (Table 8). The Legume pathology/virology course was expanded to include disease detection, control measures, and screening techniques for pigeonpea, chickpea, and groundnut. Ten scientists from 8 countries completed the

Table 8. In-service fellow research progams, ICRISAT Center, 1987.

Program/ Discipline	Country	No. of weeks
Cereals		
Sorghum		
Pathology	The Philippines	6
Breeding	The Philippines	3
Physiology	Sudan	8
Entomology	Sudan	9
Sorghum and Millet Breeding	Mexico	5
Legumes		
Groundnut		
Pathology/ Virology	People's Republic of China	7
Cytogenetics	Republic of Korea	7
Physiology	Sri Lanka	4
Pathology	Sri Lanka	3
Pathology	Sri Lanka	3
Pathology	Sri Lanka	4
Pathology	Sudan	1
Resource Management		
Agroclimatology	Mexico	18

3-week course under the guidance of the Legumes Program staff.

In programs lasting 1 to 8 weeks, scientists from the People's Republic of China, Republic of Korea, Sri Lanka, and Sudan studied groundnut pathogen identification, detection and screening techniques, production physiology, or cytogenetics in the ICRISAT laboratories.

Plant breeders from Mexico and The Philippines studied sorghum and millet breeding methodologies for 5- and 3-week periods.

A pathologist from The Philippines spent 3 months studying several sorghum diseases and completing the associated library research.

A Sudanese entomologist completed a 9-week study on sorghum stem borer and other insect-screening techniques that could be utilized to identify insect-resistant varieties by the Sudan sorghum improvement program.

A research fellow from Mexico, guided by agroclimatologists, completed a 6-month study on the identification of climatic zones suitable for the introduction of new varieties or cropping systems for improved food production.

Postdoctoral Fellowships

Cereals Program

During a 2-year internship, a physiologist from the UK completed investigations on the relationship of the duration of the vegetative period and the phenotype in pearl millet.

An intern from the USA completed a year's study in pearl millet breeding to identify the utility of male sterile lines selected from diverse cytoplasms.

Legumes Program

A 2-year study by an Indian research fellow concentrated on the inheritance pattern of dry root rot and fusarium wilt resistance in chickpea.

Resource Management Program

A postdoctoral fellow from Chad completed one year's study on the influence of sorghum plant density on water-use efficiency and yield.

Research Scholarships

Legumes Program

An Ethiopian PhD student at the Andhra Pradesh Agricultural University (APAU) completed a thesis on the relationships among the F_2 to F_6 generations and the effect of spacing and selec-

A research scholar from Kenya (right) studying a pigeonpea flower drop problem, ICRISAT Center, 1987.

tion in the F_4 on performance in the F_5 generation in chickpea.

An Indian PhD student from the Haryana Agricultural University completed a 2-year study on the variability in the chickpea blight pathogen *Ascochyta rabiei.*

An Indian PhD student at the APAU completed his thesis on the epidemiology of rust and leaf spot diseases of groundnut.

A PhD student from the Federal Republic of Germany finalized a 3-year thesis related to responses of groundnut to photoperiods.

Resource Management Program

A Dutch student from Cornell University, USA, completed research for a PhD thesis entitled "Determinants and Implications of Regional Variation in the Speed and Ceiling of Diffusion" that concentrated on the adoption of improved cereal cultivars in India.

An MSc student from Mozambique studying at the APAU completed his thesis research on the effects of staggered sowing dates and plant proportions in a legume/cereal intercrop.

Research for an MSc thesis at APAU was completed by a student from Somalia on the effects of sowing dates and irrigation on the yield of two rainy-season sorghum cultivars.

A student from North Carolina State University, USA completed the data analysis for his PhD thesis on marketed surplus, household inventories, and price expectations in the semi-arid tropics of India.

Research Scholar Regional and National Activities

ICRISAT Sahelian Center

Staff at the ISC guided several MSc and PhD students on research projects in different programs.

Two students from Benin and Niger produced research papers on yield losses due to infestation of *Coniesta (Acigona) ignefusalis*; effect of soil fertility on crop establishment in pearl millet and influence of sowing date on the incidence of downy mildew.

In the Resource Management Program, a student from l'Institut pratique de dévelopement rural (IPDR), Niger studied soil management practices for rainfed agriculture.

A student from the University of Niamey studied soil analysis procedures.

A Nigerien student pursuing her MSc degree in France at the Centre national d'études agronomiques de regions chaudes, Montpellier, completed a study on animal traction.

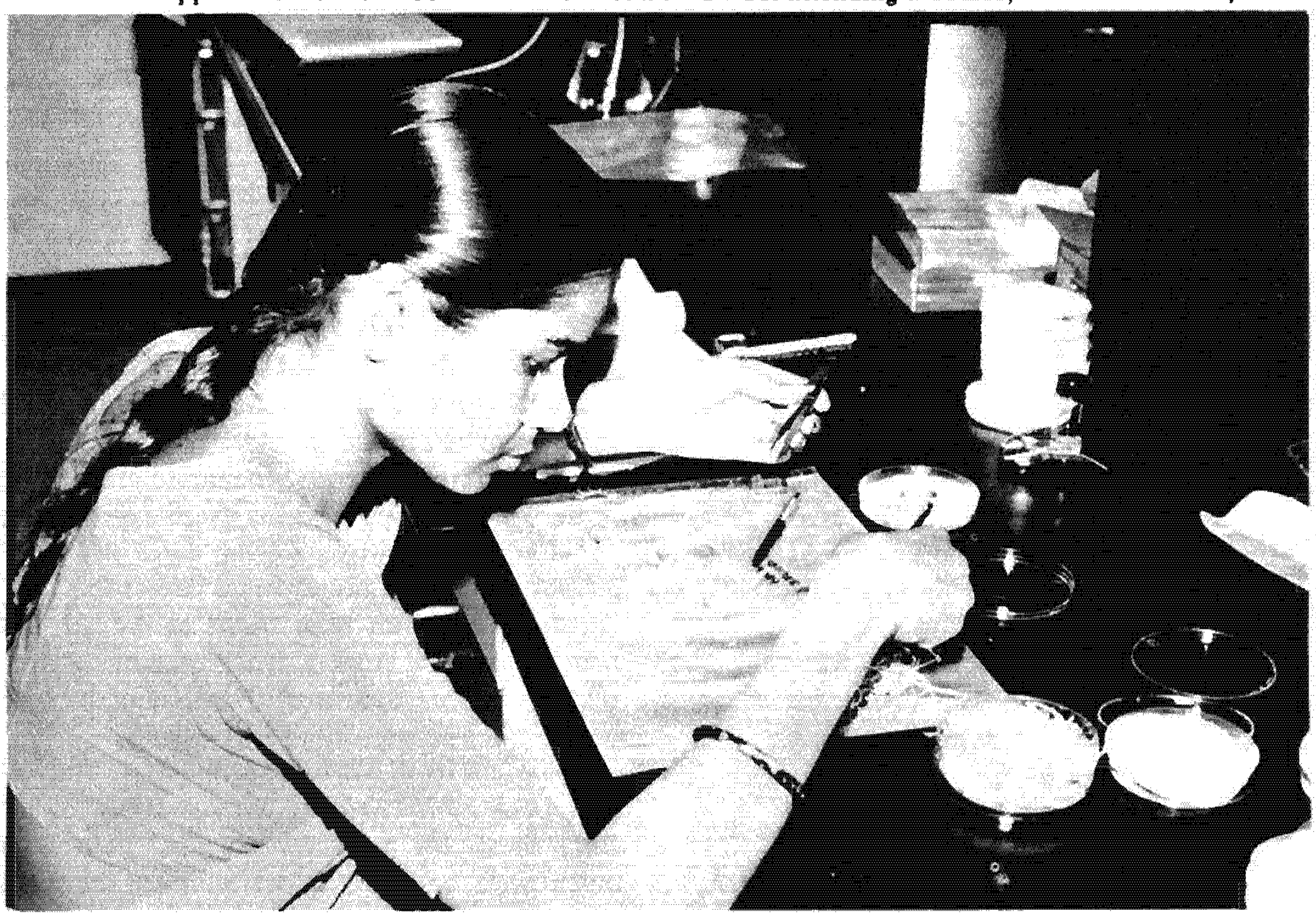
One Nigerien student pursuing her PhD at the University of Louvain, Belgium studied forage legumes associated with pearl millet.

Two Dutch students pursuing MSc degrees at Wageningen University, The Netherlands, studied animal traction and the effects of weed infestation on crop production.

Three PhD students from University of Hohenheim, Federal Republic of Germany, worked on plant nutrition, soil characterization, and animal traction.

Another PhD student from the University of Hohenhiem, Federal Republic of Germany, conducted thesis research on the phosphorus and micronutrient components of groundnut nutrition.

A short-term apprentice from the Government of India's NBPGR attending a course, ICRISAT Center, 1987.



Students from the University of Niamey were supervised on degree research projects related to seed and seedling disease and techniques for diagnosis of diseases of groundnut.

Mali

Students from the Agricultural College, Katibougou, Mali were guided by ICRISAT scientists on field studies dealing with a sorghum and groundnut intercropping system, sorghum production agronomy, and the adaptability of improved millet cultivars.

Burkina Faso

Diploma students from the Université de Ouagadouga, conducted research on techniques to control *Striga* and insects attacking the sorghum panicle. They also investigated the effects of agronomic management on the yield of improved and local pearl millet varieties.

Apprentice Activities

At ICRISAT Center, flowering events of selected lines of pearl millet in relation to ergot development were studied by a first-degree student from The Netherlands. A British first-degree student at Oxford University investigated the control and ecology of termites in groundnuts and techniques for evaluating the chemical basis of host-plant resistance to insects. An apprentice from The Netherlands completed a study program on ways of estimating sorghum yield in response to weather and soil fertility.

RESEARCH SUPPORT ACTIVITIES

Contents

Cover photo: Harvesting groundnuts using a mechanized digger developed by the Farm Development and Operations Unit, ICRISAT Center, 1987.

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

For offprints, write to: Information Services, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India.

RESEARCH SUPPORT ACTIVITIES

Farm Development and Operations

Adequate research support in terms of quality of farm operations and precision of application are essential to obtain meaningful and reliable research data.

The Farm Development and Operations unit (FDO) at ICRISAT Center develops and maintains land and water resources, undertakes farm operations, and provides support to field experimentation. The unit aims to improve the quality of experimentation with precision equipment and timely operations. We adopt farming practices that improve and sustain productivity of farmland and optimize manpower resources.

In 1987, research support was provided to all field and greenhouse experiments. Services were provided for land preparation, sowing, cultivation and harvesting, insect, disease, and weed control, threshing and seed drying, and irrigation and drainage (Tables 1 and 2). Field slopes, roads, drains, and farm structures were maintained. The unit also maintained and landscaped the ICRISAT Center grounds.

During the year, 13 ha of lowlying and saline land was reclaimed and brought under production. Part of the land was used to produce sorghum seed of SPV 351 and a cover crop of maize. Land improvements were made at the Gwalior cooperative research station.

The unit constructed causeways, culverts, and a new 3.5-km road and fence on the southern boundary of the farm. We replaced a 4.35-km barbed-wire fence with more secure chainlink fencing.

A new precision-space vacuum planter was fabricated to sow groundnut and chickpea at 60-cm row spacing. A digger was modified to mechanize groundnut harvesting and a plot combine was assembled and successfully used during the pigeonpea harvest.

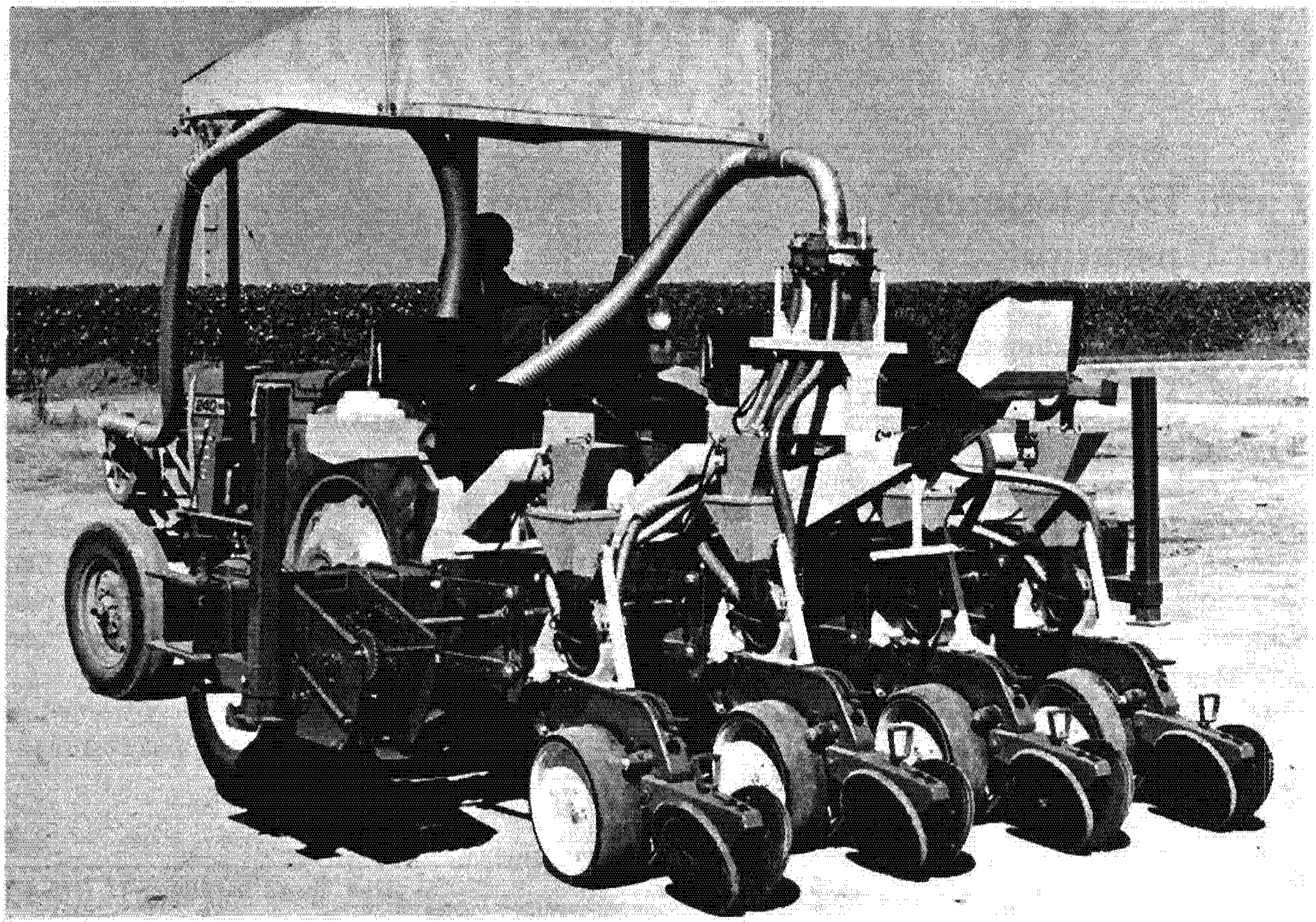
Fifteen in-service candidates were trained in experiment station management and pest man-

Table 2. Total area hand weeded, ICRISAT Center, 1987.

Crop	Area (ha)	No. of mandays	Mandays ha^{-1}	Cost ha^{-1} (Rs)
Sorghum	54.46	2265	42	624.00
Pearl Millet	69.60	3596	52	780.00
Chickpea	65.51	2023	31	463.00
Pigeonpea	53.14	4286	81	1209.00
Groundnut	87.72	6041	69	1035.00

Table 1. Area irrigated and volume of water used, ICRISAT Center, 1987.

Crop	Alfisol (ha)	Vertisol (ha)	Total (ha)	Volume of water used ('000 m^3)		
				Alfisols	Vertisols	Total
Sorghum	22.0	46.0	68.0	135.0	39.9	174.9
Pearl Millet	69.0	0.5	69.5	160.0	3.5	163.5
Chickpea	1.7	26.0	27.7	4.0	56.0	60.0
Pigeonpea	12.0	30.0	42.0	27.5	87.5	115.0
Groundnut	69.0	3.5	72.5	270.0	8.4	278.4
Total	173.7	133.0	306.7	596.5	193.5	791.8



A 4-row, 60-cm precision-spaced groundnut/chickpea planter developed by FDO, ICRISAT Center, 1987.

A plot combine harvesting chickpea, ICRISAT Center, 1987.

agement. FDO staff participated in a training workshop conducted by the Legumes On-farm Testing Unit (LEGOFTEN) by lecturing and demonstrating on techniques for groundnut tillage and irrigation.

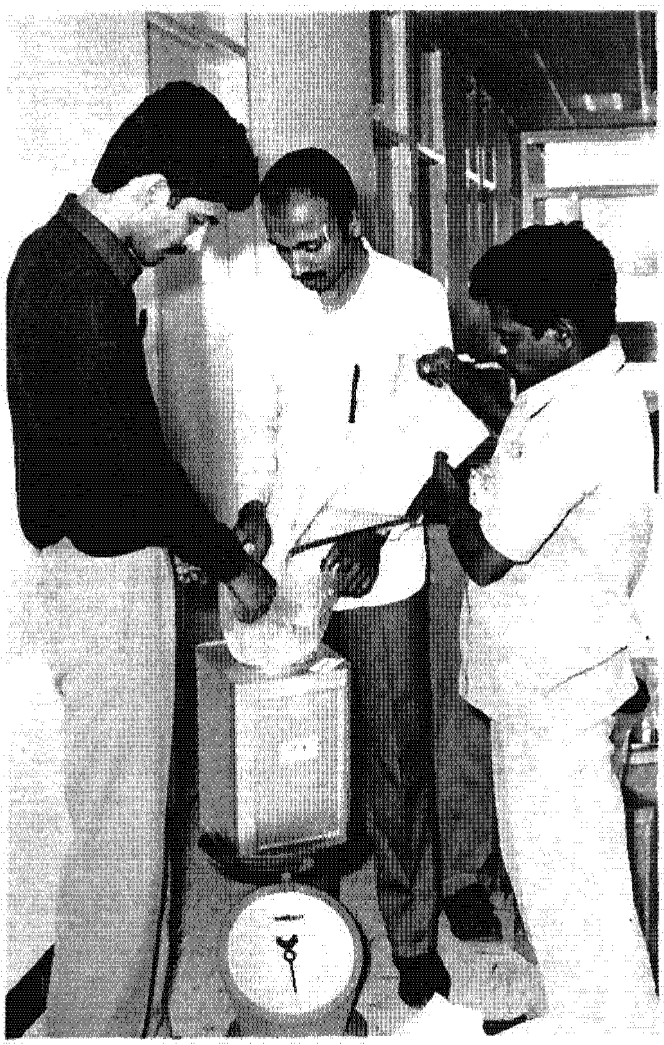
Plant Quarantine

The Plant Quarantine Unit continued to liaise with the regional plant quarantine station of the National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR), Hyderabad on the release of imported seed material and for testing ICRISAT mandate crop seeds prior to export. The Unit also assisted the NBPGR quarantine staff to examine plants grown in the Post-Entry Quarantine Isolation Area (PEQIA) at ICRISAT Center. The emphasis during both import and export was on providing healthy, disease-free germplasm to scientists for the advancement of crop research.

Plant Material Exports

During 1987 we exported 54 953 seed samples of ICRISAT mandate crops, minor millets, and such other crops as maize, teosinte (*Euchlaena mexicana*), and *Leucaena leucocephala*, a sample of *Striga asiatica*, 785 samples of plant material, and 243 units of rhizobial and mycorrhizal cultures to cooperators and scientists in 97 countries (Table 3). The material included germplasm accessions from the ICRISAT gene bank, international trials and nurseries for multilocational testing, and samples used in laboratory studies on food and fodder quality, and biochemical, pesticide, mycotoxin, and brewing analyses.

Plant Quarantine staff pack seeds for export, ICRISAT Center, 1987.



Plant Material Imports

The quarantine division of the NBPGR released 3280 seed and plant samples of our mandate crops and minor millets received from 21 countries (Table 4). While 2614 seed samples of cereals and pulses were released for postentry growout after thorough examination and chemical treatment, 666 sorghum and pigeonpea seed samples were released after physical inspection for biochemical and food quality analyses. Groundnut seeds were tested by the enzyme-linked immunosorbent assay (ELISA) technique for peanut stripe virus, before being raised for 6 weeks in an insect-proof screenhouse prior to their release.

Post-Entry Quarantine Isolation Area (PEQIA)

To prevent the escape and spread of any plant pests and pathogens, all plant-propagating materials released by the NBPGR are grown for one season in the PEQIA. This year, 3533 samples of our mandate crops and minor millets were grown, and inspected regularly throughout their growing period by NBPGR plant quarantine personnel. Healthy plants were harvested and their seeds released to ICRISAT scientists.

Table 3. Seed material exports of ICRISAT mandate crops, 1987.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
AFRICA							
Algeria			138				
Benin	14	24		68	26		
Botswana	125	2		5	24		
Burkina Faso	2 706	74			12		
Burundi	64				86		
Cameroon	297	870			23		
Cape Verde Islands				1			
Chad	38	104		20			
Côte d' Ivoire	144						
Egypt		10	183		58		
Ethiopia	49		2 184	6			
Gambia	3	56	8	13			
Ghana	43			4	183		
Guinea	88		60	5	116		
Kenya	2 328		144	1 000	157		
Liberia	4			19	34		
Libya			120				
Malawi				12	616		
Mali	704	17	10	7			
Mauritania	35						
Morocco			138				
Mozambique	72						
Niger	84	1 151		3	1 048		
Republic of South Africa				21	39		
Rwanda	408						6
Senegal		54			1		
Somalia	720		2		176		
Sudan	85	3	161	6	116	200	
Swaziland	14	6					
Tanzania				23			
Togo	72			10			
Tunisia			138				
Uganda			384	554	361		
Zaire	2 542	935		22			
Zambia	605	342		63	20		
Zimbabwe	2 654	1 416	4	71		26	6
ASIA							
Afghanistan			14				
Bangladesh			838	40			
Bhutan	10			4	17		
Burma	321	21	325	230	159		
Indonesia		20		134	6 593		
Iran			298	29	4		
Iraq					58		
Israel	50		8				
Japan	15	24	7	10			
Korea	196	40		42	311	192	
Kuwait	3		1				
Nepal			998	486	156		
Pakistan	1 377	625	1 177	71	23		
People's Republic of China	446	24	63	32	35		

Continued

Table 3. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Qatar	200	30					
Saudi Arabia							2
Sri Lanka	74		296	200	176	20	
Syria			65		3		
Taiwan		4				50	
Thailand	411			17	129		
The Philippines	857	2	320	496	161		
Vietnam	95	44	296	138	79		
Yemen (AR)	114	4	138	4			
Yemen (PDR)	35						
THE AMERICAS							
Argentina	218	2	284				
Barbados	9			1			
Belize			94	63			
Bolivia				2			
Brazil			20				
Canada				2	1		
Chile			140				
Cuba					58		
Dominican Republic					94		
El Salvador	134						
Guatemala				2			
Guyana				158			
Haiti				44			
Honduras				29	130		
Mexico	745	148	534	21			
Nicaragua	4			19			
Peru			316	15			
Puerto Rico				1			
Trinidad	94			1			
USA	325	231	152	47	94		
Venezuela	8			16			
EUROPE							
Austria					4		
Belgium			16		7		
Denmark	7						
Federal Republic of Germany	4		14	1			
France	250		253	30			4
Hungary	15						
Italy	361	26		20	123	447	
Romania			7				
Spain		2					
The Netherlands	2			2			
Turkey			146				
UK	236	21	156	1	49	20	1
USSR	41		14				
AUSTRALASIA							
Australia	182	171	22	116	107		
Fiji				7			
Solomon Islands				15	93		
Total	20 737	6 503	10 686	4 479	11 760	955	19

Table 4. Seed material imports of ICRISAT mandate crops, 1987.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
AFRICA						
Burkina Faso	12		113			
Ethiopia	4					
Kenya				45		
Mali					112	
Morocco			122			
Niger		123				
Somalia	249					
Sudan					1	
Tanzania	269	339				
Zambia				61		
Zimbabwe	644	135				
ASIA						
Pakistan			10			
THE AMERICAS						
Belize				18		
Brazil					3	
Mexico	222					
USA	49	48			501	
EUROPE						
France		6				
Greece					16	
Italy		82		12	35	
UK	3					6
AUSTRALASIA						
Australia	40					
Total	1492	846	132	136	668	6

Statistics Unit

The Statistics Unit renders consultancy services to ICRISAT staff and scientists from collaborative projects at various stages of their research, from planning experiments to analyzing the data and drawing inferences. We also lecture trainees on design and analysis of experiments, statistical methods, and biometrical genetics, and help them prepare their project reports. We assist the staff on usage of statistical software.

During 1987, a trainee from Malawi was trained on statistical computing using GENSTAT and SAS packages. Two scholars sought our assistance in completing their MSc dissertations in groundnut agronomy and one research scholar for his PhD dissertation in chickpea breeding. Another research scholar has been

Postentry quarantine inspection of imported groundnut germplasm, ICRISAT Center, 1987.

working on the use of auxilliary information in sample surveys for his PhD.

We participated in inhouse reviews, planting plan meetings, and visits to experimental trials, and assisted in the preparation of inhouse review proceedings. We reviewed the Annual Report, scientific papers for the Editorial Committee and articles for newsletters.

We processed several large data sets for scientists working at other ICRISAT locations. A staff member was sent to the Sahelian Center to provide training on statistical software and to assist in data processing. We installed a microcomputer version of the GENSTAT package for several programs and units.

Our consultancies with the staff and collaborators during 1987 averaged over 82 per month. Based on these consultations, the following projects were pursued.

- A nonlinear model. We developed a procedure to fit a nonlinear model when both the variables are subject to errors and applied it to pearl millet data.
- Effect of outliers. We analyzed a series of field data on chickpea to detect outliers; and found that eliminating outliers played a remarkable role in reducing the error variability.
- Stability of intercropping systems. We examined data on intercrop and sole crop systems of sorghum, pigeonpea, pearl millet, and

groundnut for stability and risk in productivity.

- Stochastic optimum proportion. We compared intercrop systems with shared systems of sole crops, and obtained an optimum proportion of component crops under the shared system that minimizes risk for specified yields and monetary returns.
- Screening groundnut for seed resistance. The influence of environmental factors on groundnut seed infection by *Aspergillus flavus* and other fungi complicates resistance screening over seasons and locations since levels of infection can vary considerably within genotypes. We used statistical methods to separate genotypes into different resistance/susceptibility categories and to examine the distribution of resistance in spanish and valencia types of groundnuts.

We plan to continue studying the sensitivity of genotypes to drought imposed by the line-source sprinkler using a model allowing for spatial correlation, optimal allocation of land resources to minimize risk in crop production, and the intersite transfer of varieties.

During the year, one staff member received specialized training on "Structured System Analysis and Design" in a course organized by Computer Maintenance Corporation (CMC) of India at Madras. We participated in three international conferences, and delivered seminars and invited lectures on statistical methods applied in agriculture.

Computer Services

The Computer Services Unit provides timesharing to ICRISAT research personnel on a VAX-11/780 computer system, and to the ICRISAT administration on a VAX-11/750 computer system. The VMS operating system is used on both computer systems. We develop interactive systems, provide data-entry services, install software packages, install microcomputer software, and provide seminars and individualized instruction on computer usage to all staff members.

State of Development

A major effort was made in 1987 to increase the efficiency of the administrative applications in terms of computing resources. Phase I of the financial accounting system was revised to improve and extend its performance. Phase II was tested, but was not released due to a shortage of computer resources. The supplies management system was given an interim revision that improved its performance, as well as that of the overall system. The personnel database system was enhanced by the addition of several report generation procedures, and query and modification facilities. The salary-processing system, in operation since 1982, was completely redesigned, and nearly redeveloped so that it can be integrated with the personnel database and financial accounting systems. The leave-management system was revised to improve its performance and to make use of batch processing in off-hours.

The publications tracking system developed for the Editorial Committee and released in 1986 was extended to incorporate all ICRISAT publications. It formed the basis for a new publication "ICRISAT in Print" and is now used to generate quality reports for At ICRISAT, for publication listings in the Annual Report, and to track all reprint orders. The research project management information system was improved with the addition of a component that incorporates progress reports in the database.

A network was established between the two VAX computer systems using Ethernet hardware and DECNet networking software. The network facilitated the local delivery of our international electronic mail, and permitted use of the research VAX-11/780 for administrative applications during off-hours. Two terminal servers were added to the network to give Computer Services' terminals easy accessibility to both VAX systems. Four microcomputers were added to the network using either asynchronous ports or Ethernet controllers, and the DECNet DOS networking software. An additional laser printer, that can be simultaneously connected to three computer systems, was purchased to help support the increased demand for laser printing services. A 456 Megabyte disk unit was added to the VAX-11/750 to accommodate the growing storage requirements of the administrative departments, and the memory of the VAX-11/780 was increased to 16 megabytes.

A Rainbow microcomputer was installed in the New Delhi office, and the staff there were trained in the use of word processing and spreadsheet software. A modem was installed with the microcomputer in order to establish an electronic mail link between New Delhi and our VAX-11/780 computer system.

Nearly 50 new IBM-compatible microcomputers were purchased by various departments during the year as additional resources for word processing, spreadsheet analysis, and small database management. More than 35 additional staff members were trained in the fundamentals of word processing and spreadsheet analysis, and 24 Directors, Principal Staff, and Division Heads were introduced to computers, word processing, spreadsheet analysis, and database management, in a specially designed 2-day seminar.

Representatives from Computer Services attended three DEC user group meetings and two conferences. Five staff members attended training courses of 1-2 weeks' duration in India. One staff member attended training courses in the USA on teaching the Mass-11 Word Processing system and on using the dBASE III Plus database management system.

A computer audit study was performed by the Tata Consultancy Services during the first half of the year. The recommendations of that study were accepted in principle and will help shape our activities in the coming year. Many applications will be redesigned to distribute their functions between microcomputers and VAX computers. The approach used will include a study of the feasibility of networking PCs with the VAX systems. A MicroVAX 3600 computer system will replace the administrative VAX-11/750. Every research group will be provided with PC AT-class microcomputers that will run the micro versions of statistical packages such as GENSTAT and SAS. This should offload much of the statistical analysis from the VAX-11/780.

Library and Documentation Services

Acquisition

During 1987, we added about 1900 documents to our collection (Table 5).

We continued to assist the ICRISAT Sahelian Center (ISC) library with the acquisition, processing, and transference of 115 books. The Assistant Librarian from ISC underwent 4 weeks of training at ICRISAT Center in library techniques and services including hands-on training in automated library functions and operations.

The microcomputer-based serials data system developed during 1986 was used to produce a Catalog of Serials 1987 that lists the holdings of all serial publications at ICRISAT Center. This Catalog was widely distributed to institutions throughout the SAT.

Two staff members participated in the first-ever meeting of CGIAR Documentation and Information Services personnel at The Centro Internacional de la Papa (CIP), Lima, Peru in May 1987. Thrust areas identified at the meeting were: support to the development of national and regional capacities to manage and deliver agricultural information, support to Center research programs as they move into more strategic and basic research, and greater cooperation between information programs of the IARCs. The ICRISAT library was asked to lead a program to produce a union catalog of serials holdings in different IARCs and began to work on this in 1987.

Table 5. Status of acquisitions, ICRISAT Library, 1987.

Documents	Additions during 1987	Total holdings (Dec 1987)
Books and Reports	874	22232
Bound volumes of periodicals	592	13071
Annual Reports	219	1536
Reprints, Photocopies, etc.	58	5851
Microforms	24	820

We also participated in an international project funded by the International Development Research Center (IDRC) to evaluate the potential of Compact Disk-Read Only Memory (CD-ROM) as a medium for information delivery. A CD-ROM player and a test database of the CAB International (CABI) was provided for this purpose.

We acquired a second microcomputer, an IBM-PC/AT compatible, which is being used to create and maintain databases, and for other library housekeeping functions, and CD-ROM applications. Future plans include increased applications of new information technology in ICRISAT's library and in its information storage and retrieval activities. Specific action programs are envisaged in consonance with the recommendations of the Lima meeting.

Documentation Services

The Selective Dissemination of Information (SDI) service was expanded to include 16 new recepients representing a 9% growth over 1986. The service now goes to 192 users in 32 countries of the SAT. Plans were made during 1987 to automate this manual service.

We conducted 61 literature search services including 22 online searches to meet specific requests for comprehensive and problem-oriented information. The availability of these search results was widely publicized to enable other interested users to benefit from the service.

The Central Reprography Unit attached to the Library provides Institute-wide photocopying, microcopying, and offset printing services. In 1987, the unit produced 928 959 pages of photocopies and 12 750 offset masters used to print program-level publications. We continued to microfiche out-of-print ICRISAT publications.

A total of 145 items of ICRISAT-generated conventional and non-conventional literature was input to FAO's International Information System for Agricultural Sciences and Technology (AGRIS) database.

Semi-Arid Tropical Crops Information Service (SATCRIS)

Work envisaged in the SATCRIS project, funded in part by IDRC and approved in November 1986, began in earnest in 1987.

The major objectives of SATCRIS are to:

- Participate in global/international information networks and systems through collaborative action and to provide input to such systems.
- Develop a comprehensive database relevant to ICRISAT mandate crops and associated information.
- Strengthen information-handling capabilities at the ISC.
- Provide a package of information services to a carefully selected clientele throughout the SAT who have research and development responsibilities for the crops mandated to ICRISAT.
- Use modern tools and techniques to provide access to information.
- Sensitize users in Africa to SATCRIS resources, services, and capabilities through user-oriented workshops.

Database development. The SATCRIS database was conceptualized and implemented using the BASIS software package acquired in 1986. The database at SATCRIS is being developed from subsets of machine-readable data from the CABI and AGRIS databases. Locally generated input is integrated with the subsets received from the two global databases.

Automated SDI service. We began work to introduce an automated SDI service to replace the existing manual service. The new service scheduled to begin in 1988 will search the CABI and AGRIS database subsets and local input to provide a dissemination service that will answer specific needs.

Specialized abstracts service. An agreement was signed with CABI to make their Sorghum and Millets Abstracts a joint publication with

ICRISAT. Subscriptions to the abstracts journal were provided free of charge to 400 addresses in 39 countries of the SAT. Coverage of the abstracts journal will be expanded with input from ICRISAT. Two new abstracts services, one on chickpea and pigeonpea, and another on groundnut, are to be produced from 1988 in collaboration with CABI.

Training. A senior documentalist was deputed to the Agricultural Information Bank for Asia (AIBA), Philippines, for intensive training in AGRIS methodologies. The training has helped improve the quality of our input to AGRIS.

Information Services

Information Services is responsible for the publication and dissemination of information about ICRISAT's research to scientists and policymakers in developing countries, to the international scientific community, donors, and to informed laymen. Information Services provides support to ICRISAT scientists in the preparation of such graphic aids as tables, figures, posters, photographs, and slides. It provides a French-language translation service to administrative and scientific staff.

Dissemination of research findings and institute-related information is accomplished in a variety of ways. Apart from bringing out Institute-level publications, Information Services publicizes scientific achievements through news releases, and film, video, and slide presentations made either internally or by external agencies. In 1987, one video program produced for the Institute by the Educational Media Research Centre (EMRC) of the Central Institute of English and Foreign Languages (CIEFL), entitled "Scattering plenty over a smiling land" was telecast over India's national network. More television programs detailing various aspects of ICRISAT's work in India have been initiated. A new slide set used to introduce visitors and donors to the Institute's activities, and also available on sale, was produced during the year.

The 30 institute-level publications this year included books, progress reports, information and research bulletins, 7 full-length workshop proceedings and 4 summary proceedings, and 11 issues of various newsletters. All these were published in-house, and the majority were printed at ICRISAT Center. Two issues of Nouvelles d'ICRISAT were published and distributed from the ICRISAT Sahelian Center. A special publication, "ICRISAT in West Africa" (L'ICRISAT en Afrique occidentale) was published for the ISC at ICRISAT Center.

Information Services also provides the Secretariat to the Editorial Committee, which operates an internal peer-review system for manuscripts authored by Institute scientists for the international scientific press. During 1987, the Editorial Committee approved 172 papers by ICRISAT staff for submission to journals, conference proceedings, and for publication as institute serials. Sixty four journal articles and 69 conference papers previously approved by the Committee were published. Of these, 46 were edited by Information Services staff during the review process. These titles are listed at the end of the concerned sections of this Report and reprints can be obtained on request from the relevant Program Offices.

The Editorial Committee completed a 4-year project on the computerization and restoration of its archives. A complete cumulative catalog of publications since the inception of the Institute, "ICRISAT in Print", was brought out on the Institute's 15th anniversary. The catalog lists 1450 entries that were categorized and indexed with the help of the Library and Documentation and Computer Services. New publications will be added to the database and an update to the catalog will be brought out each year.

During the year, the Composing Unit exposed and processed approximately 3555 m of phototypesetting paper for publications, slides, and other typographical requirements. Some 230 computer graphics were made to illustrate various Institute publications. Newsletters were directly set on the units's laser printer, with considerable savings on material and manpower resources.

The Art Unit handled more than 1100 pieces of artwork, in addition to their graphic and design work on Institute-level publications. This included line figures, photo-page layouts, posters, maps, forms, overlays, page paste-ups, and cover designs. A new Repromaster 2200 model process camera was installed in the Art Unit to produce precise reproprints.

The Photographic Unit received requests for approximately 1750 jobs, which involved the processing of 1140 color and black and white films and 9375 prints of different sizes. The Printshop ran a total of 3.15 million impressions this year, a majority of which represented print-jobs for major Institute-level publications.

The Distribution Unit dispatched a total of 23 731 copies of priced publications. Of these, 20 736 were sent gratis to libraries, and to cooperating scientists in the SAT. About 38 300 copies of nonpriced publications were dispatched.

Publications

Institute Publications

Annual Progress Reports

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Research highlights 1986. Patancheru, A.P. 502 324, India: ICRISAT. 52 pp. ISSN 0257-2532. (RHE 008)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Progrés de la recherche 1986. Patancheru, A.P. 502 324, India: ICRISAT. 52 pp. ISSN 0257-2494. (RHF 008)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Annual report 1986. Patancheru, A.P. 502 324, India: ICRISAT. 404 pp. ISSN 0257-2478. (ARE 013)

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. At ICRISAT nos. 17, 18, 19, and 20. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2486. (NAE)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Nouvelles de l'ICRISAT nos. 9 and 10. Niamey, Niger: ICRISAT Sahelian Center. ISSN 0257-2524. (NAF)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Sorghum and Millets Information Center. 1987. La Lettre du SMIC nos. 19, 20, and 21. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2516. (NSF)

Other Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. ICRISAT publications 1987. Patancheru, A.P. 502 324, India: ICRISAT. 32 pp. (GAE 009)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Publications de l'ICRISAT 1987. Patancheru, A.P. 502 324, India: ICRISAT. 32 pp. (GAF 009)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. About ICRISAT. Patancheru, A.P. 502 324, India: ICRISAT. 8 pp. (GAE 015)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. L'ICRISAT. Patancheru, A.P. 502 324, India: ICRISAT. 8 pp. (GAF 015)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. ICRISAT in West Africa. Niamey, Niger: ICRISAT Sahelian Center. 12 pp. (GAE 019)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. L'ICRISAT en Afrique occidentale. Niamey, Niger: ICRISAT Sahelian Center. 12 pp. (GAF 019)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Looking ahead: a 10-year plan. Patancheru, A.P. 502 324, India: ICRISAT. 86 pp. (GAE 016)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. ICRISAT in print: a cumulative record of publications 1975-86. Patancheru, A.P. 502 324, India: ICRISAT. 134 pp. (GAE 018)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Crop improvement in India: varieties, hybrids, and lines developed by ICRISAT. Patancheru, A.P. 502 324, India: ICRISAT. (RLE 008)

Audiovisual Material

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. ICRISAT at a glance. ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-064-3. (SSE 001)

Journal Articles

Murty, D.S., Singh, M., and **Nicodemus, K.D.** 1987. A genetic study of popping quality in sorghum. Euphytica 37:5-8. (JA 630)

Haravu, L.J., Jadhav, P.S., and **Sreeramana, R.** 1987. A microcomputer-based book acquisition system in India using dBASE II. Program 21(1):37-48. (JA 582)

Panchbhai, S.D., Varma, B.K., and **Ravinder Reddy, Ch.** 1986. Presence of *Panagrolaimus* sp. (Nematoda: Panagrolaimidae) in seeds of pearl millet [*Pennisetum americanum* (L.) Leeke]. Nematologica 32(2):236-237. (JA 576)

Singh, M. and **Sithanantham, S.** 1984. A statistical procedure for testing the host plant preference under choice and no choice situation. International Journal of Science and Engineering 1(3):47-67. (JA 349).

Singh, M. 1985. The adequacy of genetic model based on components of mean when some generation variances are zero. Indian Journal of Genetics and Plant Breeding 42(2):288-291. (JA 258)

Singh, M. 1987. A non-normal class of distribution function for dose-binary response curve. Journal of Applied Statistics 14(1):91-97. (JA 628)

Conference Paper

Varma, B.K., and **McDonald, D.** 1987. Groundnut rust disease and plant quarantine. Pages 55-58 *in* Groundnut rust disease: proceedings of a Discussion Group Meeting, 24-28 Sep 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 408)

ICRISAT Governing Board—1987

ICRISAT Senior Staff—as of December 1987

ICRISAT Center

Administration

L.D.Swindale, Director General
J.S.Kanwar, Deputy Director General
M. Goon, Assistant Director General (Administration)
K.B.Srinivasan, Assistant Director General (Liaison)
B.C.G.Gunasekera, Advisor to Director General for Donor Relations
S.J.Phillips, Special Assistant to Director General for Educational Affairs
W.E.Urban, Advisor on Research Management Systems (until Apr)
V.Balasubramanian, Sr Executive Officer (Director General's Office)
Joyce Gay, Sr Adm Secretary to DG
M.S.S.Reddy, Scientist (on contract, until Aug)
Sunetra Sagar, Sr Adm Secretary to the DDG (until Sep)
Surendra Mohan, Sr Adm Officer, Office of the DDG (from Aug)
K. Sampath Kumar, Sr Secretary, Office of the DDG
S.Krishnan, Asst Manager (Admn) Office of Adviser to DG for Donor Relations
C.Geetha, Sr Secretary, Office of the ADG (Admn)
P.Sosamma Nair, Adm Officer, Office of the ADG (Liaison)
D.Mitra, Fiscal Manager
A.Banerji, Assistant Manager (Fiscal)
V.S.Swaminathan, Sr Accounts Officer
A.N.Venkataswamy, Sr Accounts Officer
C.P.Rajagopalan, Accounts Officer
P.A.V.N.Kumud Nath, Accounts Officer
B.K.Vasu, Accounts Officer
K.Narayana Murthy, Accounts Officer
T.Kulashekhar, Accounts Officer
T.K.Srinivasan, Accounts Officer
B.K.Johri, Personnel Manager (on leave from Apr)
P.M.Menon, Personnel Manager (Acting, from Apr)
N.S.L.Kumar, Sr Personnel Officer
P.Suryanarayana, Sr Personnel Officer
A.Hameed, Personnel Officer (from Jul)
A.J.Rama Rao, Sr Secretary (Personnel)
R.Vaidyanathan, Purchase and Stores Manager
C.R.Krishnan, Asst Manager (Purchase and Stores)
K.P.Nair, Sr Purchase Officer
D.K.Mehta, Sr Stores Officer
D.V.Rama Raju, Sr Purchase Officer
K.C.Saxena, Sr Stores Officer
K.R.Natarajan, Shipping and Purchase Officer
Joseph Banji, Purchase Officer
A.Lakshminarayana, Sr Scientific Liaison Officer (Visitors' Services)
Harish Sethi, Scientific Liaison Officer
Georgina Fredericks, Adm Officer (Visitors' Services)
K.K.Sood, Sr Security Officer
A.Ekbote, Security Officer
K.K.Vij, Sr Adm Officer (Delhi Office)
V.Lakshmanan, Asst Manager (Administration, until Dec)
N.Surya Prakash Rao, Sr Resident Medical Officer
G.Vijayakumar, Transport Officer (until Apr)
K.Jagannadham, Adm Officer (Transport)
A.Rama Murthy, Travel Officer
V.V.Ramana Rao, Adm Officer

Research Programs

Cereals

Program Office

J.M.J. de Wet, Program Director, Cereals
K.Santhanam, Asst Manager (Adm)
Nirmala Kumar, Adm Officer (until Apr)

Sorghum Group

S.Z.Mukuru, Principal Plant Breeder
L.K.Mughogho, Principal Plant Pathologist (on sabbatic)
J.M.Peacock, Principal Plant Physiologist (on sabbatic from May)
K.F.Nwanze, Principal Cereals Entomologist
D.S.Murty, Plant Breeder (on leave)
B.L.Agrawal, Plant Breeder
Belum V.S.Reddy, Plant Breeder
P.K.Vaidya, Plant Breeder
N.Seetharama, Plant Physiologist
P.Soman, Plant Physiologist
Suresh Pande, Plant Pathologist (on leave)
R.Bandyopadhyay, Plant Pathologist
S.L.Taneja, Entomologist
H.C.Sharma, Entomologist (on sabbatic until Oct)
H.D.Patil, Sr Research Associate (on leave from Jun)
K.David Nicodemus, Sr Research Associate
D.J. Flower, International Intern
H.Kokubu, Postdoctoral Fellow (from July)

Pearl Millet Group

S.B.King, Principal Plant Pathologist
F.R.Bidinger, Principal Plant Physiologist
J.R.Witcombe, Principal Plant Breeder

K.K.Lee, Principal Cereals Microbiologist
C.T.Hash, Associate Principal Plant Breeder (from Apr)
K.N.Rai, Plant Breeder (on sabbatic from Apr)
B.S.Talukdar, Plant Breeder
Pheru Singh, Plant Breeder (on leave from Aug)
S.B.Chavan, Plant Breeder
G.Alagarswamy, Plant Physiologist (on secondment)
V.Mahalakshmi, Plant Physiologist
S.D.Singh, Plant Pathologist
R.P.Thakur, Plant Pathologist (on sabbatic until Jun)
S.P.Wani, Microbiologist
K.R.Krishna, Microbiologist
M.N.Pawar, Sr Research Associate (until Apr)
B.P.Reddy, Sr Research Associate
P.Q. Craufurd, International Intern (until Feb)
C.T. Hash Jr., International Intern (until Mar)
E. Weltzien, Postdoctoral Fellow (from Nov)

Kenya

V.Y.Guiragossian, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa

Mexico

C.L.Paul, Team Leader and Principal Sorghum Agronomist
R.Clara, Scientist, Sorghum Breeder

Legumes

Program Office

Y.L.Nene, Program Director, Legumes
D.G.Faris, Principal Coordinator, Asian Grain Legumes Network (on sabbatic from Aug)
C.L.L.Gowda, Acting Coordinator, AGLN (from Aug)
D.M.Pawar, Sr Agricultural Officer (Cooperative Trials, LEGOFTEN)
Surendra Mohan, Sr Adm Officer (until Apr)
P.Rama Murthy, Adm Officer
G.J.Michael, Adm Officer

Pulses Group

W.Reed, Principal Entomologist (until Nov)
C.Johansen, Principal Agronomist
H.A.van Rheenen, Principal Plant Breeder, Chickpea
Laxman Singh, Principal Plant Breeder, Pigeonpea
A.B.S.King, Principal Entomologist, ICRISAT/ODNRI
J.Arihara, Associate Principal Physiologist
N.Ae, Associate Principal Microbiologist
H.J.Hansen, Asst Principal Plant Pathologist, ICRISAT/DANIDA
K.Okada, Asst Principal Microbiologist
D.Sharma, Sr Plant Breeder, Pigeonpea (until Jul)
K.C.Jain, Plant Breeder, LEGOFTEN
Onkar Singh, Plant Breeder, Chickpea (on sabbatic from Jul)
K.B.Saxena, Plant Breeder, Pigeonpea
S.S.Lateef, Entomologist
M.P.Haware, Plant Pathologist (on leave)
S.C.Sethi, Plant Breeder, Chickpea
N.P.Saxena, Agronomist (Physiology)
O.P.Rupela, Agronomist (Microbiology)
J.V.D.K.Kumar Rao, Agronomist (Microbiology) LEGOFTEN
A.M.Ghanekar, Plant Pathologist
Jagdish Kumar, Plant Breeder, Chickpea
S.Sithanantham, Entomologist (on leave from Jul)
S.C.Gupta, Plant Breeder, Pigeonpea
M.V.Reddy, Plant Pathologist
Y.S.Chauhan, Agronomist (Physiology)
S.B.Sharma, Plant Nematologist
M.D.Gupta, Sr Research Associate
N.V.Ratnam, Sr Research Associate
J.H.Miranda, Sr Research Associate, Chickpea
Sheila Vijay Kumar, Sr Research Associate
L.Krishna Murthy, Sr Research Associate
P.K.Anand Rao, Postdoctoral Fellow (until Jan)
Nandita Sarkar, Postdoctoral Fellow
S.K.Singh, Postdoctoral Fellow (from May)
F.B.Lopez, Postdoctoral Fellow (from Jun)
A.Schroth, Research Scholar (from Oct)

Groundnut Group

D.McDonald, Principal Plant Pathologist
J.P.Moss, Principal Cytogeneticist
D.V.R.Reddy, Principal Plant Virologist
J.H.Williams, Principal Plant Physiologist (on sabbatic from May)
J.A.Wightman, Principal Entomologist
S.N.Nigam, Principal Plant Breeder
F.Waliyar, Asst Principal Plant Pathologist
L.J.Reddy, Plant Breeder
P.Subrahmanyam, Plant Pathologist (on leave)
P.T.C.Nambiar, Microbiologist (on sabbatic from Apr)
P.W.Amin, Coordinator and Entomologist, LEGOFTEN
G.V.Ranga Rao, Entomologist
A.K.Singh, Cytogeneticist (on sabbatic until Jun)
V.K.Mehan, Plant Pathologist
D.C.Sastri, Cytogeneticist
M.J.Vasudeva Rao, Plant Breeder
S.L.Dwivedi, Plant Breeder
R.C.Nageswara Rao, Plant Physiologist
V.M.Ramraj, Plant Physiologist
N.Sivananda Reddy, Sr Research Associate
Y.Sudhakar Yekula, Postdoctoral Fellow (from Jun)

C.S.Gold, Postdoctoral Fellow (from Sep)
R.A.Naidu, Postdoctoral Fellow (from Jan)

Syria

K.B.Singh, Principal Chickpea Breeder
M.P.Haware, Principal Chickpea Pathologist

Pakistan

M.S.Rahman, Principal Chickpea Breeder/ Plant Pathologist

Resource Management

Program Office

J.L.Monteith, Program Director, Resource Management
S.K.Sharma, Sr Research Associate
R.S.Aiyer, Sr Adm Officer
S.Ramachandran, Adm Officer

Agronomy Group

S.M.Virmani, Principal Agroclimatologist
J.R.Burford, Principal Soil Chemist (on sabbatic until May)
C.K.Ong, Principal Agronomist, Cropping Systems
R.J.Van Den Beldt, Principal Agronomist, Agroforestry (until Mar)
R. Tabo, Principal Agronomist (from Aug)
A.Schütt, Asst Principal Engineer, Soil Fertility Unit (ICRISAT/University of Hamburg)
Piara Singh, Soil Scientist
A.K.S.Huda, Agroclimatologist
K.L.Sahrawat, Soil Chemist
T.J.Rego, Soil Scientist
M.S.Reddy, Agronomist (until Aug)
M.Natarajan, Agronomist (until Jul)
A.Ramakrishna, Agronomist
C.S.Pawar, Entomologist
A.A.H.Khan, Engineer
R.Tabo, Postdoctoral Fellow (until Jul)
J.N.Daniel, Postdoctoral Fellow (from Sep)

Engineering Group

K.B.Laryea, Principal Soil Physicist
T.Takenaga, Principal Agricultural Engineer
G.D.Smith, Principal Soil Scientist, ICRISAT/QDPI (from Feb)
Sardar Singh, Soil Scientist
K.L.Srivastava, Agricultural Engineer
R.K.Bansal, Agricultural Engineer (on leave)
R.C.Sachan, Agricultural Engineer
Prabhakar Pathak, Agricultural Engineer
N.K.Awadhwal, Agricultural Engineer/Soil Physicist
V.M.Mayande, Engineer
M. Bonsu, Postdoctoral Fellow (from Aug)

Economics Group

T.S.Walker, Principal Economist
P.J.Matlon, Principal Economist (on sabbatic)
R.A.E.Müller, Principal Economist
Karen Ann Dvorak, Principal Economist, ICRISAT/IFDC (until Sep)
N.S.Jodha, Sr Economist (on leave from Apr)
R.N.Athavale, Sr Hydrologist (until Jun)
R.D.Ghodake, Economist (until Apr)
R.P.Singh, Economist (on sabbatic from Apr)
M.Asokan, Sr Research Associate (on study leave from Dec)
K.G.Kshirsagar, Sr Research Associate (on study leave from Apr)
K.V.Subba Rao, Sr Research Associate
M.J.Bhende, Sr Research Associate
V.Bhaskar Rao, Sr Research Associate
P.Parthasarathy Rao, Sr Research Associate

Support Programs

Biochemistry

R.Jambunathan, Principal Biochemist and Program Leader
Umaid Singh, Biochemist
V.Subramanian, Biochemist
S.Sivaramakrishnan, Biochemist
P.Subrahmanyam, Sr Adm Officer
Santosh Gurtu, Sr Research Associate
M.S.Kherdekar, Sr Research Associate
S.Suryaprakash, Sr Research Associate

Electron Microscopy

A.K.Murthy, Engineer

Genetic Resources

M.H.Mengesha, Principal Germplasm Botanist and Program Leader
K.E.Prasada Rao, Sr Botanist
R.P.S.Pundir, Botanist
V.Ramanatha Rao, Botanist
S.Appa Rao, Botanist
P.Remanandan, Botanist
T.R.K.Satyanarayana, Administrative Officer
Y.Saideshwara Rao, Postdoctoral Fellow (from Jun)

Plant Quarantine

B.K.Varma, Chief Plant Quarantine Officer (until Nov)
N.C.Joshi, Chief Plant Quarantine Officer (on contract, from Dec)
Upendra Ravi, Sr Research Associate
N.Rajamani, Sr Adm Officer

Fellowships and Training

D.L.Oswalt, Principal Training Officer and Program Leader
B.Diwakar, Sr Training Officer
T.Nagur, Sr Training Officer
S.K.Dasgupta, Sr Training Officer (on sabbatic until May)
Faujdar Singh, Training Officer
V.S.Raju, Sr Secretary (until Oct)

Information Services

D.A. Fuccillo, Head
J.B.Wills, Research Editor
Susan D. Hall, Research Editor
S.M.Sinha, Asst Manager, Art and Production
D.R.Mohan Raj, Editor
J.J.Abraham, Editor
Madhu Reddy, Editor (until Jan)
V.Sadhana, Editor (from Apr)
H.S.Duggal, Sr Photographic Supervisor (until Sep)
G.K.Guglani, Sr Art Visualizer
T.R.Kapoor, Sr Composing Supervisor
A.Antonisamy, Printshop Supervisor
A.B.Chitnis, Sr Photographer
N.V.N.Chari, Adm Officer

Statistics

Murari Singh, Statistician

Computer Services

J.W.Estes, Computer Services Officer
S.M.Luthra, Manager (Computer Services)
J.Sai Prasad, Asst Manager (Computer Services)
T.B.R.N.Gupta, Senior Computer Programmer/Analyst
C.Kameswara Rao, Computer Programmer/Analyst (until Apr)
S.V.Nanda Kishore, Computer Programmer/Analyst
J.Gnanasekharan, Computer Programmer/Analyst (until Oct)
E.A.Vinod Kumar, Computer Programmer/Analyst (from Nov)
G.Subba Raju, Computer Programmer/Analyst (from Nov)

Library and Documentation Services

L.J.Haravu, Manager
P.K.Sinha, Sr Documentation Officer
P.S.Jadhav, Sr Library Officer
S.Prasannalakshmi, Sr Library Officer
R.G.Naidu, Documentation Officer
V.Venkatesan, Library Officer (on leave from Aug)

Housing and Food Services

D.A.Evans, Manager (from Feb)
S.Mazumdar, Asst Manager (Food Services)
B.R.Revathi Rao, Asst Manager (Housing)
D.V.Subba Rao, Asst Manager (Warehouse)
D.N.Sar, Canteen Officer

Physical Plant Services

V.P.McGough, Manager
W.B.Symons, Principal Engineer (from Aug)
Sudhir Rakhra, Chief Engineer (Civil)
D.Subramaniam, Chief Engineer (Electrical)
C.K.Belliappa, Asst Manager (Workshop) (until Jan)
S.K.V.K.Chari, Sr Engineer (Electronics and Instrumentation) (until Jan)
N.S.S.Prasad, Sr Engineer (Electronics and Instrumentation)
A.R.Das Gupta, Sr Engineer (Communication)
D.C.Raizada, Sr Engineer (Airconditioning)
K.Ravi Kumar, Sr Engineer (from Apr-Oct)
R.Thiyagarajan, Engineer (Automobiles) (until Mar)
A.N.Singh, Engineer (Heavy Equipment and Tractors)
S.W.Quader, Engineer (Office Equipment)
K.R.C.Bose, Engineer (Civil)
K.Satyanarayana Raju, Engineer (from May)
V.Madhusudan Rao, Engineer
Y.Chiranjeevi Rao, Engineer
S.P.Jaya Kumar, Sr Adm Officer

Farm Development and Operations

D.S.Bisht, Manager (from Jul)
S.N.Kapoor (Acting Manager until Jul), Manager (Farm Machinery)
S.K.Pal, Sr Plant Protection Officer
K.Ravindranath, Sr Engineer (Farm Machinery)
M.Prabhakar Reddy, Sr Agricultural Officer
N.V.Subba Reddy, Sr Horticulture Officer
M.C.Ranganatha Rao, Sr Engineer
S.Abid Ali Khan, Agricultural Officer
C.Rama Reddy, Agricultural Officer
Akbar Pasha, Engineer
S.C.Gupta, Engineer

T.A.Krishnamurthi, Sr Adm Officer (until Apr)
Surendra Mohan, Sr Adm Officer (from Apr to Aug)
V.S.Raju, Adm Officer (from Oct)

West African Programs

ICRISAT Sahelian Center, Niger

Administration

R.W.Gibbons, Executive Director, West African Programs, and Director, ICRISAT Sahelian Center
D.C.Goodman Jr, Regional Adm Officer (until Mar)
M.G.Wedeman, Regional Adm Officer (on special assignment from Apr)
M.Adjei-Fah, Adm Secretary
M.D.Diallo, Regional Fiscal officer (from Oct)
I.Agani, Accountant
K.A.Moussa, Personnel and Transport Officer
Solange Delanne, Executive Asst (Liaison)
B.Amadou, Adm Asst (Travel) (from Nov)
A.R.Tanko, Purchase officer
I.Laouali, Computer Programmer/Analyst
I.J.Cachalo, Bilingual Secretary

Research Programs

Pearl Millet Improvement Program

K.Anand Kumar, Principal Millet Breeder and Team Leader
S.O.Okiror, Principal Millet Breeder/Regional Trials Officer
S.N.Lohani, Principal Millet Breeder (Burkina Faso)
M.Mahamane, Bilingual Secretary (from Jul)
L.Marchais, Principal Geneticist (ORSTOM)
S.Tostain, Principal Geneticist (ORSTOM)
M.J.Lukefahr, Principal Millet Entomologist
A.Mamalo, Research Technician
J.Werder, Principal Millet Pathologist
A.A.Cissé, Research Asst (from Jul)
L.K.Fussell, Principal Millet Agronomist (on sabbatic until Sep)
T.J.Stomph, Sr Research Asst

Groundnut Improvement Program

B.J.Ndunguru, Principal Groundnut Agronomist and Team Leader
D.C.Greenberg, Principal Groundnut Breeder
P.Subrahmanyam, Principal Groundnut Pathologist

Resource Management Program

C.Renard, Principal Agronomist and Team Leader,
M.Manzo, Research Asst
M.V.K.Sivakumar, Principal Agroclimatologist (on sabbatic from Oct)
S.Abdoussalem, Research Asst
A.Bationo, Principal Soil Chemist (IFDC)
M.C.Klaij, Principal Soil and Water Management Scientist
P.Ouedraogo, Sr Research Asst
A.Tékété, Principal Agronomist (University of Hohenheim) (until Dec)
J.Kaziende, Research Asst
B.R.N'tare, Principal Cowpea Breeder/Agronomist (IITA)
M.S.Dicko, Principal Animal Nutritionist (ILCA) (on sabbatic until May)
S.Coulibaly, Research Technician
J.C.Hopkins, Postdoctoral Fellow (IFPRI) (from Jul)
R.J.Van Den Beldt, Principal Agronomist/Agroforestry (from May)
M.Djibey, Research Asst (from May)
J.Toll, IBPGR Field Officer for West Africa (from Feb)
V.Watt, IBPGR Collector for the Sahel (from Jun)
A.N'Diaye, Bilingual Secretary (from Mar)

Support Programs

Farm Operations

P.G.Serafini, Research Farm Manager
R.van Midde, Technical Asst (SNV)
P.Koudogbo, Chief Mechanic
B.Mallam, Security Officer

Construction

B.D.Marvaldi, Project Development Officer

Statistics

B.Gilliver, Principal Statistician
G.Ouoba, Computer Programmer

Information/Documentation

C.Giroux, Regional Information Officer
A.Dodo, Translator
F.Gbaguidi, Librarian
H.Diori, Documentalist (from Mar)

Burkina Faso

Administration

C.M.Pattanayak, Principal Sorghum Breeder
and SAFGRAD/ICRISAT Coordinator
A.Tenkouano, Research Associate
A.Coulibaly, Bilingual Adm Secretary
B.T.Ouedraogo, Adm Asst (General Service)
S.Lingani, Adm Asst (Accounts)
L.Yoni, Computer Technician

Research

K.V.Ramaiah, Principal Cereal Breeder—*Striga*
D.S.Murty, Principal Sorghum Breeder
M.D.Thomas, Principal Sorghum Pathologist
G.Hoffman, Principal *Striga* Agronomist (from Aug)
N.Kaboré, Technician
T.Traoré, Technician
S.Sawadogo, Technician

Mali

S.V.R.Shetty, Principal Agronomist and Team Leader
N.F.Beninati, Principal Breeder
I.Kassambara, Research Associate (Sotuba)
A.Coulibaly, Research Associate (Cinzana)
S.Touré, Adm Asst
B.Sogoba, Accounts Asst

Southern Africa Programs

SADCC Regional Sorghum and Millet Improvement Program, Zimbabwe

L.R.House, Executive Director, Southern Africa
and Project Manager, SADCC/ICRISAT Program
S.P.Ambrose, Regional Adm Officer
A.B.Obilana, Principal Sorghum Breeder
S.C.Gupta, Principal Millet Breeder
D.S.Bisht, Station Development and Operations Officer
(until Jun)
W.A.J.de Milliano, Principal Cereals Pathologist
M.Osmanzai, Principal Cereals Agronomist
K.Leuschner, Principal Cereals Entomologist
F.York, Farm Manager
W.K.Morgan, Asst Adm Officer

Regional Groundnut Improvement Program, Malawi

K.R.Bock, Principal Groundnut Pathologist
and Team Leader
G.L.Hildebrand, Principal Groundnut Breeder (from Aug)

Acronyms and Abbreviations Used in this Annual Report

AC	Agricultural Corporation (Burma)
ACIAR	Australian Centre for International Agricultural Research
ACT	Arhar Coordinated Trial
ADAB	Australian Development Assistance Bureau
ADB	Asian Development Bank
AFC	African Forestry Commission
Afpop	African population
AGLN	Asian Grain Legumes Network
AGRHYMET	Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (Niger)
AHT	Advanced Hybrid Trial
AIBA	Agricultural Information Bank for Asia (The Philippines)
AICAP	All India Coordinated Agrometeorology Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICPIP	All India Coordinated Pulses Improvement Project
AICPMIP	All India Coordinated Pearl Millet Improvement Program
AICSIP	All India Coordinated Sorghum Improvement Project
AN	Ammonium Nitrate
APAU	Andhra Pradesh Agricultural University (India)
ARSHAT	Asian Regional Sorghum Hybrid Adaptation Trial
ARSVAT	Asian Regional Sorghum Variety Adaptation Trial
ART	Arhar Regional Trial
AVT	Advanced Variety Trial
AWHC	Available Water-Holding Capacity
AYT	Advanced Yield Trial
BAP	Benzyl Amino Purine
BEC	Bristled Early Composite
BLRV	Bean Leaf-Roll Virus
BND	Bud Necrosis Disease
BSEC	Bold Seeded Early Composite
CABI	Commonwealth Agricultural Bureaux International (UK)
CAN	Calcium Ammonium Nitrate
CDA	Controlled droplet applicator
CD-ROM	Compact Disk-Read Only Memory
CENARGEN	Centro Nacional de Recursos Geneticos (Brazil)
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (Mexico)
CIP	Centro Internacional de la Papa (Peru)
CIDA	Canadian International Development Agency
CILSS	Comité permanent inter-Etats de lutte contre la sécheresse dans le Sahel (Mali)
CLAIS	Comisión Latinoamericano de Investigadores en Sorgo (Guatemala)
CMC	Computer Maintenance Corporation (India)
CNEARC	Centre national d'études agronomiques des régions chaudes (France)
CNRADA	Centre national de recherche agronomique et de développement agricole (Mauritania)
COTRINOR	INRAN/ICRISAT Cooperative Trial North Zone

COTRISUD	INRAN/ICRISAT Cooperative Trial South Zone
CRIDA	Central Research Institute for Dryland Agriculture (India)
CRSP	Collaborative Research Support Program (USA)
CV	Coefficient of Variation
cv	cultivar
DAE	Days after Emergence
DAF	Days after Flowering
DANIDA	Danish International Development Agency
DAP	Diammonium Phosphate
DAS	Days after Sowing
D_2C	Dwarf Composite
DEC	Digital Equipment Corporation (USA)
DIECA	Diethyldithiocarmabic Acid
DM	Downy Mildew
DM-T	Dry Matter-Transpiration
EACT	Early Arhar Coordinated Trial
EARSAM	East African Regional Sorghum and Millet (Network; and Advisory Committee)
EC	Electrical Conductivity
EC	Early Composite
EEC	European Economic Community
ELC	Elite Composite
ELISA	Enzyme-Linked Immunosorbent Assay
ELPN	Elite Products Nursery
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (Brazil)
EMVT	Early-Maturing Varieties Trial
ERC	Ergot-Resistant Composite
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific (Thailand)
EXACT	Extra-early Arhar Coordinated Trial
FAO	Food and Agriculture Organization of the United Nations (Italy)
FSVPT	Full Season Varieties Preliminary Trial
FYM	Farmyard Manure
GLIP	Grain Legume Improvement Program
GRAV	Groundnut Rosette Assistor Virus
GRU	Genetic Resources Unit
GSND	Groundnut Streak Necrosis Disease
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Federal Republic of Germany)
HAU	Haryana Agricultural University (India)
HFP	High Fertility Population
HiGroP	High Growth Rate Population
HiTIP	High Tillering Population
IAA	Indole Acetic Acid
IARI	Indian Agricultural Research Institute
IBA	Indole Butyric Acid
IBPGR	International Board for Plant Genetic Resources (Italy)
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IBSRAM	International Board for Soil Research and Management (Thailand)

ICARDA	International Center for Agricultural Research in Dry Areas (Syria)
ICGVT	International Confectionery Groundnut Varietal Trial
ICHRN	International Chickpea *Heliothis* Resistance Nursery
ICIPE	International Centre of Insect Physiology and Ecology (Kenya)
ICRC	ICRISAT Restorer Composite
ICSCSS	ICRISAT Center-Sahelian Center Seedling Screen
ICSN	International Chickpea Screening Nursery
ICSN-DL	International Chickpea Screening Nursery Desi Long-duration
ICSN-DM	International Chickpea Screening Nursery Desi Medium-duration
ICSN-DS	International Chickpea Screening Nursery Desi Short-duration
IDN	International Drought Nursery
IDRC	International Development Research Centre (Canada)
IER	Institut d'économie rurale (Mali)
IEGVT	International Early Groundnut Varietal Trial
IFDC	International Fertilizer Development Center (USA)
IFDRGVT	International Foliar Diseases Resistant Groundnut Varietal Trial
IFPRI	International Food Policy Research Institute (USA)
IITA	International Institute of Tropical Agriculture (Nigeria)
ILCA	International Livestock Centre for Africa (Ethiopia)
IMZAT	ICRISAT Pearl Millet African Zone-A Trial
IMLGVT	International Medium and Late Groundnut Varietal Trial
INERA	Institut national d'études et de recherches agricoles (Burkina Faso)
INIFAP	Instituto Nacional de Investigadores Forestales y Agropecuarias (Mexico)
INRA	Institut national de la recherche agronomique (Morocco)
INRAN	Institut national de recherches agronomiques du Niger
INRZFH	Institut national de la recherche zootechnique forestière et hydrobiologique (Mali)
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)
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
IPMRN	International Pearl Millet Rust Nursery
IPRGVT	International Pest-resistant Groundnut Varietal Trial
IRA	Institut de la recherche agronomique (Cameroon)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (France)
IRHO	Institut de recherches pour les huiles et oléagineux (France)
IS-C	International Sorghum Conversion
ISC	ICRISAT Sahelian Center (Niger)
ISDMN	International Sorghum Downy Mildew Nursery
ISGMN	International Sorghum Grain Mold Nursery
ISRA	Insitut sénégalais de recherches agricoles (Senegal)
ISSBN	International Sorghum Stemborer Nursery
ISSFN	International Sorghum Shoot Fly Nursery
IVC	Inter-Varietal Composite

IVPD	In Vitro Protein Digestibility
IVSCAF	In Vitro Seed Colonization by *Aspergillus flavus*
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya (India)
KARI	Kenya Agricultural Research Institute
Kn	Kinetin
LabraP	Large Grain Population
LBC	Late Backup Composite
LEGOFTEN	Legume On-Farm Testing and Nursery
LER	Land Equivalent Ratio
LFP	Low Fertility Low Plant Population
LGSP	Large Seeded Gene Pool
LID	Limited Irrigation Dryland
LID-AF	Limited Irrigation Dryland-Alternate Furrows
LWP	Leaf Water Potential
MASVYT	Mesoamerican Sorghum Variety Yield Trial
MBEC	Mixed Bristled Early Composite
MC	Medium Composite
MDEC	Mixed Dwarf Early Composite
MFR	Multifactor Resistant
MOU	Memorandum of Understanding
MPI	Max-Planck Institute (Federal Republic of Germany)
ms	male sterile
MS	Murashige and Skoogs
NAA	Napthalene Acetic Acid
NARC	National Agricultural Research Centre (Pakistan)
NBPGR	National Bureau of Plant Genetic Resources (India)
NABARD	National Bank for Agriculture and Rural Development (India)
NDFRS	National Dryland Farming Research Station (Kenya)
NEC	New Early Composite
NELC	New Elite Composite
NPN	Nonprotein Nitrogen
NPU	Net Protein Utilization
NRA	Nitrate Reductase Activity
NRP	National Research Programs
ODNRI	Overseas Development National Resources Institute (UK)
ORD	Organisme régional de développement (Burkina Faso)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
PARC	Pakistan Agricultural Research Council
PARP	Partially Acidulated Rock Phosphate
PB	Phytophthora Blight
PBLN	Potential B-line Nurseries
PCCMCA	Cooperative Program for the Improvement of Crops and Animals (Panama)
PCLSV	Peanut Chlorotic Leaf Streak Virus
PCNB	Pentachloronitrobenzene
PCV	Peanut Clump Virus
PE	Potential Evapotranspiration
PEG	Polyethylene Glycol

PEQIA	Post-Entry Quarantine Isolation Area
PHT	Preliminary Hybrid Trial
PMAHT	Pearl Millet Advanced Hybrid Trial
PMAVT	Pearl Millet Advanced Variety Trial
PMC	Pollen Mother Cell
PMDMN	Pearl Millet Disease Monitoring Nursery
PMIHT	Pearl Millet Initial Hybrid Trial
PMIN	Pearl Millet Inbred Nursery
PMIVT	Pearl Millet Initial Variety Trial
PMLVT	Pearl Millet Late Variety Trial
PMPVT	Pearl Millet Preliminary Varieties Trial
PMV	Peanut Mottle Virus
PON	Pigeonpea Observation Nursery
PMPT	Pearl Millet Pathology Trial
PRLN	Potential R-Lines Nursery
PRP	Parc-W Rock Phosphate
PRW	Parc-W
PStV	Peanut Stripe Virus
PVT	Preliminary Variety Trial
PYSV	Peanut Yellow Spot Virus
PYT	Preliminary Yield Trial
RBD	Randomized-Block Design
RUE	Radiation-Use Efficiency
RLD	Root Length Density
RMP	Resource Management Program
RSLE	Regional Sorghum Line Evaluation Trial
RSAVT	Regional Sorghum Advanced Variety Trial
RSPVT	Regional Sorghum Preliminary Varietal Trial
SADCC	Southern African Development Coordination Conference (Bostwana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SAT	Semi-Arid Tropics
SATCRIS	Semi-Arid Tropical Crops Information Service
SCRI	Scottish Crop Research Institute (UK)
SDI	Selective Dissemination of Information
SDU	Sorghum Diastatic Units
SM	Sterility Mosaic
SMAAR	Syrian Ministry of Agriculture and Agrarian Reform
SPAT	Sorghum Population Adaptation Trial
SPB	Single-Plant Bulk
SPP	Single-Plant Progenies
SRC	Smut-Resistant Composite
SSP	Single Superphosphate
TADD	Tangential Abrasive Dehulling Device
TAES	Texas Agricultural Experiment Station
TARI	Tanzania Agricultural Research Institute
TCA	Trichloroacetic Acid
TDM	Total Dry Matter
TDRI	Tropical Development Research Institute (UK)

TGMR	Threshed Grain Mold Rating
TN	Total Nitrogen
TNAU	Tamil Nadu Agricultural University (India)
TRP	Tahoua Rock Phosphate
TSP	Triple Superphosphate
TSWV	Tomato Spotted Wilt Virus
USAID	United States Agency for International Development
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
UPN	Uniform Progeny Nursery
VAM	Vesicular Arbuscular Mycorrhizae
WADMON	West African Downy Mildew Observation Nursery
WADMVN	West African Downy Mildew Variability Nursery
WAE	Water Application Efficiency
WASDRN	West African Sorghum Disease Resistance Nursery
WASHAT	West African Sorghum Hybrid Adaptation Trial
WASVAT	West African Sorghum Variety Adaptation Trial
WATDCO	Water Deficit Coefficient
WCASRN	West and Central African Sorghum Research Network
WhiGraP	White Grain Population
WHO	World Health Organization of the United Nations

Cummulative list of currently cultivated ICRISAT cultivars and parents issued before 1987 by the PMIC.

Original name	ICRISAT name	Release name	Remarks	Notice
Sorghum cultivars/varieties				
SPV 351	ICSV 1	CSV 11	Released cultivar in India (1984).	84/8
SPV 386	ICSV 2	ZSV 1	Released cultivar in Zambia (1983).	84/15
SPV 475	ICSV 112	SV 1	Released cultivar in Zimbabwe (1985). Recommended for release in India (1987)	86/1
		UANL-I-187	Released cultivar in North Mexico (1987)	
Sorghum hybrid				
CSH 11 (SPH 221)	ICSH 153	CSH 11	Released cultivar in India (1986). (Male-sterile, 296A, from AICSIP).	86/3
Pearl millet cultivars/varieties				
WC-C75	ICMV 1	WC-C75	Released cultivar in India (1982). Released cultivar in Zambia (1987).	84/1
IBV 8001	ICMV 2	-	Cultivars in prerelease stage in	84/2
IBV 8004	ICMV 3	-	Senegal.	
ICMS 7703	ICMV 4	ICMS 7703	Released variety in India (1985).	86/4
ITMV 8001	ICMV 5	ITMV 8001		86/5
ITMV 8002	ICMV 6	ITMV 8002	Released cultivars in Niger (1985).	86/6
ITMV 8304	ICMV 7	ITMV 8304		86/7
Pearl millet male-sterile lines				
81A	ICMA 1	-	Parent of ICMH 451	86/8
81B	ICMB 1	-		86/8
834A	ICMA 4	-	Parent of ICMH 501	84/3
834B	ICMB 4	-		84/3
Chickpea cultivars/varieties				
ICCC 4	ICCV 1	ICCC 4	Released cultivar in Gujarat State, India (1983), and Nepal (1987)	84/9
ICCC 32	ICCV 6	-	Prerelease in Central and Northwest Plain Zones of India.	86/11
Pigeonpea cultivars/varieties				
ICP 8863	ICPV 1	Maruti	Recommended by AICPIP as source of resistance to wilt (*Fusarium udum*). Released in Karnataka State, India (1985).	84/11
ICPL 87	ICPL 87	Pragati	Short-duration, high-yielding variety. Released in India (1986).	86/9
ICPL 151	ICPL 151	Jagriti	Short-duration, high-yielding variety. Prerelease in India as Jagriti.	86/10
Groundnut cultivars/varieties				
Robut 33-1-7-4	ICGS 1	-	A selection from ICGS 1 released as Spring Groundnut 84 in Punjab State, India (1986).	86/13
Robut 33-1-18-8-B1	ICGS 11	ICGS 11	Released for postrainy-season cultivation in Central and Peninsular India (1986).	86/14

List of ICRISAT material identified by the Plant Material Identification Committee (PMIC) in 1987.

Original name	ICRISAT name	Release name	Remarks	Notice
Sorghum cultivar/variety				
SAR 1	ICSV 145	ICSV 145	Resistant to *Striga asiatica* in India. Recommended for cultivation in *Striga* endemic areas of India, except Karnataka.	87/1
Pearl millet hybrids				
ICMH 451	ICMH 451	ICMH 451 (MH 179)	Released cultivar in India (1986).	87/2
ICMH 501	ICMH 501	ICMH 501 (MH 180)	Released cultivar in India (1986).	87/3

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

ISSN 0257-2478

Printed at ICRISAT

ICR 88-0038