ICRISAT ANNUAL REPORT 1986

Cover: Systematic design used in an agroforestry study on crop/tree interaction and orientation effects on deep Alfisols. We found that over 3 years *Leucena leucocephala* row orientation had no effect on growth of sunflower or sorghum intercrops. ICRISAT Center, 1984-1986.

ADVISOR
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ICRISAT
ANNUAL REPORT 1986

International Crops Research Institute for the Semi-Arid Tropics
(ICRISAT), Patancheru, Andhra Pradesh 502324, India

1987

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.

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(ICRISAT), Patancheru,
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Contents

About This Report

This Annual Report covers the 1986 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 seven countries of Africa, and in Mexico, Syria, and Pakistan, where ICRISAT scientists are posted. Pertinent agroclimatic information is presented in the Agroclimatic Environment section.

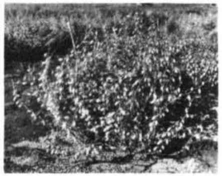
Following the merger in 1985 of Farming Systems and Economics programs into the Resource Management Program, other changes have occurred in 1986 in the management structure. The previous Sorghum and Pearl Millet programs have been amalgamated into a Cereals Program; and work carried out previously on chickpea, pigeonpea, and groundnut is now integrated in the Legumes Program. In this Report, however, research achievements in respect of the Institute's five mandate crops are presented by crop, as in previous years, 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 preluded 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 Annual Report are also available on request from program offices.

ICRISAT uses the Systeme international d'unites (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.

A list of elite ICRISAT plant materials issued by the Institute's Plant Material Identification Committee appears at the end of this Report. In the text the ICRISAT designation for each plant material is given first, followed by its released designation or name in parentheses (where different) or its original name.

ICRISAT's Five Crops

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

Introduction

The year 1986 saw ICRISAT make further progress in the development and strengthening of our programs in Africa, as well as in our research at ICRISAT Center, thanks to adequate funding. This was the first year since 1979 with full funding of our budget request.

In Africa, we now have substantial research programs in the western and southern parts of the continent. In the near future, we expect to develop a program in the eastern region as well. Buildings of the new ICRISAT Sahelian Center (ISC) at Sadore, near Niamey, Niger, are scheduled to be ready for occupancy in 1988. A 1.5 ha block of land is being acquired from the City of Niamey, for the Training and Visitors' Center, which will accommodate 15 French-speaking, in-service trainees each season.

The new buildings of the ICRISAT Sahelian Center under construction, at Sadore, Niger.

The ICRISAT Mali program, assessed as "extremely cost-effective" by an outside evaluation team, completed 10 years of work combining plant breeding, agronomy, and product acceptability. It provided an infrastructure for crop research in Mali, trained Malian scientists, and provided technical assistance in breeding and agronomy. Tests are now under way in the second phase of the ICRISAT Mali program to develop improved technologies for cereal/groundnut or cereal/cowpea intercropping and labor-saving techniques for weed control. Future research will aim at developing crop lines that utilize the agroclimatic resources more efficiently. We are pleased to note that 50 Malians had been trained at ICRISAT Center up to the end of 1986, most of whom now contribute their knowledge and skills to the national program of Mali or to the ICRISAT Mali Program.

In Asia, ICRISAT signed two separate agreements with Bangladesh and Burma providing for collaborative research in those countries on sorghum, legumes, and dryland farming systems.

Following a recent challenge from the Chairman of the Consultative Group for International Agricultural Research to the International Agricultural Research Centers, ICRISAT Center has made a distinct shift towards more strategic and interdisciplinary research. New approaches planned will include harnessing biotechnology to improve grain quality and enable wider use of sorghum and pearl millet, and more innovative computer application in the analyses of genotype x environment interactions. Microcomputers are being used also to speed up progress in plant breeding, particularly in pearl millet.

During the year, ICRISAT's management was reorganized, with the Governing Board's approval. The five mandate crops were grouped under two programs, replacing four existing crop improvement programs. Sorghum and pearl millet are now dealt with in the Cereals Program, and pulses (chickpea and pigeonpea) and groundnut in the Legumes Program. The new structure provided for a Deputy Director General, two Assistant Directors General (for Administration and for Liaison), three Program Directors based at ICRISAT Center (heading the Resource Management, Cereals, and Legumes Programs), and two Executive Directors based in Africa. The changes reflect ICRISAT's increasing commitments in Africa and are expected to achieve better coordination of its efforts worldwide.

The Asian Grain Legumes Network was established to speed up exchange of materials and information between ICRISAT and countries in South and Southeast Asia. The network will seek to relate ICRISAT's research efforts on legumes to those of other regional and international organizations. Its ultimate goal will be to ensure that appropriate new technology, which can increase legume productivity, reaches farmers as quickly as possible. Delegates at the Consultative Group Meeting for Eastern and Central African Regional

Research on Grain Legumes, held in December 1986, urged ICRISAT's presence within that region to assist in increasing legume productivity there.

Regional networks involving cereals were initiated in Africa. At the Fifth Eastern Africa Regional Workshop on Sorghum and Millet held at Bujumbara, Burundi, the participants proposed the setting up of a centralized regional information unit at Nairobi, Kenya, organized by the ICRISAT/Semi-Arid Food Grain Research and Development (SAFGRAD) coordinating office, to improve information collection and dissemination. The participants proposed that this unit form part of an Eastern Africa Regional Sorghum and Millet (EARSAM) network.

Several crop varieties or hybrids developed from ICRISAT material were released to farmers during the year. ICPL 87, an early-maturing ICRISAT pigeonpea variety with good ratoonability, was officially released to farmers in peninsular India as Pragati (meaning progress). Newspapers reported that farmers had harvested more than 4 t ha^{-1} of this pigeonpea variety, using an

Botswana's Assistant Minister for Agriculture, Mr G.M. Oteng (second from right) with Resource Management Program scientists viewing a cropping systems experiment with ICPL 87, the pigeonpea variety recently released in India, at ICRISAT Center.

ICRISAT multiple-harvest technique. This account led to a flood of requests for seed from farmers, seed companies, and extension officials from various Indian states. Farmers who grew the variety in Rangareddy district in Andhra Pradesh were enthusiastic about it because its low height enabled easy spraying with insecticides and, at one location, dry seed yields up to 5.2 t ha^{-1} (two harvests, 180 days) were reported. In Maharashtra, the variety's relatively large seed and its superior yield performance found favor, while in Madhya Pradesh, where the variety is intended for cropping in rotation with wheat, ICPL 87 gave higher yields than the control cultivar, UPAS 120.

For the first time, an ICRISAT sorghum hybrid, ICSH 153 was released in India as CSH 11 for cultivation in all regions that grow rainy-season sorghums. ICRISAT economists found that Indian farmers, who grew the hybrid, harvested 2.85 t ha^{-1} of grain and 890 kg ha^{-1} of fodder. Most of them found CSH 11 superior to the popular hybrid, CSH 9. It is encouraging that one of the two Indian seed companies multiplying this hybrid sold 171.7 t of its seed in Karnataka in 1986; a year ago the figure was only 18 t.

Similarly, ICRISAT's pearl millet variety ICMV 1, released in India as WC-C75 in 1982, is preferred by farmers over competing cultivars because of its grain and fodder yields. Seed production had spread in 1986 to nine states of India, which represent 60-65% of the country's total pearl millet area. The demand for breeder seed of this variety is increasing. ICRISAT supplied 560 kg of breeder seed to seed production agencies in India from January 1985 to April 1986 in response to their requests for 900 kg, suggesting an even greater popularity in the coming years. According to data provided by the Indian Council of Agricultural Research (ICAR), targeted seed production of this variety will cover 1.5 million ha during the 1987 rainy season. The variety is expected to be released in Zambia and the Yemen Arab Republic as well.

ICRISAT's collaborative work with the International Center for Agricultural Research in the Dry Areas (ICARDA) showed that winter-sown chickpeas have a much greater yield potential than the traditional spring-sown chickpea in West Asia. However, such crops could be devastated by ascochyta blight and very low temperatures. During 1986, we made considerable progress in selecting genotypes that are tolerant to low temperatures. ICRISAT already has a well-established project in Pakistan working on ascochyta blight. Participants this year at the International Chickpea Scientists' Meet, held in Pakistan and cosponsored by the Pakistan Agricultural Research Council and ICRISAT, reviewed this cooperative work.

Research on drought continued to be of high priority to ICRISAT. A spacious rainout shelter, funded in part by Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), was commissioned at ICRISAT Center to be utilized by Institute scientists in strategic research to combat drought.

The rainout shelter in operation at ICRISAT Center.

Rainfall variability from year to year limits productivity in the West African Sahel, an important mandate region for ICRISAT. Unfortunately, no strategies have yet been evolved, that consider actual or intraseasonal weather there, to cope with such climatic variations. From detailed analysis for numerous locations in West Africa, our Resource Management Program at ISC showed that a strong association exists between the date of onset of rains and the length of the growing season. This analysis was applied during the 1986 rainy season, when rains arrived 20 days earlier than average. Since this pointed to a longer growing season, we planned for a sequential crop of early-maturing cowpea after the pearl millet crop. The rainfed crop of pearl millet yielded 1.2 t grain and 3.7 t straw ha^{-1}. Sequential cowpea yielded no grain, but 0.42 t hay ha^{-1} which, in economic terms,is substantial.

President Seyni Kountche of Niger (with grain in hand) discusses cowpea seed characteristics with ICRISAT scientists and members of his entourage during a visit to ICRISAT Sahelian Center.

Research at ISC also showed that application of crop residues helps increase crop yields and reduces the aluminium and hydrogen saturation of the exchange complex. In collaboration with the International Institute of Tropical Agriculture (IITA), we are evaluating a large number of short-cycle cowpeas to improve the productivity of the pearl millet/cowpea intercrop, a popular cropping system with farmers in the Sahel.

ICRISAT's virologists, entomologists, and pathologists began work in new greenhouses completed this year. These provide controlled phytosanitary facilities for the continuing study of viruses, fungi, and insects that attack ICRISAT mandate crops.

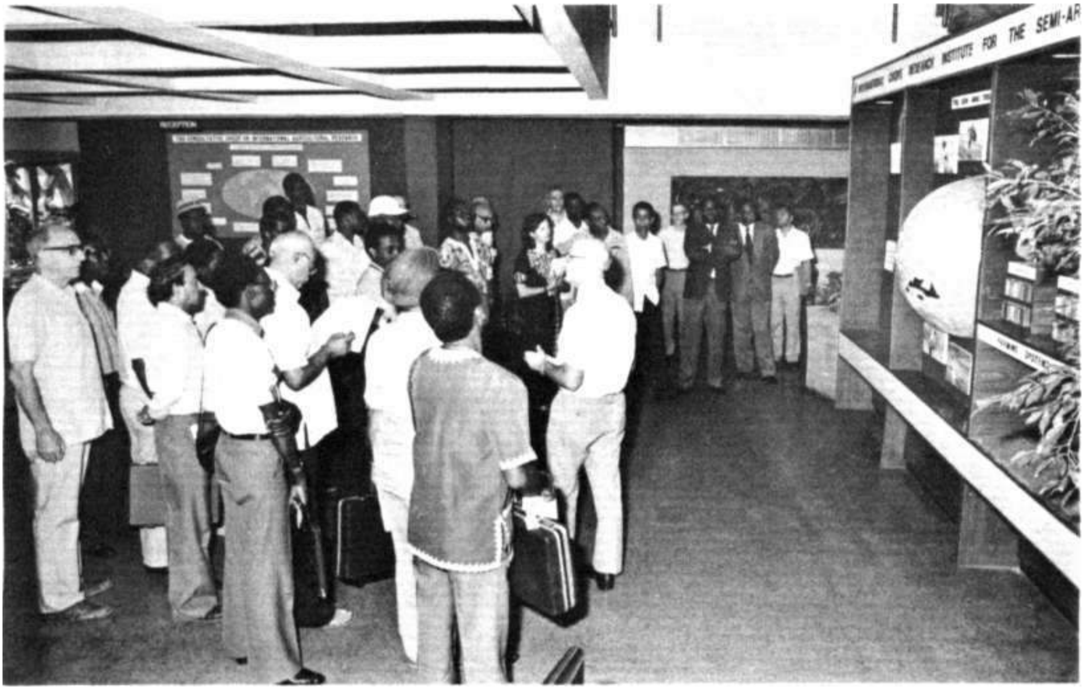
Reliable and reproducible results in the screening and selection of lines for resistance to insect pests require optimum and uniform levels of insect infestation. This is seldom possible under natural infestation conditions. At ICRISAT, a new insect-rearing laboratory has been installed where the sorghum stem borer, *Chilo partellus,* can be mass-produced under controlled conditions. Two other pest species, *Spodoptera litura* and *Mythimna separata,* are also being reared. This new facility is expected to hasten the screening of large quantities of germplasm and breeding material.

ICRISAT initiated germplasm evaluation in several national and regional locations. In these programs, undertaken in collaboration with agricultural research organizations in Cameroon, Ethiopia, India, Kenya, and Zimbabwe, germplasm lines from ICRISAT's gene bank were delivered to the national programs for sowing, joint evaluation, and selection. ICRISAT continues to help national programs identify promising germplasm lines for utilization in their respective countries, with emphasis on lines growing in their original and natural habitats. This collaborative research has been received enthusiastically by national programs, and ICRISAT plans to extend such activities to other countries of the semi-arid tropics.

Scientists from the National Bureau of Plant Genetic Resources (India) and ICRISAT's Genetic Resources Unit view a pearl millet evaluation plot at ICRISAT Center.

Trainees from five continents at ICRISAT Center sing a welcome song on ICRISAT Annual Day.

Food policymakers representing 14 African countries and concerned international and regional agencies being briefed on the Institute's mandate by Director General L.D. Swindale in the Center foyer.



In ICRISAT's gene bank, we added 2952 new accessions of our mandate crops and 466 of minor millets from 29 countries in 1986, bringing the total number of accessions maintained and conserved in the bank to 89 117. During the year, we distributed 38 064 packets of seed samples around the world in response to requests.

As many as 181 persons from 44 countries participated in individualized and intensive training programs comprising 4 492 manweeks at ICRISAT Center, to develop skills in areas that fall within the Institute's mandate. Another batch of nine scientists from five Southern African Development Coordination Conference (SADCC) countries participated in an intensive 4-week sorghum and millet training course at Matopos, Zimbabwe, while six students from Niger were supervised and trained at the ISC.

Many international workshops and meetings were held during 1986, sponsored or cosponsored by ICRISAT. The International Agricultural Research Centers' (IARC) Workshop on Farming Systems Research (FSR), held at ICRISAT Center, examined existing approaches to FSR in the IARCs, and discussed the respective roles of national and international research agencies in FSR. An International Pearl Millet Workshop, held at ICRISAT Center, was attended by 109 scientists from 22 countries. It addressed major areas of research, production, and utilization of the crop. A Consultant's Meeting on

The U.S. Ambassador to India, Mr John Gunther Dean (second from right) and Mrs Dean show interest in the cytogenetics work on groundnut in a laboratory at ICRISAT Center.

Research on Drought Problems in the Arid and Semi-Arid Tropics, also held at ICRISAT Center, considered priority areas for applied research to improve crop production under drought conditions.

Over 12500 persons visited ICRISAT Center in 1986. Prominent among them were some 25 food policymakers representing 14 African countries and concerned international and regional agencies. The group evinced particular interest in ICRISAT's technology for double-cropping Vertisols in areas with dependable rainfall. Other visitors included Mr Yogendra Makwana, India's Minister of State for Agriculture and Cooperation; Mr G.M. Oteng, Botswana's Assistant Minister for Agriculture; Mr John Gunther Dean, U.S. Ambassador to India; and Mr Shimelis Adugna, Ethiopia's Ambassador to India. Visitors at ISC included President Seyni Kountche of Niger, accompanied by Niger's Minister of Agriculture and officials of INRAN. Also visiting the ISC were Ministers of Foreign Affairs of Mali and Niger; the Ambassador of Niger in Mali; and the Ambassadors of the Peoples Republic of China, the Federal Republic of Germany, Mali, and the USA in Niger.

We look forward to achieving even greater success in 1987 in our efforts to make resource-poor farmers of the semi-arid tropics more confident of the harvests to come.

F.V. MacHardy
Chairman, Governing Board

L.D. Swindale
Director General

AGROCLIMATIC ENVIRONMENT

Semi-arid tropical regions of the world (shaded). Numbers indicate locations where ICRISAT staff worked in 1986.

Cover photo: ICRISAT trials at Bhavanisagar, India, rainy season 1986.

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AGROCLIMATIC ENVIRONMENT

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

India

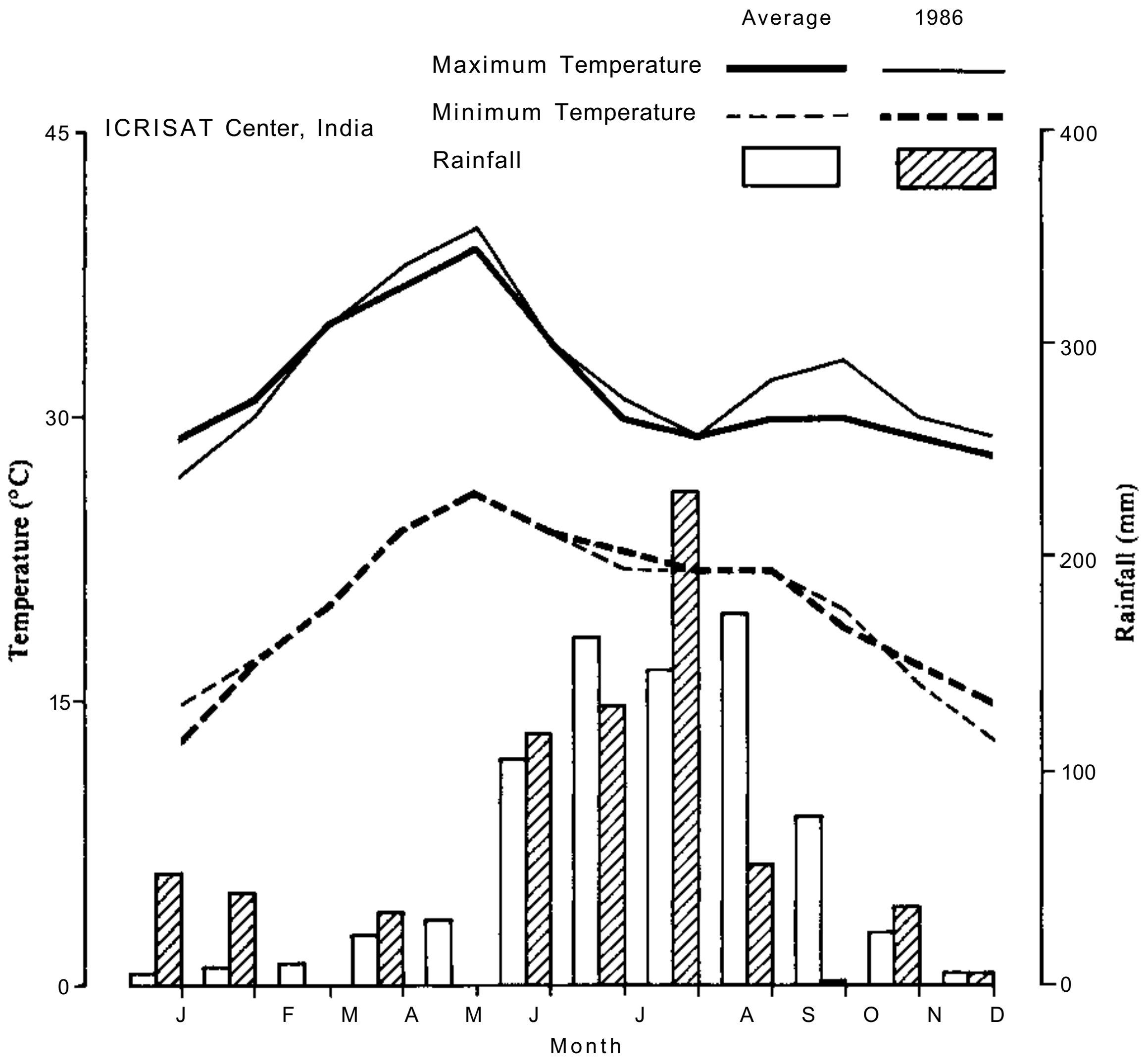
ICRISAT Center, Patancheru

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

Seasons. Three distinct seasons characterize much of India. In the Hyderabad area the rainy season, also known as the monsoon or kharif, usually begins in June and extends into early October. More than 80% of the 782 mm average annual rainfall falls in those months, during which rainfed crops are grown. The postrainy winter season (mid-October through January), also known as the postmonsoon or rabi, is dry and cool and days are short. During this period crops can be grown on Vertisols on stored soil moisture. The hot, dry, summer season lasts from February until rains begin again in June.

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 pratice, two sorghum crops a year can be grown at the Center, one 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 1986 at Patancheru was 713 mm, 69 mm below average. Rainfall received in January and February was 97 mm as against the average of 15 mm. The start of the rainy season was quite favorable. Rainfall in June and July was nearly normal, and in August 56% more rain fell than in an average year. However, only 58 mm rain fell in September and October, compared with the average 253 mm. This resulted in drought conditions during the grain-filling period in many rainy-season crops, and restricted the sowing and establishment of postrainy-season crops. Maximum temperatures in September and October were 2-3° C higher than average.



The low and irregular rainfall in the 1986 rainy season did not favor development of groundnut rust (*Puccinia arachidis*) or late leaf spot *(Phaeoisariopsis personata)* diseases, but levels were sufficiently high to permit effective resistance screening of germplasm accessions and breeding lines that received supplementary irrigation on Alfisols. Rainfed groundnut trials failed because of the drought in October. Contrary to all previous results intercropping pearl millet and groundnut (1:3) on the Alfisols led to a 20% drop in crop yield, because of the unfavorable rainfall pattern. Pearl millet yields were average to slightly below average in dryland sowing (2.0-2.5 t ha^{-1}). With supplemental irrigation (during grain filling) yields were considerably higher (3.0-3.5 t ha^{-1}).

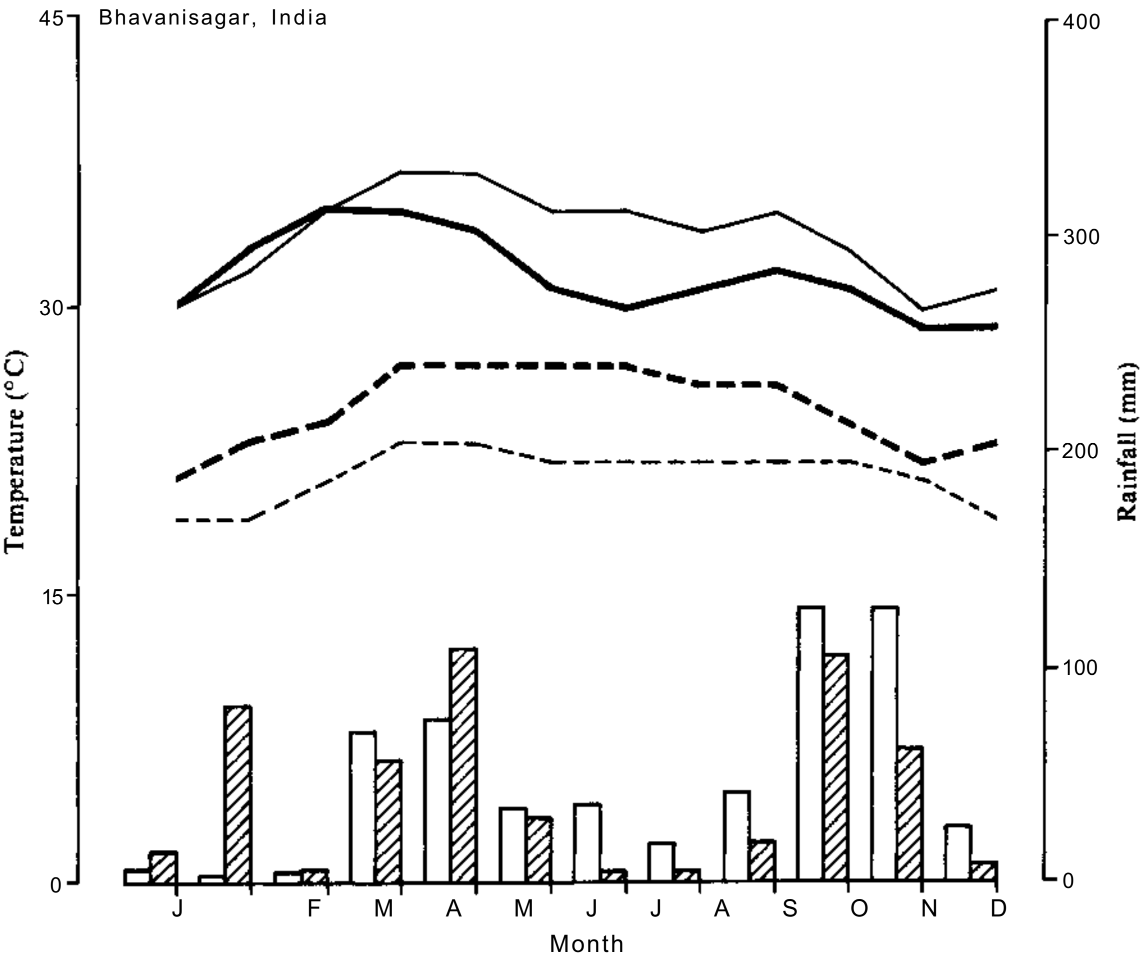
On the deep Vertisols postrainy-season crops, e.g., chickpea sown during the first week of October, did not germinate until after the rain on 7 November; because of the unusually long dry period these crops remained under stress and needed supplemental irrigations. Chickpea wilt (*Fusarium oxysporum* f. sp *ciceri*) symptoms appeared earlier than usual due to high temperatures early in the growing season.

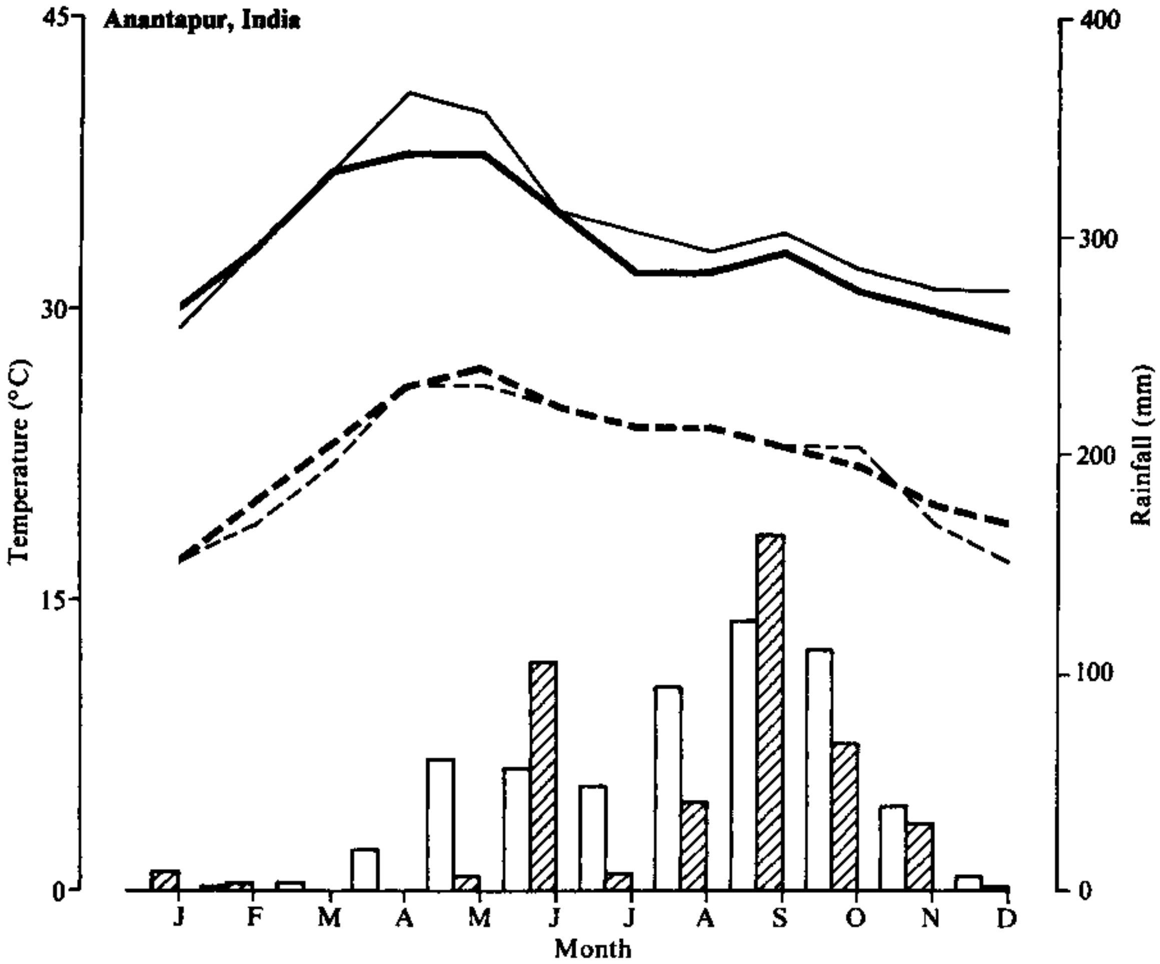
Other Research Locations

India

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

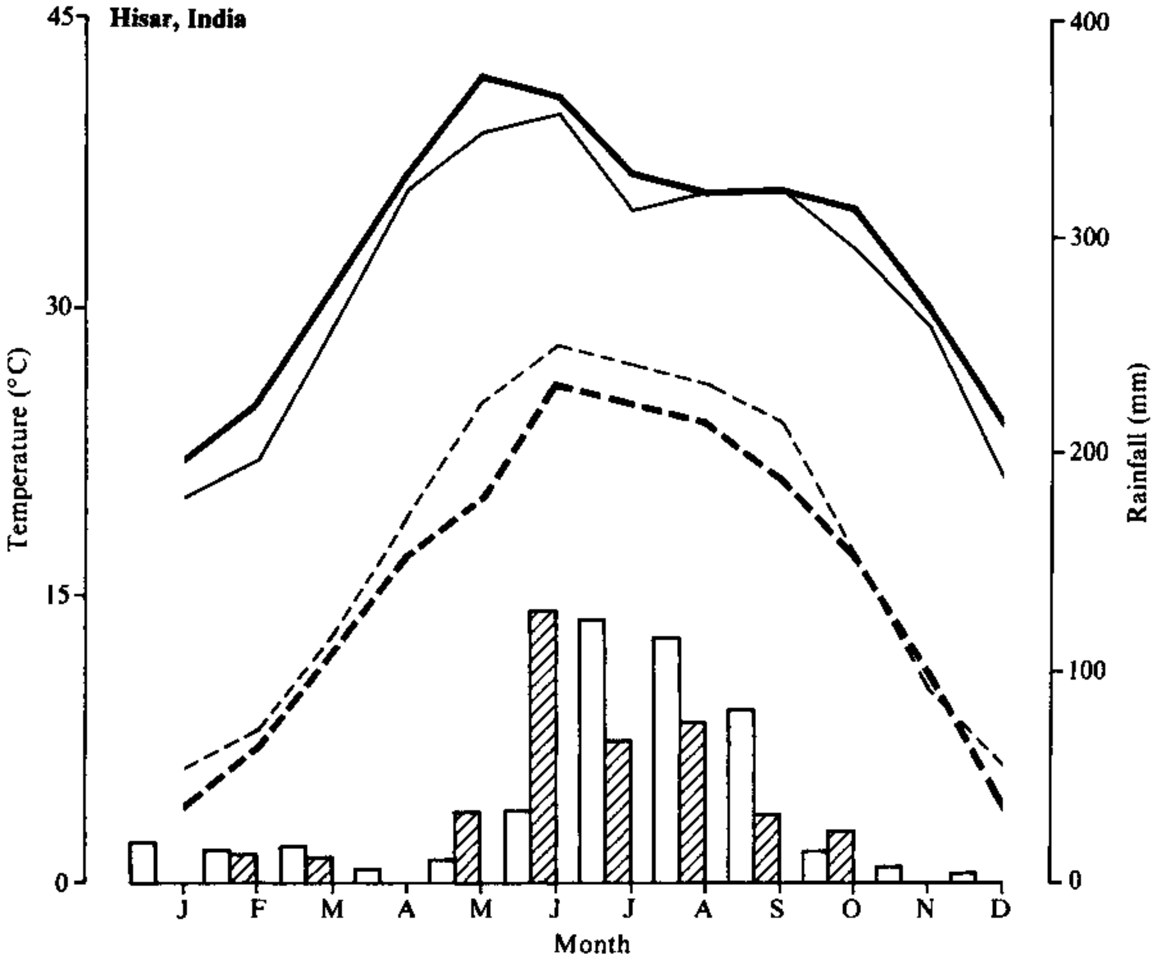
Bhavanisagar (11°N, 77° E, 574 mm rainfall). Here we screen sorghum for diseases and pests and test pearl millet, and groundnut on Alfisols (AWHC 80 mm), at a daylength analog similar to the Southern Sahelian bioclimatic zone of Africa. Annual rainfall was 504 mm, 12% below average, and 42% of it fell in May and October. The low rainfall necessitated supplemental irrigation of groudnut trials. Daily maximum temperatures were 2-5° C above average from April to October. Daily minimum temperatures were warmer than the average in all months, the difference ranging between 1 and 5°C.



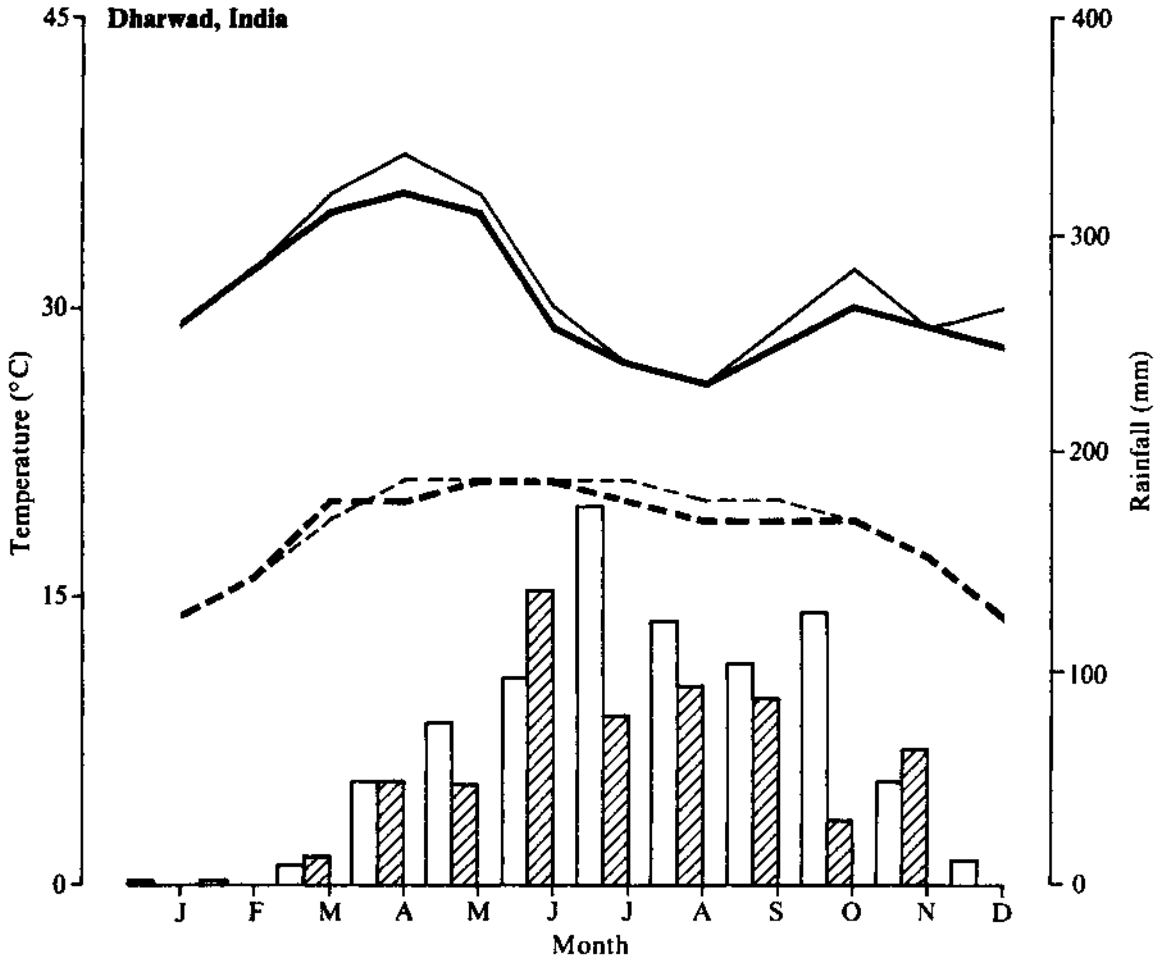


Anantapur (77 15°N, 73° E, 562 mm rainfall). This is a drought-prone area where we screen pearl millet, sorghum, and groundnut under low rainfall conditions in the rainy seasons on Alfisols (AWHC 50 mm). Annual rainfall in 1986 was 436 mm, 22% below average. Rainfall was above average in June by 88% and in September by 31%, while rainfall was below average in July by 83%, in August by 57% and in October by 38%. This late drought resulted in failure of rainfed groundnut trials in October, but provided a very good rainfall pattern for screening pearl millet for response to midseason stress (June sowing) and terminal stress (August sowing). Pearl millet trials sown in early August experienced some stress during grain-filling, but yields were generally good (2.5t ha"[1]). Late-sown trials (early September) experienced severe stress during flowering and grain-filling and yields were only about 1t ha^{-1}. Several varieties previously identified as tolerant of such conditions yielded relatively well (1.3-1.51 ha"[1]). Daily maximum air temperatures were 2-3° C higher in April, May, and July. Daily minimum temperatures were near average in all months.

Hisar (29° N, 75° E, 450 mm rainfall). Here chickpea and pearl millet are tested under the climatic conditions in which they are mostly grown, and short-duration, rainy-season pigeonpeas are tested in a region where they are increasingly being grown in rotation with wheat. This location also provides our main site for testing sorghum for stem borer *(Chilo partellus)* resistance. The soils are Entisols with 150-200 mm AWHC. Annual rainfall in 1986 was 383 mm, 14% below the average; 33% of the rain fell in June. Many pigeonpea yield trials were lost this year because of waterlogging and soil salinity problems. Early season establishment and growth were good for pearl millet because of adequate soil water after the rain in June. Crops come under more stress by the time they were flowering and yields in irrigated sowings were seriously affected. The low rainfall necessitated supplemental irrigation of groundnut trials. Daily maximum and minimum temperatures were generally lower than average.



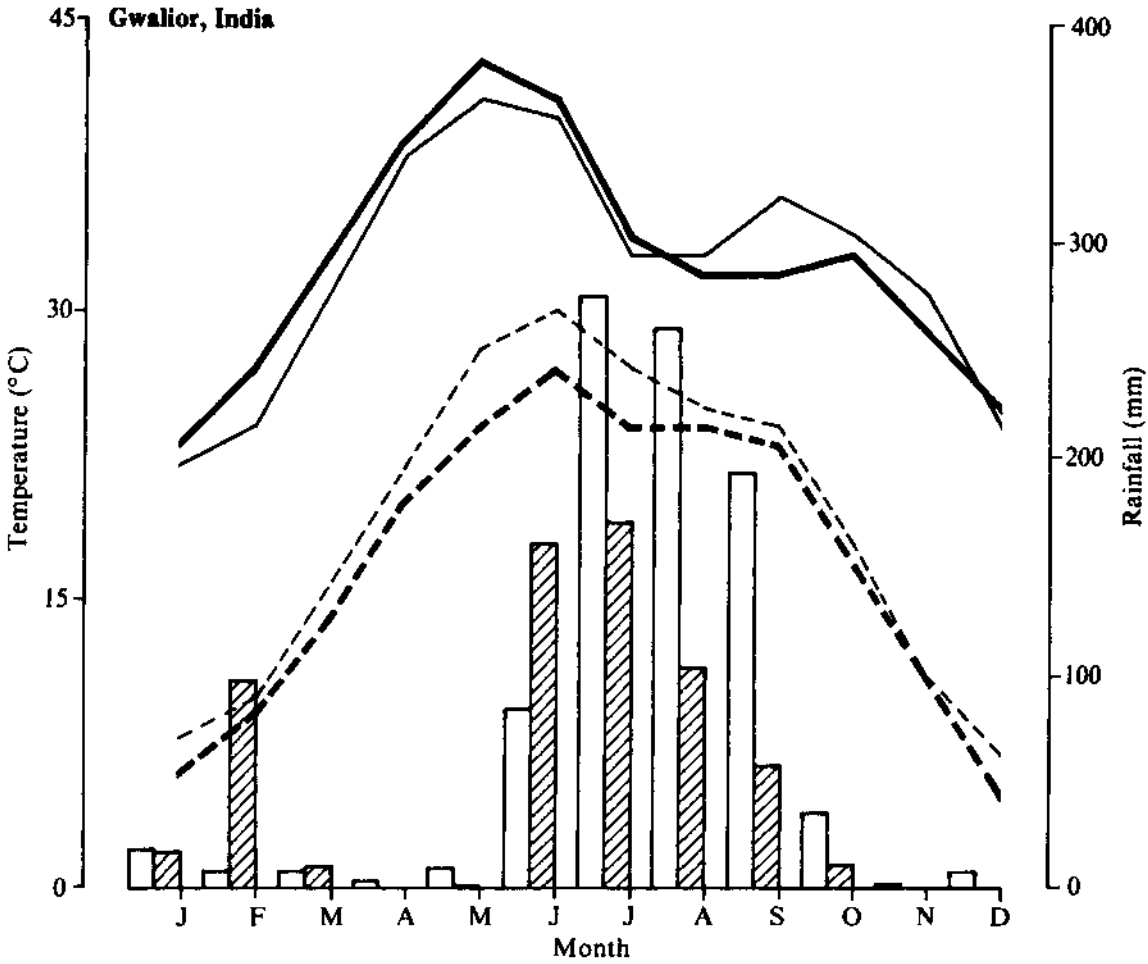
Dharwad (15° N, 75° E, 818 mm rainfall). An especially good Vertisol (AWHC 150 mm) site for pest and disease screening, e.g., screening sorghum for downy mildew (*Peronosclerospora sorghi*). This year chickpea trials were conducted for the first time at this location. The annual rainfall in 1986 was 593 mm, 28% below average. Rainfall from June to October was 423 mm, 32% below the average; this drought adversely affected rainfed groundnut trials. Daily maximum and minimum temperatures were within 1°C of the average values except in April, October, and December when daily maximum temperatures were 2°C higher than the average.



Gwalior (26° N, 78° E, 899 mm rainfall). An area on Inceptisols (AWHC 150 mm), where most of India's long-duration pigeonpea that is extensively used as an intercrop in northern India is grown, and we are working to develop lines resistant to diseases and insect pests. In 1986 podfly *(Melanogromyza obtusa)* built up large and damaging populations. Rainfall received during the rainy season (June to October) in 1986 was 498 mm, 41% below the average. Daily maximum temperatures were 3°C below average in February and 4°C above average in September. Daily minimum temperatures were 3-4° C lower than the average in May, June, and July.

ICRISAT Sahelian Center, Niger

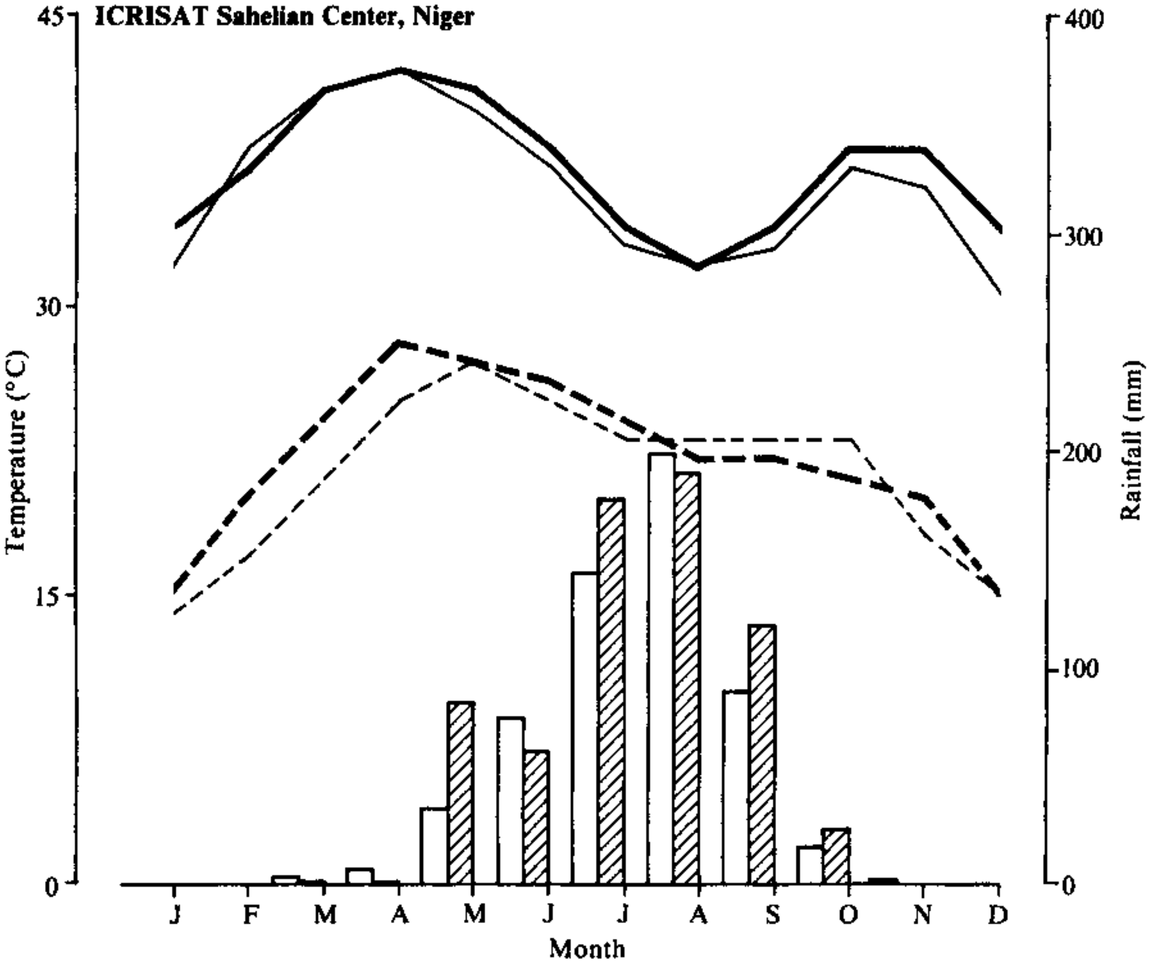
The ICRISAT Sahelian Center (ISC) is our principal research base for pearl millet and groundnut and the farming systems associated with these crops in the Southern Sahelian bioclimatic zone of West Africa. The ISC is located at 13°N, 2°E near the village of Say, 45 km south of Niamey. The experimental farm, extending over 500 hectares is covered by reddish colored, friable, sandy soils (AWHC 50-75 mm[1]) with low native fertility and low organic matter.



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

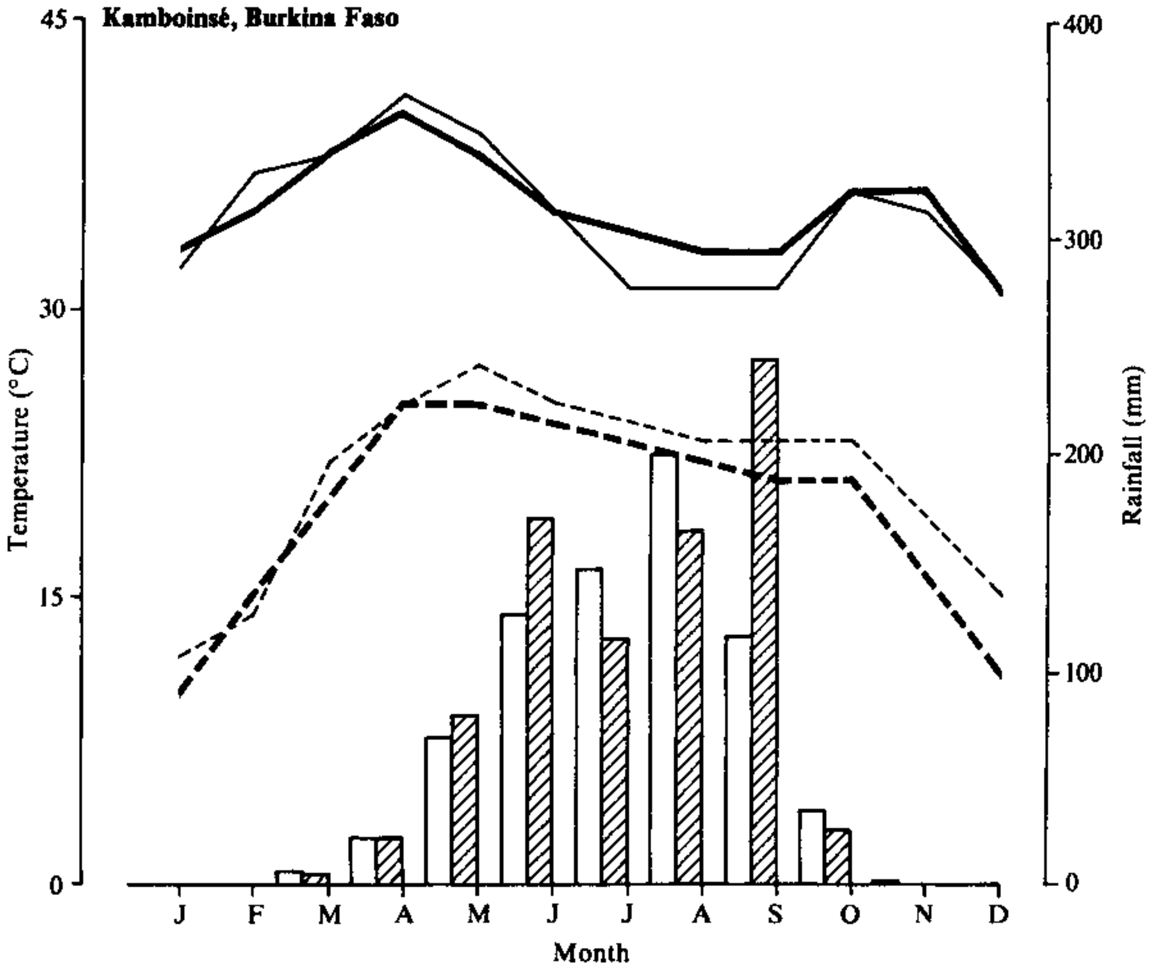
Crops. The main crop grown in the Niamey region is short-duration pearl millet (90 to 110 days) which is sown with the first rains towards the end of May and beginning of June. To advance generations and to help in seed multiplication, an irrigated off-season nursery is grown from January to April. Intercropping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

Weather. Rainfall in 1986 was 657 mm, 87 mm above average for Niamey. Distribution of rainfall was quite good except for a dry spell from the end of May until the middle of June, which necessitated resowing several trials. Monthly rainfall was above average in May, July, September, and October; this meant that moisture was not a limiting factor for most of the season. Maximum air temperatures were slightly below average while minimum temperatures were above normal from January to July.



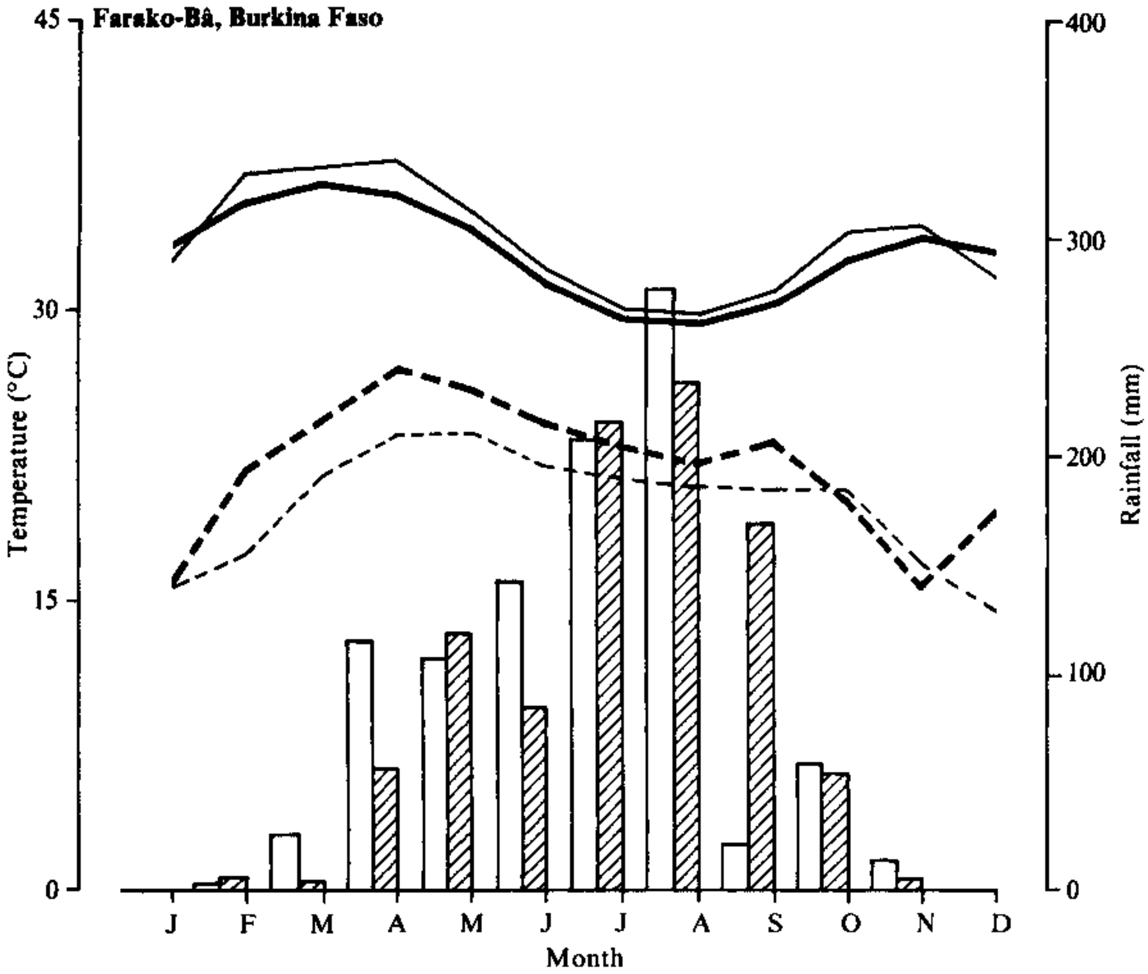
Burkina Faso

Kamboinse (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, pearl millet, and socioeconomic studies in villages. The length of the cropping season is about 120 days from June/July to October/November. Sorghum, pearl millet, maize, groundnuts, and cowpea are the major crops in the region. Soils vary from gravelly sandy loams to silty loams depending on their position in the toposequence. The depth of the soil profile over laterite ranges from 0.3 m to 1.2 m on the lower slopes. The AWHC of the soils varies from 30 to 100 mm. The rainfall in 1986 was 819 mm, 14% above the average. Eighty-four percent of the annual rainfall was received in the rainy season of June to September. Daily maximum temperatures were 2-3° C lower in July, August, and September, and daily minimum temperatures were 1-2°C lower over the same period.



Farako-Ba in south-western Burkina Faso (11°N, 4° W, 1083 mm rainfall) is a relatively high-rainfall location where we test sorghum in the Northern Guinean bioclimatic zone, and our work on sorghum diseases in West Africa is carried out.

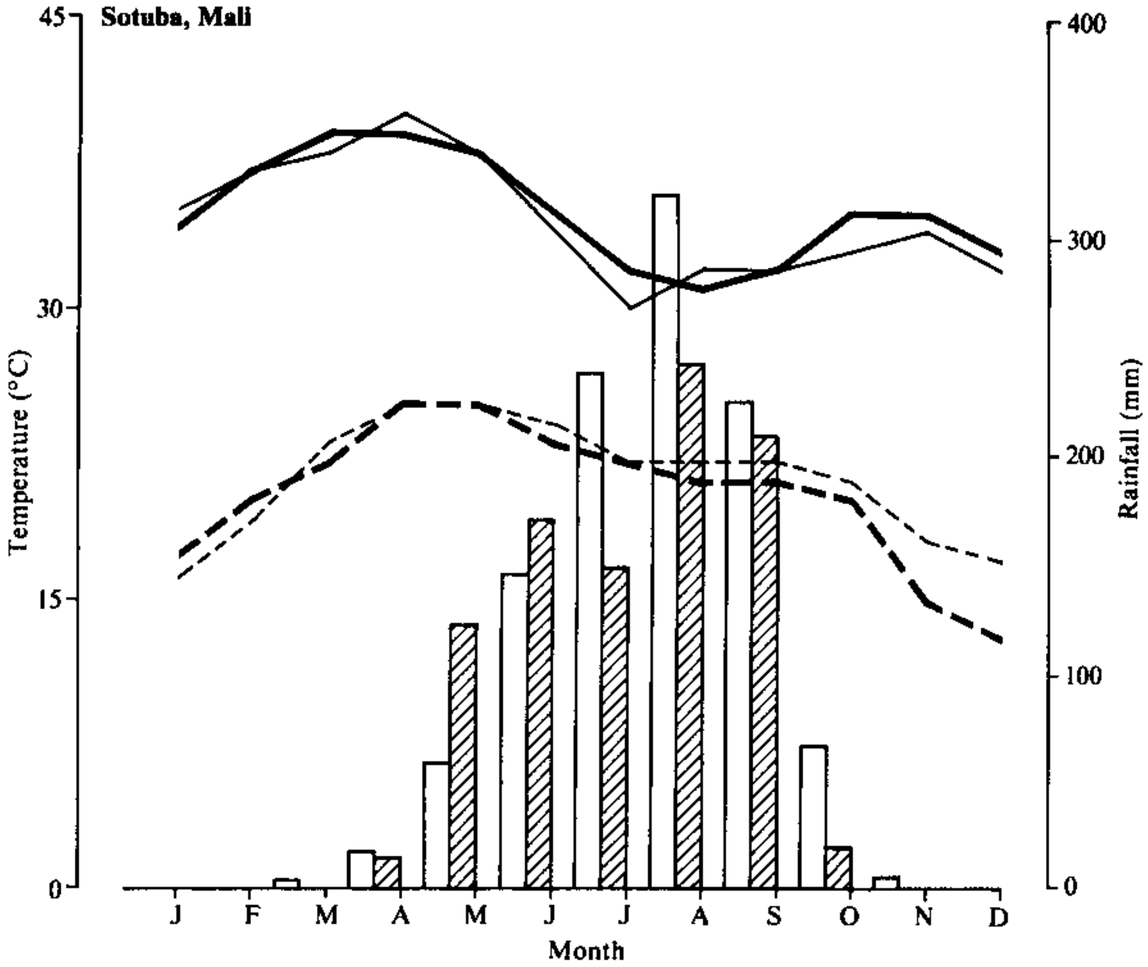
The length of the cropping season is about 160 days from May/June to October/November. August is usually the wettest month of the year (average 277 mm), but in 1986 the August rainfall was below average. This was followed by an unusually high rainfall in September. Maximum temperatures were slightly higher than usual but minimum temperatures were lower until September.



Mali

Cinzana (13° N, 6° W, 700 mm rainfall)—in the Southern Sahelian bioclimatic zone, where we conduct research on sorghum, pearl millet, and agronomic practices associated with these crops. The length of the cropping season is about 120 days from June/July to September/October. Soils are tropical ferruginous, some humus bearing hydromorphic loams, and sandy loams (AWHC 120-150 mm). Rainfall in 1986 was 632 mm, 10% below the average. Early pearl millet cultivars under testing were able to escape the late-season drought.

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. Soils are tropical ferruginous, leached to hydromorphic types (loam and clay loam), with AWHC 150-200 mm. The total rainfall in 1986 was 918 mm, 121 mm fell in May against an average of 58 mm, but, in July there was 37% less than average, and the August total was 24% below average. Late-flowering sorghum cultivars encountered drought during grain-filling but improved genotypes escaped because of their earliness.



Sudan

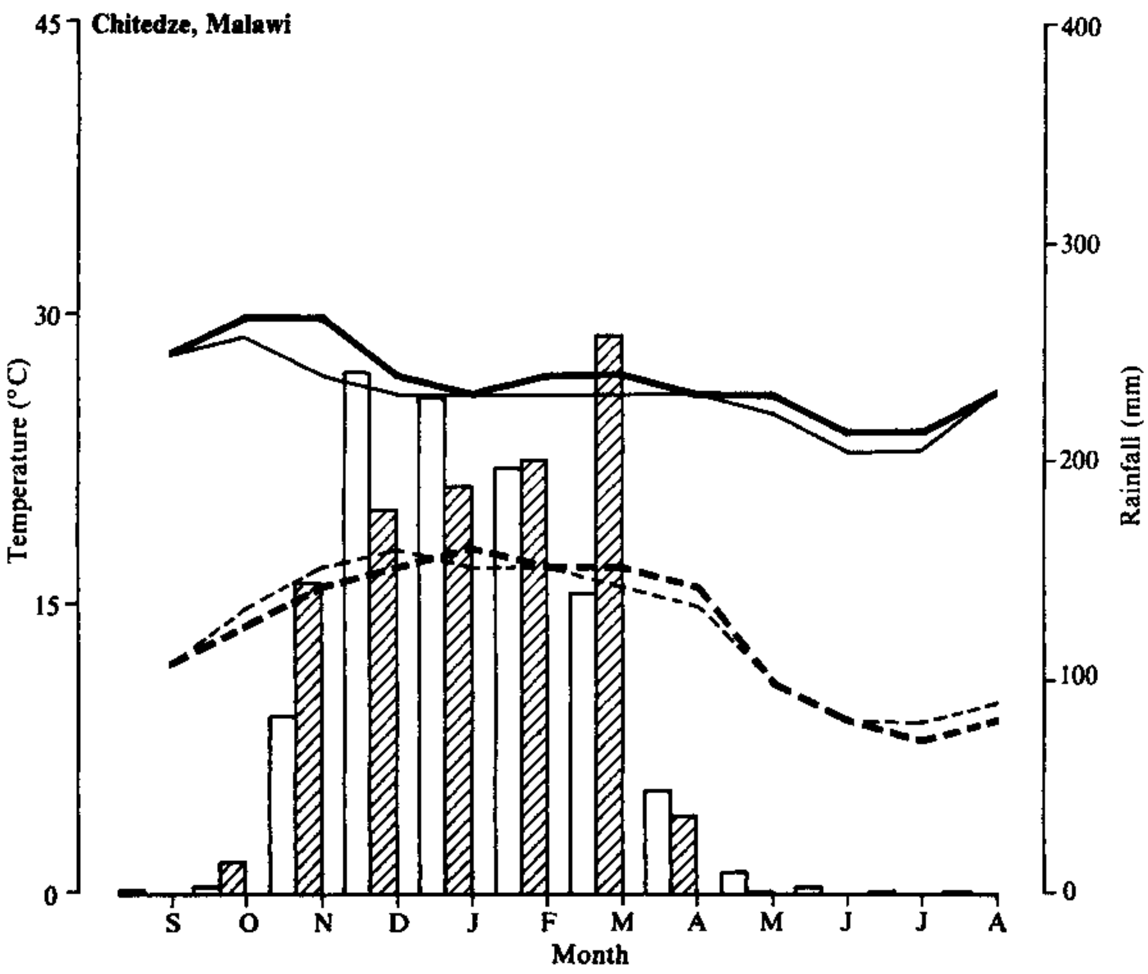
El Obeid (13°N, 30°E, 418 mm rainfall), where our breeder works on pearl millet. In 1986 the rainfall over the pearl millet trials ranged from 300 to 360 mm and location yields were low, few pearl millet genotypes outyielded the local control, Ugandi.

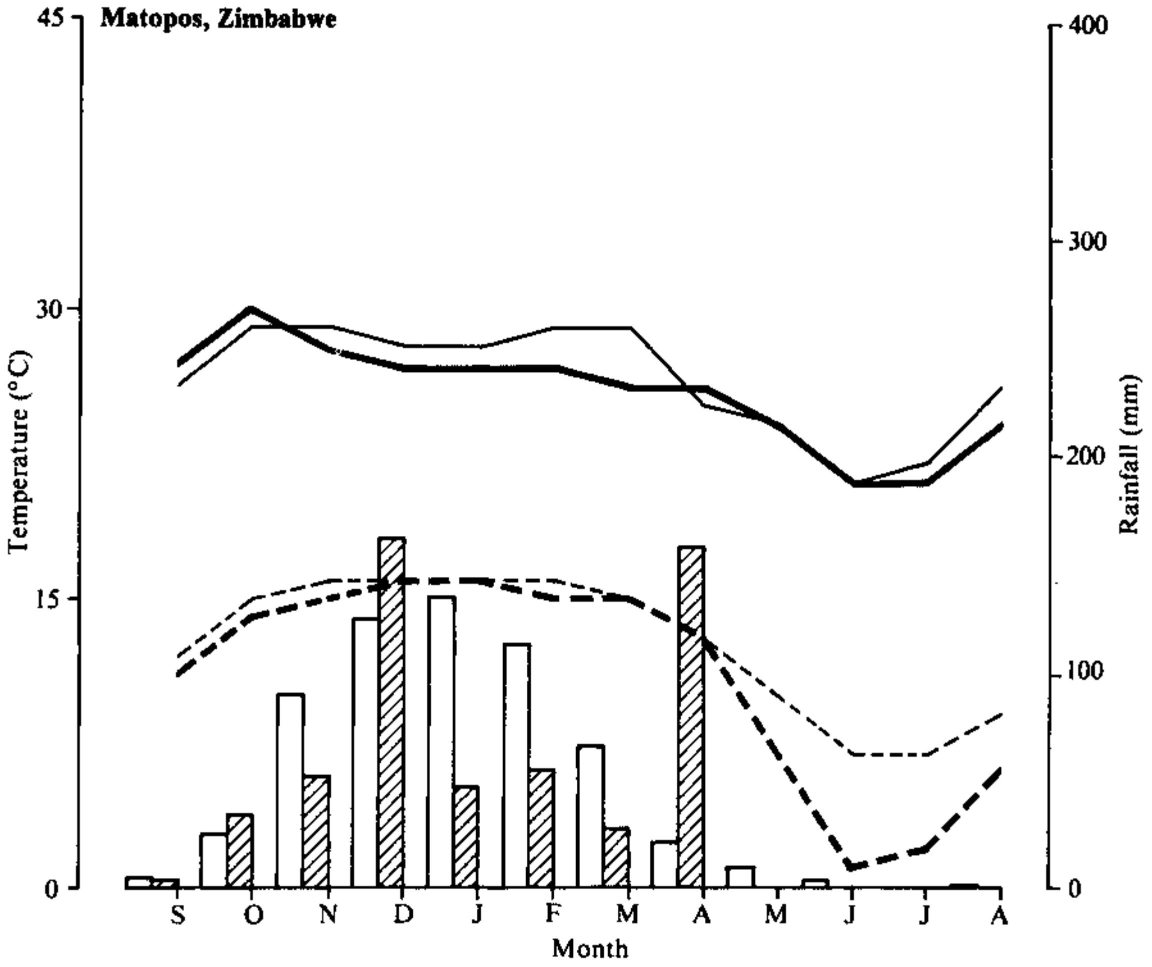
Kenya

Nairobi—(1°S, 37°E, 1066 mm rainfall), the center of the Eastern Africa ICRISAT Regional Network that tests sorghum and pearl millet in four major agroecological zones: high (>1800 m), intermediate, and low elevations, and very dry lowlands. Because of the large number of network locations it is not pertinent to give their agroclimatic details here.

Malawi

Chitedze (14°S, 34° E, 957 mm rainfall)—where our Regional Groundnut Improvement Program for Southern 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. Rainfall during the growing season (November 1985 to April 1986) was 1003 mm, 7% above the long-term average (936 mm). Rainfall was above average in November (76%) and March (86%). Distribution was good and there were no dry spells; while this was conducive to high yields, it was also highly favorable for the development of early leaf spot disease *(Cercospora arachidicola).* Daily maximum and minimum temperatures were near average except in November when maximum temperatures were 3°C below average.



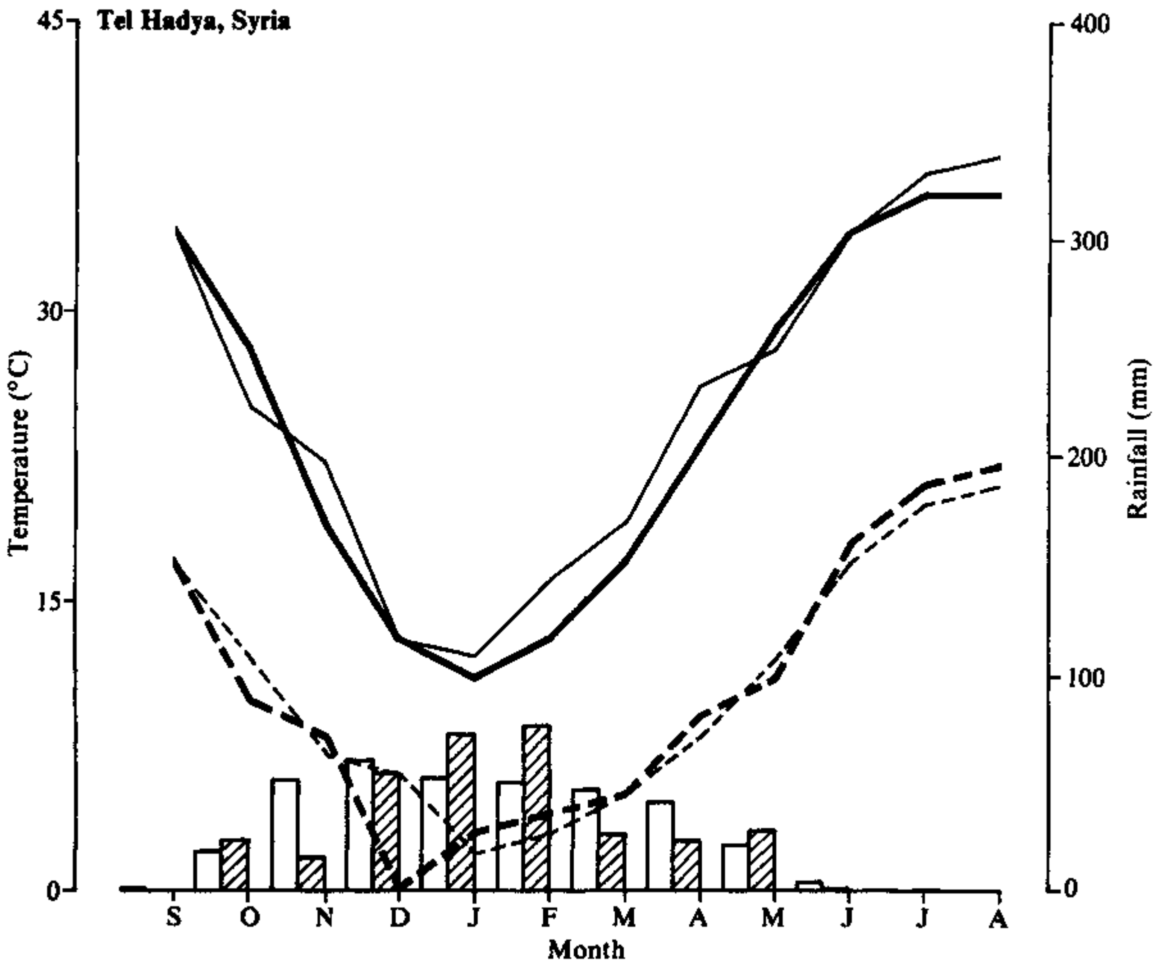


Zimbabwe

Matopos near Bulawayo (20° S, 29° E, 588 mm rainfall)—where our sorghum and millet improvement program for the nine African countries of the SADCC region is based at Matopos Research Station. Sorghum, millets, and maize are important cereal crops in the region. The growing season is from October/November to March/April. Soils range from sandy soils with AWHC 60 mm, to deep clayey soils, with AWHC 180 mm. Rainfall from September 1985 to August 1986 was 534 mm, 60% of which fell in December and April. Rainfall in January, February, and March was below average. Daily maximum temperature was 2-3° C higher than the average in February and March, while daily minimum temperatures were 3-6° C lower than average in June, July, and August. In 1986 there was a severe epiphytotic of sorghum downy mildew *(Peronosclerospora sorghii)* at Matopos. During the dry season ratoon sorghum crops showed higher incidences of this disease than the rainfed crop.

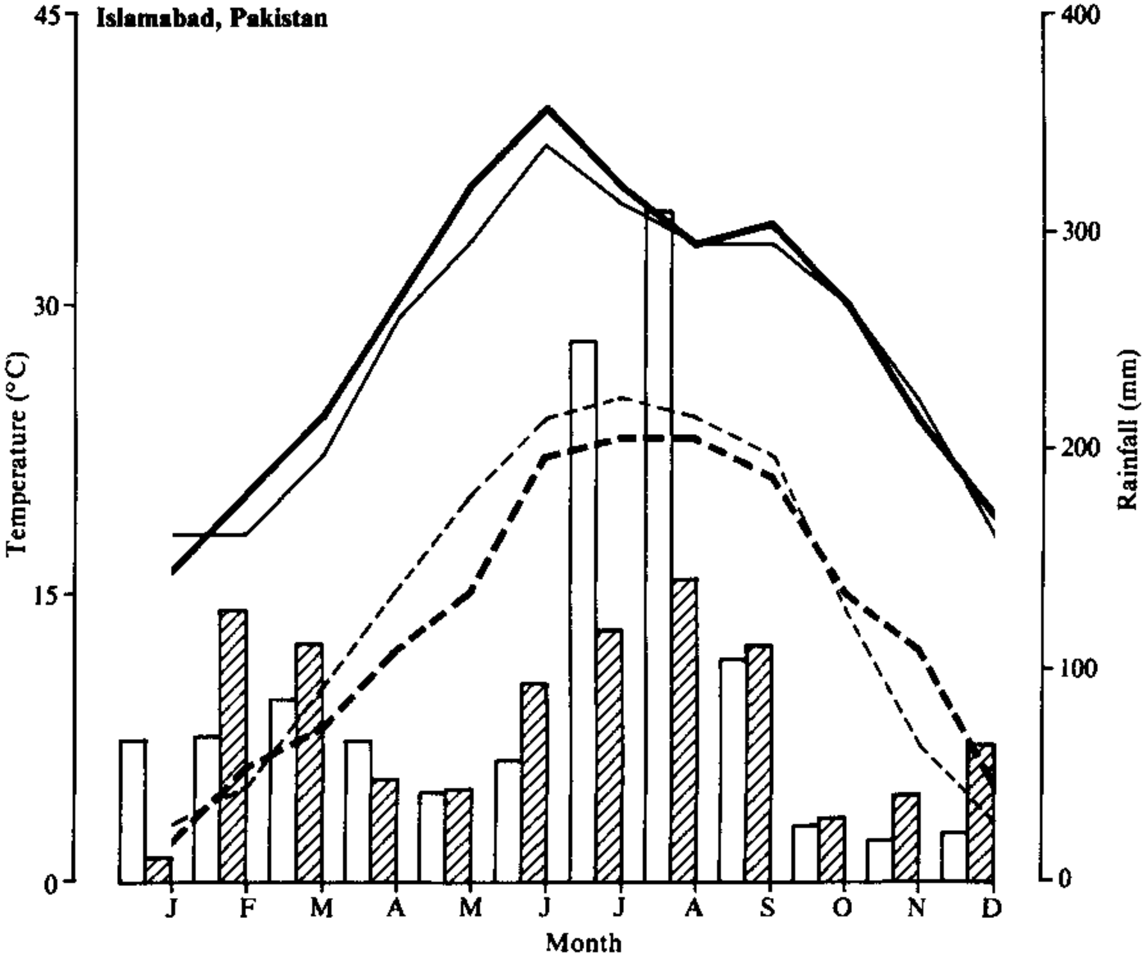
Syria

Tel Hadya near Aleppo (36° N, 37° E, 340 mm rainfall)—where ICRISAT staff work with ICARDA on kabuli 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, lentils, and faba beans are important crops in the region. The program's main aim is to develop cold-tolerant chickpea varieties suitable for winter sowing, and to stabilize production by developing genotypes resistant to drought and ascochyta blight *{Ascochyta rabiei).* Rainfall in 1986 was near to average, but its distribution pattern was abnormal. The growing season was warmer than average and there were only 17 days below 0° C compared with the average 30 days below 0°C. Because of the warmer temperatures chickpea crops matured earlier than usual. The 1985/86 season was not favorable for ascochyta blight testing, even susceptible lines were not killed as in average years. The blight epidemic started late, with temperature and relative humidity conditions in the first week in April 1986 similar to those in the first week of February 1984. The ICRISAT/ICARDA program also uses Jinderiss (36° N, 36° E) in Syria and Terbol (34° N, 36° E) in Lebanon as principal trial locations.



Pakistan

Islamabad—(34° N, 73° E, 1116 mm rainfall), where our breeder/ pathologist works in cooperation with the National Agricultural Research Center (NARC); the emphasis is on research to develop chickpeas resistant to ascochyta blight. Annual rainfall in 1986 was 931 mm, 17% below the average. Rainfall from June to October was 486 mm, 35% below the seasonal average. Rainfall in July was 117 mm (average 250 mm) and in August 140 mm (average 309 mm). Daily maximum temperatures were 2-3° C lower than average in May and June. Daily minimum temperatures were 2-5° C lower than average in April, May, June, and July; and 1-5°C higher in October, November, and December.



Mexico

El Batan—(19°N, 99° W, 750 mm rainfall), where our staff based at CIMMYT, work on high altitude (1500-2300 m) cold-tolerant (6-20° C) sorghums and material adapted for low (0-800 m) and intermediate (800-1800 m) elevations in Latin America and the Caribbean. Because trials are grown over a wide area it is not pertinent here to give data for any single location.

GENETIC RESOURCES UNIT

Contents

Cover photo: A new source of dwarfing gene (d_4) in pearl millet (IP 10402) identified at ICRISAT Center, 1986.

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GENETIC RESOURCES UNIT

That the genetic resources of the world are seriously threatened with extinction is of major concern. The replacement of diverse and primitive landraces by uniform and higher-yielding cultivars, deforestation, the ever-increasing population and its spread into rural and remote areas of the world all contribute to genetic erosion. Once landraces and wild relatives of our crop plants are lost, they can never be recovered. The diversity in genetic resources is a basic necessity for crop improvement, and for the development of new cultivars. It is essential that this important natural resource be collected and conserved for present and future generations.

Collection, maintenance, evaluation, cataloging, conservation, and distribution of germplasm accessions are the responsibilities of gene banks throughout the world. The best possible methods of conservation must be used in order to preserve seed viability as long as possible so as to avoid frequent seed increases that lead to genetic drift. Conservation is planned for many generations, and it is essential to maintain the genetic integrity of each accession. ICRISAT has this responsibility for its five mandate crops; sorghum, pearl millet, chickpea, pigeonpea, and groundnut, and for six minor millets.

During 1986 we explored certain parts of the world including Central America; eastern, southern, and western Africa; and South Asia looking for germplasm samples that had not previously been collected. These explorations resulted in additional, valuable germplasm accessions for our gene bank and also gave us an opportunity to observe at first hand the genetic diversity, and the extent of genetic erosion in the areas we explored.

The Genetic Resources Unit (GRU) collects as much genetic diversity as possible, employs the best currently known techniques and researches new ones for pollination control and germplasm evaluation, computerizes the information, provides optimum seed storage conditions to maintain viability as long as possible, monitors seed viability of stored accessions, and makes the ICRISAT collection freely available to plant scientists throughout the world.

Present and Future Areas of Collection

We have identified the priority areas for collecting germplasm of our mandate crops based on their representation in our gene bank, the threat of genetic erosion, information on genetic diversity in the area, and discussions with the International Board for Plant Genetic Resources (IBPGR), and national scientists in source areas. Countries/areas where germplasm for each crop has yet to be collected are listed below in order of priority:

Sorghum Yemen PDR, Venezuela, Nepal, Chad, Ghana, Turkey, Uganda, Mozambique, Syria, Burma, Ivory Coast, Somalia, and India (Bihar bordering Uttar Pradesh, Sub-Himalayan region, Western Ghats, Andhra Pradesh, and Maharashtra). Australia has high priority for wild species.

Pearl millet Niger, Chad, Angola, Egypt, Mauritania, Pakistan, Burkina Faso, Uganda, Guinea, Togo, Namibia, Zaire, Central African Republic, Sudan, Kenya, Somalia, Mozambique, Tanzania, Sri Lanka, Korea, Saudi Arabia, and India (Tamil Nadu, Haryana, and Madhya Pradesh).

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

Table 1. ICRISAT gene bank accessions in 1986 and to date, showing crop and number of countries represented.

	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Accessions in 1986	1508	527	512	352	53	2952
No. of countries	11	6	4	18	3	29
Total to date	28072	18 148	14 875	10818	11 641	83 554
No. of countries	83	42	41	48	89	126

Table 2. Additions to ICRISAT germplasm collection in 1986.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
AFRICA					
Burkina Faso	-	87	-	-	-
Cape Verde Islands	-	-	-	6	-
Ethiopia	-	-	-	11	-
Kenya	-	-	-	32	-
Lesotho	249	-	-	-	-
Malawi	-	-	-	5	-
Niger	-	15	-	-	-
Nigeria	66	-	-	2	-
South Africa	27	-	-	2	-
Sudan	36	-	-	-	-
Swaziland	182	-	-	-	-
Tanzania	5	12	-	-	-
Zimbabwe	640	261	-	-	14
ASIA					
Bangladesh	-	-	131	-	-
India	83	118	357[1]	89	16
Indonesia	-	-	-	2	-
Peoples Republic of China	37	-	-	-	-
Philippines	-	-	-	4	-
Yemen AR	182	34	-	-	-
EUROPE					
Italy	-	-	9	3	-
AMERICA					
Barbados	-	-	-	23	-
Dominican Republic	1	-	-	33	-
Grenada	-	-	-	13	-
Jamaica	-	-	-	1	-
Puerto Rico	-	-	-	32	-
St. Lucia	-	-	-	4	-
St. Vincent	-	-	-	19	-
Trinidad and Tobago	-	-	-	71	-
USA	-	-	15	-	23
Total accessions	1508	527	512	352	53

1. This includes one accession from Hisar, 75 from Legume Pathology, and 6 from Chickpea Breeding developed through research.

Pigeonpea Caribbean Islands, South and Central America, Philippines, Indonesia, Bangladesh, Burma, Uganda, Bhutan, Peoples Republic of China, India, Zaire, Angola, Zambia, Thailand, and West Africa and Australia for wild species.

Groundnut Brazil, Burma, India, Indonesia, Venezuela, Peru, Ecuador, Malagasay Republic, Niger, Ghana, Sudan, Thailand, parts of Mozambique, Tanzania and Zambia, Ethiopia, Chad, parts of Mali, Ivory Coast, Egypt, Bolivia, Mexico, Paraguay, and Uruguay.

Table 3. Additions to minor millets collection in 1986 and cumulative totals, 1976-1986.

Species	Accessions in 1986	Cumulative total
Eleusine coracana (finger millet)	37	1993
Setaria italica (foxtail millet)	68	1328
Panicum miliaceum (proso millet)	3	757
Panicum sumatrense (little millet)	75	377
Echinochloa spp (barnyard millet)	65	582
Paspalum scrobiculatum (kodo millet)	218	526
Total	466	5 563

Germplasm Assembly

We still need to collect, especially the wild species and wild relatives of all our mandate crops. The total numbers of accessions assembled to date for each mandate crop are shown in Table 1 along with the number of countries represented in our gene bank. Countrywise acquisitions are shown in Table 2. We have also assembled 5563 accessions of minor millets from 38 countries (Table 3).

Germplasm Maintenance

The seed collections are stored in either aluminum or polythene cans at +4° C and 20% relative humidity (RH), they are continuously monitored for viability, and rejuvenated whenever necessary. In order to avoid genetic drift when accessions are grown for maintenance and rejuvenation, all possible precautionary measures are taken. Sorghum, which may outcross, is maintained by selfing at least 20 representative heads (Fig. 1). Pearl millet, which is cross-pollinated, is maintained by enclosing several heads in a large bag. Pigeonpea, which is often cross-pollinated mainly by insects, is maintained by enclosing the entire plant or branches in large muslin cloth bags. Chickpea and groundnut are self-pollinated crops, and hence pollination control is not necessary. However, in groundnut only those pods which are attached to the pegs are collected. The number of accessions of each crop rejuvenated in 1986 is shown in Table 4. The presented data include many accessions rejuvenated to maintain stocks in order to meet the demand for seed of our accessions.

Table 4. Germplasm accessions grown for rejuvenation and multiplication during 1986.

	No. of accessions	
Crop	Cultivated	Wild
Sorghum	7220	245
Pearl millet	2002	-
Chickpea	876	22
Pigeonpea	2 259	45
Groundnut	4262	80
Minor millets	466	-

Figure 1. To meet increasing requests for seed, about 7000 sorghum accessions were multiplied using the selfing technique. ICRISAT Center, postrainy season, 1986.

Germplasm Evaluation

Evaluation is the key to germplasm utilization. GRU has its own evaluation program, and also collaborates with scientists of related disciplines in ICRISAT and national programs. During 1986 we characterized 10045 accessions of all crops at ICRISAT Center. In addition a large number of samples were evaluated in cooperation with various national agencies (Table 5). A total of 2000 pearl millet accessions were sent to Southern African Development Coordination Conference (SADCC), Bulawayo for joint evaluation with the SADCC/ICRISAT program. Collaborative research in genetic resources between ICRISAT and NBPGR was initiated during the year, and joint evaluations of germplasm of ICRISAT mandate crops was carried out at various locations in India. Under this program, 12681 accessions of all crops have been either characterized or sown for characterization (Table 5). Although this is the first year for organizing the collaborative trials at several NBPGR locations, good results have been obtained. The enthusiasm and cooperation that we received from NBPGR of the Indian Council of Agricultural Research (ICAR), India, is not only most encouraging but also exemplifies our continuing effort in germplasm evaluation and use in the semi-arid tropics (Fig. 2). This success was the result of earlier discussions that lead to joint efforts. In collaboration with the All India Coordinated Millets Improvement Project (AICMIP), a set of 2000 pearl millet germplasm accessions were evaluated at Pune, India.

We are also collaborating with the National Dryland Farming Research Station (NDFRS), Kenya to evaluate 500 pigeonpea accessions at

Table 5. Collaborators, locations, number of accessions, and type of material evaluated under joint evaluation programs, 1986.

Crop	Collaborator	Location	No. of accessions	Type of material
Sorghum	NBPGR, India	Hisar	2000	Photoperiod sensitive
	NBPGR, India	Trichur	2000	Photoperiod sensitive
	NBPGR, India	Issapur	1500	Forage sorghums
	NBPGR, India	Hisar	1500	Forage sorghums
	NBPGR, India	Jhansi	1500	Forage sorghums
	NBPGR, India	Akola	1500	Forage sorghums
Pearl millet	NBPGR, India	Jodhpur	2000	Selected germplasm
	SADCC/ICRISAT, Zimbabwe	Bulawayo	2000	accessions from SADCC countries, South Africa and working collection
Chickpea	NBPGR, India	New Delhi	1320	Long-duration accessions
	NBPGR, India	Jodhpur	1320	Long-duration accessions
	NBPGR, India	Gwalior	1320	Long-duration accessions
	PGRC/E, and ARC, Ethiopia[1]	Debre Zeit	1033	Selected accessions
Pigeonpea	NBPGR, India	Issapur	479	Short-duration accessions
	NBPGR, India	Akola	353	Medium long-duration accessions
	NBPGR, India	Gwalior	353	Medium long-duration accessions
	NBPGR, India	Gwalior	40	East African origin
	NDFRS, Kenya[2]	Machakos	500	Long-duration accessions
		Kiboko	500	Long-duration accessions
Groundnut	NBPGR, India	Jodhpur	2000	Selected accessions

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

Machakos and Kiboko. Similarly, in collaboration with the Plant Genetic Resources Center (PGRC/E) and the Agricultural Research Center (ARC), Alemaya University of Agriculture, Ethiopia, 1033 chickpea accessions were sown for evaluation at Debre Zeit Research Station. These joint germplasm evaluation projects are a part of our overall program for germplasm enhancement and utilization in different parts of the world. The program was enthusiastically accepted by all our collaborators as it has enabled them to freely tap the germplasm assembled and conserved at ICRISAT Center.

In addition to evaluation, about 38000 samples were screened by various ICRISAT crop scientists, and the results are reported elsewhere in this Report.

Germplasm Distribution

Providing ICRISAT scientists with the germplasm base for their work is one of our major activities. Accessions are screened for desirable traits, and used in breeding programs. Table 6

Figure 2. ICRISAT and NBPGR scientists jointly evaluating sorghum germplasm at the NBPGR Regional Research Station, Akola, India, rainy season, 1986.

gives the distribution of each crop's accessions to various disciplines within ICRISAT during 1986.

In addition to the 38 064 samples supplied to scientists at ICRISAT Center, 24298 samples were sent to scientists in India, and 16497 samples to scientists in other countries (Table 7).

Table 6. Seed samples supplied to ICRISAT Crop Programs in 1986.

	Cereals		Legumes			
Discipline	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Physiology	1470	506	21	667	-	2 664
Pathology	2 904	27	1807	1772	4 109	10619
Entomology	2 780	2	514	679	89	4064
Microbiology	33	27	-	-	33	93
Breeding	4217	779	191	824	369	6 380
Biochemistry	12 250	-	58	865	987	14160
Cytogenetics	-	-	-	-	13	13
Plant Quarantine	-	-	12	11	-	23
Training	40	8	-	-	-	48
Total	23 694	1349	2 603	4818	5 600	38064

Table 7. Germplasm samples distributed in 1986.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (1+2+3)	No. of countries
Sorghum	23 694	13 309	10384	47 387	40
Pearl millet	1349	5080	2644	9073	18
Chickpea	2603	1400	1704	5 707	10
Pigeonpea	4818	1888	1 160	7866	24
Groundnut	5 600	2621	605	8 826	19
Total 1986	38 064	24298	16 497	78 859	
Cumulative total to date	389978	137 508	174 829	702315	

Sorghum

This year 1508 new accessions were rejuvenated and added to our gene bank raising the total to 28072. The new accessions, assembled by collection and correspondence, came from 11 countries (Table 2).

In November 1986, a collection expedition was organized in collaboration with NBPGR to the tribal areas of the Indian States of Orissa, Bihar, and Madhya Pradesh. In these areas, primitive sorghums are cultivated by tribal people. These sorghums belong to the taxonomic race Guinea and subrace Roxburghii, and are being replaced by improved cultivars. We collected 177 accessions that show wide variation in panicle shape, seed color, seed size, and seed glume covering.

We grew 2105 accessions from Algeria (23), Australia (13), Burundi (45), Cameroon (306), China (164), Korea (75), Rumania (10), Rwanda (80), Taiwan (1), Uganda (641), USSR (139), Venezuela (7), Yemen Arab Republic (574), and Zaire (27) in the postentry quarantine isolation area (PEQ1A) for inspection and release.

In our collaborative evaluations with NBPGR (Table 5), sorghum accessions from India and the Yemen Arab Republic performed well at all the Indian locations, but the collections from Nigeria and Ethiopia performed poorly. We identified 165 genotypes, mostly dual-purpose food and forage types, that are consistently superior at all these *locations.*

In the rainy and postrainy seasons 1346 newly assembled accessions were characterized and evaluated at ICRISAT Center using IBPGR/ICRISAT sorghum descriptors. We rejuvenated and multiplied 7220 cultivated accessions and 245 accessions of wild species during 1986 (Table 4).

Computerization of evaluation data has been completed from IS 1 to IS 25240. The evaluation data are being analyzed to select specific character combinations, class count, and state count that will be used to prepare a germplasm catalog.

We supplied 687 accessions to the SADCC/ICRISAT Sorghum and Millet Improvement Project, and 591 accessions to ICRISAT scientists working in Burkina Faso. We also supplied 9106 accessions (Table 7) to national programs including Brazil (1864), China (532), Colombia (711), Korea (735), Mexico (397), USA (473), and the Yemen Arab Republic (1031) for use in their research programs.

Pearl millet

A total of 527 accessions from six countries (Table 1) was added to the collection during the year raising the total accessions in the ICRISAT gene bank to 18148. A total of 740 cultivated and 131 wild relatives of pearl millet samples collected from Cameroon, 20 samples from Uganda, 9 from USSR, and 1 sample from Venezuela were sown in the PEQIA.

We participated in two germplasm collection missions in India with NBPGR. The first, to western Rajasthan in October 1986, collected 111 samples of pearl millet landraces. Near Bikaner we found and collected three distinct types of *Cenchrus* species growing together. This species is the closest wild relative of *Pennisetum.* One collected type has leathery glumes and spiny bristles, another has long, plumose bristles, and the third very short bristles (Fig. 3). During the second mission in November we collected 4 samples of pearl millet, and 28 wild relatives of *Pennisetum* from the tribal areas of Orissa, Bihar, and Madhya Pradesh.

We evaluated 412 new accessions for 20 descriptors during the rainy season. In addition, all the accessions assembled from Nigeria (971) and Burkina Faso (385) were sown in the rainy season for evaluation and classification. Based on the number of days to 50% flowering, spike size, tillering, and pigmentation, all the accessions from Nigeria were classified as 'gero', 'maiwa', and 'dauro'landraces. The short-duration accessions from Burkina Faso produced short conical spikes with large grain. The long-duration types suffered from severe drought, this resulted in a reduction in spike length and a lack of upper spikelets. There was considerable variation in the flowering of the photoperiod-sensitive types; some accessions from Cameroon, Mali, and Sudan flowered between 105 and 115 DAS, while 'sanio' from Senegal and Mali, 'maiwa' and 'dauro'from Nigeria, and the majority of the accessions from Tanzania flowered between 115 and 130 days. Most of the accessions from Sierra Leone and the Central African Republic did not flower even after 136 days, revealing that they require photoperiods shorter than 11 h. We also rejuvenated approximately 2000 accessions (Table 4).

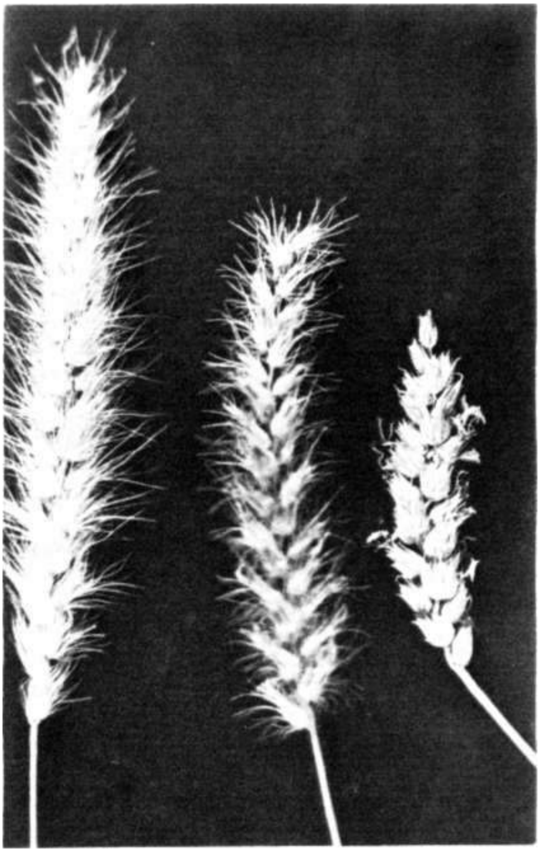


Figure 3. *Cenchrus* spikes showing left to right, leathery glumes and spiny bristles, long, plumose bristles, and very short bristles. This genus is a close wild relative of pearl millet.

The joint evaluation at NBPGR Regional Station, Jodhpur (Table 5) provided a unique opportunity to screen for drought resistance as less than 200 mm of rain fell at that location during the growing season. From this evaluation (Fig. 4) the millet breeder in Jodhpur selected 86 accessions and the ICRISAT millet breeder selected 18 accessions for possible future use in breeding drought-tolerant populations. Because of the drought plant height was drastically reduced except in local types. Accessions that flowered and produced heads were the short-duration accessions from Botswana, Ghana, Togo, and Uganda, and some Indian material. However, most of the long-duration and/or photoperiod-sensitive material wilted and died.

About 2000 accessions from six SADCC countries (995), South Africa (115), and a set of working collection (890) with diverse origin and morphological variation were sent to SADCC/ ICRISAT Sorghum and Millet Improvement Program, Zimbabwe for joint evaluation (Table 5).

Figure 4. ICRISAT and NBPGR scientists evaluating a pearl millet joint evaluation trial. The droughted location provided an excellent opportunity to select promising drought-tolerant lines. NBPGR Regional Station, Jodhpur, rainy season, 1986.

Passport and evaluation data for accessions IP 00001 to IP 12431 are entered in the computer and are retrievable. We have compiled the first draft of an ICRISAT pearl millet germplasm catalog that includes passport and evaluation data.

Chickpea

In March we participated in a joint germplasm collection expedition with Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) and NBPGR to Madhya Pradesh, the largest chickpea-producing state in India. In this region chickpeas exhibit wide variability (Fig. 5). We collected 274 samples consisting of 'gulabi', 'kabuli large', double-podded (Fig. 6), and tuberculated seed types.

We added 512 accessions from four countries, bringing our total gene bank holding to 14 875 (Table 1). Also included in the collection were 75 lines with resistance to fusarium wilt (*Fusarium oxysporum* f.sp *ciceri*) the results of selection by ICRISAT pulse pathologists.

Whilst evaluating 356 Ethiopian accessions at ICRISAT Center during 1985/86, we identified 25 accessions that outyielded the control cultivar, Annigeri. Five of these, ICC 12518, 12567, 12579, 12609, and 12694 were significantly superior. We identified two more new lines from mutant progenies, one has a green-tipped flower vexillum in contrast to the usual overall pink color, a character that can be used as a marker gene. The other line has relatively thick and upright branches and might prove to be responsive to higher inputs.

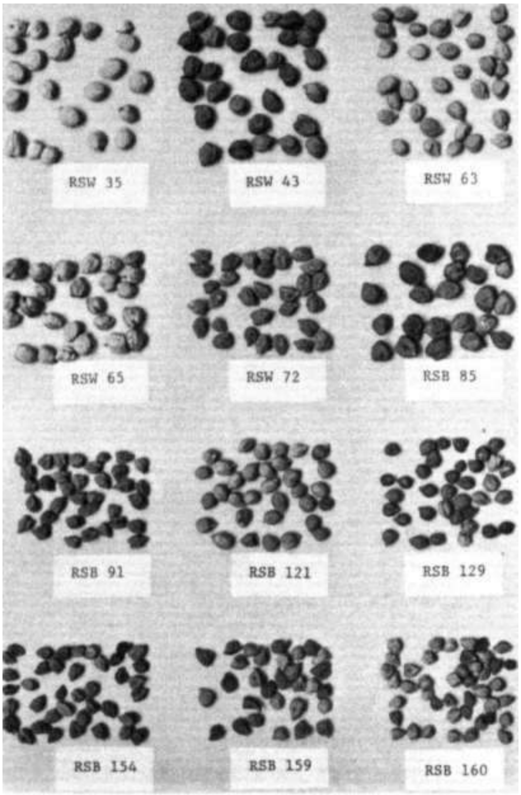


Figure 5. Chickpea samples showing a wide variability in seed types among accessions collected in Madhya Pradesh, India, 1986.

Figure 6. A double-podded chickpea collected during a joint ICRISAT/JNKVV/NBPGR collecting expedition to Madhya Pradesh, India, 1986.

In the 1986/87 season, during our joint evaluations in Ethiopia (Table 5) we identified a few accessions that performed well, these will be further tested in Ethiopia, where the chickpea growing season lasts from September to December, enabling us to evaluate in mid-December. Our Indian evaluations could not be made until 1987 because of the difference in growing seasons. In collaboration with NBPGR, long-duration accessions have been sown for evaluation at New Delhi, Jodhpur, and Gwalior in an attempt to find genotypes that are adapted to perform better at specific locations (Table 5). In addition to 1150 accessions grown for characterization, we sowed 876 accessions for rejuvenation at ICRISAT Center (Table 4), and a set of 140 accessions from Bangladesh for evaluation.

Long-duration chickpeas and 22 accessions of wild *Cicer* species were grown in a small plot of land that had been solarized. The plants appeared to be free from fusarium wilt showing the efficiency of this treatment in reducing the soilborne inoculum of the wilt pathogen.

Among the 2603 samples we supplied to ICRISAT pathologists, entomologists, and biochemists to be screened against diseases and insects, and for seed quality characters, were 22 accessions of wild *Cicer* species (Table 6).

We have transferred seeds of all our accessions in aluminum cans to our new medium-term cold storage facility.

We analyzed and summarized the germplasm evaluation data, and these, together with passport data on all accessions, have been compiled for publication in the ICRISAT Chickpea Germplasm Catalog.

Pigeonpea

We registered 352 new pigeonpea accessions in the gene bank (Table 1). These included material collected from the Caribbean region during 1985, and from India during 1986. The total pigeonpea collection has now been raised to 10818 accessions (Table 1).

A collection expedition in February-March resulted in securing 112 representative landraces from Jamaica, Guyana, and Venezuela. Of these, 94 have already been cleared by NBPGR and are growing in the PEQIA for further inspection and seed increase (Fig. 7). They will be evaluated in the 1987 rainy season. Most of the collections are medium-long to long-duration types with impressive vegetable-type characteristics (Fig. 8). Their 100-seed mass varied from 7 to 26 g with a mean of 15 g.

Among the accessions we characterized and rejuvenated were 920 accessions originating from 11 countries. This included collections from India (691), Trinidad and Tobago (70), the Dominican Republic (52), Puerto Rico (33), Barbados (23), St. Vincent (21), St. Lucia (17), and Grenada (13). We evaluated 574 accessions from the world collection, that could not be

Figure 7. Our new collection of perennial pigeonpeas from the Caribbean region is a valuable source of high biomass, and has considerable potential for use as fuel wood as well as food.

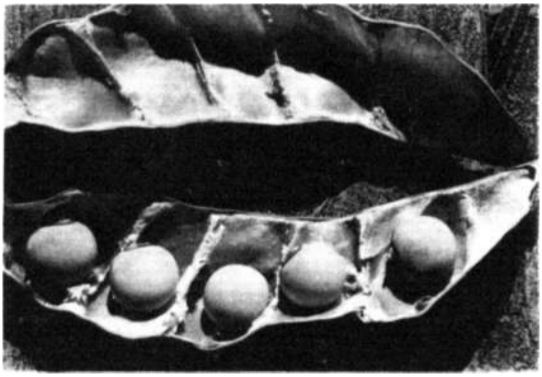


Figure 8. A vegetable-type pigeonpea collected in Jamaica. These genotypes resemble garden peas and are highly valued in the Caribbean and Central American regions.

evaluated in earlier seasons. We also evaluated a set of 30 medium-duration landraces, with such yield attributes as high numbers of branches and racemes, for yield potential and various agronomic traits. Using Bahar, which has similar plant type and maturity characteristics, as a control we evaluated 16 medium-long duration accessions with superior agronomic traits. ICRISAT pigeonpea breeders have included 9 accessions from this set in a trial at Gwalior.

A working collection (735 accessions) with depleted seed stocks, or with seeds of low viability (604 accessions) was rejuvenated (Table 4). This working collection includes all the accessions that are in high demand, and those widely used in breeding programs. We rejuvenated 45 wild species accessions in the botanic garden.

From 900 accessions that were screened during 1985/86, we found 116 to be less sensitive to photoperiod. These are being further tested and purified under lights that extend daylength to 16 h.

The wild gene pool of pigeonpea now consists of 240 accessions representing 46 species belonging to six genera. We grew 31 new wild species samples from Indonesia in the PEQIA screenhouse, they include *Atylosia scarabaeoides* (L.) Benth. (17), *Rhynchosia* spp (8), and *Flemingia* spp (6).

We began joint evaluation programs with NBPGR at Issapur, Akola, and Dholi (Table 5). Collaborating with ICRISAT pigeonpea breeders and NBPGR 353 medium long-duration (131-160 days to 50% flowering) accessions and 40 accessions originating from countries in eastern Africa were sown at Gwalior. We are collaborating with the NDFRS, Kenya and have sown a set of 500 long-duration (> 160 days to 50% flowering) accessions at Machakos and Kiboko (Table 5). We hope that this joint project will help to identify genotypes suitable for crop improvement programs in Kenya.

We finished entering passport data for the newly registered accessions, and the evaluation data for the 1984/85 rainy season at ICRISAT Center in the computer, and are now entering the 1985/86 data. The evaluation data from Hisar on the extra-early and early pigeonpea accessions for the year 1983/84 (203 accessions) and 1984/85 (140 accessions) are also available on computer. Our germplasm catalog has been compiled and is in press.

Groundnut

During the year we added 53 accessions from three countries (Table 2) to an existing collection of 11588, thus raising the total to 11641 (Table 1). The 14 accessions from Zimbabwe mentioned in Table 2 are collections made by GRU scientists during 1985. In addition, accessions obtained from South Korea (77), Cameroon (10), and Mali (28) (collected in 1986) are in the PEQIA.

In October we participated in a joint germplasm collection mission with lTnstut d'economie rurale (IER), Mali (Fig. 9) to groundnut-producing areas in Koulikoro, Kayes (Kita area), Segou, Mopti, and Sikasso regions. A total of 146 samples was collected, and their variability appears to be very significant. The samples include erect, spreading bunch, and runner types belonging to var *hypogaea* and var *vulgaris*. A few samples appear to belong to var *fastigiata* but this is yet to be confirmed. We obtained 2-and 2-3-4-seeded types with small, medium, and bold pods. Most of the collected samples

Figure 9. Collecting groundnut germplasm from a farmer's field in Mali. Left, a former ICRISAT trainee presently working with l'Institut d'economie rurale; center, a groundnut farmer who cultivates a wide range of groundnut and other crop species.

have either tan or red seed, but we also collected a few samples with pale tan, dark tan, rose, and variegated (red and white) seeds. During this collection we made observations on pests and diseases of groundnut crops in farmers' fields, and noted the symptoms of a previously unreported disease (Fig. 10).

In collaboration with NBPGR during October we explored western Rajasthan and the tribal areas of Orissa, Bihar, and Madhya Pradesh in India and collected 55 samples.

We sowed 1833 accessions during the rainy season and 1783 accessions during the postrainy season for rejuvenation (Table 4) and characterization as per the IBPGR/ICRISAT groundnut descriptors. In collaboration with our legume virologists seed of all these accessions were tested for the presence of peanut mottle virus (PMV), before sowing, using the enzyme-linked immunosorbent assay technique (ELISA). Only virus-free seeds were sown, the virologists also checked the plants in the field and helped us identify and destroy plants with PMV symptoms. We are only distributing seed from virus-free plants and this has given us more confidence in the purity and safety of the ICRISAT groundnut germplasm that we distribute to users. We also rejuvenated 575 accessions in the greenhouse.

We sowed a trial of 96 bold-seeded accessions in collaboration with the groundnut breeders. The results of this trial will help us supply the Legumes Program with good bold-seeded accessions to be included in their confectionary groundnut breeding program.

During the year we undertook a large-scale seed increase of wild *Arachis* species. In December

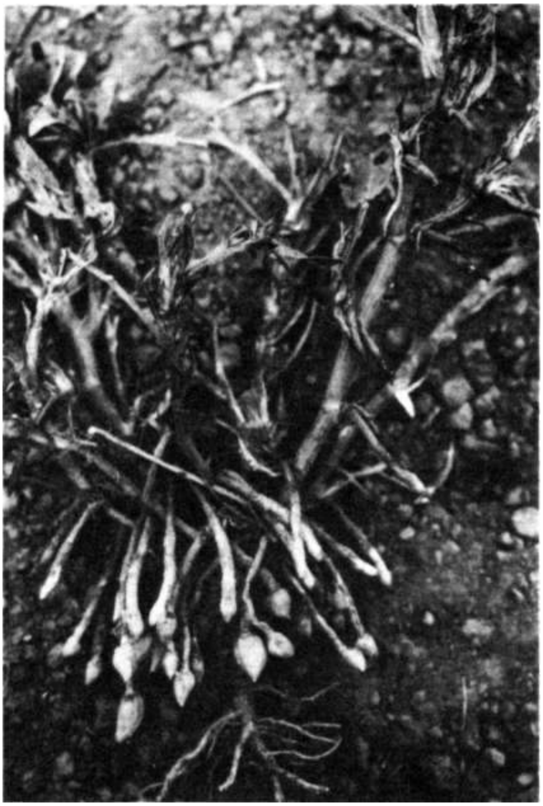


Figure 10. Groundnut plant with symptoms of "stubby peg', an unidentified disease observed in Malian farmers' fields during a germplasm collection expedition, 1986.

1985 and January 1986 we pregerminated and sowed seeds of 80 wild species accessions in the field, spaced as far apart as possible. The numbers of seeds harvested for each accession ranged from a few hundred to a few thousand. From those accessions that produced limited number of seeds we took cuttings and planted these in the greenhouse to further increase our stocks.

In collaboration with the Legumes Program we screened 4200 accessions for insect and disease resistance, and determined 100-seed mass and shelling percentage for 2200 accessions.

We tested the viability of 439 accessions, and as a result 71 accessions with reduced viability have been rejuvenated and their stocks replenished (Table 4). We examined fresh seed dormancy in 393 accessions that were harvested during March-April and found 18 accessions belonging to ssp *fastigiata* with a dormancy period exceeding 30 days. During harvesting the rainy season crop, we tested 800 accessions belonging to ssp *fastigiata* and found 21 with fresh-seed dormancy of more than 30 days. These could be used in breeding short-duration groundnut cultivars with fresh-seed dormancy.

We completed computerization of passport data on 31 descriptors for 11300 accessions. Data on 10000 accessions for 21 evaluation descriptors are now in the computer, and the data on the remaining 1641 accessions are being tabulated.

Minor millets

We sowed 466 new accessions of six crop species received from the NBPGR Regional Research Station, Akola for rejuvenation (Table 4) during the year raising our total gene bank holdings to 5563 (Table 3).

During 1986 we acquired 1060 new accessions from Burundi (11), Uganda (596), Korea (126), USSR (143), and Zimbabwe (184) through NBPGR. These will be sown in the PEQIA for inspection and release.

We supplied 2138 accessions to NBPGR for evaluation at Akola, India (Fig. 11). We also supplied 398 accessions to the SADCC/ICRISAT Sorghum and Millet Improvement Program, Zimbabwe for evaluation and use in the SADCC region.

Looking Ahead

We will continue to collect from priority areas germplasm of all our five mandate crops. More national programs are seeking ICRISAT help with germplasm collection in their countries, and we shall assist wherever we can. Our collaborative collection work with NBPGR in India will continue.

Figure 11. ICRISAT and NBPGR scientists working on minor millets germplasm at NBPGR Regional Research Station, Akola, India. ICRISAT supplied 2138 accessions to this station in 1986.

The joint germplasm evaluations in collaboration with NBPGR will continue. This will provide information on the expression and performance of our germplasm in different regions of India and will enhance the use of the available diversity. Similarly, the regional germplasm evaluations in eastern, southern, and West Africa, and at the ICRISAT Sahelian Center will be pursued with more concerted efforts. We will also continue our collaborative pulse germplasm evaluations with PGRC/E, Ethiopia, and NDFRS, Kenya.

Introgression work in sorghum and chickpea will continue in cooperation with legume cytogeneticists to transfer genes from wild to cultivated species, using modern techniques such as embryo rescue, and tissue culture to accomplish wide crosses.

Our long-term cold store will soon be open for all the five crops, thus improving our conservation facilities. Monitoring stored material will be streamlined to identify accessions losing viability and ensure timely rejuvenation.

The chickpea and pigeonpea germplasm catalogs will soon go to press. We hope to complete compilation of sorghum, pearl millet, and groundnut germplasm catalogs thus completing a new series of ICRISAT publications.

Publications

Journal Articles

Appa Rao, S., Mengesha, M.H., and Rajagopal Reddy, C. 1986. New sources of dwarfing genes in pearl millet (*Pennisetum americanum*). Theoretical and Applied Genetics 73(2): 170-174. (JA 429)

Appa Rao, S., Mengesha, M.H., Sibale, P.K., and Rajagopal Reddy, C. 1986. Collection and evaluation of pearl millet *(Pennisetum)* germplasm from Malawi. Economic Botany 40(l):27-37. (JA 444)

Appa Rao, S., Mengesha, M.H., Vyas, K.L., and Rajagopal Reddy, C. 1986. Evaluation of pearl millet germplasm from Rajasthan, India. Indian Journal of Agricultural Sciences 56(l):4-9. (JA 482)

Prasada Rao, K.E., Obilana, A.T., and Mengesha, M.H. 1985. Collection of kaura, fara-fara and guineense sorghums in northern Nigeria. Journal d'Agriculture Traditionnelle et de Botanique Appliquee 32:73-81. (JA 434)

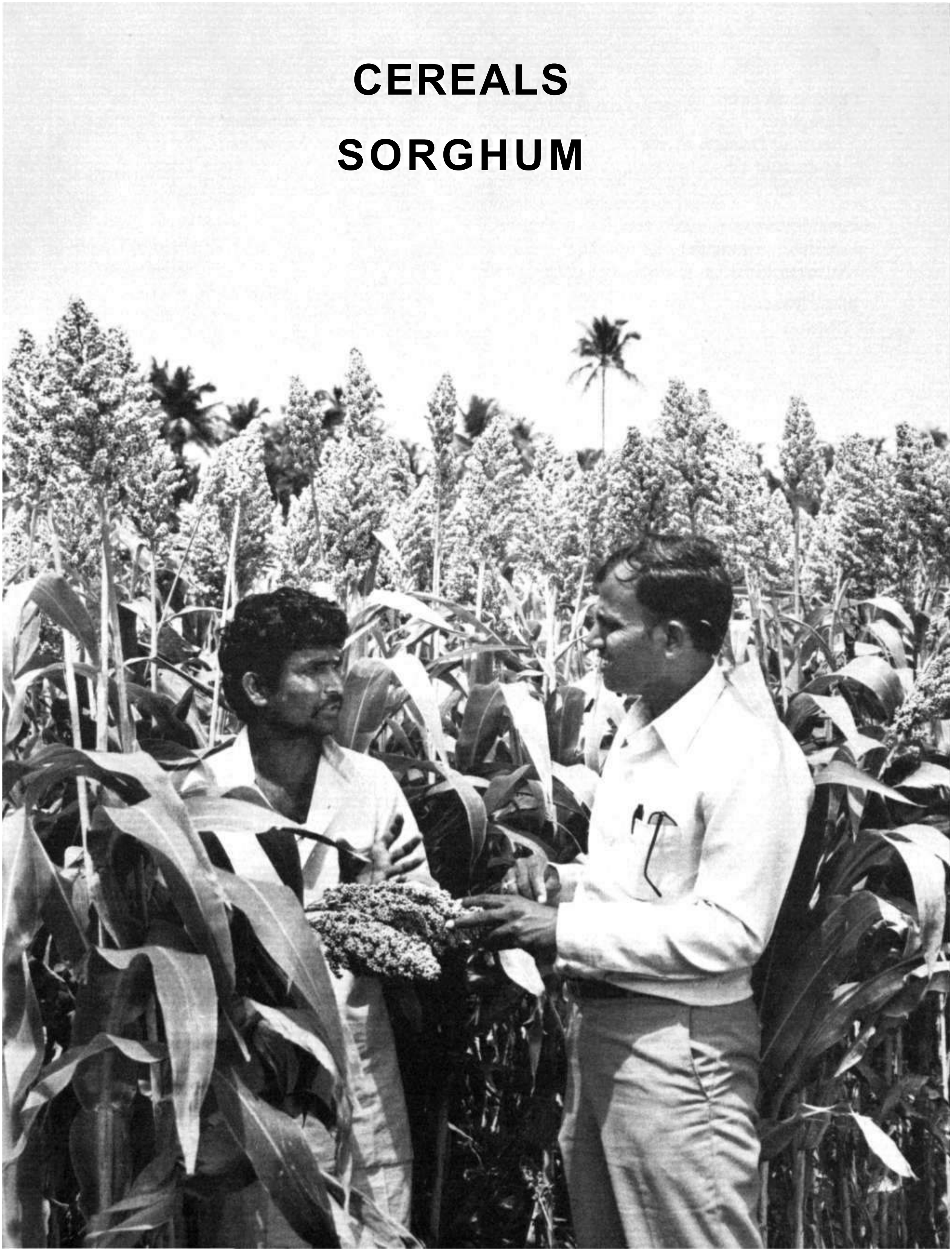
Rao, N.K., van der Maesen, L.J.G., and Remanandan, P. 1985. Breaking seed dormancy in *Atylosia* species. Seed Research !3(2):47-50. (JA 389)

Conference Papers

Remananden, P. 1986. Genetic variation in pigeonpea germplasm. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 280)

CEREALS

SORGHUM



Contents

Cover photo: ICRISAT-bred sorghum hybrid ICSH 153 growing in a farmer's field in Karnataka State, India. During 1986 the Government of India released this hybrid as CSH 11 for general cultivation in all sorghum-growing areas of India. The farmer (left) is discussing his crop with a member of ICRISAT staff (right), rainy season 1986.

The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Annual Report 1986. Patancheru, A.P. 502324, India: ICRISAT.

For offprints, write to: Cereals Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502324, India.

SORGHUM

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

Major research activities in India are concentrated at ICRISAT Center but we use other locations where high stress factors regularly occur, to adequately screen germplasm accessions and breeding material for resistance to various stresses. Locations for stem borer and leaf diseases are Hisar and Pantnagar, in northern India. Anantapur in southern India is used for drought, Bijapur and Akola for *Striga asiatica,* Dharwad for sorghum downy mildew and midge, and at Bhavanisagar (near Coimbatore) we evaluate material for adaptation to latitudes near the equator, and for resistance to grain molds (Fig. 1).

In West Africa the program concentrates on the development of genotypes for two distinct ecological zones, the Sudanian with intermediate rainfall (600-900 mm) based at Ouagadougou, Burkina Faso, and the Northern Guinean with high rainfall (900-1200 mm) based at Bamako, Mali. Frequent drought, poor seedling establishment, and the parasitic weed, *Striga hermonthica,* are the major yield-limiting factors in the intermediate rainfall zone. Leaf diseases, grain molds, and panicle pests pose serious problems in the high rainfall zone. Soils with low fertility and poor water-holding capacity are common to both zones. Accordingly, our breeding program evaluates germplasm lines and breeding material in both zones, and elite materials are systematically tested across a range of ecological conditions. Grain processing and food quality are also important considerations in these testing programs.

Figure 1. ICSV 202, an ICRISAT-bred sorghum variety at present in All India Coordinated Sorghum Improvement Program (AICSIP) advanced yield trials growing at Bhavanisagar, Tamil Nadu where ICRISAT evaluates material for adaptation to latitudes near the equator and for resistance to grain molds.

The Eastern Africa Regional Network operates from Nairobi, Kenya and concentrates on the development of cold-tolerant varieties and hybrids for high altitude (> 1800 m) areas, and varieties and hybrids for lower altitudes. At a meeting in Nairobi in June 1986 under the aegis of the Cooperation for Development in Africa (CDA), the Directors of Agricultural Research of five eastern African countries (Burundi, Kenya, Rwanda, Somalia, and Uganda) identified sorghum and millets as priority commodities for regional research, and agreed that ICRISAT be responsible for developing and implementing a CDA-supported project on these crops.

The regional program for southern Africa, Southern African Development Coordination Conference (SADCC/ICRISAT Sorghum and Millet Improvement Program) is based in Bulawayo, Zimbabwe. It has three fundamental objectives: 1. To strengthen the research capabilities of the national programs by providing genetic material to breeding programs, developing research techniques, and assisting in formulation of research programs. This objective encourages the development of regional cooperation among scientists of participating countries; 2. to provide and facilitate training at ICRISAT Center in India, in the SADCC region, and at overseas universities; and 3. to assist in upgrading facilities for field research, advancing generations, and crossing in off-season nurseries.

The Mexico and Central American regional team, based at the headquarters of the Centro Internationalde Mejoramiento de Maizy Trigo (CIMMYT) in Mexico, works in close cooperation with the national programs in the region. Its objectives are to breed cold-tolerant (6-25° C) sorghum varieties and hybrids adapted to high altitudes (1500-2500 m), and to improve the local cultivars adapted to low and intermediate elevations in the region. Improved genotypes are expected to have high and stable yields, resistance to pests and diseases, and good grain quality.

This report integrates the work conducted by ICRISAT Center and the regional programs, networks, and teams, and gives research results from 1986 as well as those from previous years not included in earlier Annual Reports.

Physical Stresses

Drought

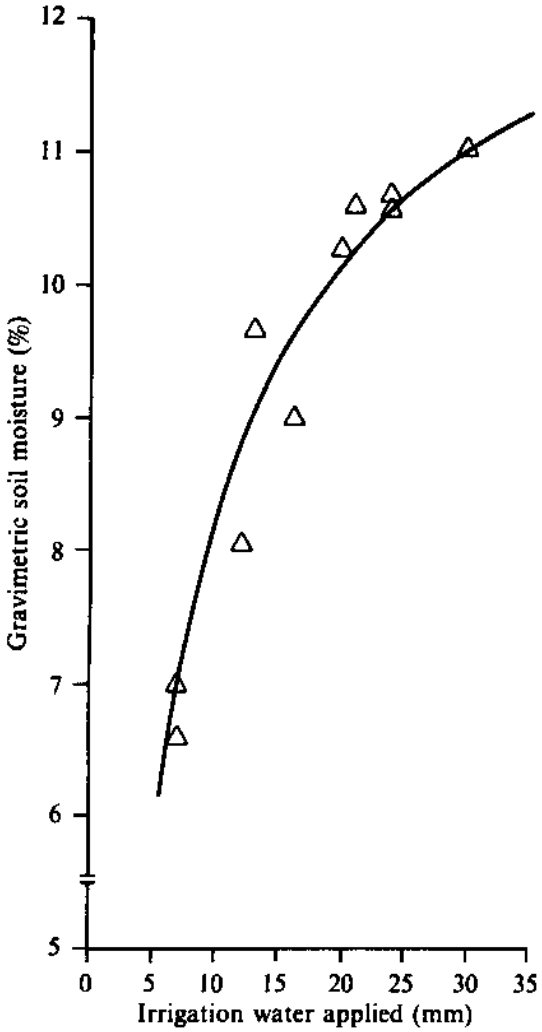
Seedling Drought Stress

Poor seedling emergence can result from a lack of soil moisture at the time of sowing. In farmers' fields the seedbed moisture varies from 2.7 to 18.6% at sowing (ICRISAT Annual Report 1981, p. 60). This wide range of moisture content influenced germination and emergence, and resulted in sparse and variable plant stands. Pot-experiments in the greenhouse have shown that there is genotypic variation in emergence when soil moisture is limited. We have now developed a field technique to screen for emergence in Alfisols with limited soil moisture during the hot dry summer season. We applied differential irrigation using a line-source sprinkler system to an absolutely dry Alfisol. This provided a series of environments that differed in soil moisture content and temperature. Because in naturally occurring drought environments changes occur in both these factors and complex interactions exist between them, we did not attempt to separate them in this experiment.

We disced and rotavated the soil and prepared broadbeds (1.2m wide) each one representing an environment. These were divided into plots 2 m long, with a 0.5 m path between plots. Using a John Deere 7100 planter, we sowed sorghum seeds 50 mm deep and pearl millet seeds 30 mm deep (ICRISAT Annual Report 1983, pp 69-71).

After sowing, the beds were carefully smoothed before using the line-source technique to apply a linear gradient of water from about 5 mm to 30 mm (Fig. 2) across seven broadbeds. Each test entry was sown in every bed along the gradient in the range of 10 to 30 mm applied water. Test entries were replicated once on both sides of the line source.

We measured soil moisture (gravimetric percentage) and soil temperature at depths of 20 mm and 50 mm. Figure 3 shows the soil moisture status of the wet and dry ends of the gradient from sowing to emergence. Soil temperature in the seed zone (50 mm deep) varied with soil



$$y = 11.65 - 9.49e^{-0.093x}$$

Figure 2. Relationship between gravimetric moisture content (%) in the top 100 mm of soil and amount of irrigation water applied (mm) in a seedling drought-stress trial, ICRISAT Center, dry season 1984.

moisture, with the lowest temperature at the wet end of the gradient and the highest at the dry end of the gradient (Table 1). We standardized the different trials in a season by the amount of water applied to the dry soil. There was a high correlation (r = 0.96, $P < 0.001$) between the applied water and the actual soil moisture content (Fig. 2). Though the relationship is sigmoid, the method provided a useful range of soil moisture in which to test genotypic emergence ability. The curvilinearity of the relationship was expected as the moisture content did not increase beyond field capacity (11.5%), and led us to restrict the range of test environments from 25 mm to 10 mm applied water. Even though the soil environment changes with such other factors as air temperature and cloud cover, the technique was capable of providing different levels of soil moisture and soil temperatures, as shown in Table 1.

Seedling emergence measured on the 5th day after sowing (5 DAS) at different ends of the gradient differed significantly ($P < 0.001$); and there were highly significant ($P < 0.001$) genotypic differences in both pearl millet and sor-

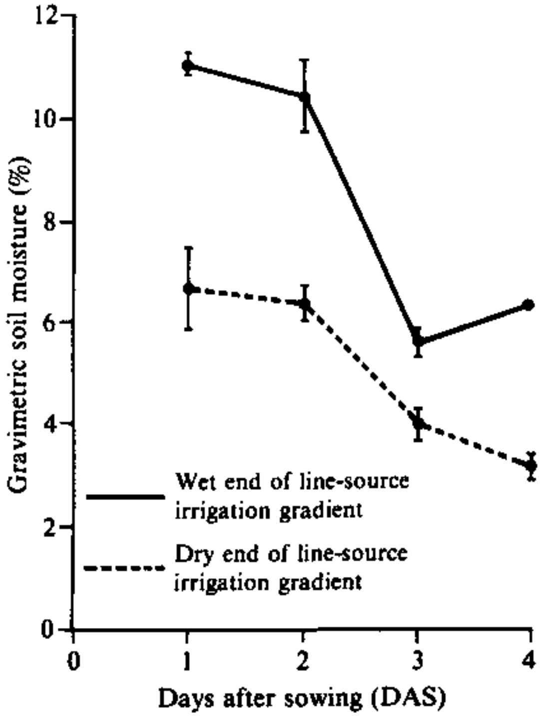


Figure 3. Change in gravimetric moisture content (%) in seed-zone soil (25-50 cm deep) in wet and dry ends of a line-source irrigation gradient from sowing to seedling emergence (DAS), ICRISAT Center, dry season 1984.

Table 1. Seed-zone soil temperature (50 mm deep) for the wet and dry ends of the line-source irrigation gradient for the experimental period and the corresponding air temperature measured at 1400 h, ICRISAT Center, dry season 1984.

Days after sowing	Seed-zone soil temperature (°C) Wet	Seed-zone soil temperature (°C) Dry	Air temperature(°C)
1	32.2 (±0.7)[1]	36.8 (±0.6)	30.2
2	37.5 (±0.4)	40.9 (±0.7)	33.5
3	32.8 (±1.0)	35.5 (±1.0)	34.0
4	35.9 (±0.4)	37.8 (±0.5)	35.1

1. Figures in parentheses are SEs.

ghum. The emergence response of the different genotypes was linear with applied water, so only data for the wet and dry ends of the gradient are presented here. Figure 4 shows the frequency distribution of a set of 166 sorghum genotypes for emergence at the wet and dry ends of the gradient. The difference in position of the histograms shows the influence of soil moisture deficit on this group of genotypes. The overall emergence percentage at the dry end of the gradient varied widely (10 to 90%) indicating the existence of useful variability among genotypes. While 54% of the genotypes achieved >70% emergence at the wet end of the gradient, some 17% of the entries achieved the same emergence at the dry end of the gradient. The technique was thus able to differentiate the material for the ability to emerge under conditions where moisture was limited.

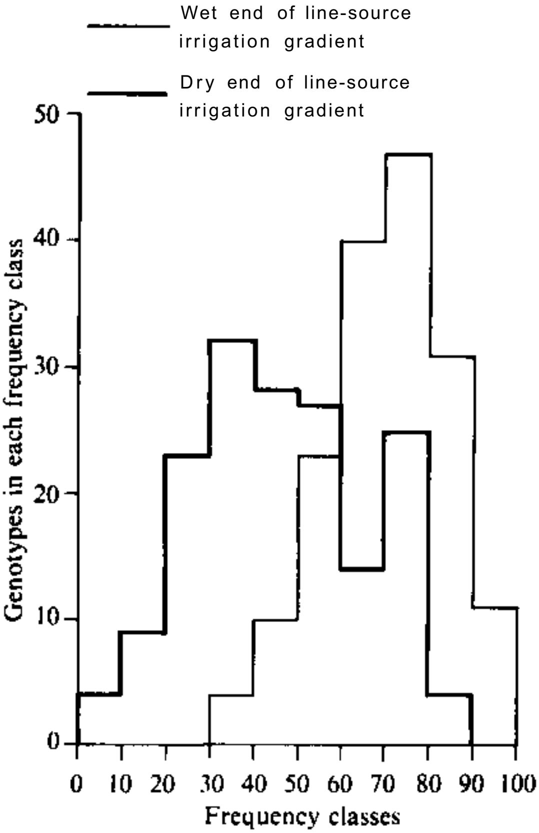


Figure 4. Distribution of emergence percentage (frequency classes) of 166 sorghum genotypes in wet and dry ends of a line-source irrigation gradient, ICRISAT Center, dry season 1984.

Midseason Drought Stress

We reported earlier, experiments on the physiological basis for resistance to midseason heat and drought stress (ICRISAT Annual Report 1985, pp 30-33). Results obtained in 1985 indicated that resistant lines maintained higher relative leaf water contents (RLWC) as leaf water potentials declined, possibly due to osmotic adjustment. An objective of this year's research was to establish whether osmotic adjustment occurred in resistant genotypes, and whether this parameter could account for the marked differences in performance of susceptible and resistant genotypes. The contrasting genotypes examined were IS 12744, IS 12739, IS 17605 (drought-susceptible), IS 1347, IS 13441 (drought-resistant), and the ICRISAT drought-resistant breeding material, hybrid ICSH 109 (SPH 263) and variety ICSV 213, that have been the highest-yielding genotypes over a number of seasons at Anantapur, our midseason drought testing location.

The genotypes were sown on 12 March 1986 in a split block design. There were four treatments: A control treatment (WWWW) that was furrow-irrigated at weekly intervals; two drought stress treatments in which irrigation was withheld at 20 DAS, and then for a period of 23 days (WDWW) equivalent to early midseason stress, and 43 days, (WDDW) equivalent to a long midseason stress; and a further stress treatment in which water was withheld at 46 DAS for 23 days (WWDW) representing a late midseason stress. Figure 5 shows representive plants of hybrid ICSH 109 (SPH 263) in the different treatments at 88 DAS .

Measurements of air, leaf and soil temperatures, windspeed, rainfall, relative humidity (RH), and incident and intercepted radiation were made every 5 minutes with readings averaged for each hour. Detailed measurements of leaf-water relations were made weekly on the youngest fully expanded leaf, prior to dawn and at 1300 h. Leaf-water potential was measured with a pressure chamber; osmotic potential with a calibrated Roebling osmometer; and RLWC as outlined in the ICRISAT Annual Report 1985 (p. 31). From these measurements we calculated the turgor potential and osmotic adjustment (defined as the difference between the osmotic potential

Figure 5. Representative plants of sorghum hybrid ICSH 109 (SPH 263), showing the growth stage at 88 days after sowing in four drought-stress treatments (WWWW = irrigated control; WDDW = long midseason stress; WDWW = early midseason stress; WWDW = late midseason stress), ICRISAT Center, dry season 1986.

at full turgor of irrigated and drought-stressed leaves).

When fired leaf material was removed from the sample (this was not done in 1985; ICRISAT Annual Report 1985, pp 31-33) the RLWC and leaf-water potential measurements did not clearly distinguish between resistant and susceptible genotypes, and were relatively insensitive to stress development.

Resistant genotypes such as IS 13441 had a higher capacity for osmotic adjustment than susceptible genotypes IS 12739 and IS 12744. Most of this adjustment occurred soon after water was withheld and at high leaf-water potentials. As a result, resistant genotypes were able to maintain a positive turgor despite lower leaf-water potentials (-2.8 MPa) than susceptible genotypes (-2.0 MPa). The rate of dry matter production became negligible in both resistant and susceptible genotypes at predawn leaf-water potentials of -0.55 MPa, despite turgor being maintained to much lower leaf-water potentials.

Resistant genotypes with a high capacity for osmotic adjustment had similar stomatal responses to leaf water potential to susceptible genotypes with low capacities for osmotic adjustment. Large changes occurred in stomatal conductance and leaf rolling soon after water was withheld from plants when leaf turgor potentials were constant. Leaf rolling was coincident with a reduction in radiation-use efficiency. Therefore, even if osmotic adjustment had delayed leaf rolling the gain in productivity would have been small.

On the basis of these turgor-related processes we can conclude that there would be little advantage in selecting for plants with a higher capacity for osmotic adjustment in an environment experiencing midseason stress.

In addition to taking measurements of the plant water status, we also took weekly measurements of dry matter production of shoots and roots, and leaf areas of the four treatments. Figure 6 shows the effect of the different treat-

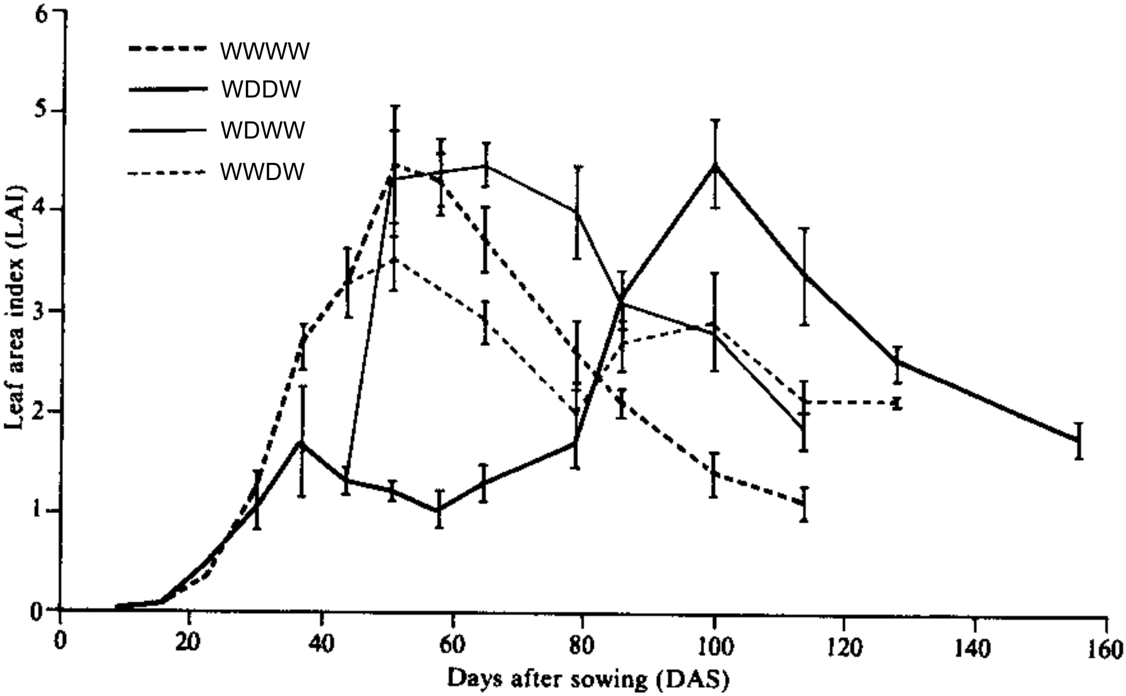


Figure 6. Effect of four drought-stress treatments (WWWW - irrigated control; WDDW = long midseason stress; WDWW = early midseason stress; WWDW = late midseason stress) on leaf development, measured as leaf area index (LAI) in plants of sorghum hybrid ICSH 109 (SPH 263), ICRISAT Center, dry season 1986.

ments on the leaf area development of ICSH 109 (SPH 263).

With a view to understand some of the biochemical changes associated with midseason drought stress in these lines we measured proline content and nitrate reductase activity (NRA). We measured the levels of proline and NRA of the youngest fully expanded leaf (two leaves, two plants, two replicates) in both the irrigated control and drought-stressed plots. Proline was shown to accumulate in resistant lines in contrast to the susceptible ones. Their recovery rate shows a good positive correlation with their proline levels. NRA decreased with drought stress in all genotypes and shows good negative correlation with osmotic adjustment and leaf-water potential. More detailed analysis of the relationships between proline and NRA, and growth and leaf-water parameters will be reported later.

Terminal Drought Stress

In India sorghum is grown on stored soil moisture in the postrainy (rabi) season on about 6.5 million ha, accounting for about 40% of the total sorghum-growing area. Postrainy-season crops undergo both nitrogen (N) and terminal drought stresses. The reasons for low productivity in sorghum during the postrainy season were discussed earlier (ICRISAT Annual Reports 1979/80, 1981, 1982, and 1983). We examined the relative importance of, and interaction between these two stresses in 1980, 1981, and 1985. We grew hybrid CSH 8R in a split-block design on a deep Vertisol during the postrainy seasons under 3 regimes of applied water (irrigation): I_0 = no water applied; I_1 = 40 mm irrigation water applied at panicle initiation; I_2 = 2 irrigations of 40 mm at panicle initiation, and a single irrigation 60 mm at the boot stage, and 2 levels of applied N: N_0 = no N applied; N_{80} = 80 kg N ha^{-1} applied at sowing. Each year, at sowing the soil profile was fully charged with water (about 220 mm of plant-available water to a depth of 2 m). The initial levels of available NO_3-N in the soil to a depth of 1.2 m were 40.0 kg ha^{-1} in 1980, 13.3 kg ha^{-1} in 1981, and 22.6 kg ha^{-1} in 1985.

In the N_0 treatment grain yields over years were influenced by the amount of initial soil N present at sowing (Table 2). In each year the mean grain and above-ground biomass yields, and N uptake increased significantly with the application of N and water, and these inputs also acted synergistically. For example, the grain yield (average over 3 years), in the $N_{80}I_2$ treatment was 114% more than in N_0I_0. The effect of added N on N uptake (difference in N uptake between N_0 and N_{80} treatments) was highest in 1981, when the initial soil N was lowest.

Average seasonal water use across both fertility levels was only 150 mm in the N_0I_0 treatment (Table 2) but increased by about 40% in I_1, and 101% in I_2. Added N had little effect on water use. Differences in water use among years were also small. Water-use efficiency (WUE) values for both biomass and grain yields decreased with the number of irrigations, but increased with applied N, especially during 1981 and 1985, when the soil N levels were low. Differences in WUE across years were greater in the N_0 treatments compared to N_{80}. However, fertilizer-use efficiency [kg grain (kg N applied)$^{-1}$], increased from 10 in I_0 to 18 in I_1, and 24 in I_2 treatments. These results indicate the importance of both nutrient supply and WUE for increased yields, and should be considered when selecting genotypes for stored-soil moisture environments.

Plant Nutrition

Vesicular Arbuscular Mycorrhizae (VAM)

We conducted inoculation trials with VAM (a mixture of *Glomus constrictum, Glomus mosseae,* and *Acaulospora morroweae*) at two Indian locations using 10 sorghum genotypes including those selected from previous field trials based on their relative rate of VAM colonization and responsiveness to inoculation. At Bhavanisagar, 3 genotypes, IS 22403, IS 22471, and CSH 5, showed significant increases in total above ground biomass, and 2 genotypes, IS 4769, and CSH 5, showed significant increases in grain yield due to VAM inoculation. At ICRISAT Center, 2 geno-

Table 2. Effect of nitrogen (N) and water (irrigation, I) regimes on performance of sorghum hybrid CSH 8R on a Vertisol, ICRISAT Center, postrainy seasons 1980, 1981, and 1985.

	Yield (t ha^{-1})				Water use (mm)		Water-use efficiency (kg ha^{-1} mm^{-1})				N uptake (kg ha^{-1})	
	Grain		Biomass				Grain		Biomass			
Treatments[1]	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
Irrigation levels												
I_0	2.25	3.06	5.71	7.45	150	178	15.0	17.6	37.5	4.31	49.3	74.4
I_1	2.69	4.13	6.52	9.25	234	227	12.5	18.6	30.8	4.22	49.0	102.6
I_2	2.88	4.82	7.16	10.66	312	348	9.1	13.9	23.0	30.8	54.8	89.1
Years												
1980	3.75	4.65	10.67	12.36	231	247	17.0	19.9	47.9	52.8	73.7	100.7
1981	1.37	3.81	3.40	7.60	218	255	6.4	14.9	16.0	30.1	12.7	69.1
1985	2.68	3.55	5.32	7.40	247	250	13.2	15.3	27.5	32.2	66.8	96.3
Mean	2.60	4.00	6.46	9.12	232	251	12.2	16.7	30.4	38.7	51.1	88.7
SE												
N	±0.10		±0.18		±6		±0.6		±1.5		±1.4	
I	±0.11		±0.15		±4		±0.9		±1.5		±3.7	
N (I)[2]	±0.16		±0.26		±8		±1.3		±2.4		±4.1	
N (Year)[2]	±0.19		±0.41		±1		±1.4		±2.5		±2.3	

1. During each year main plots consisted of 3 irrigation levels (I_0, I_1, and I_2 irrigations) and subplots consisted of 2 levels of applied N—N_0 = 0 kg ha^{-1} and N_{80} = 80 kg ha^{-1}.
2. Comparing levels of first factor within the same level of second factor.

types, IS 4001 and IS 15184, showed significant increases in grain yield due to inoculation. The reasons for the observed differences in response to inoculation by different genotypes may be due to differential competition between native and exogenous mycorrhizae, and location effects on plant development.

We examined the effect of exogenously supplied phosphorus levels on the response of plants to VAM inoculation using 4 genotypes, IS 15184, IS 4001, IS 9652, and CSH 5 in pots containing sand and nutrient solution. All the genotypes responded to inoculation at 0,4, and 8 ppm and their responsiveness was nullified at high (30 and 60 ppm) inoculation levels (Table 3). The interactions between P levels and inoculation were significant (P= <0.01). This suggests that the plant is more dependent on VAM for P uptake at lower levels of P.

Nitrogen Fixation

We examined the effect of exogenous nitrogen on nitrate reductase activity (NRA) and nitrogenase (N_2ase) activity on CSH 5 grown in pots.

In all the treatments we observed the maximum specific NRA cm^{-2} of leaf at 20 DAS, after which it significantly declined (Table 4). The addition of N as urea increased specific NRA in leaves, however, at 20 DAS we only observed a significant increase in specific NRA due to N-application in plants that received 25 or 100 ppm N solution daily, and the equivalent of 40 or 80 kg N ha^{-1}. Similarly, total NRA plant^{-1} was increased by the addition of nitrogen at 25 and 100 ppm daily, or 80 kg N ha^{-1} equivalent at 40 DAS, and at 100 ppm daily at 60 DAS.

We observed that the N_2ase activity associated with CSH 5 in all treatments increased with age,

Table 3. Response (g biomass plant^{-1}) of four sorghum genotypes to phosphorus and mycorrhizal inoculation in sand culture[1], ICRISAT Center, rainy season 1986.

Available phosphors (ppm)	IS 15184 Inc[2]	IS 15184 Noninc[3]	IS 4001 Inc	IS 4001 Noninc	IS 9652 Inc	IS 9652 Noninc	CSH 5 Inc	CSH 5 Noninc	SE
0	1.25	0.05	1.34	0.13	1.63	0.23	1.50	0.16	±0.096
4	3.00	0.23	4.53	0.31	3.57	0.89	4.05	1.18	±0.205
8	5.84	2.13	8.64	3.77	5.31	4.45	6.21	4.17	±0.551
30	9.62	12.42	9.66	11.99	10.65	10.78	8.58	15.18	±1.334
60	13.33	15.17	13.71	15.33	9.11	6.86	10.22	14.29	±1.557

1. Grown in pots in a greenhouse.
2. Inc = Inoculated with *Glomus constrictum.*
3. Noninc = Noninoculated.

Table 4. Nitrate reductase activity (NRA) in leaves of sorghum hybrid CSH 5 grown in pots with different levels of mineral N at different growth stages, total nitrogen uptake, and plant dry matter at harvest (117 DAS)[1], greenhouse test, ICRISAT Center, rainy season 1986.

	Nitrate reductase activity (NRA)[2]									
	μ moles NO_2 cm^{-2}				μ moles NO_2 plant^{-1}					
	DAS				DAS				Total plant dry matter	N uptake
Treatment	20	40	60	Mean	20	40	60	Mean	(g plant^{-1})[2]	(mg plant^{-1})[2]
N ppm										
0	73	2	4	26	37.9	3.3	3.0	14.7	86	280
10	81	3	5	30	39.0	5.5	5.0	16.5	103	332
25	87	5	8	33	47.9	11.1	8.3	22.4	110	552
100	94	21	26	47	49.6	54.5	46.4	50.2	163	1720
Kg N ha^{-1}										
20	77	4	4	28	33.6	7.9	3.0	14.8	92	282
40[3]	93	3	4	33	43.6	6.8	3.9	18.1	99	322
80[3]	116	5	7	43	58.5	13.6	6.7	26.3	110	470
SE	±8	±0.6	±1.0	±2.0	±4.71	±1.58	±1.63	±1.42	±3.1	±25
Mean	89	6	8		44.3	14.7	10.9			
CV(%)	19	21	26		24	24	33	6	10	

1. Plants were grown in 6-L plastic pots filled with 7 kg Alfisol. Nitrogen was applied as urea in solution daily, or as a basal dose based on pot surface area at sowing.
2. Mean of six replications, NRA plant^{-1} calculated on total green leaf area plant^{-1}.
3. 40 and 80 kg N ha^{-1} equivalent treatments, half dose N applied at sowing, remainder at 15 DAS.

up to 81 DAS and then declined. At 81 DAS, N_2ase activity was stimulated by the addition of 20 kg N ha^{-1} equivalent or 10 ppm N in solution daily, and was reduced by the addition of 25 and 100 ppm N solution daily, or 40 and 80 kg N ha^{-1} equivalent (Fig. 7).

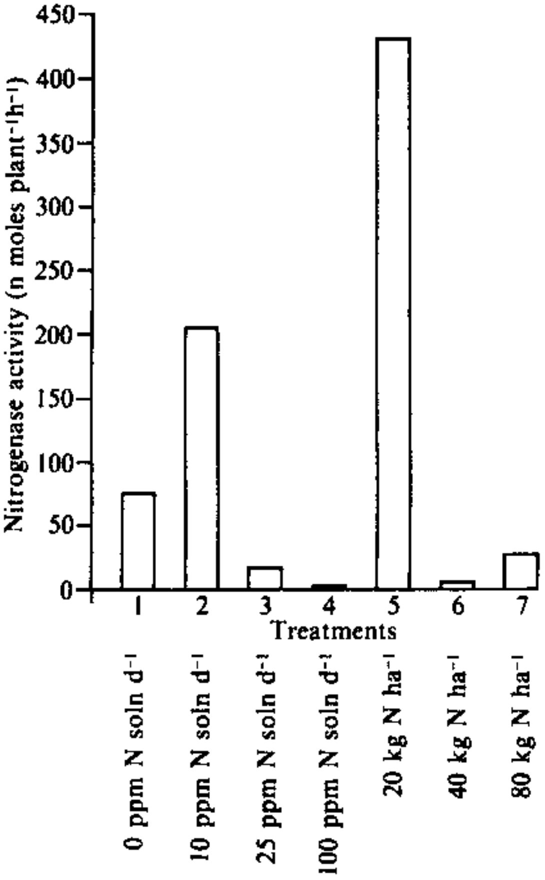


Figure 7. Effect of exogenous nitrogen levels on nitrogenase activity assayed at 81 days after sowing in intact sorghum hybrid CSH 5 plants grown in an Alfisol in pots, ICRISAT Center, 1986.

Biotic Stresses

Diseases

ICRISAT Center

Grain Molds

Fungal invasion in grain. Previous observations showed that some white-grain, mold-susceptible genotypes have dense and hard grains, a character most often associated with mold resistance in white-grain sorghums. We conjectured that fungal colonization of grains of these susceptible genotypes is restricted to the pericarp leaving the endosperm intact (ICRISAT Annual Report 1985, p.38). To test this hypothesis we examined fungal colonization of grain tissues of mold-susceptible and mold-resistant genotypes grown in the 1985 rainy season. We selected the following three categories of white-grain genotypes: a. three resistant genotypes with dense (1-2% floater) and hard (88-91% recovery after dehulling) grains, b. four susceptible genotypes with dense (2-13% floaters) and hard (89-91% recovery after dehulling) grains, and c. three susceptible genotypes with less dense (88-100% floaters) and soft (61-68% recovery after dehulling) grains. Using procedures described earlier (ICRISAT Annual Report 1985, p.37) we processed 7-10 grains of each genotype and examined microtome sections for fungal colonization under a fluorescence microscope.

The pericarp of resistant genotypes with dense and hard grains showed sparse invasion by fungal mycelia, and their aleurone layers, endosperms, and embryos were free from fungal growth. Susceptible genotypes with dense and hard grains had pericarps abundantly colonized by fungi, but their aleurone layers, endosperms, and embryos were fungus-free. Susceptible genotypes with less dense and soft grains had extensive fungal growth in all parts of the grain.

We also examined the extent of damage to starch in the endosperm under a fluorescence microscope using the classical periodic acid-Schiffs reaction in microtome sections of grain tissues. Starch granules and the protein-starch matrix in the endosperm were intact in the grains of resistant and susceptible genotypes with dense and hard grains. In susceptible genotypes with less dense and soft grains the starch granules were in different stages of disintegration, particularly in the endosperm areas adjoining the embryo and the pericarp.

These observations show that fungal growth in mold-susceptible genotypes with dense and hard grains remains restricted to the pericarp and does not affect endosperm structure. In such cases assessment of moldiness by the qualitative visual rating method that only considers superficial mold growth should be verified by ergosterol analysis, a quantitative assay of total fungal biomass in the whole grain. We are following this procedure when assessing mold in breeding material.

Food quality of molded grain. We evaluated dough and *roti* quality of one mold-resistant (IS 14384), and four mold-susceptible (ICSV 2 (SPV 386), IS 14332, Local FSRP, and SPV 104) genotypes that showed different levels of mold severity. We assessed 18 grain samples of each genotype for moldiness by both visual rating and ergosterol analysis, (ICRISAT Annual Report 1984, pp. 21-22) and for roti quality. The ergosterol content of grain samples ranged from 0.9 to 65.4 μg g^{-1}. Our results showed that molded grain produced poor quality dough with inferior texture that made unacceptable rotis. We also measured dough quality using an Instron food testing instrument equipped with a 100-kg compression cell and fitted with a back extrusion cell. We calculated the initial and final forces of back extrusion and the slope of the Instron curve. Dough made from grains of resistant genotypes had good textural properties as indicated by the low initial force (<35 kg), final force (<55 kg), and steady slope of the Instron curve (<0.8). Dough from moldy samples of susceptible genotypes had a poor extrusion pattern, with larger forces of back extrusion, and Instron curves with very steep slopes. The amount of ergosterol was significantly correlated (r = 0.77***, 69 df) with the slope of the Instron curves for IS 14384, IS 14332, ICSV 2 (SPV 386), and Local FSRP grain samples. This demonstrates the deleterious effect of grain mold on dough and roti quality in sorghum.

Relationship of head bug damage and grain mold development. We investigated damage to developing grains by head bugs (*Calocoris angustatus*) as a predisposing factor on mold incidence in a split-split plot designed experiment with three replications. Panicles of two mold-resistant, and two mold-susceptible genotypes (main plots) were caged, and we released into these cages 5 and 15 pairs of head bugs $cage^{-1}$ (sub-sub plots) at two panicle development stages (subplots)—50% flowering and the milk stage of grain development. Head bug-free, caged panicles were used as controls. Overhead sprinkler irrigation was provided from flowering to grain maturity to promote grain mold development.

We counted grains showing superficial growth of the mold-causal fungal genera *Fusarium, Curvularia,* and *Phoma* under a stereoscopic binocular microscope for one resistant (IS 2821), and one (CSH 1) susceptible genotype at the hard-dough stage of grain development when mold growth does not normally appear on the grain surface. In the absence of head bugs, resistant and susceptible genotypes had 1-4% superficially molded grains. In contrast, where 5 and 15 pairs of head bugs were released at flowering, the grains shrivelled and extensive growth, predominantly of *Fusarium* spp appeared on 98-100% grains of both genotypes. At the milk growth stage, more mold appeared on both genotypes (80-81% grains extensively colonized) when 15 pairs of head bugs were released than when 5 pairs of head bugs were released (18% grain colonization in mold-resistant IS 2821 and 66% in mold-susceptible CSH 1). These results show that head bug damage to developing grain predisposes both resistant and susceptible genotypes to mold infection. Therefore, to avoid erroneous results while screening for mold resistance, it is necessary to avoid damage by head bugs.

Breeding for resistance. At ICRISAT Center, in an advanced screening trial with two replications, we evaluated 65 F_6 to F_9 generation breeding lines, that were mold resistant in the 1985 rainy season and had uniform plant characters. These entries included 48 with white grains. The test entries were derivatives from crosses between white-grain, mold-susceptible and the colored-grain, mold-resistant parents IS 2333, IS 14384, IS 14387, and IS 14388. Four resistant and 22 susceptible controls of variable maturity periods were also included in the trial. Overhead sprinkler irrigation was used to promote mold development. We recorded Threshed Grain Mold Rating (TGMR) of grains from five panicles at 54 days after flowering (14 days after physiological maturity) on a 1 to 5 scale, where 1 = no mold, and 5 = more than 50% grain surface area molded. Among the test entries 25 had a TGMR of 2, out of which 16 were white-grained and were as resistant as the colored-grain, mold-resistant controls. The TGMR of another 20 test entries ranged from 2.1 to 3.0. The susceptible controls had a TGMR of 5.

We also evaluated 538 other breeding lines derived from crosses involving 12 mold-resistant parents and made 150 single panicle/bulk selections (Table 5) for further testing in the 1987 rainy season; either in preliminary screening trials for F_3 to F_5 progenies, or in advanced screening trials for F_6 to F_8 progenies.

Anthracnose (*Colletotrichum graminicola*)

Resistance screening. In preliminary screening at Pantnagar in northern India, we evaluated 319 germplasm accessions and 988 advanced-generation breeding lines and selected 145 accessions and 136 lines for further screening. In advanced screening, we confirmed resistance in 165 entries. In 4-5 years of resistance screening at Pantnagar, 3 germplasm accessions and 29 breeding lines have consistently shown high levels of resistance to anthracnose, the best genotypes being IS 17141, PYT 2 EI, PYT 2 E6, TRL 74 C 57, SPV 346, PS 19794, and PVT 1 E18.

Variability of *C. graminicola.* We developed procedures and facilities to study the variability of the anthracnose pathogen. We collected infected sorghum leaves from ICRISAT Center, Surat, Hubli, Udaipur, Dharwad, and Pantnagar in India, and cultured the pathogen on potato dextrose agar from them. We obtained single-spore isolates representing two from ICRISAT, and one each from the other locations from the mass cultures. We then produced conidial inoculum of the isolates on sterilized sorghum leaf medium. To study the pathogenic variability of the isolates, we selected 245 genotypes with a range of symptom types and disease severity during 1982-85 field screening at Pantnagar.

We separately spray-inoculated 25- to 30-day-old plants of each genotype with a conidial suspension (3-4 x 10^5 conidia mL^{-1}) of isolates of *C. graminicola.* Plants inoculated with each isolate were kept separate in specially designed humid chambers. Initially high humidity (100%) was maintained for 48 h after inoculation to establish the infection. Later, humidifiers were run for 8 h day^{-1} for 6 days to allow the disease to develop. Disease was recorded using two ratings; a reaction class of 0-VI, where 0 = no reaction, and VI = necrotic areas coalescing and producing abundant acervuli, and a severity scale of 1-5, where 1 = < 1% leaf area diseased and 5 = > 40% leaf area diseased.

Table 5. Summary of mold-resistance screening of sorghum breeding lines in various generations, ICRISAT Center, rainy season 1986.

Generation	Crosses represented	Progenies evaluated	Selections[1] with: white grain	Selections[1] with: colored grain
F_3	12	122	41	12
F_4	9	41	18	0
F_5	6	65	18	1
F_6	4	136	24	1
F_7	10	153	31	2
F_8	3	21	2	0

1. Made from line with a Threshed Grain Mold Rating (TGMR) ≤ 2.0.
TGMR based on a 1 to 5 scale, where 1 = no mold and 5 = more than 50% grain surface area molded.

Based on the reaction class and severity scale, we finally selected 20 genotypes for detailed investigations of the pathogenic differences among the 9 isolates of *C. graminicola.* Our results showed that the 9 isolates of *C. graminicola* were different pathotypes of the pathogen in India, and that only two genotypes, IS 7775 and IS 18688, were resistant to all pathotypes. Further work on other aspects of pathogenic variability is in progress.

Striga asiatica

Resistance screening. We screened 696 germplasm accessions and identified 12 with low *Striga* emergence. Of these, 6 are from Nigeria, 4 from USA, and one each from India and Mali. These lines will be tested for field resistance in a *Striga* sick field in 1987. In advanced screening, we evaluated 17 breeding lines including a resistant line (SARI) and a susceptible hybrid (CSH 1) as controls in a checkerboard layout in the *Striga* sick field. Five lines, SAR 29, SAR 30, SAR 36, SAR 41, and SAR 42 were resistant with 0.7% to 2.6% emerged *Striga* plants compared to 100% for CSH 1. They also yielded well, 1.83-2.29 t ha^{-1} in comparison to 1.8 t ha^{-1} of the resistant control SAR 1, and 0.51 ha^{-1} for the susceptible control CSH 1. In preliminary screening, we evaluated 68 breeding lines in a randomized complete block design for resistance and yield. We selected seven lines whose grain yields ranged from 0.94 to 2.091 ha^{-1} for advanced screening. We also screened 262 F_9, F_8, and F_6 breeding progenies in the *Striga hermonthica* sick field at Kamboinse and selected 24 entries for further evaluation.

West Africa

Striga hermonthica

Screening for resistance. We screened 86 germplasm lines identified as resistant in a 1985 pot experiment (ICRISAT Annual Report 1985, pp.41-42). Each entry was sown in 10 pots filled with *Striga*-infested soil and laid out in a randomized block design. Two resistant varieties, Framida and IS 6961, and one susceptible variety CK 60B were used as controls. Many of the test varieties were completely killed before heading because of severe *Striga* parasitization. Nine lines were selected based on the number of emerged *Striga* plants and survival percentage compared to the controls whereas the susceptible variety averaged 12.5 *Striga* plants per pot the selected lines and the two resistant control varieties averaged between 0.2 and 1.9 plants per pot. Six of these 9 lines came from Cameroon and 2 from Nigeria; although they all have low yield potential, we will subject them to field screening at several locations in West Africa in the 1987 rainy season to confirm their resistance.

We also screened 200 breeding lines in a *Striga* sick plot at Kamboinse and selected the following as resistant: ICSV 1149 BF, ICSV 1150 BF, ICSV 1151 BF, ICSV 1155 BF, ICSV 1152 BF, ICSV 1147 BF, ICSV 1095 BF, ICSV 1153 BF, ICSV 1154 BF, and ICSV 1146 BF.

Multilocational testing for resistance. Results of the 1985 International Sorghum *Striga* Nursery (ISSN) from Sudan and Cameroon confirmed the resistance of ICSV 1017 BF (IS 6961), ICSV 1007 BF, ICSV 1021 BF (Tetron), and ICSV 1018 BF (CVS 122). In Sudan, ICSV 1007 BF and IS 9830 are under multiplication for on-farm testing.

Southern Africa

Downy Mildew (*Peronosclerospora sorghi*)

Downy mildew is a commonly occurring disease in most SADCC countries. In 1986 a severe epiphytotic occurred at Matopos Research Station, and valuable observations were made at Henderson, Panmure, and Kadoma Research Stations in Zimbabwe. We selected 3000 F_2 panicles at Matopos Research Station as resistant under natural disease pressure, and for agronomically desirable traits. The Botswana varieties Marupantse and Kanye Standard were susceptible, but the Zimbabwe varieties SV 1, SV 2, the

Zambian Sorghum Variety ZSV 1 [(ICSV 2 (SPV 386)], and the hybrid PNR 8544 showed resistance. During the dry season, ratoon crops of the same genotypes showed higher incidences of downy mildew than the rainfed crop.

Leaf Blight (*Exserohilum turcicum*)

We assessed 2000 lines for resistance under natural infection conditions at Kadoma and Henderson Research Stations, and selected 100 for further screening. Pedigrees of some of the apparently resistant lines were: 1/80, IS 176, and sister lines of (SC 108-3 x CS 3541), (555 x GPR 168)-1-1, (555) IAK, (DH 52177 x E 35-1)-1-1-2, R 6956 Lason, KSV8, (148 x Framida)-2-1-2-2-1 (SAR 28), (555 x 168)-1-1-1 (SAR 1), D3R, D23R, and D24R.

Rust (*Puccinia purpurea*)

We assessed 12000 lines for resistance under natural infection conditions at Panmure and Henderson in Zimbabwe, and at Ilonga in Tanzania and selected 150 for further screening. The best entries among those apparently resistant were: ICSH 153, ICSV 197, IS 9510, IS 13505, IS 13888, and IS 13896.

Insect Pests

ICRISAT Center

Shoot Fly (*Atherigona soccata*)

Screening for resistance. In preliminary screening, we evaluated 2078 lines (832 lines from the population project, 265 advanced breeding lines from the shoot fly resistance project, 654 lines resistant to other stresses, and 327 experimental hybrids) using the interlard fishmeal technique, and selected 180 lines for further testing. In advanced screening of 793 lines (ICRISAT Annual Report 1985, p.42), 77 were selected for multilocational testing in 1987.

In multilocational testing at Dharwad and ICRISAT Center, from 72 lines screened, 16 breeding lines and 16 germplasm lines had shoot-fly damage similar to, or less than the resistant line IS 18551.

We also screened material from the following ICRISAT breeding trials: Advanced Variety Trial (AVT), Asian Regional Sorghum Variety Adaptation Trial (ARSVAT), Asian Regional Sorghum Hybrid Adaptation Trial (ARSH AT), Preliminary Variety Trial-1 (PVT-1), and Preliminary Variety Trial-2 (PVT-2) and found 19 more resistant than the susceptible control CSH 1.

We confirmed resistance of 13 wild sorghum accessions (*Sorghum versicolor, S. purpureo-sericeum,* and *S. dimidiatum*) under no-choice conditions using the cage technique (ICRISAT Annual Report 1982, p.21). Six of these accessions showed <5% damage compared to 95% in the susceptible hybrid CSH 1.

Introgression of useful genes from wild relatives of sorghum. All the wild sorghums, including para-, stipo-, and chaetosorghums, recently assembled by the Genetic Resources Unit (GRU) have been screened for shoot fly resistance using the cage technique. Four accessions of para-sorghums; IS 14262, IS 14275, IS 18938, and IS 18945 (Fig. 8 a and b) were found to have high levels of resistance to shoot fly in terms of very low egg-laying and low percentage of deadhearts.

These accessions have a chromosome number of 2n=10. They were crossed with adapted cultivated sorghums (2n=20) by the hand emasculation technique, in an attempt to introduce the resistance genes into the cultivated types. Hybrid seedlings died during the early growth stage, except for the crosses with *S. dimidiatum,* IS 18945. These presumed F_1 plants were grown in the greenhouse where they flowered with varying degrees of sterility. Some set seed when selfed or backcrossed to the cultivated parent. The F_2 and BC_1F_1 seed of these crosses will be studied for their fertility and also to determine whether the shoot fly resistant character from the wild para-sorghums was transferred.

Figure 8a. ***Sorghum dimidiatum,*** **a wild parasorghum (IS 18945) collected in Sudan that showed a high level of resistance to shoot fly, *Atherigona soccata.***

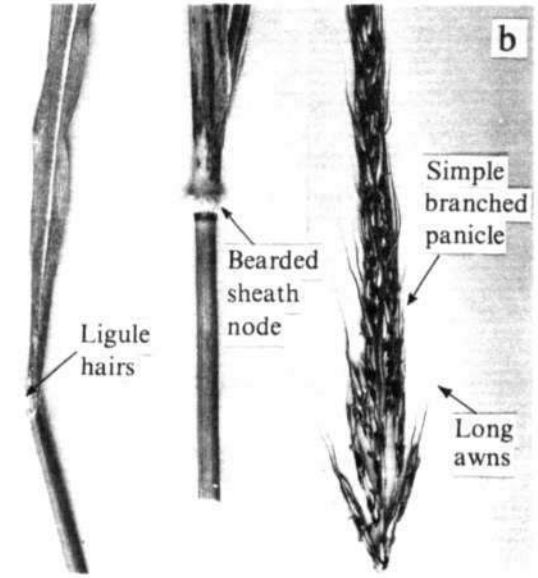


Figure 8b. IS 18945 showing ligule hairs, bearded sheath nodes, simple panicle branching, and long awns—all characteristic features of parasorghums.

Breeding for resistance. We evaluated 327 experimental hybrids, developed from resistant male parents, for their agronomic performance and nonrestoration, and found resistance in MA 9 x PS 14413. We found that 16 resistant male parents are nonrestorers. The best nonrestorer lines were PS 27618-5, PS 31250, PS 31288-1, PS 31354, and PS 31405-3. These will be converted into resistant male steriles.

We screened 312 F_3 progenies for resistance in the 1985 postrainy season and selected 69 for further testing. We evaluated 265 (F_6 and F_7) advanced lines for agronomic eliteness during the rainy season, and for shoot fly resistance during the postrainy season, and selected 22 agronomically elite and less susceptible lines. The best were PS 27618-3, PS 27620-2, PS 27655-6, PS 27656-6, PS 27989-2, PS 30812, and PS 30880.

Chemical control. We tested the efficiency of cypermethrin, a synthetic pyrethroid, for shoot fly control in the postrainy season. Using electrodyne, ultra-low volume (ULV), and knapsack sprayers we made foliar applications of cypermethrin once (6, 12, or 18 days after crop emergence (DAE)), twice (6 and 12 DAE; 12 and 18 DAE), and thrice (6, 12, and 18 DAE). We compared the effects with soil application of carbofuran in furrows at sowing time, and with nontreated plots.

Cypermethrin applied once, twice, or thrice with an electrodyne sprayer starting at 6 DAE gave significant control (5-8% deadhearts as compared to 60% in the nontreated control, and 62% in the carbofuran treatment). Control was only effective if an application at 6 DAE was included. Cypermethrin applied with ULV or knapsack sprayers did not effectively control shoot fly, nor did soil applications of carbofuran.

International Sorghum Shoot Fly Nursery (ISSFN). The nursery consisted of 11 germplasm accessions, 12 ICRISAT-bred lines, and 2 susceptible controls (CSH 1 and local) and was sent to cooperators in Asia and Africa. We received useful data from 7 locations (4 from India and 1 each from Burkina Faso, Ghana, and Thailand). From the cooperators' reports we found that IS 1054, IS 1082, IS 2123, IS 2146, IS 4663, IS 18551, and PS 18601-2-2 were resistant across locations.

Stem Borer (*Chilo partellus*)

Yield loss assessment. The yield loss assessment trial was repeated for the 2nd year (ICRISAT Annual Report 1985, p.43). Plants were infested with laboratory-reared insects (eggs and larvae) at 15,20,30,40, and 50 DAE. Maximum stem borer damage (deadhearts) and grain yield reduction occurred when plants were infested either by larvae or eggs at 15 DAE (Table 6).

Factors associated with resistance. We continued our efforts to determine the factors associated with resistance. (ICRISAT Annual Report 1985, p.43). In addition to early panicle initiation and rapid internode elongation as factors related to antibiosis we found the attachment position of the basal leaf to the stem to be an important plant trait associated with resistance. Among other biological parameters, establishment of the first instar larvae into the whorl, the time taken for the larvae to bore into the stem, larval mass, and borer survival rate were important factors. In nonpreference studies under natural infestation at Hisar, we recorded significantly lower numbers of eggs on resistant genotypes IS 5538 and IS 18580 (2 egg masses 4-m row^{-1}) than on susceptible genotypes ICSV 1 (SPV 351) and CSH 1 (25 and 41 egg masses).

Resistance screening. In preliminary screening, we evaluated 1476 genotypes under natural infestation at Hisar, and selected 59 for further testing. From the 620 genotypes in advanced screening (ICRISAT Annual Report 1985, p. 44) we selected 110 that were resistant under artificial infestation at ICRISAT Center and under natural infestation at Hisar. In other tests 20 genotypes out of 56 lines showed resistance under natural infestation at Hisar, and under 3 artificial infestation levels (15, 20, and 25 DAE) at ICRISAT Center. The most resistant genotypes are IS 2375, IS 5075, IS 8811, IS 18573, and IS 20643.

Breeding for resistance. We random mated the shoot-pest (shoot fly and stem borer) resistant population for the 6th time under natural shoot fly, and artificial stem borer infestations at ICRISAT Center and under natural shoot fly and stem borer infestations at Hisar. We will evaluate all the six cycles of this population in the 1987 rainy season to estimate progress made.

We compared the performance of 135 fertile derivatives (S_2) of the shoot-pest resistant population, and 130 advanced progenies from pedigree breeding for their resistance to stem borer under artificial (ICRISAT Center) and natural (Hisar) infestations. In general, population derivatives had better levels of resistance under both natural and artificial infestations than progenies derived from pedigree breeding. Six percent of the population derivatives showed good levels of resistance to stem borer as compared to only 0.6% of the pedigree progenies.

We made 167 crosses between 11 stem borer resistant sources and 40 agronomically elite parents during the 1985 postrainy season. We selected 41 agronomically desirable F_1s and screened their F_2 populations for resistance under natural infestation at Hisar during the rainy season. From these, we selected 40 stem borer-free plants. We also screened 80 F_4 progenies and 238 advanced shoot fly resistant lines both under natural (Hisar) and artificial (ICRISAT Center) infestations. PS 14413 and PS 14454 were the most resistant.

Sorghum Midge (*Contarinia sorghicola*)

Biology. We continued population monitoring at Dharwad and Bhavanisagar by sowing a midge-resistant genotype, TAM 2566 and a susceptible hybrid, CSH 1 at fortnightly intervals. We recorded maximum midge populations at Dharwad during the 2nd week of October, while at Bhavanisagar infestation peaked during the 2nd and 3rd weeks of February. Sorghum sown during the last week of July was heavily infested

Table 6. Effect of insect density (larval and egg infestation) and time of infestation on stem-borer damage and grain yield in two sorghum genotypes, ICRISAT Center, rainy season 1986.

Genotype	Insect density	Stem-borer damage (% deadhearts)				Grain yield (t ha^{-1})			
		Infestation stage				Infestation stage			
		15 DAE[1]	20 DAE	30 DAE	Mean	15 DAE	20 DAE	30 DAE	Mean
Larval infestation[2]									
ICSV 1 (SPV 351)	0	12	2	4	6	2.52	2.50	3.02	2.68
	1	38	13	3	18	1.72	1.80	2.26	1.93
	2	65	12	5	27	1.31	1.54	1.78	1.54
	4	81	19	18	39	0.75	1.47	1.72	1.31
	8	94	33	17	48	0.34	1.14	1.34	0.94
	12	88	40	22	50	0.38	1.08	1.24	0.90
	Mean	63	20	12		1.17	1.59	1.89	
PS 28157-1	0	2	8	4	5	2.59	2.63	2.34	2.52
	1	42	5	5	17	2.25	2.21	2.27	2.24
	2	57	13	8	26	1.83	1.89	2.11	1.94
	4	62	13	17	31	1.40	1.81	2.11	1.77
	8	95	30	19	48	0.52	1.30	1.76	1.19
	12	92	32	16	47	0.36	1.36	1.67	1.13
	Mean	58	17	12		1.49	1.87	2.04	
Egg infestation[3]									
ICSV 1 (SPV 351)	0	7	6	5	6	2.18	2.30	2.08	2.19
	10	25	12	12	16	1.67	1.81	1.76	1.75
	20	49	19	15	28	1.04	1.43	1.54	1.34
	30	57	33	19	36	0.67	1.08	1.41	1.05
	50	68	39	23	43	0.84	0.94	1.01	0.93
	Mean	41	22	15		1.28	1.51	1.56	
PS 28157-1	0	4	3	5	4	2.27	2.15	2.28	2.23
	10	19	7	7	11	1.77	2.03	2.23	2.01
	20	42	10	10	21	1.33	1.70	1.94	1.66
	30	56	21	11	29	1.16	1.66	1.77	1.53
	50	59	31	12	34	0.97	1.31	1.44	1.24
	Mean	36	15	9		1.50	1.77	2.29	

SE for comparing (for grain yield)	Grain yield under: Larval infestation	Grain yield under: Egg infestation
Insect density for same genotype	±0.15	±0.10
Infestation stage for same genotype	±0.10	±0.14
Insect density for same stage and genotype	±0.21	±0.17
Insect density for different stages and same genotype	±0.21	±0.16
CV(%)	12	15

1. DAE = days after crop emergence.
2. Insect density measured as larvae $panicle^{-1}$. 3. Insect density measured as % plants with a single egg mass.

with midge at Dharwad. We continued testing midge-attractant chemicals in a yellow trap and found that traps baited with ethanol caught the most flies.

Resistance screening. We evaluated 2000 germplasm accessions and breeding lines for resistance at Dharwad and selected 41 germplasm accessions and 69 breeding lines for further testing. In advanced screening, we selected 53 lines for further testing at Dharwad and ICRISAT Center. In multilocational testing of 150 lines under cage conditions at ICRISAT Center and Dharwad, and under natural conditions at Hisar and Pantnagar, 51 lines were selected. In addition, we screened 46 advanced breeding lines under cage conditions and retained 30 lines with low midge damage.

We sowed 14 resistant lines and one susceptible control in a split-plot design with 15 entries as the main plot, and three infestation levels (20, 40, and 60 flies) as subplots. Five panicles in each subplot were caged with the respective number of flies. Eight lines, IS 3641, IS 9807, IS 19474, IS 19512, PM 9250, PM 10291 (Fig. 9) ICSV 197 (PM 11344), and DJ 6514 suffered less damage (11-37%) than the suseptible control Swarna (71%). Resistance was maintained across all levels of infestation. Panicles infested with 20 flies showed significantly less damage than panicles infested with 40 or 60 flies. No difference in damage was noticed between the panicles infested with 40 or 60 flies.

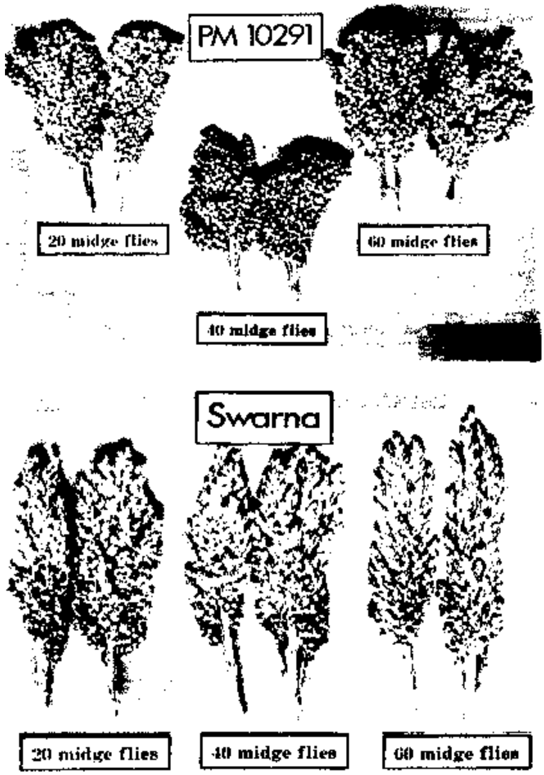


Figure 9. Stability of resistant sorghum line PM 10291 under different midge, *Contarinia sorghicola,* infestation levels. The susceptible control, Swarna, showed severe panicle damage at all infestation levels compared to PM 10291 that showed very little damage under no-choice conditions, ICRISAT Center, dry season 1986.

Breeding for resistance. We random-mated the midge- and head bug-resistant sorghum population for the 6th time under moderate midge infestation at Dharwad during the late rainy season, and made 19 midge damage-free fertile selections.

We evaluated 146 experimental hybrids, with resistant male parents at Dharwad, and identified 10 hybrids with slight damage (>75% seed set as compared to <15% in the susceptible hybrid, CSH 1). PM 7017 was identified as a good nonrestorer, resistant line.

We made 185 crosses between 11 midge-resistant lines, and 40 agronomically elite lines during the 1985 postrainy season. Forty-five agronomically desirable F_1s were selected and we screened their F_2 populations under natural infestation at Dharwad during the late rainy season. From these, we selected 347 midge damage-free panicles. We also screened 320 F_4 progenies at Dharwad and selected 58 resistant progenies.

We evaluated 384 advanced (F_6 and F_7) midge-resistant lines for their agronomic desirability under good management at ICRISAT Center, and for resistance at Dharwad during the late rainy season. From these, we found 44 lines to be both agronomically elite and resistant. The best resistant lines were PM 12586, PM

12645, PM 13978-1, PM 13987-1, PM 14023-1, PM 14370-6, PM 14415-2-2, and PM 14420-3-2.

Factors associated with midge resistance. Our studies on the mechanisms of resistance to sorghum midge involve examination of floral morphology, ovary development, total polyphenolic content (tannins), total sugars, and protein content. We evaluated 25 genotypes and found that glume size, ovary growth rate, and high tannin content were associated with resistance. All resistant genotypes had short glumes and the majority had rapid ovary development.

International Sorghum Midge Nursery (ISMN). The 1985 ISMN comprised 10 germplasm accessions, 10 breeding lines, and 5 susceptible and resistant controls. It was sent to cooperators in Asia, Africa, and Latin America. We received useful data from 8 locations (6 from India and one each from Burkina Faso and the Yemen Arab Republic). From cooperators reports we found that IS 3461, IS 7005, IS 8571, IS 19474, IS 19512, PM 7032, PM 7322, and PM 7397 were resistant to midge across locations.

Head Bug (*Calocoris angustatus*)

Biology. We monitored head bug populations at fortnightly intervals at ICRISAT Center by sampling sorghum panicles at the milk growth stage of grain development. In addition to two normal peaks during Feb-Mar and Sep-Oct, we observed an abnormal peak during July on a dry-season crop of sorghum sown in March for drought screening.

We investigated the physical and chemical factors of particular sorghum lines that are responsible for head bug oviposition preference. We found that at the time of panicle emergence toughness of glumes was higher (6-7 fold) in the nonpreferred lines, IS 17645, IS 23061, IS 9692, IS 6984, and IS 2761 than the preferred ones, CSH 5 and Swarna. Experiments also showed more olfactory responses by head bugs to the same preferred lines than to the nonpreferred ones.

Scanning electron microscopic studies on the mode of feeding in milk and soft dough stages of grain development indicated that the stylets penetrate intracellularly and that cell contents are sucked. Electrophoretic studies indicated that the damage to sorghum by head bug is not only due to mechanical laceration during feeding but is also the result of a chemical process caused by a salivary enzyme, an amylase that hydrolyses starch in the grain.

We studied head bug population increase and survival rates using different levels of infestation on 6 genotypes (2 resistant, 3 moderately resistant, and 1 susceptible). For population increase studies, we caged four sets of 10 panicles of each genotype at the preanthesis growth stage with 5, 10,15, and 20 pairs of field-collected adults, and counted the final population (nymphs and adults) 3 weeks later. Similarly, we caged three sets of 10 panicles of each genotype, one with 100, another with 250, and the third with 500 first instar nymphs for survival rate studies. We recorded the number of surviving nymphs 12 days after infestation.

Four genotypes, IS 2761, IS 9692, IS 17610, and IS 17645 supported significantly lower populations than IS 17618 and CSH 1 (Table 7). There was no significant difference in the population increases at the four infestation levels. The head bug survival rate was lower in IS 9692, IS 17610, and IS 17645 (Table 7). On average, more head bugs survived (69.6%) when plants were infested with 100 nymphs panicle^{-1} than when infested with 250 nymphs (58.6%) and 500 nymphs (49.1%).

Resistance screening. In preliminary screening we evaluated 1576 genotypes for resistance under natural head bug infestation at ICRISAT Center using the infestor row technique during the rainy season and selected 279 lines for further testing. In advanced screening of 473 lines selected in 1985 in a replicated trial, we selected 109 lines for further testing. We also evaluated 67 previously selected sorghum lines using the head cage technique, and confirmed resistance in 40 of them.

Chemical control. We tested the efficiency of

Table 7. Population build up and survival rate of head bug, *Calocoris angustatus,* at different levels of infestation on six sorghum genotypes, ICRISAT Center, postrainy season 1985.

	Population build up (number panicle^{-1})					Survival rate (%) with:			
Genotype	5 pairs	10 pairs	15 pairs	20 pairs	Mean	100 nymphs	250 nymphs	500 nymphs	Mean
Resistant									
IS 17610	11.7[1]	16.2	14.7	15.5	14.4	60.7[2]	50.3	34.4	48.4
IS 17645	10.8	11.4	12.7	16.2	12.6	67.1	43.1	36.9	49.0
Moderately resistant									
IS 2761	9.3	10.9	12.9	12.7	11.5	70.8	63.8	62.4	65.7
IS 9692	16.7	12.9	8.8	7.1	11.4	74.5	47.6	40.9	54.4
IS 17618	26.9	22.7	24.2	17.0	22.6	78.0	81.6	59.6	74.1
Susceptible									
CSH 1	19.5	17.1	25.3	22.2	21.0	66.8	58.6	49.1	63.1
Mean	15.7	15.1	16.4	15.1		69.6	58.6	49.1	
SEs for comparing:									
Genotypes			±0.56				±2.82		
Infestation level			±0.61				±2.18		
Genotype x Infestation level			±1.12				±4.88		

1. Figures are the square root transformed values of numbers panicle^{-1}.
2. Figures are angular transformed values.

neem oil (0.1, 0.2, and 0.5%), neem fraction 'G' (0.2%), and malathion for head bug control. Malathion was significantly superior to neem in reducing the head bug population and increasing grain yield.

Eastern Africa

Stem Borer (*Chilo partellus*)

In collaboration with the International Center for Insect Physiology and Ecology 134 lines were evaluated for resistance to stem borer under artificial infestation at ICIPE's, Mbita Point Field Station, Kenya.

The test material included genotypes from very dry regions, and low elevations and intermediate/high elevation zones. We measured deadheart (percentage plants), stem-tunneling (percentage length), infestation levels (number of borer larvae 10 plants^{-1}), and foliar damage (on a 1-9 scale). Only one line, 83 SR/KAT/384 was resistant in all four tests.

Plant Improvement

ICRISAT Center

Photoperiod-sensitive Landrace Conversion

We completed the first backcrossing of 26 F_4 early, dwarf, and landrace type selections, with original Kaura and Guineense landraces in 1985 postrainy season (ICRISAT Annual Report 1985, p.48) and advanced the selections to F_5. During the rainy season, we evaluated 26 F_5 progenies for their expression of early, and dwarf features and made 75 individual plant selections.

We also initiated conversion of eight white-grain Farafara landraces (IS 24706, IS 24721, IS 24722, IS 24728, IS 24741, IS 24743, IS 24756, and IS 24759) from Nigeria. These were crossed with 3 early, dwarf genotypes. In order to identify donor parents with early, dwarf, and photoperiod-insensitive traits, we evaluated a set of 80 germplasm accessions (Fig. 10). Based on visual scores for agronomic characters we selected 10 lines for further evaluation in the postrainy season.

Multifactor Resistant Populations (MFR)

We continued with further advancement of the MFR population-base materials. When developed, each population is expected to have resistances to a set of diseases and insect pests that are important in major sorghum-growing areas of the SAT (ICRISAT Annual Report 1985, pp.48-49).

BR/MFR population-base material. We grew 408 S, selections from the BR/MFR population-base material in the postrainy season 1985/86 at ICRISAT Center and in the dry season of 1986 at Bhavanisagar and selected 191 S_2s. We bulk crossed the 408 S, progenies with lines selected for the following; good agronomic characters combined with temperature insensitivity (39), photoperiod-sensitivity (22), resistance to shoot fly (9), and *Striga* (2). We also included breeding lines that are adapted to the postrainy season (131), and F_1s (98) between postrainy-adapted, and agronomically elite lines. The

Figure 10. Tall photoperiod-sensitive sorghum landraces (background) under conversion using dwarf and early source lines (foreground), ICRISAT Center, postrainy season 1984/85.

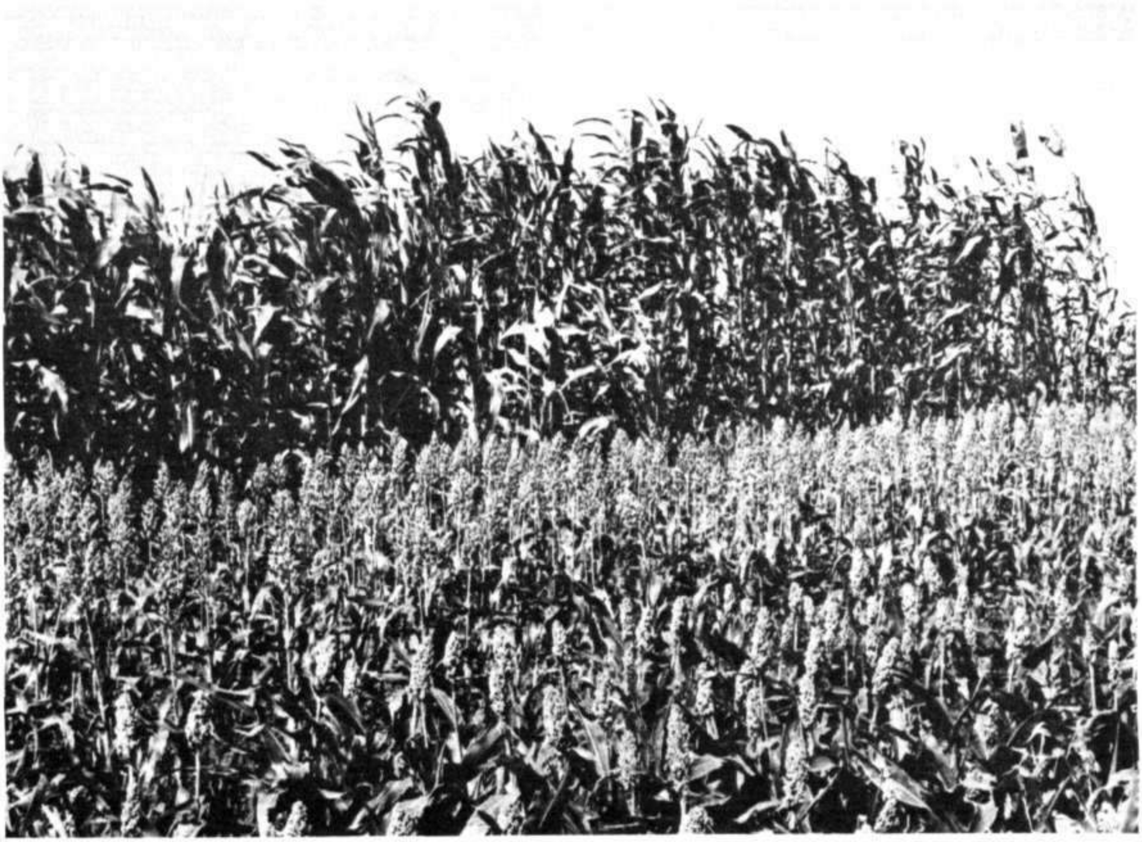


Table 8. Agronomic performance of the selected S_2 sorghum progenies of the R/MFR population-base material evaluated[1] at two Indian locations, rainy season 1986.

Pedigree	Time to 50% flowering (days)		Plant height (m)		Plant aspect[2]		Grain yield ($t\ ha^{-1}$)		
	B[3]	IC[4]	B	IC	B	IC	B	IC	Mean
R/MFR-S_2 88	72	71	2.33	2.40	2.0	2.5	7.36	4.93	6.14
R/MFR-S_2 118	64	66	1.78	2.15	1.0	3.0	7.10	4.60	5.85
R/MFR-S_2 83	71	73	2.18	2.05	1.0	3.5	7.03	4.32	5.67
R/MFR-S_2 22	66	71	1.88	2.25	1.0	3.0	6.60	4.72	5.66
R/MFR-S_2 78	68	70	2.25	2.35	2.0	3.0	6.57	4.49	5.53
R/MFR-S_2 73	71	71	2.03	2.05	2.0	2.5	5.58	5.03	5.31
R/MFR-S_2 35	72	72	1.78	1.95	1.0	1.5	5.64	4.87	5.25
R/MFR-S_2 59	70	73	2.20	2.15	1.5	2.0	5.57	4.43	5.00
R/MFR-S_2 107	73	73	2.05	1.07	2.5	1.5	5.90	3.80	4.85
R/MFR-S_2 115	68	71	2.15	2.35	1.5	2.0	5.42	4.32	4.87
R/MFR-S_2 150	70	73	2.00	1.85	1.5	2.0	4.97	4.74	4.86
R/MFR-S_2 37	70	72	1.68	2.00	1.0	2.0	5.29	3.97	4.63
R/MFR-S_2 105	69	74	1.95	1.90	2.0	1.5	5.35	3.87	4.61
R/MFR-S_2 171	72	71	1.88	2.00	2.0	1.0	4.22	4.91	4.57
R/MFR-S_2 58	71	71	1.93	2.10	2.0	1.5	4.89	4.23	4.56
R/MFR-S_2 45	71	70	1.75	2.00	1.5	1.5	4.63	4.24	4.43
R/MFR-S_2 112	72	71	1.80	2.00	1.5	1.5	4.93	3.68	4.30
R/MFR-S_2 103	68	71	1.75	2.10	1.5	1.5	5.13	3.13	4.13
R/MFR-S_2 184	83	75	1.83	2.05	2.5	1.0	4.22	3.85	4.04
R/MFR-S_2 95	69	72	2.03	2.10	2.5	1.5	4.01	3.82	3.92
R/MFR-S_2 156	71	71	1.65	1.65	2.0	1.5	3.82	3.28	3.55
R/MFR-S_2 165	75	75	2.18	1.95	2.0	1.5	3.68	3.32	3.50
R/MFR-S_2 181	77	74	1.90	2.15	2.0	1.5	3.04	3.80	3.42
R/MFR-S_2 53	75	74	1.88	1.80	2.0	1.0	3.06	3.77	3.41
Controls									
ICSV 112 (SPV 475)	75	71	1.63	1.75	1.5	2.0	5.83	4.28	5.06
ICSV 166	71	70	1.80	1.80	1.0	2.0	4.67	4.17	4.42
CSH 6	60	59	1.50	1.90	1.0	2.0	4.44	2.95	3.70
SE	±1.9	±1.1	±0.15	±0.10	i0.6	±0.5	±0.77	±0.42	
Trial mean (199 entries)	73	73	1.95	2.06	2.3	2.7	4.16	3.58	3.87
Selected mean (24 entries)	71	72	1.95	2.02	1.7	1.9	5.17	4.17	4.67
CV(%)	4	2	11	7	39	25	26	17	

1. Randomized complete block design with 2 replications.
2. Plant aspect assessed on a 1-5 scale, where 1 = most desirable and 5 = least desirable.
3. B = Bhavanisagar, Tamil Nadu, plot size 4 m^2, Alfisol, high fertility (N 80:P 30:K 30).
4. IC = ICRISAT Center, Andhra Pradesh, plot size 6 m^2, Vertisol, high fertility (N 86: P 40: K 0).

resulting half-sibs, and S_2s are being evaluated at ICRISAT Center in the postrainy season 1986/87.

R/MFR population-base material. We grew 967 S_1 selections from the R/MFR population-base material in the postrainy season 1985/86 at ICRISAT Center and in the dry season in 1986 at Bhavanisagar and selected 195 S_2s. We yield-tested these in replicated trials at ICRISAT Center and Bhavanisagar in the rainy season 1986. Table 8 gives the performance of the selected S_2 progenies. The mean grain yield of all S_2 progenies in the trial was 3.78 t ha^{-1} while the mean of the selected S_1s was 4.67 t ha^{-1}. We also screened 195 S_2s in the yield-testing trial for resistance to various yield-limiting factors and selected those resistant to shoot fly (1), stem borer (3), midge (3), and with good seedling emergence through soil crust (2). We also screened S1S derived from resistant sources x R/MFR crosses for resistance to stem borer and midge and selected 80 individual stem borer-free S_2 plants, and 46 S_2 panicles that are moderately resistant to grain mold. We also evaluated S_1 progenies derived from resistant source x R/ MFR crosses for their agronomic eliteness and selected 379 S_2s. We are growing all this selected material in the postrainy season 1986/87 for recombination.

B/MFR population-base material. We grew 390 S_1 selections from the B/MFR population-base material in the postrainy season 1985/86 at ICRISAT Center and in the dry season 1986 at Bhavanisagar and selected 195 S_2s. We yield-tested these in replicated trials at ICRISAT Center and Bhavanisagar in the rainy season 1986. Table 9 gives the performance of selected S_2 progenies. The mean grain yield of all S_2 progenies in the trial was 3.49 t ha^{-1} while the mean of the selected S_2s was 4.24 t ha^{-1}. We also screened the 195 selected S_2s in the yield trial for various yield-limiting factors and selected S_2s resistant to shoot fly (3), stem borer (2), and good seedling emergence through soil crust (3). We also screened S_1s derived from resistant sources x B/MFR crosses for resistance to stem borer and grain mold and selected 69 stem borer-free S_2 plants and 9 panicles that are moderately resistant to grain mold. We also evaluated S_1 progenies derived from resistant sources x B/MFR crosses for their agronomic eliteness, and selected 397 S_2s. We are growing all this selected material in the postrainy season 1986/ 87 for recombination.

Derived lines. We conducted an observation nursery comprised of 149 families derived from advanced cycles of our improved populations and selected 64 individual plants for further evaluation and 21 families for replicated postrainy season yield trials. We included, in the selection criteria, such traits as high seedling vigor, long internodes, nonsenescence, and round and semi-corneous bold grain with cream colored pericarp.

We evaluated 370 advanced generation lines and 76 S_4 progenies (US/R and US/B populations) in the dry season and selected 366 individual plants for rainy season adaptation. We evaluated these selections again during the rainy season, and selected 107 individual plants for screening nurseries and 16 bulks for replicated yield trials. In the selection criteria, under rainfed conditions, we included grain yield, semi-lax to compact earhead, medium to bold semi-corneous grain and tan plants with a range of height and maturity.

Evaluating Advanced Elite Varieties

We yield-tested 205 elite varieties during the 1985 rainy season in two separate trials at five Indian locations. Yield data of selected high-yielding varieties from the first trial of 36 entries are given in Table 10. These varieties were derived from diverse parents such as M 35-1, M 1009, IS 9562, IS 12611, PS 18601, IS 20509, E 35-1, ICSV 1 (SPV 351). The selected varieties, ICSV 295 and ICSV 233 were highly productive with grain yields of 4.97 and 4.931 ha^{-1} while the control variety, ICSV 112 (SPV 475) yielded 4.13 t ha^{-1} (Table 10). Another selected variety, ICSV 298, yielded well and showed resistance to shoot fly (21% deadhearts as against 45% in the susceptible hybrid control, CSH 1).

Table 9. Agronomic performance of the selected S_2 sorghum progenies of the B/MFR population-base material evaluated[1] at two Indian locations, rainy season 1986.

	Time to 50% flowering (days)		Plant height (m)		Plant aspect[2]		Grain yield ($t\ ha^{-1}$)		
Pedigree	B[3]	IC[4]	B	IC	B	IC	B	IC	Mean
B/MFR-S_2 164	84	77	1.95	1.93	2.0	3.0	6.03	4.47	5.25
B/MFR-S_2 189	72	71	1.85	2.10	3.5	4.0	5.51	4.61	5.06
B/MFR-S_2 183	75	70	2.10	2.08	3.0	3.5	3.44	6.22	4.83
B/MFR-S_2 33	71	71	1.83	1.80	2.5	4.0	4.93	4.37	4.65
B/MFR-S_2 69	78	71	1.78	1.80	2.0	2.5	4.54	4.77	4.66
B/MFR-S_2 158	74	69	1.88	1.90	2.0	3.0	4.04	5.14	4.59
B/MFR-S_2 3	69	66	1.90	2.00	1.0	3.5	5.17	4.01	4.59
B/MFR-S_2 49	76	70	1.49	1.63	1.0	2.5	5.32	3.81	4.56
B/MFR-S_2 76	71	68	1.19	1.93	2.0	3.0	4.10	5.02	4.56
B/MFR-S_2 137	69	68	2.00	1.70	1.0	2.0	4.76	4.06	4.41
B/MFR-S_2 6	73	71	1.83	1.85	1.5	2.5	3.61	5.08	4.35
B/MFR-S_2 107	70	70	1.94	1.88	3.0	3.0	3.58	5.08	4.33
B/MFR-S_2 48	78	74	1.68	1.73	2.0	2.5	4.24	4.34	4.29
B/MFR-S_2 184	77	74	1.64	1.85	2.0	2.5	3.10	5.10	4.10
B/MFR-S_2 167	77	71	1.81	1.90	2.0	2.0	2.83	5.25	4.04
B/MFR-S_2 162	76	73	1.80	1.90	1.5	2.5	2.93	5.15	4.04
B/MFR-S_2 40	76	73	1.58	1.80	1.0	2.5	4.01	4.00	4.01
B/MFR-S_2 122	71	68	1.37	1.60	1.5	1.5	3.44	4.46	3.95
B/MFR-S_2 65	71	69	1.60	1.75	1.5	2.5	4.18	3.64	3.91
B/MFR-S_2 42	69	62	1.39	1.50	2.5	2.5	4.54	3.25	3.90
B/MFR-S_2 128	76	73	1.58	1.38	1.5	2.5	3.78	3.73	3.75
B/MFR-S_2 181	71	70	1.61	1.58	1.5	1.5	3.97	3.43	3.70
B/MFR-S_2 160	72	69	1.54	1.73	1.5	2.0	3.17	4.06	3.61
B/MFR-S_2 16	75	72	1.71	1.70	1.0	1.5	2.68	4.31	3.50
B/MFR-S_2 63	80	72	1.65	1.60	2.0	1.0	3.25	3.63	3.44
Controls									
296B	72	72	1.29	1.30	1.0	1.5	4.83	4.03	4.43
MR 841	75	70	1.74	1.68	1.5	2.5	3.22	3.98	3.60
2077B	76	72	1.32	1.20	1.5	2.5	2.29	1.70	2.0
SE	±2.1	±1.0	±0.14	±0.08	±0.6	±0.5	±0.58	±0.49	-
Trial mean (199 entries)	76	72	1.82	1.85	2.3	3.0	3.12	3.87	3.49
Selected mean (25 entries)	74	70	1.71	1.79	1.8	2.6	4.05	4.44	4.24
CV(%)	4	2	11	6	35	21	26	18	-

1. Randomized complete block design with 2 replications.
2. Plant aspect assessed on a 1-5 scale, where 1 = most desirable and 5 = least desirable.
3. B = Bhavanisagar, Tamil Nadu, plot size 4 m^2, Alfisol, high fertility (N 80: P 30: K 30).
4. IC = ICRISAT Center, Andhra Pradesh, plot size 6 m^2, Vertisol, high fertility (N 86: P 40: K 0).

Table 10. Mean grain yield (t ha^{-1}) of selected sorghum varieties evaluated[1] at five Indian locations, rainy season 1986.

Entry	Pedigree	Locations[2]					
		1	2	3	4	5	Mean
ICSV 295	[(M 35-1 x M 1009)-3-2-1 x 6F_5's]-5-1-4-1-1	6.63	4.23	2.92	3.74	7.31	4.97
ICSV 233	[IS 9562 x (IS 12611 x SC 108-3)]-3-2-2-5-l	5.84	4.44	2.30	4.50	7.59	4.93
ICSV 361	(PS 18601 * SPV 351)-32-2-1-1	5.36	3.97	2.71	5.23	6.38	4.73
ICSV 331	(PS 21143 x E 35-l)-2-2-3-1	5.83	4.45	2.25	4.04	7.03	4.72
ICSV 234	[IS 20509 x (IS 12611 x SC 108-3)]-1-1-2-4-3	6.60	4.05	1.93	3.99	6.94	4.70
ICSV 298	[(M 35-1 x M 1009)-3-2-1 x 6F_5's]-5-1-4-2	5.91	4.37	2.02	3.41	7.49	4.64
ICSV 272	[(M 35-1 x M 1009)-3-2-1 x 6F_5's]-5-2-3-1-1	5.78	4.01	2.70	3.75	6.89	4.63
ICSV 273	[(M 35-1 x M 1009)-3-2-1 x 6F_5's]-5-2-3-1-2	5.67	3.96	2.46	3.82	7.01	4.58
Controls							
ICSH 153[3] (CSH 11)	296A x (SC 108-3 x CSV 4)-27-2-1	6.99	5.04	3.37	6.03	8.07	5.90
CSH 9[3]	296A x CSV 4	7.06	4.81	2.78	5.35	7.12	5.42
ICSV 112 (SPV 475)	[(IS 12622C x 555)(IS 3612C x 2219B)-5-1 x E 35-1]-5-2	6.00	3.32	2.51	2.09	6.74	4.13
SE		±0.27	±0.28	±0.22	±0.41	±0.28	±0.13
Trial mean (36 entries)		5.58	3.62	2.19	3.59	6.62	4.32
CV(%)		8	13	17	20	7	-
Efficiency *(%)*		96	97	112	101	102	-

1. 6 x 6 triple lattice design.
2. Locations:
   1 = ICRISAT Center, Andhra Pradesh, plot size 12 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 40:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, low fertility (N 43:P 20: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).
3. Hybrid controls.

In the 2nd trial, we evaluated 169 varieties including three controls, CSH 11 and CSH 9 (hybrids) and ICSV 112 (SPV 475) (variety). Sixteen varieties outyielded the control variety, ICSV 112. The selected varieties varied in days to 50% flowering (64-71 days). The best grain-yielders with over 4.3 t ha^{-1} were ICSV 543, ICSV 535, ICSV 401, ICSV 404, and ICSV 430 while the control variety, ICSV 112 (SPV 475) yielded 3.94 t ha^{-1}.

Female Parents (Male-steriles) for Hybrids

Milo cytoplasm. New female parents are being developed for adaptation to rainy and postrainy seasons.

For the rainy season, we observed 250 test-crosses and selected 20 agronomically superior nonrestorer lines for conversion to male steriles. We also evaluated 49 F_2 progenies involving BxB (single plants) and BxRxB (three-way) crosses, and selected 366 F_3 for testcrossing.

We evaluated 116 A and B pairs for postrainy-season adaptation during the dry season at Bhavanisagar, and selected 167 backcrossed plants (4th and 5th generations). From these, during the 1986 rainy season, we selected 42 pairs for postrainy-season adaptation based on such traits as grain size, height, and nonsenescence, and SO pairs for rainy season adaptation, based on high grain yield. From the evaluation of 117 A and B pairs in 1985 rainy season, we selected 15 pairs for their bold (100-grain mass >3 g) semicorneous grain and height (2.0-2.5 m). We produced hybrids by crossing these A lines with selected restorers.

Nonmilo cytoplasm. The lack of fertility restoration on nonmilo sources (A_2, A_3, and Maldandi) prevents their use in commercial hybrid production. From preliminary evaluation of 921 F_1 hybrids made between the nonmilo cytoplasm females and the germplasm lines as males, we selected 130 germplasm lines that restored fertility on A_2 cytoplasm, 95 on A_3, and 25 on Maldandi. These germplasm lines have been crossed again to nonmilo cytoplasm females to confirm their ability to restore fertility.

Hybrid Evaluation

We made 306 hybrids using 45 of our new male-sterile lines and 63 restorer lines and 5 hybrids on

Table 11. Mean grain yield (t ha^{-1}) of selected sorghum hybrids evaluated[1] at five Indian locations, rainy season 1986.

		Locations[2]					
Entry	Pedigree	1	2	3	4	5	Mean
ICSH 281	296A x (SC 108-3 x Diallel)-21-2-3-3	5.11	5.86	3.77	5.27	7.39	5.48
ICSH 109	296A x [(SC 108-3 x E 35-1) CSV 4] -2-2-1-1	5.78	6.48	4.00	4.33	6.53	5.42
ICSH 310	ICSA 32 x (SC 108-3 x CSV 4)-27-2-1	5.55	6.32	3.11	3.69	7.29	5.19
ICSH 301	ICSA 30 x (SC 108-3 x CSV 4)-27-2-1	4.85	5.63	2.70	6.46	5.96	5.12
ICSH 336	ICSA 40 x (SC 108-3 x 148)-18-4-1	4.78	5.94	3.96	5.55	6.02	5.12
ICSH 319	ICSA 35 x (SC 108-3 x 148)-18-4-1	4.81	5.92	3.50	4.69	6.66	5.11
Controls							
Hageen Durra 1	ATX 623 x Karper 1597	4.19	3.98	2.40	5.79	5.22	4.31
ICSH 153 (CSH 11)	296A x (SC 108-3 x CSV 4)-27-2-1	5.14	6.14	4.16	4.88	6.77	5.42
CSH 9	296A x CSV 4	5.19	5.24	3.67	4.22	6.83	5.03
ICSV 112[3] (SPV 475)	[(IS 12622C x 555)(IS 3612C x 2219B) -5-1 x E 35-1]-5-2	4.48	4.31	2.98	2.85	6.31	4.19
CSH 6	2219A x CSV 4	4.08	4.16	1.69	4.70	5.82	4.09
SE		±0.22	±0.25	±0.30	±0.56	±0.31	±0.16
Trial mean (36 entries)		4.75	5.39	3.03	4.49	6.22	4.77
CV(%)		8	8	17	22	9	-
Efficiency (%)		96	95	104	111	130	-

1. 6 x 6 triple lattice design.
2. Locations.
   1 = ICRISAT Center, Andhra Pradesh, plot size 12 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 40: P 40: K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 12 m^2, Alfisol, low fertility (N 43:P 20: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).
3. Variety control.

296 A, a male-sterile line developed by the Indian National Program. We evaluated these 311 experimental hybrids in 3 separate trials during the 1986 rainy season, at various Indian locations. Data on the agronomic performance of the most productive hybrids are presented in Tables 11 and 12. The hybrids ICSH 310, ICSH 301, ICSH 336, and ICSH 319 involving new male steriles, yielded as well as the released commercial hybrids, CSH 9 and ICSH 153 (CSH 11) (Table 11). The major criteria used to select these hybrids for further evaluation is higher seed production. The selected hybrids presented in Table 12 produced significantly higher grain yield when compared to the commercial hybrids, CSH 9 and ICSH 153 (CSH 11).

West Africa

Germplasm Evaluation

We continued our efforts to identify diverse germplasm accessions that would contribute to sorghum improvement in the Northern Guinean Zone. We evaluated 70 selected germplasm lines at Farako-Ba from 79 previously selected as resistant to various leaf diseases, and with good grain quality (ICRISAT Annual Report 1985, p. 57). We used early maturing improved, and late-maturing local varieties as controls, in replicated trials sown on 14 June and 14 July. Based on their average grain yield and reaction to pests and diseases for the 2nd consecutive year, we selected 12 entries for advanced yield tests. Ten accessions (IS 956, IS 3555, IS 9225, IS 9738, IS 9672, IS 20129,IS 20130,IS 21658,IS 21609, and IS 21629) were the least susceptible to leaf diseases. Six accessions (IS 6991, IS 3573, IS 9928, IS 6938, IS 23141, and IS 13922) exhibited no midge damage and were selected for further testing in 1987.

Observation Nurseries

Breeding lines (674) introduced from ICRISAT Center, ICRISAT's Mexico and Central American team, and the national programs of Nigeria, The Gambia, and Mali were evaluated in observation nurseries sown at Farako-Ba in comparison with local controls. We selected 70 lines for further yield testing and use in crossing programs. Several of these lines combined high levels of resistances to leaf diseases and midge with good grain quality and agronomic characters. These will serve as a good base for breeding programs in the Northern Guinean Zone.

Preliminary Variety Yield Trials

In an attempt to identify superior early maturing varieties suitable for July sowing in the Northern Guinean Zone, we grew replicated yield trials at two representative locations (Farako-Ba Research Station and Koho village) using 30 elite varieties identified during 1985. On average, the hybrid control, ICSH 153 (CSH 11) gave the highest grain yield (2.71 t ha^{-1}) followed by the varieties Framida (2.59 t ha^{-1}) and 1CSV 2 (SPV 386) (2.51 t ha^{-1}). The local variety Gnofing gave the lowest yield (1.7 t ha^{-1}). ICSV 247 and ICSV 111 also yielded well.

Five preliminary trials consisting of 116 entries for the Sudanian Zone, were evaluated at Kamboinse and Farako-Ba. These entries were obtained from the *Striga* breeding program, and also from selections from the backcrossing program. We identified a number of high-yielding genotypes (ICSV 1082 BF, ICSV 1083 BF, ICSV 1087 BF, ICSV 1084 BF, ICSV 1089 BF, ICSV 1088 BF, ICSV 1085 BF, ICSV 1142 BF, ICSV 1091 BF, and ICSV 1143 BF). Two of these combined high yield with resistance to grain mold and several leaf diseases. They are ICSV 1089 BF (2.35 t ha^{-1} compared to 2.10 t ha^{-1} for ICSV 1002 BF,the control) and ICSV 1091 BF (1.87 t ha^{-1} compared to 1.6 t ha^{-1} for SPV 35, the control). Another selection, ICSV 1143 BF, combined high yield with resistances to grain mold, head bugs (*Eurystylus marginatus*), and leaf diseases with the exception of grey leaf spot (*Cercospora sorghi*). ICSV 1144 BF, ICSV 1145 BF, and ICSV 1146 BF also showed good levels of resistance to head bugs.

Table 12. Performance of selected experimental sorghum hybrids evaluated[1] at three Indian locations, rainy season 1986.

Entry	Pedigree	Time to 50% flowering (days)			Plant height (m)			Grain yield (t ha^{-1})			
		1[2]	2	3	1	2	3	1	2	3	Mean
ICSH 434	ICSA 9 × [(148 × E 35-1) × CSV 4]-5-3-4-1	64	65	66	1.60	1.60	1.86	5.26	5.78	5.39	5.48
ICSH 459	ICSA 24 × (IS 20509 × SPV 471)-4-2	65	63	66	1.36	1.50	1.56	5.98	4.60	5.68	5.42
ICSH 381	ICSA 1 × [MR 840 (2077B × IS 9327) -7-1-3-2 × (R 27 × R 2797)]-15-2-2-2	68	66	65	1.66	1.54	1.66	4.71	5.12	6.25	5.36
ICSH 444	ICSA 31 × [SAFRA (SC 108-3 × E 35-1) CSV 4]-3-4-2-4-2	61	63	63	1.63	1.94	1.99	5.76	5.05	5.22	5.34
ICSH 418	ICSA 17 × [SPV 352 × (CK 60B × IS 84)]-4-1	64	65	65	1.75	1.91	1.91	4.67	5.75	5.53	5.32
Controls											
ICSH 153 (CSH 11)	296A × (SC 108-3 × CSV 4)-27-2-1	67	65	66	1.92	1.86	2.04	3.89	5.71	6.51	5.37
CSH 9	296A × CSV 4	68	64	66	1.75	1.74	1.95	2.10	5.23	6.03	4.45
ICSV 112[3] (SPV 475)	[IS 12622C × 555)(IS 3612C × 2219B) -5-1 × E 35-1]-5-2	75	72	71	1.50	1.75	1.78	1.06	2.79	3.99	2.61
SE		±1.3	±0.8	±1.1	±0.8	±0.5	±0.6	±0.6	±0.4	±0.6	±0.3
Trial mean (144 entries)		65	64	64	1.65	1.84	1.94	4.10	4.52	4.64	4.42
CV(%)		3	2	2	7	4	5	20	13	18	13-20
Efficiency (%)		118	101	96	121	102	104	101	135	114	101-135
ICSH 574	ICSA 42 × (CSV 4 × GG × 370)-2-1-1-6-2	68	69	72	1.92	1.90	1.76	7.29	3.67	2.88	4.61
ICSH 542	ICSA 28 × [(IS 19614 (148 × E 35-1) -11-1 × CSV 4]-5-3-2-2	67	65	67	1.51	1.40	1.62	7.18	3.58	3.03	4.60
ICSH 638	ICSA 37 × [SPV 652 × (SC 108-3 × CSV 4)]-2-1	67	70	69	1.81	1.84	1.97	6.55	3.64	3.25	4.48
ICSH 528	ICSA 32 × [(MR 840 × MB 4) × R 2797]-15-3-2	69	68	69	1.90	1.80	1.82	7.05	3.87	2.43	4.45
ICSH 548	ICSA 38 × [SPV 352 × (CK 60B × IS 84)]-6-4-3	69	66	66	1.90	1.99	2.06	5.93	4.48	2.93	4.45
Controls											
CSH 9	296A × CSV 4	71	66	68	1.82	1.80	1.88	5.41	4.00	2.40	3.94
ICSH 153 (CSH 11)	296A × (SC 108-3 × CSV 4)-27-2-1	68	67	68	1.87	1.64	1.74	5.34	3.07	2.86	3.76

Continued

Table 12 *Continued*

Entry	Pedigree	Time to 50% flowering (days)			Plant height (m)			Grain yield (t ha^{-1})			
		1[2]	2	3	1	2	3	1	2	3	Mean
ICSV 112[3] (SPV 475)	[(IS 12622C × 555)(IS 3612C × 2219B) -5-1 × E 35-1]-5-2	62	58	63	1.49	1.61	1.70	5.46	1.92	1.61	3.00
SE		±1.8	±0.8	±1.2	±0.11	±0.06	±0.08	±0.72	±0.51	±0.46	±0.33
Trial mean (144 entries)		68	66	68	1.77	1.76	1.83	5.36	2.98	2.41	3.59
CV (%)		4	2	3	8	5	6	19	24	27	19-27
Efficiency (%)		102	97	98	108	101	103	121	101	99	99-121

1. 12 × 12 triple lattice design.
2. Locations:
   1 = Bhavanisagar, Tamil Nadu, plot size 4 m^2, Alfisol, high fertility (N 80:P 30:K 30).
   2 = ICRISAT Center, Andhra Pradesh, plot size 6 m^2, Alfisol, high fertility (N 86:P 40:K 0).
   3 = ICRISAT Center, Andhra Pradesh, plot size 6 m^2, Alfisol, low fertility (N 43:P 20:K 0).
3. Variety controls.

Advanced Variety Yield Trials

The short-duration advanced trial consisted of 25 varieties and two controls, ICSV 1002 BF and ICSV 16-5 BF. Most of the entries flowered between 60 and 70 days. The few selected varieties that had higher grain yields than the controls are reported in Table 13. Their superiority in grain yield over the controls was significant at Kamboinse but not at Farako-Ba. Their yield levels were similar to those of the controls under low management, and in a *Striga* sick plot at Kamboinse. All the selections exhibited good seedling establishment under low management. Head bug incidence was very high, ICSV 16-5 BF was least damaged. Many of the lines showed excellent levels of resistance to most of the common West African leaf diseases except oval leaf spot (*Ramulispora sorghicola*). None of the selections were resistant to grain mold, but the control ICSV 16-5 BF, was less susceptible than the others.

The medium-duration advanced trial consisted of 25 varieties including the control, ICSV 1002 BF. All the entries flowered between 70 to 80 days. We selected 6 varieties on the basis of their overall performance, their results are presented in Table 14. Under low management ICSV 1063 BF, ICSV 1098 BF, and ICSV 110 BF significantly outyielded the control. Under good management at Kamboinse and Farako-Ba ICSV 1063 BF and ICSV 1110 BF also significantly outyielded the control. Another selection, ICSV 1108 BF yielded well and had combined resistances to grain mold and many leaf diseases. The selections exhibited good seedling establishment under low management, but their levels of resistance to head bug and grain mold need to be improved.

In other advanced trials, ICSV 1095 BF showed resistance to leaf diseases and grain mold, and ICSV 1147 BF, ICSV 1148 BF, and SPV 35 control were less damaged by head bug.

Hybrid Evaluation

We observed 454 preliminary hybrids sown in mid-July along with their parents and early mat-

Table 13. Performance of selected short-duration, advanced, elite sorghum varieties at Kamboinse and Farako-Ba, Burkina Faso, rainy season 1986.

Genotype	Locations and grain yield (t ha^{-1})[1] KB[5] GM	FB GM	KB LM	KB ST	Mean	Time to 50% flowering (days)	Mean seedling estab.(%)[2] KB LM	Head bug[3] KB	Grain mold[4] KB
ICSV 1002-1 BF	2.96	2.18	1.43	1.93	2.13	65	85	3.7	5.0
ICSV 1002-2 BF	3.06	2.28	1.50	1.45	2.07	67	94	3.7	4.3
ICSV 1002-3 BF	3.28	2.00	1.20	1.41	1.98	63	84	3.4	4.5
ICSV 1014-1 BF	2.84	2.06	1.72	1.23	1.96	60	92	3.3	4.3
Controls									
ICSV 16-5 BF	2.13	2.51	1.65	1.50	1.94	76	94	2.4	3.5
ICSV 1002 BF	1.93	2.25	1.50	-	1.89	78	88	3.8	3.8
SE	±0.33	±0.17	±0.19	±0.33		±2	±6	±0.23	±0.25
Trial mean (25 entries)	2.27	2.04	1.30	1.13		67	86	3.6	3.9
CV (%)	25	14	26	41		6	12	11	14
Efficiency (%)	100	183	176	-					

1. 5 x 5 balanced lattice, plot size 7.5 m^2 in Kamboinse (GM and LM) and Farako-Ba (GM). Checkerboard design, plot size 6 m^2 in Kamboinse *Striga* sick plot.
2. Mean seedling establishment (%) was estimated by the proportion of hills with at least one seedling over the total number of hills sown.
3. Based on a 1 to 5 scale,wherc 1 = normal grain with a few feeding punctures, <10% grains with eggs, and 5 = grain highly shrivelled and tanned, and >60% grains with eggs.
4. Based on a 1 to 5 scale, where 1 = no mold, and 5 = more than 50% grain surface area molded.
5. KB = Kamboinse, FB = Farako-Ba, GM - Good management (soil plowed and fertilizer applied), LM = Low management (no plowing and no fertilizer), ST = *Striga* sick plot.

uring control varieties, at Farako-Ba. The hybrids produced from crosses involving disease-resistant parents identified last year (ICRISAT Annual Report 1985, p. 61) were generally free from leaf diseases and showed no symptoms of lodging. Female parents ICSA 1, ICSA 2, ICSA 11, ICSA 26, ICSA 38, and ICSA 40 that were introduced from ICRISAT Center combined good levels of leaf disease resistance with high grain yield. We selected 30 hybrids for advanced tests.

On-farm Testing

During the 1985 rainy season we evaluated 9 varieties including a local variety used as control, in two villages, Koho and Kolbila, in Burkina Faso. The treatments included two management practices, and two sowing dates. Our yield data indicated that in both villages the improved management treatments that included plowing and fertilizer application significantly improved yield over the traditional management treatment that did not have these inputs. ICSV 16 BF and ICSV 1049 BF performed very well in both the villages as compared to the local control. ICSV 16 BF, however, had harder endosperm, and better food quality than ICSV 1049 BF.

The results of farmer-managed trials in Kolbila, Pabre, and Kamboinse villages during 1986

Table 14. Performance of selected medium-duration advanced, elite sorghum varieties at Kamboinse and Farako-Ba, Burkina Faso, rainy season 1986.

Genotype	Location and grain yield (t ha^{-1})[1]					Time to 50% flowering (days)	Mean seedling estab.(%)[2] KB LM	Head bug[3] KB	Grain mold[4] FB
	KB[5] GM	FB GM	KB LM	KB ST	Mean				
ICSV 1063 BF	2.49	2.67	1.74	1.77	2.17	76	81	3.6	4.1
ICSV 1093 BF	2.61	2.71	1.47	1.76	2.14	70	98	3.6	3.8
ICSV 1098 BF	2.61	2.55	1.73	1.66	2.14	71	85	3.8	3.3
ICSV 1108 BF	2.31	3.08	1.47	1.26	2.03	73	94	3.8	3.1
ICSV 1109 BF	2.73	2.34	1.45	1.52	2.00	70	92	3.5	4.1
ICSV 1110 BF	1.57	2.33	1.89	1.40	2.01	77	87	3.6	3.4
Control									
ICSV 1002 BF	1.86	2.19	1.06	-	1.70	81	80	3.5	3.7
SE	±0.27	±0.26	±0.20	±0.30		±2	±6	±0.18	±0.24
Trial mean (25 entries)	2.19	2.47	1.37	1.25		74	88	3.6	3.8
CV (%)	21	19	25	34		4	11	9	14
Efficiency (%)	102	114	140	-					

1. 5 x 5 balanced lattice, plot size 7.5 m^2 in Kamboinse (GM and LM) and Farako-Ba (GM), Checkerboard design, plot size 6 m^2 in Kamboinse *Striga* sick plot.
2. Mean seedling establishment (%) was estimated by the proportion of hills with at least one seedling over the total number of hills sown.
3. Based on a 1 to 5 scale,where 1 = normal grain with a few feeding punctures, <10% grains with eggs, and 5 = grain highly shrivelled and tanned, and >60% grains with eggs.
4. Based on a 1 to 5 scale, where 1 = no mold and 5 = more than 50% grain surface area molded.
5. KB = Kamboinse, FB = Farako-Ba, GM = Good management (soil plowed and fertilizer applied), LM = Low management (no plowing and no fertilizer), ST = *Striga* sick plot.

clearly demonstrated the superiority of ICSV 16-5 BF (a selection from ICSV 16 BF) over local varieties. In addition to high and stable grain yields with good food quality, it had excellent seedling establishment and was less susceptible to grain mold and head bugs.

Southern Africa

Hybrids

In a preliminary testcross evaluation (Fig. 11) of 900 experimental F_1 hybrids, sown at Matopos in late December with supplementary irrigation during the crop season, we selected 313 hybrids that yielded over 5.0 t ha^{-1} compared to the overall mean yield of 3.8 t ha^{-1} and control mean yield of 3.6 t ha^{-1}. Among these 313 hybrids eight yielded between 7.0 t ha^{-1} and 8.3 t ha^{-1}. These are SPL 32A x RSV 18K, SPL 9A x IS 10384, SPL 23A x IS 10384, M 40079A x 6/27, IS 0418A x PAB-41, 2219A x IS 10483, SPL 10A x (M 66118-3 x CS 3541)-9-1, and SPL 23A x (IS 12611 x SC 108-3)-4-4-8. Six of these eight hybrids had female parents bred at ICRISAT Center.

Among advanced hybrids received from the ICRISAT Center, the highest yielder was MA 12 x (SC108-3 x CS3541) (SC110-14 x SC108-3 x 148)-12-5-136, with 5.9 t ha^{-1}.

Figure 11. ICRISAT plant breeder (right) evaluating experimental sorghum hybrids during the 1985/86 cropping season at Matopos, Zimbabwe. These hybrids resulted from testcrosses involving new female parents bred at ICRISAT Center.

Breeding Nurseries

Nurseries of 250 A and B lines were grown at Matopos, Aisleby, and Mzarabani, Zimbabwe. From visual observation, we selected the 16 best A and B line pairs and increased their seed. These include: ATX 623, MA 4, D2 A, M 40079A, CK 74A, SPL 9A, SPL 10A, SPL 23A, SPL 109A, 2219A, 1319A, IS 0418A, IS 10638A, SPL 32A, 1319A, and SPL 106A. We will evaluate their combining abilities in further testcross trials. A second set of 144 new A and B line pairs received from ICRISAT Center were observed for uniformities of flowering and we selected 31 pairs to be used in hybrid development.

One SADCC regional trial, Regional Sorghum Preliminary Varietal Trial (RSPVT) with 22 entries, and one Latin American regional trial, Latin American Regional Sorghum Variety Yield Trial (LARSVYT), with 64 entries, gave the highest yields ranging from 3.2 to 4.1 t ha^{-1}, and 4.0 to 4.8 t ha^{-1}. Average yields were 2.9 t ha^{-1} in the RSPVT trial and 3.5 t ha^{-1} in the LARSVYT trial. Highest yielders were SV 1 (4.1 t ha^{-1} in RSPVT) and 80L 27836 (5.8 t ha^{-1} in LARSVYT).

Mexico and Central America

Breeding for the Highlands (1500-2300 m)

At El Batan we evaluated six elite lines for adaptation to the low temperature environment and yield. General agronomic aspect, average days to 50% flowering, and plant height were good (Table 15). The average yield of 5.02 t ha^{-1} was excellent but future evaluations under farmers' dryland conditions will be necessary to test suitability for the highland farming environment.

Population improvement for cold tolerance continued, with the sowing of 636 S_3 lines for advancing to S_4, agronomic characteristics were very important criteria in the selection process. A new population (BCTP, Batan Cold Tolerant Population) was formed by using the best cold-tolerant lines. During the 1986 cycle early male-

Table 15. Characteristics of new cold-tolerant sorghum lines, El Batan, Mexico, 1986.

Line	Yield ($t\ ha^{-1}$)	General aspect[1]	Time to 50% flowering (days)	Plant height (m)
CT874 x L.S.844	7.93	3.5	111	1.41
77CS866-1 x 76BTP139-1	5.05	3.0	111	1.12
P74AS388 x Man 64	4.97	3.0	113	0.98
IS 1266 x BT18-1	4.22	2.0	106	1.52
76BTP96 x CYF3-10	4.02	2.0	106	1.00
Toluca 1	3.99	3.0	97	1.30
SE	±0.80			
Mean	5.03	3.0	107	1.22
CV (%)	16			

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

sterile genotypes and early fertile genotypes of good plant type were recombined.

We advanced 192 pairs of A and B lines to the 7th backcross. We also advanced 2224 entries by the pedigree method to F_2 and F_3 and selected them for adaptation to the cold environment (6-20°C).

We selected 38 lines for good seedling vigor and evaluated 25 new lines for grain yield. We sowed eight advanced lines in large plots for seed increase prior to agronomic evaluation in farmers' fields.

Breeding for Intermediate (800-1800 m) and Lowland (0-800 m) Altitudes

We evaluated 96 pairs of A and B lines; 90 from ICRISAT Center, and 6 from Texas A&M University for general agronomic eliteness, yield, and grain quality. Nine of these yielded >4.0 $t\ ha^{-1}$ and 3 were excellent in agronomic eliteness.

We confirmed midge (*Contarina sorghicola*) tolerance in the following lines: PM 7322, PM 7422-2, PM 7397, received from ICRISAT Center, and detected resistance in IS 7005, IS 18733, IS 8571, AF28, IS 3471, IS 19474 and IS 19512. We confirmed rust (*Puccinia purpurea*) resistance in ICSV 1 (SPV 351), SPV 346 M 35610, M 36013, M 36172, PM 6745, PVT IE 24, PVT 2EI, PVT 2E 35, PVT IE 25, received from ICRISAT Center, and also in TAM 2566.

Food Quality

West Africa

Brewing Quality

A significant proportion of sorghum grown in West Africa has red and brown grain types and these are used to produce thin fermented porridges and alcoholic beverages. In Burkina Faso, traditional sorghum beer, popularly known as *dolo* is produced by small-scale breweries. Sorghum is steeped, germinated, and dried to prepare the malt. Mash is prepared by mixing the ground malt and ground bark from baobab (*Adansonia digitata*) trees with water. After clarification, the substrate is boiled with water and filtered to remove bran. The wort is boiled, cooked, and inoculated with yeast from a previous batch of beer. Fermentation occurs overnight and actively fermenting beer is ready the next morning. *Dolo* is a relatively clear red liquid with a sweet pleasant taste and with low solid content. The beer has a low (1-4%) alchohol content and its continued fermentation produces an unpleasant, sour taste.

We evaluated eight sorghum genotypes, exhibiting differences in their grain color, endosperm texture, and presence/absence of subcoat (M 35-1, ET3491, ICSV 111, Lulu Dwarf, Co 4, W.S. 1297, Dobbs, and Framida) for their dolo-making quality in cooperation with three domestic breweries located in the Kamboinse village. Each of the genotypes was brewed independently in paired tests along with the local brown variety by different breweries. The beer samples were evaluated for color, taste, smell, consistency, and conservation (on a scale of 1-3, where 1=good, 3=poor) by a selected set of five panelists. The women who brewed the samples evaluated malting and brewing qualities. *Dolo* produced from the brown-grain Dobbs and white-grain Lulu Dwarf were rated the poorest for beer quality. The local brown grain variety was the most acceptable, followed by Framida, M 35-1, and Co 4. Genotypes W.S. 1297, ICSV 111, and ET 3491 also produced acceptable beer.

The color of *dolo* from the local brown grain variety was light red (5YR5/2 on Munsell's soil color chart) and was preferred to the others. *Dolo* from white-grain and types like M 35-1 exhibited a pale yellow color (10YR7/2 on Munsell's soil color chart) and was new to the panelists. However, other beer-quality features of white-grain types were rated good to acceptable. It was concluded that not all brown-grain types are suitable for brewing and malting, and that some white-grain types could be used to produce *dolo* by mixing them with a proportion of red grains to achieve the desired color.

Cooperation with National Programs

Multilocational Trials and Nurseries

International Sorghum Variety Adaptation Trial (ISVAT 85)

ISVAT 85 consisted of 25 entries including a local control and 3 ICRISAT-bred controls ICSH 153 (CSH 11), ICSV 1 (SPV 351), and ICSV 2 (SPV 386). We distributed 77 sets of seed to 22 cooperators: Asia (29), North America (1), Central America (15), South America (13), West Africa (10), eastern Africa (5), and southern Africa (4). Data on selected varieties from 32 locations are presented in Table 16. The varieties, ICSV 112 (SPV 475), ICSV 110, ICSV 189, ICSV 162, and ICSV 194 yielded 4.21-3.881 ha^{-1} while the control variety, ICSV 1 (SPV 351) yielded 3.771 ha^{-1} across locations. The varieties differed in their specific adaptation. For example, ICSV 111 and ICSV 194 yielded well in India, while ICSV 198 recorded the highest grain yield in Ghana, and ICSV 112 gave the highest grain yield in Pakistan. Some of these selected varieties were less susceptible to yield-reducing factors; ICSV 193, and ICSV 114 to *Striga asiatica,* ICSV 197 (PM 11344) to midge, ICSV 110, ICSV 186, and ICSV 2 (SPV 386) to downy mildew, and ICSV 112 (SPV 475), ICSV 110, ICSV 189, ICSV 162, ICSV 198, ICSV 111, ICSV 102, and ICSV 197 to anthracnose.

Cooperators from Pakistan suggested that the trial should include early types while Ghana required late varieties. Cooperators from Argentina and Colombia indicated that the varieties were too tall and late for their locations. Cooperators in Egypt, Ethiopia, The Gambia, Ghana, Mali, India, Pakistan, The Philippines, and the Yemen Arab Republic, all selected varieties for inclusion in their programs.

International Sorghum Hybrid Adaptation Trial (ISHAT 85)

ISHAT 85 consisted of 25 hybrids including a local control and 3 ICRISAT-bred controls ICSH 153 (CSH 11), CSH 9, and ICSV 112 (SPV 475). A total of 40 sets were distributed to 35 cooperators: Asia (18), Central America (5), South America (8), West Africa (3), eastern Africa (2), and southern Africa (4). The selected grain yield data from 22 sets are presented in Table 17; these indicate that ICSH 109, ICSH 159, ICSH 110, ICSH 120 (Fig. 12), and ICSH 162 were highly stable and productive with grain yields of 5.51-5.21 t ha^{-1} across locations, while

Table 16. Mean grain yield (t ha^{-1}) of top-yielding entries in the International Sorghum Variety Adaptation Trial (ISVAT 85)[1], 1985.

Entry	Pedigree	Locations[2] 1	2	3	4	5	6	7	8	9	10	11
ICSV 112 (SPV 475)	[(IS 12622C × 555)(IS 3612C × 2219B) -5-1 × E 35-1]-5-2	5.03	3.53	4.87	7.69	4.45	1.61	0.68	1.82	1.95	1.95	1.13
ICSV 110	[(SC 423 × CSV 4) × E 35-1]-2-1	4.40	2.06	4.96	4.05	3.45	1.14	0.84	2.12	2.39	0.83	0.84
ICSV 189	(E 35-1×US/R 703)-2-1-1-2-2	4.65	2.67	4.28	5.82	4.00	1.32	0.71	2.65	2.14	1.37	1.03
ICSV 162	[CSV 4 × (GG × 370)]-2-1-4-4	4.30	2.32	4.50	4.16	4.00	0.98	1.02	1.75	2.02	1.65	0.70
ICSV 194	(R 16xM 35-1)-1-3-1-6-1	5.22	2.09	4.28	4.59	3.45	1.06	0.61	2.07	2.67	1.36	1.49
ICSV 186	(SC 108-3 × CSV 4)-14-1	4.51	2.41	4.56	5.30	4.19	1.55	0.40	2.11	2.32	0.76	0.74
ICSV 198	[(M 35-1 × M 1009)-3-2-1 × 6F$_5$'s]-5-2-3-2	4.99	2.50	3.83	4.78	2.71	0.73	0.62	2.23	1.66	1.06	1.86
ICSV 111	[(SPV 35 × E 35-1) × CSV 4]-8-1	5.30	2.79	3.86	4.13	2.71	1.84	0.44	1.82	1.39	1.49	1.59
ICSV 126	[(SC 108-3 × Swarna) × E 35-1]-6-2	4.24	1.99	4.81	4.52	3.74	1.09	0.36	1.47	2.28	0.98	0.67
ICSV 102	(E 35-1 × RS/B 394)-1-1-2	4.23	1.74	4.14	4.81	2.62	1.00	0.41	2.37	2.31	1.92	1.78
ICSV 138	[CSV 4 × (GG × 370)]-2-1-1-1-4	4.29	2.73	4.63	2.35	3.29	1.69	0.37	1.51	2.44	0.88	0.78
ICSV 197 (PM 11344)	(IS 3443 × DJ 6514)-1-1-1-1-1	4.20	1.95	3.20	3.64	2.50	0.68	0.64	2.69	2.81	1.85	0.84
ICSV 193	(148 × Framida)-39-2-4-1-1-2-1	4.84	3.08	3.17	3.58	2.43	1.38	0.46	1.67	1.13	1.26	1.03
ICSV 161	(E 35-1 × US/B 487)-2-1-4-1-1	4.37	1.24	3.10	4.30	2.79	0.44	0.84	1.50	2.56	1.13	1.10
ICSV 114	[SRN 4841 × (WABCxP-3-3)]-7-3	4.32	2.31	3.36	3.76	4.33	1.23	0.77	1.47	1.20	1.33	1.23
Controls												
ICSH 153 (CSH 11)[3]	[296A × (SC 108-3 × CSV 4)]-27-2-1	6.22	3.28	4.44	5.51	3.50	2.38	1.08	1.08	2.20	2.10	1.13
ICSV 1 (SPV 351)	(SC 108-3 × CSV 4)-19-1	4.59	2.76	4.07	5.15	3.93	2.11	1.02	1.50	2.23	0.88	1.57
ICSV 2 (SPV 386)	(SC 108-4-8 × CSV 4)-88	4.68	2.05	4.29	3.24	3.33	0.62	0.70	2.32	2.10	1.41	0.78
Local		4.23	2.26	3.15	3.95	3.74	1.87	1.23	2.60	0.44	1.22	1.74
SE		±0.19	±0.18	±0.23	±0.60	±0.30	±0.39	±0.18	±0.32	±0.38	±0.25	±0.16
Trial mean (25 entries)		4.55	2.37	3.93	4.25	3.18	1.27	0.65	1.84	1.98	1.16	1.06
CV (%)		9-35	11-32	15-25	25	16	43	47	37	33	37	26
Efficiency (%)		84-161	96-102	81-150	135	93	103	100	110	94	92	99

1. 5 × 5, lattice, plot size 2.25 m^2 at Melkasa, Ethiopia and 12.0 m^2 at ICRISAT Center, India.
2. Locations:
   1 = India mean of eight tests: a) ICRISAT Center and b) Anantapur, Andhra Pradesh, c) Bhavanisagar, Tamil Nadu, d) Dharwad, Karnataka, e) Jalna and f) Karad, Maharashtra, g) Pantnagar, Uttar Pradesh and h) Surat, Gujarat; 2 = Pakistan three tests:a) Dadu, b) Yousufwala, and c) Islamabad; 3 = The Philippines four tests: a) Laguna b) Manila, c) Isabela, and d) Bacnotan; 4 = Seikviw, Thailand; 5 = Taiz, Yemen Arab Republic; 6 = Giza, Egypt; 7 = Melkasa, Ethiopia; 8 = Ilonga, Tanzania; 9 = The Gambia; 10 = Farako-Bâ, Burkina Faso; 11 = Tamale, Ghana.
3. Hybrid control.

Continued

Table 16 *Continued*

Entry	Pedigree	Locations[2] 12	13	14	15	16	17	18	19	Mean
ICSV 112 (SPV 475)	[(IS 12622C × 555)(IS 3612C × 2219B) -5-1 × E 35-1]-5-2	0.95	4.12	2.76	5.53	8.96	4.84	4.06	5.94	4.21
ICSV 110	[(SC 423 × CSV 4) × E 35-1]-2-1	0.97	4.90	2.36	6.23	7.79	3.58	5.15	9.68	3.98
ICSV 189	(E 35-1×US/R 703)-2-1-1-2-2	0.93	4.05	3.50	5.59	7.27	2.95	5.20	8.01	3.97
ICSV 162	[CSV 4 × (GG × 370)]-2-1-4-4	0.82	4.32	2.14	4.62	10.41	2.02	5.59	9.33	3.88
ICSV 194	(R 16xM 35-1)-1-3-1-6-1	0.82	4.09	3.07	5.59	7.05	2.61	4.09	7.17	3.88
ICSV 186	(SC 108-3 × CSV 4)-14-1	0.79	3.21	2.18	4.94	8.15	4.01	9.40	6.12	3.87
ICSV 198	[(M 35-1 × M 1009)-3-2-1 × 6F$_5$'s]-5-2-3-2	0.88	3.57	3.02	4.80	10.10	4.08	4.52	6.84	3.85
ICSV 111	[(SPV 35 × E 35-1) × CSV 4]-8-1	0.46	2.76	2.81	3.90	8.97	2.72	2.79	7.88	3.81
ICSV 126	[(SC 108-3 × Swarna) × E 35-1]-6-2	0.99	5.64	3.16	5.08	9.58	1.81	4.56	8.11	3.79
ICSV 102	(E 35-1 × RS/B 394)-1-1-2	1.01	3.83	3.53	5.47	8.13	4.11	8.71	6.25	3.76
ICSV 138	[CSV 4 × (GG × 370)]-2-1-1-1-4	0.86	3.34	1.89	5.08	9.24	1.40	5.89	9.03	3.75
ICSV 197 (PM 11344)	(IS 3443 × DJ 6514)-1-1-1-1-1	1.23	4.49	3.54	3.62	8.69	4.71	6.99	6.38	3.56
ICSV 193	(148 × Framida)-39-2-4-1-1-2-1	0.70	2.84	3.20	4.08	6.68	4.17	6.87	5.73	3.55
ICSV 161	(E 35-1 × US/B 487)-2-1-4-1-1	0.73	3.56	3.25	3.73	10.04	3.90	5.20	5.72	3.36
ICSV 114	[SRN 4841 × (WABCxP-3-3)]-7-3	0.67	2.57	2.88	3.56	7.85	3.41	2.68	6.56	3.34
Controls										
ICSH 153 (CSH 11)[3]	[296A × (SC 108-3 × CSV 4)]-27-2-1	0.88	5.01	3.52	6.44	9.58	2.86	5.37	8.03	4.56
ICSV 1 (SPV 351)	(SC 108-3 × CSV 4)-19-1	0.95	3.60	3.23	4.86	9.22	3.67	6.18	4.65	3.77
ICSV 2 (SPV 386)	(SC 108-4-8 × CSV 4)-88	0.98	3.83	2.63	4.96	8.28	2.76	5.27	6.83	3.68
Local		0.71	4.01	3.20	4.54	8.93	3.65	3.47	6.60	3.49
SE		±0.22	±0.36	±0.45	±0.48	±0.76	±0.53	±0.69	±0.55	±0.86
Trial mean (25 entries)		0.82	3.82	2.76	4.79	8.33	3.12	5.46	7.01	3.68
CV (%)		47	16	29	17	16	29	22	12-20	9-47
Efficiency (%)		94	111	101	152	104	107	101	100-104	81-161

1. 5 × 5, lattice, plot size 2.25 m^2 at Melkasa, Ethiopia and 12.0 m^2 at ICRISAT Center, India.
2. Locations:
   12 = Sotuba, Mali; 13 = San Salvador, El Salvador; 14 = El Zamorano, Honduras; 15 = David-chiriow, Panama; 16 = Manfredi, Argentina; 17 = Palmira, Colombia; 18 = Guayaquil, Ecuador; and 19 = Venezuela two tests: a) Maracay and b) Aragua.
3. Hybrid control.

Table 17. Mean grain yield (t ha⁻¹) of top-yielding entries in the International Sorghum Hybrid Adaptation Trial (ISHAT 85)[1], 1985.

Entry	Pedigree	Locations[2] 1	2	3	4	5	6	7	8	9	10	Mean
ICSH 109	296A × [(SC 108-3 × E 35-1)-5-1 × CS CSV 4]-2-2-1-1	6.03	3.10	6.50	4.96	6.99	5.26	5.56	8.07	4.91	6.70	5.51
ICSH 159	296A × (FLR 266 × CSV 4)-4-3-2-1	5.90	2.82	7.30	5.34	7.83	4.08	4.52	9.35	3.64	6.18	5.38
ICSH 110	296A × (SC 108-3 × CSV 4)-51-1	4.75	2.80	7.08	6.19	7.49	3.94	4.28	8.40	4.36	5.30	5.26
ICSH 120	296A × (Diallel-475-746)-4-2-1-5	5.43	3.08	5.76	5.83	5.75	3.97	5.26	9.82	4.85	5.98	5.22
ICSH 162	SPL 115A × (FLR 101 × IS 1082)-4-2	5.29	2.69	7.65	5.43	6.69	4.92	4.62	10.49	4.02	6.09	5.21
ICSH 106	296A × (SC 108-3 × CSV 4)-20-2-2	5.64	3.14	6.93	4.64	6.75	4.22	5.35	9.46	4.52	4.88	5.18
ICSH 138	296A × (FLR 266 × CSV 4)-2-2-2-3-2	5.53	2.82	5.15	5.95	6.86	4.64	4.82	10.35	3.05	5.37	5.14
ICSH 173	296A × [(SC 108-3 × CSV 4)-14-1 × 1807B × (SC 108-3 × E 35-1)-5-1 × CSV 4]-3-4-4-4	5.68	2.16	7.14	5.00	6.68	4.35	4.12	9.07	3.35	4.73	4.92
ICSH 142	SPL 195A × (FLR 101 × IS 1082)-4-2	5.19	2.60	6.51	5.02	6.50	3.93	3.11	9.59	3.88	5.14	4.81
ICSH 180	D 3A × [(SPV 105 × SC 108-4-8) × CSV 4]-14-2-1	5.41	2.39	5.68	4.81	7.14	4.40	4.23	8.32	3.19	5.00	4.79
ICSH 155	MA 10 × (IS 12611×SC 108-3)-1-1-3	4.64	1.97	6.22	5.09	7.10	4.88	2.84	10.39	5.53	6.40	4.77
Controls												
ICSH 153 (CSH 11)	296A × (SC 108-3 × CSV 4)-27-2-1	5.37	2.84	5.51	4.79	7.92	3.84	3.09	9.60	3.38	5.37	4.91
CSH 9	296A × CSV 4	5.09	2.92	5.77	4.57	7.51	2.21	6.00	10.45	2.36	5.69	4.87
ICSV 112 (SPV 475)[3]	[(IS 12622C × 555)(IS 3612C × 2219B) -5-1 × E 35-1]-5-2	4.03	2.43	4.49	4.32	6.20	4.03	2.60	9.09	3.33	4.96	4.10
Local		4.95	2.50	4.00	3.62	5.41	3.13	4.73	8.64	4.01	5.14	4.41
SE		±0.19	±0.15	±0.61	±0.27	±0.49	±0.33	±0.80	±0.56	±0.61	±0.31	±0.11
Trial mean (25 entries)		5.16	2.53	5.93	4.94	6.60	3.90	4.38	9.12	3.81	5.29	4.80
CV(%)		10-24	12-31	18	14-14	13	14	32	11	28	10-15	10-32
Efficiency (%)		87-119	98-107	91	136-217	113	101	100	100	91	130-131	87-217

1. 5 × 5 lattice, plot size 3.5 m² in Venezuela and 12.0 m² at ICRISAT Center, India.
2. Locations:
   1 = India mean of eight tests: a) ICRISAT Center, Patancheru and b) Anantapur, Andhra Pradesh, c) Bhavanisagar, Tamil Nadu; d) Dharwad, Karnataka, e) Jalna, and f) Karad, Maharashtra; g) Pantnagar, Uttar Pradesh, h) Surat, Gujarat, 2 = Pakistan mean of four tests: a) Dadu, b) Bahawalpura, c) Yousufwala, and d) Islamabad; 3 = Manila, The Philippines; 4 = Thailand two tests a) Seikviw, and b) Suphanburi; 5 = Wad Medani, Sudan; 6 = San Salvador, El Salvador; 7 = El Zamorano, Honduras; 8 = Manfredi, Argentina; 9 = Palmira, Colombia; and 10 = Venezuela two tests: a) Chaguaramas and another location.
3. Variety control.

Figure 12. ICSH 120, an ICRISAT-bred sorghum hybrid that was selected from the International Sorghum Hybrid Adaptation Trial (ISHAT 85) on the basis of its yield stability and production across locations, ICRISAT Center, rainy season 1986.

the local control yielded 4.41 t ha^{-1}. Some of the selected hybrids showed resistance to downy mildew: ICSH 159, ICSH 138, ICSH 178, ICSH 142, ICSH 180, and ICSH 155 and anthracnose: ICSH 109, ICSH 110, ICHS 106, and ICSH 155.

Argentina reported the highest grain yields followed by Sudan, and The Philippines. The material was too late and tall for Argentina and Venezuela. Cooperators from Pakistan requested parental seed of ICSH 106, ICSH 133, ICSH 138, ICSH 145, and ICSH 153 (CSH 11).

West African Sorghum Variety Adaptation Trials (WASVAT-1 and -2)

We organized two regional variety trials—WASVAT-1 comprising 20 early-maturing entries and WASVAT-2 comprising 20 medium-maturing entries (including controls), contributed by the West Africa Regional Network, and the national sorghum improvement programs of Burkina Faso and Mali. Seed was dispatched to 11 cooperators in Benin, Burkina Faso, Cameroon, The Gambia, Ghana, Guinea Bissau, Mali, Niger, Nigeria, and Togo. Results received so far indicate that in addition to the hybrid control ICSH 153 (CSH 11) ICRISAT varieties ICSV 16-5 BF, ICSV 1055 BF, ICSV 197, ICSV 126, and ICSV 1056 BF performed well.

West African Sorghum Hybrid Adaptation Trial (WASHAT)

We supplied seed of WASHAT 86 to cooperators at 14 experimental stations in 8 countries —Burkina Faso, Cameroon, Ghana, Ivory Coast, Mali, Niger, Nigeria, and Togo. This trial included 32 test hybrids and four controls (early and late-maturing varieties). Current information indicates that the trial was carried out at all the locations. However, final results are yet to be received from many locations. At Nyankpala, Ghana, on average, the best early maturing variety control Naga White, yielded 3.15 t ha^{-1} while several hybrids yielded more than 4.00 t ha^{-1} (Table 18). Similarly at Farako-Ba, Burkina Faso, the best variety control, Framida, yielded 2.58 t ha^{-1} while several hybrids yielded more than 3.50 t ha^{-1}. At both these locations the trial was sown during the 2nd fortnight of July and rainfall during grain filling was nil at Nyankpala and minimal at Farako-Ba.

Seed Distribution

ICRISAT Center

In response to seed requests, we provided improved varieties, hybrids, parents, and resistant

Table 18. Mean grain yields (t ha^{-1}) of top-yielding entries in the West African Sorghum Hybrid Adaptation Trial (WASHAT), rainy season 1986[1].

Entry	Pedigree	Nyankpala	Farako-Ba	Kamboinse	Mean
ICSH 208	ICSA 3 x (SC 108-3 x CS 3541)-11-2-3 CSV 4	3.99	3.60	3.02	3.54
ICSH 230	ICSA 11 x [(SC 108-3 x E 35-1)]-2-2-1-1	4.32	3.26	3.09	3.56
ICSH 229	ICSA 11 x (SC 108-3 x CS 3541)-27-2-1	4.31	3.59	3.02	3.64
ICSH 109	296A x [(SC 108-3 x E 35-1) CSV 4]-2-2-1-1	4.83	2.40	2.46	3.23
ICSH 134	2219A x (UCHV 2(GG x 370)-4-2-3	3.14	3.36	2.71	3.07
ICSH 159	296A x (FLR 266 x CSV4)-4-3-2-1	3.73	3.27	2.58	3.19
ICSH 178	SPL117A x [UCHV 2(GG x 370)]-4-2-3	3.53	2.95	3.24	3.24
ICSH 336	ICSA 40 x (SC 108-3 x 148)-18-4-1	2.78	3.73	2.89	3.13
ICSH 331	ICSA 38 x (SC 108-3 x 148)-18-4-1	3.21	3.48	2.60	3.13
Control[2]	Improved variety	3.21	2.72	2.30	
SE		±0.34	±0.27	±0.34	
Site mean		3.34	2.73	2.38	
CV(%)		18	17	24	
Efficiency		105	170	106	

1. 6 x 6 simple lattice, plot size 7,5 m^2 at Nyankpala, Ghana; 16 m^2 at Farako-Ba and 15 m^2 at Kamboinse, Burkina Faso.
2. The control entry was variable with location, the highest yielding improved variety was considered, i.e., Naga White at Nyankpala, Framida at Farako-Ba, and ICSV 1002 BF at Kamboinse.

sources to our cooperators. By the end of November 1986 we had supplied 14254 samples of sorghum seed. In Asia, India received the maximum number of samples (15%) followed by Pakistan (6%). In Africa, 14% of the supplies were sent to Burkina Faso, and 6% to Zimbabwe. Of the total samples supplied, 56% were breeding material. These included: hybrids 34%, varieties 26%, population derivatives 10%, A and B pairs and R lines 9%, resistant sources 8%, and miscellaneous 13%. During Sorghum Field Days breeders from different national programs selected 450 hybrids, 50 varieties, 74 parents (A,B, and R), and one population.

West Africa

We supplied seed of 70 germplasm accessions, selected for disease resistance, adaptation to local conditions, and good grain quality, to eight national programs in West Africa. We also supplied seed of some A and B lines, elite varieties, and hybrids on request to the national programs of Ghana, Mali, Niger, and Sierra Leone. We supplied large quantities of seeds of our improved varieties ICSV 1002 BF and ICSV 1001 BF to researchers and preextension agencies in Benin, Burkina Faso, and Togo.

ICRISAT Cultivars Released or in Prerelease Stage

The ICRISAT-bred hybrid ICSH 153 (SPH 221) was formally released in India as CSH 11 by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties, Government of India, for cultivation in all areas where rainy-season sorghums are grown. Our postrainy-season hybrid, SPH 280, and a rainy-season variety, ICSV 112 (SPV 475) are being tested in All India Minikit Tests under farmers' field conditions. One midge-resistant variety,

Figure 13. ICSV 197, an ICRISAT-brcd sorghum variety that has been recommended by the All India Coordinated Sorghum Improvement Project (AICSIP) for on-farm trials in midge-endemic areas of Karnataka State, India, ICRISAT Center, rainy season 1986.

ICSV 197 (PM 11344) (Fig. 13) has been recommended by the All India Coordinated Sorghum Improvement Project (AICSIP) Workshop for on-farm trials in midge-endemic areas in Karnataka State. Nine of our varieties and nine hybrids are in various stages of testing by AICSIP. We are increasing the breeder's seed for the released variety ICSV 1 (CSV 11) and the restorer line MR 750 (male parent of CSH 11) to meet the requirements of the State and National Seeds Corporations in India.

Workshops, Conferences, and Seminars

India

Sorghum Field Days

We conducted separate Field Days at ICRISAT Center, Bhavanisagar, and Anantapur. The International Sorghum Field Day held at the Center on 16-17 September was attended by 14 scientists from India, 3 from Kenya, 1 from Burundi, and several in-service trainees from Africa and Asia who observed our experiments in the field. Seven scientists from Tamil Nadu attended the field day organized at Bhavanisagar, and 7 from Andhra Pradesh attended the one at Anantapur. Following the Field Days, we had useful discussions with the visiting scientists that lead to our identifying areas for possible cooperation with their national programs.

West Africa

First Meeting of the Advisory Committee of the West African Sorghum Research Network

This inaugural meeting was held at Ouagadougou, 11-13 January 1986. The Committee addressed issues on sorghum plant improvement which may help the national programs in the region. Figure 14 shows the Committee during their visit to Kamboinsfe Research Station.

Participants at the Second Workshop on Sorghum Research and Improvement in West Africa held in Bamako, 21-24 October 1985, voted in favor of holding the workshop every alternate year, and conducting group visits to national programs during the intervening years, preferably during the cropping season. Consequently, under the leadership of ICRISAT, a group of national researchers from Benin, Central African Republic, The Gambia, Mauritania, Nigeria, and Senegal visited national research programs in Cameroon, The Gambia, Nigeria, and Senegal from 23 September to 6 October,

Figure 14. Members of the Advisory Committee to the West Africa Sorghum Research Network with ICRISAT sorghum breeder (far right) looking at an off-season nursery during a visit to Kamboinse Research Station at the time of their first meeting in Ouagadougou, Burkina Faso, 11-13 January 1986.

1986. The visiting national scientists were able to exchange views on the sorghum production problems, and the on-going research programs in the countries visited.

Following another recommendation of the workshop that the researchers in national programs are made more aware of the research programs of international institutes, several researchers from national programs (Ghana, Guinea Bissau, Mali, Niger, and Sierra Leone) visited the research stations located at Kamboinse, Saria, and Farako-Ba in Burkina Faso during 13-16 October, 1986 to observe our breeding material, experimental varieties and hybrids, and male steriles, and to select material of interest to them. The visitors also had the opportunity to observe the Burkinabe national research effort on sorghum improvement.

Eastern Africa

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

This workshop was held at Bujumbura, Burundi 5-11 July 1986. There were 50 participants who came from Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. All the participants are active workers in sorghum and millet research and presented their research findings in different disciplines. Special papers on tannins, *Striga,* cropping systems, and drought were presented by members of US AID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA) (INTSORMIL) and ICRISAT. The major recommendations of the workshop were that: the regional network be given an identity—this has resulted in the formation of the Eastern Africa Regional Sorghum and Millet (EARSAM) Network; and an Advisory Committee should be formed to provide overall guidance for the networking activities.

The following common priority areas of research were identified:

- Breeding: Crop improvement for high and low altitudes.
- Agronomy: Soil and crop management, drought studies.
- Entomology: Stalk borer and shoot fly.
- Pathology: *Striga,* ergot, and grain mold control.

The proceedings of this meeting are available from the SAFGRAD/ICRISAT Regional Office, Nairobi, Kenya. The Sixth Regional Workshop will be held in Somalia in 1988.

As recommended during the fifth EARSAM workshop, the Advisory Committee members met in Ethiopia between 20 and 25 October, 1986 to provide overall guidance for networking activities, and to prepare long and short-term action plans based on research priorities of regional interest. Network research priorities for sorghum and millets, current status of research, and approaches to solve research problems were discussed.

Advisory Committee members visited lowland and highland breeding nurseries in Ethiopia, selected sorghum genotypes for their national programs, and identified 150 genotypes that will be included in the regional observation nurseries for 1987.

Southern Africa

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

This workshop was held at Lusaka, Zambia, 6-10 October 1986. The objectives were to discuss the results of last season's research and make plans for the next season for each member country in the SADCC region. Of the 60 participants, 20 were from the host country, and others came from Angola, Botswana, Lesotho, Swaziland, Tanzania, Zimbabwe, the donor agencies for the regional program, and scientists from ICRISAT Center and the SADCC/ICRISAT Regional Program, Bulawayo. Almost all the participants were actively involved in sorghum and millet research. Of the 35 papers presented by national representatives, 24 were on different aspects of sorghum and millet research in the SADCC region. Special topics covered by invited speakers included distribution and control of *Striga* spp of sorghum and pearl millet in the SADCC region; practices adopted by small farmers in the production of finger millet (*Eleusine coracana*); nutritional aspects of sorghum, and prospects for sorghum utilization.

The main activity of the SADCC/ICRISAT Program during 1986 included strengthening the national research capabilities by providing a short course and individual training to national scientists, technicians, and farm machinery operators at Matopos.

National Scientists from seven SADCC countries (Botswana, Lesotho, Malawi, Swaziland, Tanzania, Zambia, and Zimbabwe) along with scientists from ICRISAT Center and the SADCC/ICRISAT Regional Program visited Botswana, Lesotho, Swaziland, and Zimbabwe from 20-30 March 1986 on a monitoring tour to gain a better understanding of the research needs of sorghum and millet in the countries they visited. The multidisciplinary group spent time selecting material for use in their programs, identified pests and diseases, and scored trials for pest and disease incidence.

The main recommendations of the Workshop were to help strengthen the national programs by providing training in different aspects of crop production and protection. Steps should also be taken to assemble and document the traditional knowledge on processing sorghum and millet for human consumption, identify specific areas in crop production, protection, and utilization, and to invite specialists to address the participants at forthcoming workshops. The workshop recommended that scientists from the SADCC countries, ICRISAT Center, and regional programs should visit Zimbabwe, Zambia, and northern Malawi for the 1987 monitoring tour. The Fourth Regional Workshop will be held in Matopos, Bulawayo, Zimbabwe, in September 1987.

The proceedings of this meeting will be available from the SADCC/ICRISAT Sorghum and Millet Improvement Program, P.O. Box 776, Bulawayo, Zimbabwe.

Looking Ahead

ICRISAT Center

In population improvement for MFR we will recombine selected S_2s of the respective populations with the desirable segregants identified from F_2s of the resistant sources x B/MFR or sources x R/MFR or sources x 5BR/MFR base populations. More emphasis will be placed on screening these desirable segregants for resistances to various stresses and for good agronomic traits.

We will continue to develop new female parents for hybrid production. We will study more systematically the newly developed females for their combining abilities and adaptation to different seasons.

We will verify the reference nonmilo cytoplasm lines and further confirm the restoration observed in some germplasm lines.

We will composite a *Striga* asiatica-resistant population to strengthen its level of resistance, and improve it using recurrent selection methods.

The conversion of photoperiod-sensitive and tall landraces to day-neutral shorter plant types will continue with emphasis on guinea sorghums from West Africa and special-purpose landraces to diversify the genetic base of breeding material.

We will continue to study the underlying mechanisms associated with factors affecting seedling emergence and mid-season heat and drought stress. In collaboration with scientists at the Welsh Plant Breeding Station, Aberystwyth, UK we will increase our activity in the identification of enzymes and proteins associated with high and low temperature stress. Research on the problems of terminal stress will be increased.

We will continue to search for more efficient plant/VAM combinations in relation to phosphorus uptake by examining VAM colonization or VAM inoculation response at different locations.

We will initiate work on the establishment of the primary causal organisms of root and stalk rot diseases. We will increase our efforts to introduce grain mold resistance into elite breeding lines. We will complete studies on the inheritance of downy mildew disease, and initiate experiments to characterize factors associated with resistance. Resistance screening for anthracnose disease will be continued at Pantnagar. Studies on the variability of sorghum anthracnose pathogen will be completed.

We will make more crosses to improve the agronomic desirability of tall and loose-panicled white-grain, mold-resistant breeding lines by reducing their plant height and panicle laxity.

West Africa

Efforts to identify late-maturing (135 days) improved varieties suitable for the Northern Guinean Zone will be intensified. Female and male parents adapted to West Africa will be exploited to identify high-yielding hybrids suitable for different rainfall zones. In collaboration with national programs, germplasm and early segregating generation materials will be screened for resistance to stress factors in their respective hot-spot locations.

Eastern Africa

SAFGRAD/ICRISAT will continue to generate genotypes for the high, intermediate, and low agroecological zones.

The need to characterize the different sorghum-growing environments in the region is important. Agroclimatic data from each country in the region will be collated in order to group similar zones of adaptation.

New projects will be developed for resistance to drought, *Striga,* stem borers, ergot, and other yield-limiting factors. Hot spot locations will be identified where material can be screened for these factors.

Southern Africa

Country crossing blocks and regional cooperative trials will be organized; these will include selections made on monitoring tours of the SADCC countries in 1986. Emphasis will be placed on both variety and hybrid development.

Selected varieties and hybrids will be subjected to quality tests in the coming seasons. Sorghum collected in Zimbabwe and elsewhere in the region will be classified and evaluated for quality and acceptability of food traits. This is planned to be a joint project with the Food Science Department of the University of Zimbabwe. Attempts will be made to improve the genetic base and performance of locally adapted cultivars for drought tolerance. Several lines, with specific processing, beer, food, and feed quality traits are being evaluated for their grain utilization potential.

The pathologist will monitor diseases in the SADCC region and identify hot spot locations. He will adapt and develop screening techniques, identify sources of resistance, and attempt to incorporate these traits into high-yielding varieties and hybrids.

Publications

Institute Publications

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A. P. 502 324, India: ICRISAT. ISBN 92-9066-111-9. (CPE 037)

Journal Articles

Agrawal, R.P., Jhorar, B.S., Maiti, R.K., Raju, P.S., and Peacock, J.M. 1986. Effect of soil crusting on seedling emergence in sorghum genotypes. International Journal of Tropical Agriculture 4(1): 15-22. (JA 310)

Bandyopadhyay, R. 1986. Sooty stripe. Pages 13-14 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 539)

Bandyopadhyay, R. 1986. Rust. Pages 23-24 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 545)

Bandyopadhyay, R. 1986. Grain mold. Pages 36-38 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 546)

Giller, K.E., Wani, S.P., and Day, J.M. 1986. Use of isotope dilution to measure nitrogen fixation associated with the roots of sorghum and millet genotypes. Plant and Soil 90:255-263. (JA 493)

Jambunathan, R., Butler, L.G., Bandyopadhyay, R., and Mughogho, L.K. 1986. Polyphenol concentrations in grain, leaf, and callus tissues of mold-susceptible and mold-resistant sorghum cultivars. Journal of Agricultural and Food Chemistry 34(3):425-429. (JA 520)

Jordan, W.R., and Peacock, J.M. 1986. Water and temperature stresses. Pages 59-60 *in* Compendium of sorghum diseases (Fredericksen, R.A., ed.) St. Paul, Minnesota, USA: American Phytopathological Society.

Mughogho, L.K. 1986. Oval leaf spot. Page 15 *in* Compendium of sorghum diseases (Frederiksen, R. A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 544)

Mughogho, L.K. 1986. Loose kernel smut. Pages 18-21 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 542)

Mughogho, L.K. 1986. Ergot. Pages 39-40 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 543)

Pande, S. 1986. Charcoal rot. Pages 29-30 *in* Compendium of sorghum diseases (Frederiksen, R. A., ed.). St. Paul, Minnesota, USA: American Phytopathological Society. (JA 541)

Taneja, S.L., and Leuschner, K. 1986. A simple trap for monitoring sorghum shoot fly. Indian Journal of Plant Protection 14(l):83-86. (JA 413)

Taneja, S.L., Seshu Reddy, K.V., and Leuschner, K. 1986. Monitoring of shoot fly population in sorghum. Indian Journal of Plant Protection 14(2):29-36. (CP 310)

Vasudeva Rao, M.J. 1986. Witch weed, *Striga* spp. Pages 54-56 *in* Compendium of sorghum diseases (Frederiksen, R.A., ed.) St. Paul, Minnesota, USA: American Phytopathological Society. (JA 540)

Vasudeva Rao, M.J., Raghavender, B., and Mukuru, S.Z. 1986 Physiological specialization in *Striga asiatica* (L.) Kuntz with reference to parasitization on sorghum, *Sorghum bicolor* (L.) Moench. Cereal Research Communications 14(2): 185-190. (JA 573)

Conference Papers

Agrawal, B.L., Sharma, H.C., Abraham, C.V., and Vidyasagar, P. 1986. Screening and breeding sorghum for midge resistance. Pages 7.1-7.9 *in* Proceedings of the First Australian Sorghum Conference, 4-6 Feb 1986, Gatton, Queensland, Australia. Gatton, Queensland, Australia: Organizing Committee of the Australian Sorghum Conference. (CP 231)

Krishna, K.R. 1986. Vesicular-arbuscularmycorrhiza for efficient use of fertilizer phosphorus. Pages 167-177 *in* Soil biology: proceedings of the National Symposium on Current Trends in Soil Biology, 25-27 Feb 1985, Hisar, Haryana, India. Hisar, Haryana, India: Haryana Agricultural University. (CP 253)

Sharma, H.C., and Leuschner, K. 1986. Mechanisms and diversity of resistance to the sorghum midge, *Contarinia sorghicola* Coq. Pages 3.8-3.19 *in* Proceedings of the First Australian Sorghum Conference, 4-6 Feb 1986, Gatton, Queensland, Australia. Gatton, Queensland, Australia: Organizing Committee of the Australian Sorghum Conference. (CP 233)

Soman, P., Bidinger, F.R., and Jayachandran, R. 1986. Evaluation of genotypic differences in seedling emergence through soil crusts under field conditions. Pages 270-277 *in* Assessment of soil surface sealing and crusting: proceedings of the Symposium, 23-27 Sep 1985, Ghent, Belgium. Ghent, Belgium: Flanders Research Centre for Soil Erosion and Soil Conservation. (CP 220)

Soman, P., Jayachandran, R., and Peacock, J.M. 1986. Genotypic variation in sorghum for seedling emergence under conditions of high soil temperature and surface crusting. Pages 5.30-5.37 *in* Proceedings of the First Australian Sorghum Conference, 4-6 Feb 1986, Gatton, Queensland, Australia. Gatton, Queensland, Australia: Organizing Committee of the Australian Sorghum Conference. (CP 250)

Wani, S.P. 1986. Nitrogen fixation associated with cereals and forage grasses. Page 227-240 *in* Soil biology: proceedings of the National Symposium on Current Trends in Soil Biology, 25-27 Feb 1985, Hisar, Haryana, India. Hisar, Haryana, India: Haryana Agricultural University. (CP 229)

Wani, S.P. 1986. Measurement of nitrogen fixation. Pages 215-218 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India. (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.). Hisar, Haryana, India: Haryana Agricultural University. (CP 236)

Wani, S.P. 1986. Cereal nitrogen fixation: problems and potentialities. Pages 7-22 *in* Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 258)

Wani, S.P. 1986. Research on cereal nitrogen fixation at ICRISAT. Pages 55-68 *in* Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 259)

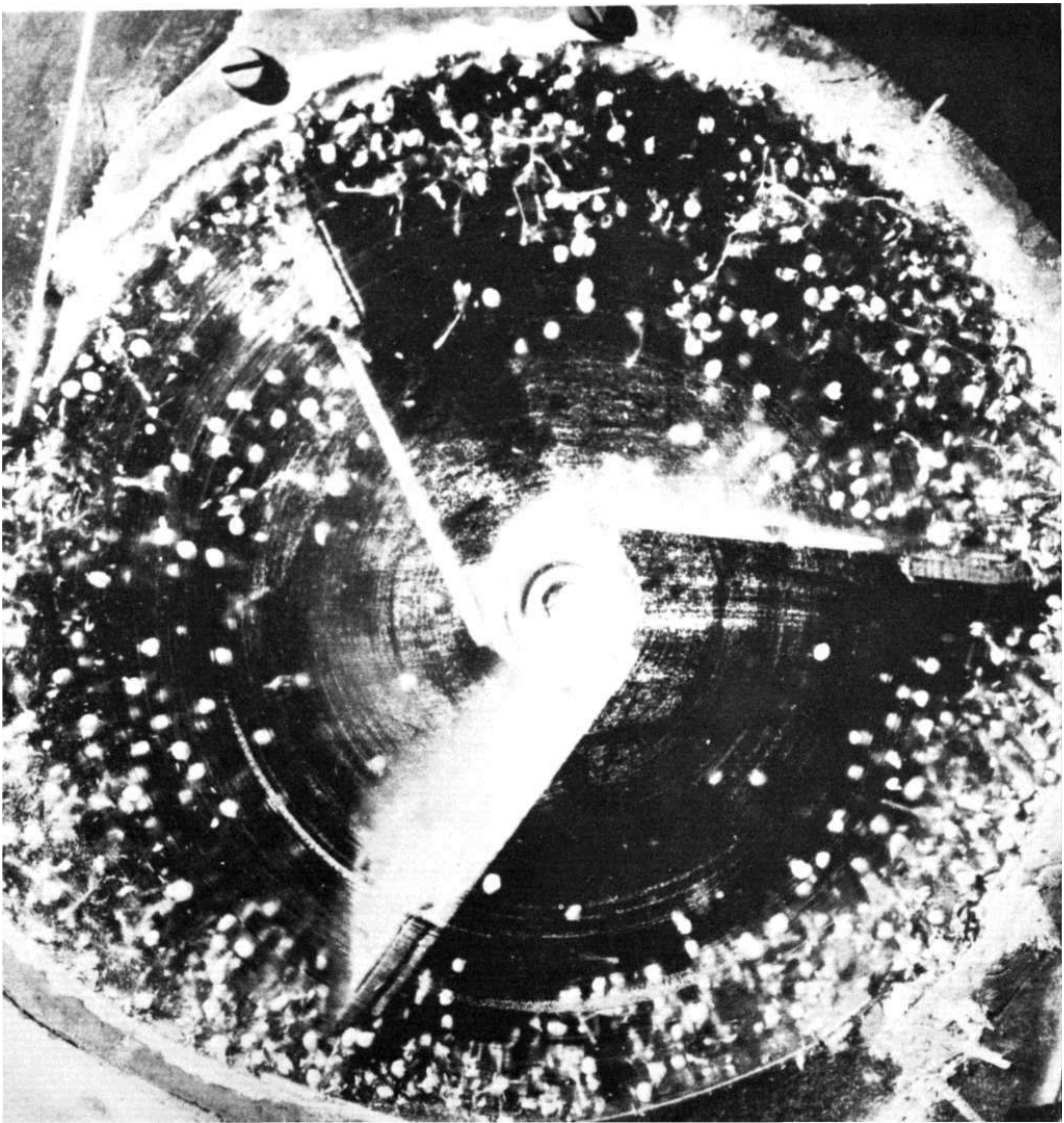
Wani, S.P., and Lee, K.K. 1986. Developments in nonlegume N_2-fixing systems. Pages 163-166 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India. (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.). Hisar, Haryana, India: Haryana Agricultural University. (CP 235)

Thesis

Hashi, M.A. 1986. Effect of recurrent selection on general and specific combining abilities of two random-mating sorghum populations (*Sorghum bicolor* L. Moench). M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 85 pp.

CEREALS

PEARL MILLET



Contents

Cover photo: Pearl millet panicle inside the drum of a single-head threshing machine, ICRISAT Center, 1986.

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PEARL MILLET

The Pearl Millet Annual Report for this year contains a new section—Cooperation with National Programs. In this section, we have drawn together the various support and collaborative functions which all ICRISAT pearl millet programs provide to national programs in some 25 countries of Africa and Asia. These activites include: 1. the continuing supply of a wide range of breeding material, from breeding lines with new genetic variation to open-pollinated varieties or hybrids ready for immediate testing in national trials; 2. organization of joint yield trials with national programs, designed to identify the best available material for national or regional use; 3. organization of international/ regional disease resistance nurseries designed to identify stable, reliable sources of disease resistance for use by national program scientists; and 4. the production of breeder seed of ICRISAT-bred varieties and hybrids to be multiplied by public and private seed production agencies for direct supply to farmers. This cooperative area of ICRISAT's work on pearl millet will continue to expand as we breed or identify more genetic material of use to national programs. This cooperation is strengthened by our regular program of workshops, scientists'field days, and training provided to national program scientists, and in 1986 by the second International Pearl Millet Workshop held at ICRISAT Center in April.

We have also strengthened collaboration among our own millet programs at ICRISAT Center, ICRISAT Sahelian Center (ISC), and the Southern African Development Coordination Conference (SADCC)/ICRISAT regional program centered in Zimbabwe, by establishing collaborative research projects and by better organizing the exchange of genetic materials and scientists between programs. The best material from the SADCC/ICRISAT program and the ICRISAT Center advanced trials will now be sent to the ISC each year for preliminary evaluation of seedling establishment ability in the harsher Sahelian conditions. Those entries that are selected will be included in two Initial Variety/Hybrid Trials conducted by ISC scientists. Only the best entries from these trials will then go to national programs. This preliminary evaluation at ISC will assure that the time of national program scientists is not spent growing trials which often contain much nonadapted material. At the same time, it will assure that national programs do have regular access to new material of potential value to them.

To make materials from ICRISAT Center and ISC available to SADCC national programs, a similar scheme has been established. After initial evaluation of these materials for agronomic and/or resistance traits by SADCC/ ICRISAT program scientists the best entries will move to national programs via a Pearl Millet Introduced Varieties Trial, or as breeding stocks.

Both ISC and the SADCC/ICRISAT program will, in turn, increase the flow of promising varieties and breeding materials to the ICRISAT Center program. These will be evaluated and used primarily in the genetic diversification project, assuring a flow of elite African germplasm into the Center program's breeding projects. This should, in time, increase the adaptation of ICRISAT Center varieties to conditions in both the Sahelian and southern African millet-growing areas.

This year, the All India Coordinated Millet Improvement Project (AICMIP) released two ICRISAT hybrids for general cultivation in India, the first ICRISAT pearl millet hybrids to be so recommended. Both are on ICRISAT male-sterile lines, indicating that the greater investment in breeding for male steriles made several years ago is now paying dividends. A more encouraging pay-off to national programs (other than the release of ICRISAT's hybrids) has been the widespread use of ICRISAT's new male-sterile lines by public and private sector breeders in India to produce their own hybrids.

Physical Stresses

Crop Establishment

Evaluation of Seedling Emergence

Seedling emergence rates in pearl millet are typically low, whether measured in farmers' fields (ICRISAT Annual Reports, 1981, pp. 59-61, and 1985, pp. 84-85) or in well-managed research station fields. Although the rates are higher in the latter case (Table 1), they are still well below what would be expected, assuming both good seed and good sowing techniques and conditions.

Poor emergence rates are not generally explainable by standard laboratory germination test results. Correlations of emergence and laboratory germination are often very low; on an average germination percentage accounted for less than 35% of the variation of field emergence for the data reported in Table 1. For seed collected from farmers' fields, standard germination tests were particularly poor in predicting field emergence; being able to account for only 2 to 10% of the variation in field emergence.

Table 1. Pearl millet seedling emergence rates in various studies, India and Niger, 1981-86.

	Seedling emergence (%)		
Study/ Experiment	Mean	Variance[1] (SD^2)	Range
Farmers' fields (20)			
Sikar, India, 1983	11	123	2- 37
Farmers' fields (23)			
Niamey, Niger, 1985	29	419	8- 94
ICRISAT Center, field			
Composite progenies, 1982			
NEC (512)	36	219	11- 62
SSC (343)	40	264	13- 72
D_1C (513)	30	177	8- 63
D_2C (125)	32	216	9- 92
ICRISAT Center, greenhouse			
Composite progenies, 1986			
MC (1000)	68	168	2-100
IVC (200)	60	224	0-100
NELC (765)	66	150	0- 98

1. Of individual field or progeny means as appropriate.

We have devised a simple greenhouse test that gives better prediction of potential field emergence. In this test, 10-cm diameter pots are filled to within 5 cm of the top with a very sandy Alfisol and placed on a capillary matting. This is a felt-like material that when wet, distributes moisture evenly over its surface, and supplies water by capillary action to the soil in the pots, through the holes in the bottom of the pots. After the soil is wetted, 20 seeds of each entry are placed on the surface and covered with 3 cm of dry soil. This upper layer wets rapidly from moisture supply above and below the seed without any compaction of the soil. Seedlings emerge within 3 days and are counted on the 5th day after sowing (DAS). Mean rates of emergence in this test are considerably higher than those in the field (Table 1) but still well below 100%.

We evaluated this greenhouse test for its ability to predict field emergence in a set of 200 composite progenies. We sowed individual progenies in pots in the greenhouse as described above and in a sandy Alfisol field with a precision planter in October 1985, when soil temperatures were moderate (28.0±0.7°C). The field was regularly irrigated with sprinklers to maintain adequate soil moisture (14.5±1.5% in the 0-10 -cm profile) for germination and emergence.

The greenhouse emergence predicted 67% of the variation in field emergence at normal, 3-cm sowing depth and 64% of the variation at a deeper, 8-cm sowing depth. Emergence from 8 cm deep was 29%, less than the 34% from 3 cm, but is within the range of normal sowing depths found on farmers'fields. In comparison, laboratory germination percentage for the same set of lines accounted for only 45% variance of field emergence from both 3-cm and 8-cm sowing depths.

We are now using this simple greenhouse test to discard composite progenies with poor emergence before these are sown in the field for agronomic evaluation. This procedure will not only improve the efficiency of progeny testing, and possibly allow some saving of seed (by allowing reduction in sowing rates), but may also provide a simple, efficient method of selecting for improved emergence ability in the composites. Heritability estimates of emergence calculated from within and between family mean squares on one set of 1000 S_1 progenies that had a range of emergence from 2 to 100% (based on 60 seeds), indicated that emergence ability is highly heritable (h^2 = 0.49 ± 0.049). However, this is an upper limit to the h^2 as environmental as well as genetic causes were responsible for the similarity within families.

Seedling Establishment under Drought Stress

We continued research at ISC on the refinement and use of a simple field screening method for evaluating drought resistance during the seedling establishment phase (seedling survival), using two water levels, a regularly irrigated control and a nonirrigated stress treatment, (ICRISAT Annual Report 1985, p. 87).

Using this method we evaluated the seedling drought resistance of 25 genotypes, largely breeding materials of Sahelian origin, on two occasions between February and April 1986. All genotypes had seedling survival percentages greater than that of the susceptible control, MBH 110 (Figure 1a and 1b), and in the second test some were better than the resistant control, Sadore Local (Figure 1b). This was not the case for 15 breeders' lines from the Sudanian Zone, selected in a much more favorable crop establishment environment at Samaru, Nigeria. All had lower seedling survival percentages than the resistant control, although some were not significantly lower in the second test (Figure 1c and 1d). These results again highlight the need to screen all breeding selections for seedling survival, to eliminate lines that have poor seedling establishment in the drier Sahelian Zone.

We compared the seedling survival percentages estimated on the two occasions for each trial (i.e., Figure 1a vs. 1b and 1c vs. 1d), to evaluate the repeatability of the results. Percentage survival, the main criterion for selection, was reasonably repeatable ($r = 0.60$, $P < 0.01$; and $r = 0.59$, $P < 0.05$). The most resistant and susceptible lines maintained their ranks, whereas there was some change in rank for the middle-order genotypes. We will attempt, in future tests, to improve the repeatability of the evaluation by using insecticides to reduce seedling damage caused by soil insects, and by sowing on ridges instead of on the flat to reduce the problem of differences in sowing depth and the damage to seedlings from blowing surface sand.

In another screen we tested 18 entries, selected for tolerance to end-of-season drought, for resistance to seedling drought stress. Percentage survival of all entries was less than the resistant control, underlining the need to consider droughts that occur at different physiological stages of crop growth as separate problems, and to develop drought-screening techniques suitable for each of these stages.

Drought Stress

Selection for Drought Tolerance

We have earlier reported a procedure for estimating genotype drought response (ICRISAT Annual Reports 1978-79 pp. 66-68, and 1982 pp. 65-66). This method considers the residual variation in grain yield under stress (after the effects of yield potential and drought escape on yield under stress have been removed) as an estimate of drought response. Where this residual drought response index (DRI) is positive—i.e., the actual yield under stress is greater than that expected from the effects of drought escape and yield potential—a genotype is considered to be tolerant to stress. We are now concentrating on looking for genotypic traits associated with a high, positive DRI that could be used as selection criteria in a breeding program for drought tolerance.

Since pearl millet genotypes can have considerable variation in yield component arrangement (i.e., panicles $plant^{-1}$, grains $panicle^{-1}$, etc.), at a similar grain yield level, we initially determined if there was any advantage in one yield component structure over another under drought stress. If so, selection for genotypes adapted to stress could be considerably simplified. We

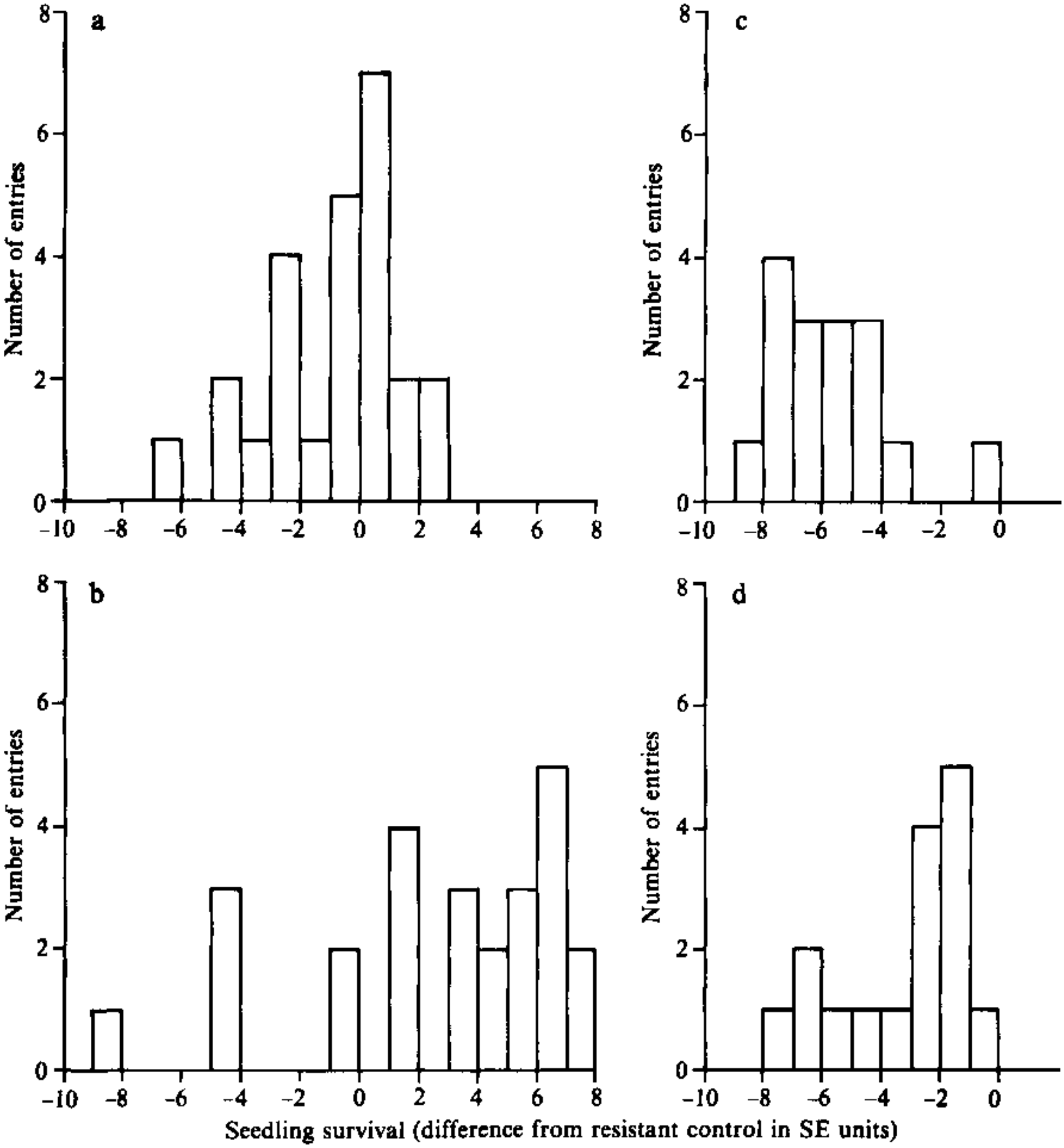


Figure 1. Seedling survival distributions from repeated tests of 25 pearl millet breeding lines of Sahelian origin (a, b) and 16 breeding lines of Sudanian origin (c, d). Data are expressed as differences from the resistant control (Sadore Local) in multiples of the SE. ISC, Sadore, Niger 1986.

determined this by correlating DRI with yield components both in the absence of stress (irrigated control) and the terminal stress treatments. There were no significant associations between DRI and yield component structure measured in the irrigated treatment, suggesting no a priori advantage under stress to any yield structure.

When we repeated the correlations of DRI and yield components measured in the stress (reflecting the effects of stress on yield component expression), a number of significant relationships emerged (Table 2). DRI was generally more highly correlated to grain number unit area^{-1} than to individual grain mass, although individual grain mass (which was entirely determined during stress) was significantly correlated to DRI in 4 out of 6 years. The component of grain number unit area^{-1} most closely related to DRI was grain number panicle^{-1}, which suggests a better ability to set grains under stress in tolerant genotypes. However, the best predictor of DRI was grain yield panicle^{-1}, which represents an integrated evaluation of the ability to both set (grain number) and fill (grain mass) grains under these conditions (Figure 2).

It is quite logical that better grain setting or grain filling should be an expression of tolerance to drought occurring at and after flowering, as these are the major developmental/growth processes occurring during this time and are clearly closely related to grain yields produced under stress. We also considered two alternative ways of expressing such tolerance: grain yield panicle^{-1} as a proportion of that in the nonstressed control (to allow for inherent differences in panicle size) and threshing percentage, i.e., the ratio of grain to total panicle mass (which expresses the proportion of potential panicle yield realized). Neither was better correlated to DRI than grain

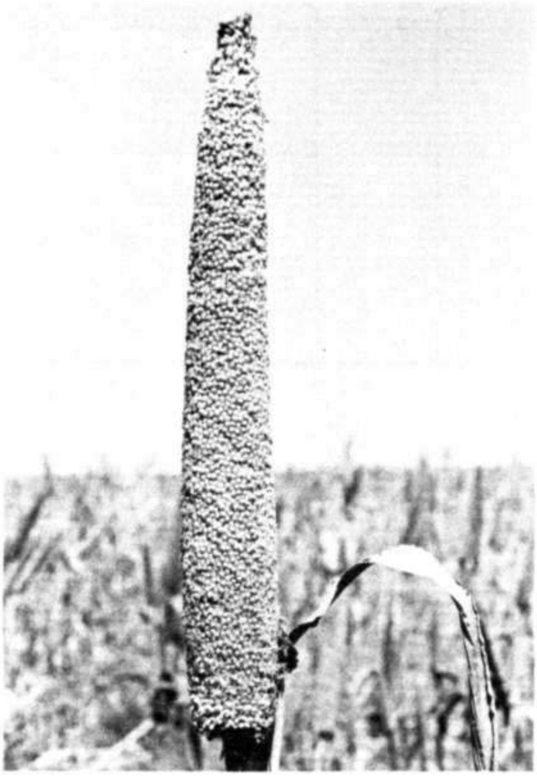


Figure 2. Pearl millet panicle with complete grain set and relatively good grain filling, despite drought during flowering and grain filling, as evidenced by its incomplete emergence from flag leaf sheath, ICRISAT Center, dry season 1986.

Table 2. Correlations of drought response index (DRI) and yield components measured in the terminal stress treatment. Data from pearl millet advanced drought trials, ICRISAT Center, 1981-86.

	Correlation coefficient					
Yield component	1981	1982	1983	1984	1985	1986
Grains m^{-2}	0.46***	0.45***	0.58***	0.26	0.59***	0.30***
Panicles m^{-2}	0.10	0.06	0.33**	0.06	0.14	0.13
Grains panicle^{-1}	0.53***	0.37***	0.26*	0.57***	0.41***	0.42**
Individual grain mass	0.25*	0.40***	0.01	0.50***	0.07	0.26**
Grain yield panicle^{-1}						
Stress	0.69***	0.58***	0.28*	0.72***	0.35**	0.65***
Stress/control	0.44***	0.51***	0.28*	0.68***	0.43***	0.35***
Threshing (%)	0.43***	0.59***	0.45***	0.65***	0.44***	0.39***
No. of trial entries	72	72	72	54	90	81

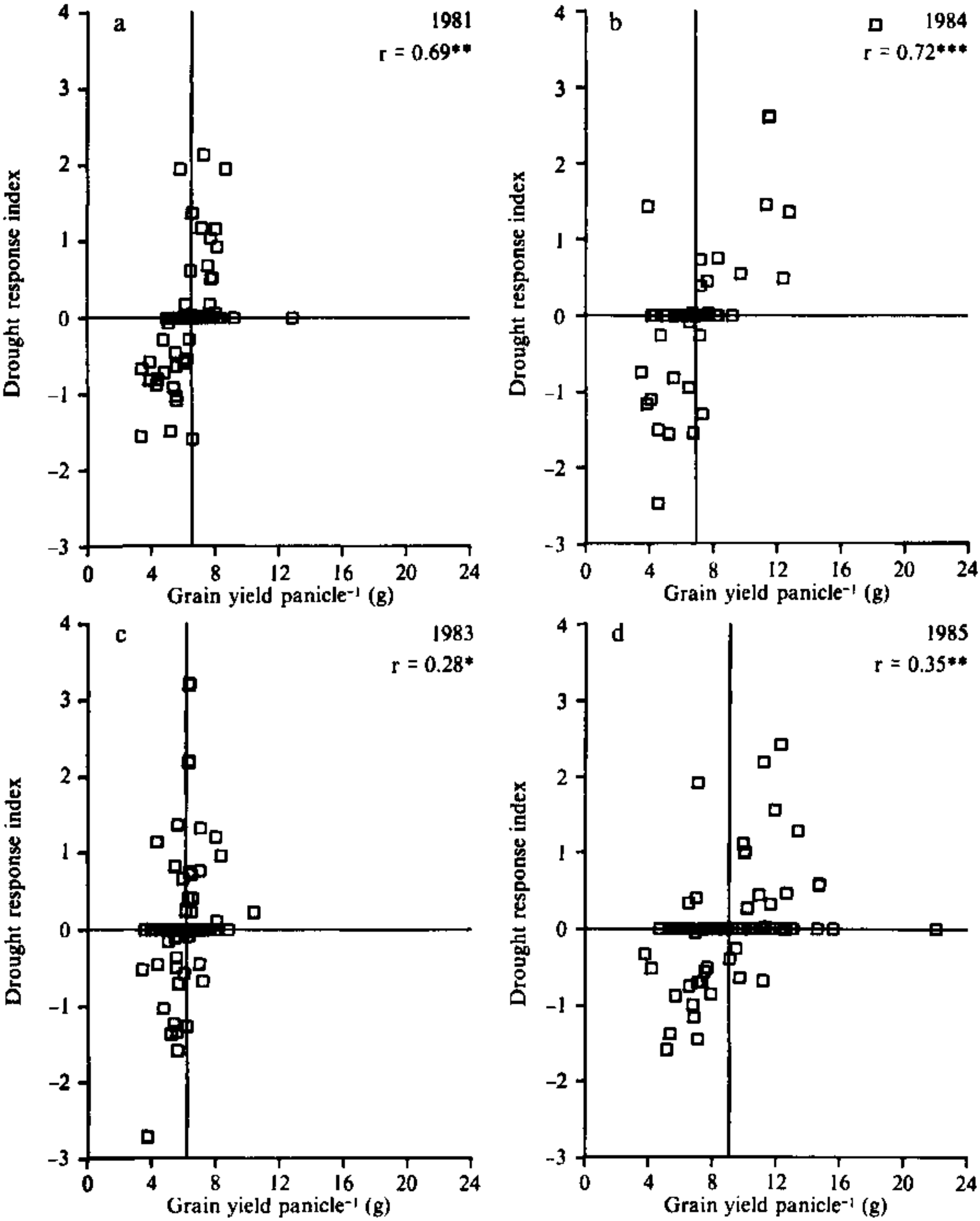


Figure 3. Relationship between individual pearl millet genotype grain yields panicle^{-1} (g) under terminal drought stress, and genotype drought response index. Vertical lines represent the mean grain yield panicle^{-1} from the experiment. Data are for the years with the highest (a, b) and lowest (c, d) correlations of the two variables (Table 2), ICRISAT Center, dry seasons 1981-86.

yield panicle^{-1} alone (Table 2). Since both require extra measurements, they have no advantage over grain yield panicle^{-1}.

In 4 of the 6 years the relationship between DRI and grain yield panicle^{-1} in the stress treatment was strong enough to consider yield panicle^{-1} as a selection criterion for DRI (r = 0.58 to 0.72, P< 0.01, Table 2). Selection of materials with grain yield panicle^{-1} exceeding the population mean value in each of these years would have selected nearly all of the lines with a positive DRI and very few with negative DRI (Figure 3a and b). Similar selection in the 2 years with lower correlations of DRI and grain yield panicle^{-1} (r = 0.28 to 0.35, P< 0.05) would still have been effective in selecting the majority of lines with positive DRI (Figure 3c and d). Grain yield panicle^{-1} may thus be an effective selection criterion for tolerance to terminal stress.

We are currently testing this hypothesis in two populations (Early Composite, EC II and Bold Seeded Early Composite, BSEC). During the 1986 dry season, we grew 900 S_1 progenies of EC II in a replicated trial in the irrigated and terminal stress treatments in the drought nursery. Grain yield panicle^{-1} in the absence of stress ranged from 4 to 21 g, with a modal class (n = 234) of 10-12 g. The progenies in this modal class had grain yields panicle^{-1} ranging from 1 to 10 g in the terminal stress treatment, with only small effects of drought escape (r = 0.03 NS) or panicle number (r = 0.23, P<0.01) on grain yield panicle^{-1}. This broad range in grain yield panicle^{-1} and its effective independence from the two factors just cited, suggest that differences in drought response exist among progenies in this population.

We will use grain yield panicle^{-1} under terminal stress as one of the criteria to select progenies for recombination of the composites for the next cycle of selection and to produce varieties for multilocational testing. We will repeat this process for at least three cycles of selection and then evaluate the performance of both cycle bulks and varieties under terminal stress, for changes in both grain yield and drought resistance (DRI), to assess the effectiveness of successive cycles of selection for better grain yield panicle^{-1} under stress.

Biotic Stresses

Foliar Diseases

Downy Mildew (*Sclerospora graminicola*)

Virulence studies. In a collaborative project with the University of Reading, UK, we expanded research on the virulence of *S. graminicola* to include new collections of the pathogen from Mali, Niger, Nigeria, and Senegal, and for the first time, collections from southern Africa. The reactions of several pearl millet lines and cultivars to these collections, and to those obtained earlier from India, again showed that collections from the eastern and central parts of West Africa are more aggressive than those from Senegal or India. There were no remarkable differences in virulence among collections from Mali, Niger, and Nigeria. We did, however, find virulence differences among collections from Senegal and southern Africa. For example, the line 700546 was resistant to all isolates from these areas, except to one isolate from Zambia. Similarly, cultivars BK 560, MBH 110, and ICMV 4 (ICMS 7703) were resistant to all collections of *S. graminicola* tested from Zambia and Zimbabwe, except one sample from Zambia to which they were moderately susceptible. These findings emphasize the importance of thoroughly testing cultivars for their reaction to the downy mildew (DM) pathogen as it exists in the areas where they might be grown by farmers.

We found qualitative differences among the *S. graminicola* collections studied at the University of Reading in the type of DM symptoms produced on cultivar BJ 104. Collections from India and African countries generally produce a high frequency of stunting and low sporulation in DM-infected plants of BJ 104. However, one *S. graminicola* collection from Zambia produced a high frequency of plants with normal DM symptoms.

Recovery from downy mildew. We identified and studied a previously unreported type of response to DM in which seedling plants that exhibit DM symptoms subsequently outgrow

Table 4. Downy mildew (DM) incidence and recovery in pearl millet genotypes through three generations of selection (S_1 to S_3) for the recovery trait, ICRISAT Center, 1984-1986.

Genotype	S_0[1] Number of plants	S_0 DM (%)	S_0 Recovery (%)	S_1 Number of selected progenies	S_1 Mean DM (%)	S_1 Mean recovery (%)	S_2 Number of selected progenies	S_2 Mean DM (%)	S_2 Mean recovery (%)	S_3 Number of selected progenies	S_3 Mean DM (%)	S_3 Mean recovery (%)
ICMA 1 (81A)	181	9	27	8	52(41-65)[2]	60(52-80)	10	58(35-70)	74(46-97)	16	56(18-93)	84(52-92)
841 A	147	25	30	5	48(36-75)	57(37-80)	10	68(52-80)	80(41-94)	10	62(26-90)	90(42-96)
SDN 503-2	86	29	36	10	48(25-65)	61(39-90)	7	68(53-81)	76(64-88)	19	66(32-88)	74(33-97)
P 1449	96	33	40	7	48(25-65)	61(39-90)	9	25(8 -50)	66(50-90)			
Susceptible control												
NHB 3	170	88	0		82	0		79	0		92	0

1. S_0 generation inoculated as seedlings in the greenhouse; S_1 to S_3 generations sown in the DM nursery.
2. Numbers in parentheses indicate range in progeny means.

the disease. This phenomenon, which we call 'recovery' is expressed in two ways: 1. in main shoots, where symptom-free new leaves and panicles form after one or more early formed leaves show DM symptoms, and 2 in secondary shoots, where symptom-free basal shoots arise from plants showing DM symptoms on the main shoot. Prior to discovery of the recovery phenomenon, it was generally believed that once systemic DM symptoms appear on a plant all leaves and panicles appearing thereafter will show systemic infection symptoms.

The recovery resistance trait is probably widespread in pearl millet, since we found it in 28 of the 33 genotypes examined, although the frequency of occurrence varied considerably among genotypes (Table 3). Furthermore, the trait was expressed at all three locations where it was tested in India and was also observed in Mali and Niger. Both sexual and asexual sporulation are generally reduced in infected tissues of plants that recover, compared to infected tissue of plants that do not recover. After recovery, new infection symptoms rarely develop, even following injection of a sporangial suspension into the growing point or after plants are cut back to encourage fresh tillering. This suggests that recovery may also involve a degree of acquired immunity. The recovery trait also appears to be heritable as we were able to increase its frequency by pedigree selection (Table 4).

We believe recovery resistance might be an effective defense mechanism to be exploited in at least some DM-resistance breeding activities, but this needs further examination.

Resistance screening. Each year, pathologists and breeders at ICRISAT Center screen several thousand early to advanced lines and populations, in the DM nursery, and we are now increasing the amount of material we screen in the greenhouse. Breeding material gives us a vast source of DM resistance in agronomically sound material. We are therefore now screening few genetic resources accessions because often these are not agronomically useful.

We have started a program at ICRISAT Center to improve the level of DM resistance in 12

Table 3. Downy mildew incidence and recovery reaction of selected pearl millet genotypes, greenhouse test, ICRISAT Center, 1984-86.

Genotype	Origin	No. of plants inoculated	Downy mildew incidence (%)	Recovery[1] (%)
Accessions				
P 8830-2	Zimbabwe	32	9	67
ICML 15 (700516)	Nigeria	24	17	50
IP 1930-7	India	117	14	44
P 3281-1	Togo	34	20	41
E 298-2-1-8	India	137	18	40
SDN 503-2	Nigeria	86	29	36
EB 83-2-4	India	68	82	25
700512-3	Nigeria	125	20	24
P 43-1	Cameroon	30	30	22
P 1449-2	Senegal	96	33	22
ICML 16(700651)	Nigeria	96	9	22
MPP 7147-2-1-8	India	48	42	20
J 1593	India	32	34	18
P7	Mali	325	4	17
P 310-1	Mali	34	27	11
IP 3646-1	India	29	34	3
7042	Chad	215	84	1
Advanced breeding lines				
841A	India	147	25	30
5141A	India	87	77	28
ICMA 1 (81A)	India	181	13	27
ICMA 3 (842A)	USA	139	13	*11*
ICMA 4 (834A)	India	297	38	10
111A	India	155	9	9
ICMP 84814	India	220	22	2
Tift 23A	USA	140	92	0
ICMA 2 (843A)	USA	212	72	0
833A	India	224	5	0
J 104	India	205	97	0[2]
Varieties and hybrids				
ICMH 84814	India	149	31	39
BJ 104	India	68	83	25
ICMV 1 (WC-C75)	India	347	15	22
ICMV 4 (ICMS 7703)	India	286	25	8
NHB 3	India	170	88	0

1. Recovery is based on the number of infected plants. The majority of plants that did not show recovery died within 30 DAS.
2. Data from field screening, 1982.

varieties derived from four breeding composites. We assessed S_2 and S_3 progenies during 1986 for both DM resistance and agronomic traits, and selected approximately 1500 single plants for DM resistance, earliness, tillering, and panicle type.

In Niger, our best location for screening for DM resistance is currently at the Institut national de recherches agronomiques du Niger (INRAN) station at Bengou, where we sowed five trials and nurseries that included a total of 315 entries. We also evaluated three nurseries from ICRISAT Center. Some entries showed a high level of resistance and the standard control NHB 3, that is not so susceptible in Niger as it is at ICRISAT Center, had 10 to 30% DM infection. We hope to be able to improve DM screening at Bengou in 1987 by introducing sprinkler irrigation to increase relative humidity (RH) during dry periods.

Utilization of resistance. We are transferring DM resistance to selected pollinators and male-sterile lines from three sources of stable resistance, ICML 12 (P7), ICML 16 (700651), and ICML 13 (SDN 503). We hope that this will produce hybrid parents and hybrids with more stable DM resistance.

Rust (*Puccinia penniseti*)

Plant age and susceptibility. We initiated a field experiment to study the relationship between host stage of development and susceptibility to rust. At ICRISAT Center, we sowed three rust-susceptible cultivars five times, at intervals of 15 days during the late rainy and early postrainy seasons. As the natural incidence of rust is usually highest during the winter months (November-January), the staggered sowings exposed plants of different maturities to high levels of rust pressure. We assessed plots for rust development at 15-day intervals from the seedling stage to maturity. There was a general increase in rust severity with increase in plant age, with a dramatic increase in severity after flowering. These results agree with earlier observations, and they emphasize the importance of evaluating materials for rust reaction at similar stages of host maturity.

Resistance screening. We screened about 1100 entries consisting of genetic resources accessions, breeding materials, and lines previously evaluated for rust under natural disease pressure at Aurangabad, Bhavanisagar, ICRISAT Center, and Mysore. A large number of entries, including breeding materials with resistance based on a single dominant gene from ICML 11 (IP 2696-1-4), remained rust free or had less than 10% infection. Many of these entries are agronomically good. We completed the second backcross to incorporate a single dominant gene for rust resistance into the popular male-sterile line, ICMA 1 (81 A).

Rust appears to be important in localized areas of the SADCC region. We found varying reactions among entries screened from Brazil, India, Nigeria, Senegal, Sudan, and Zimbabwe, with those from Nigeria that had a high frequency of susceptibility. Two lines, ICML 11 (IP 2696-1-4) and P 1564, that are highly resistant to rust in India were also highly resistant in the SADCC region.

False Mildew (*Beniowskia sphaeroidea*)

Reports of the false mildew disease have generally been limited to southern and eastern Africa; we found it in Malawi, Tanzania, Zambia, and Zimbabwe in 1986. In a multilocational, regional nursery, we found reaction to false mildew consistent across two locations, with 7042 DMR and ICMPS 1500-7-3-2 showing high levels of resistance (disease severity <5%). Based on limited experience, we believe that scoring for reaction to false mildew is best done during the grain-filling period.

Panicle Diseases

Ergot (*Claviceps fusiformis*)

Mechanism of resistance. We continued to elucidate the mechanism of ergot resistance in selected lines of pearl millet in a collaborative project with Imperial College, University of London, UK (funded by the Overseas Development Administration, ODA).

Ergot infection occurs through fresh receptive stigmas at the time of flowering, consequently we paid special attention to the gynoecial structure and pollen biology of pearl millet. We found that hyphal penetration and growth remain intercellular throughout the gynoecial tissue but are markedly polarized towards the chalazal pad through which nutrients enter the ovule. At the time of inoculation the gross gynoecial structure appears to be the same for both resistant and susceptible lines.

Our observations at the cellular level, on the interactions between pathogenic hyphae and resistant host tissue, did not indicate a hypersensitive response in the host tissue adjacent to invading hyphae.

Concurrent investigations at the field level and under controlled experimentation indicated that ergot escape may be mediated through a postpollination, stigmatic constriction phenomenon. Rapid compatible self pollination, 12-24h after stigma emergence, induced collapse in a localized region of the stigma preventing subsequent entry and invasion by ergot hyphae. Postpollination stigmatic constriction occurrs as a normal event in flowering and appears to be ubiquitous throughout pearl millet. Specialized ultrastructural techniques have been developed at ICRISAT Center to examine the mechanism of constriction, and to elucidate biochemical events that elicit cellular collapse. The lack of a distinct hypersensitive reaction in resistant host tissue, and the complexity of ergot infection indicates that resistance is polygenically controlled; the expression of resistance involving multiple interactions between pathogen and host. This view is in accord with field data that illustrated the instability of this trait.

Resistance screening. During 1986 we screened 2300 breeding and pathology entries for resistance at ICRISAT Center (rainy and postrainy seasons) and Aurangabad (rainy season) using artificial inoculation. We continued to identify and produce ergot-resistant (ER) lines with emphasis on concentrating resistance genes from diverse sources and selecting progenies with desirable agronomic traits. During the postrainy season we screened 238 pathology entries including Togo x ER F_5 lines, ICMPES populations, test crosses, and accessions from Mozambique and Sierra Leone, and we selected 73 entries with high levels of resistance (<5% severity) and desirable agronomic traits for further testing (Table 5).

During the rainy season we screened over 750 pathology entries including Togo x ER F_4 lines, advanced ER inbreds, and ER F_8 lines. Of these, we evaluated 381 entries at both ICRISAT Center and Aurangabad. A large number of entries, 285 (71%), possessed both high levels of ergot resistance (< 5% severity) and desirable agronomic traits.

The high quantity and good distribution of rainfall in Niger in 1986 favored ergot infection at ISC, Sadore. The disease was also commonly found in farmers' fields in Niger, but it was of little economic importance. As the conditions for ergot infection were favorable, entries of the ICRISAT Pearl Millet African Zone A Trial (IMZAT), were evaluated following artificial inoculation at ISC, Sadore (Figure 4). The infection severity was between 13 and 40% with a mean of 26%. In the same trial, mean ergot infection under natural conditions at Bengou was only 2%.

Smut (*Tolyposporium penicillariae*)

Biology. We concluded a 3-year study in which every 15 days we monitored the levels of *T. penicillariae* sporidia in the air above two fields at ICRISAT Center. Airborne sporidia are essential for primary infection of the floral-infecting smut disease. Our results indicate that initiation of sporidial release generally follows rains by several days to a few weeks, and that moderate to high levels of airborne sporidia are present at ICRISAT Center from about mid-August to mid-October. Levels of airborne sporidia appear to be positively correlated to RH, with high spore levels coinciding with periods of high RH. Thus, moderate to high levels of sporidia are naturally present in the air during the rainy season at the same time that pearl millet flowers. We also found airborne sporidia during the dry season, but only after showers.

Table 5. Summary of results from screening for ergot resistance in pearl millet, ICRISAT Center (IC) and Aurangabad (AB), rainy (R) and postrainy (PR) seasons, 1986.

Material	Entries screened	Location and season	Entries in the ergot severity (%) class[1]						Entries from which ER[2] panicles selected
			0-<1	1-5	6-10	11-20	21-30	>30	
Togo x ER F_4 lines	40	IC PR	0	3	10	17	7	3	23
Togo x ER F_5 lines	124	IC R	9	45	27	29	10	4	48
	124	AB R	3	33	34	25	23	6	12
Advanced ER inbreds	172	IC R	79	70	11	8	3	1	157
	172	AB R	46	106	17	2	0	I	
ER F_8 lines	85	IC R	54	28	1	0	0	2	68
	85	AB R	44	37	2	0	0	2	
ICMPES[3]	81	IC PR	0	32	18	20	5	6	32
Testcrosses	39	IC PR	0	0	0	2	15	22	
Accessions	78	IC PR	0	14	13	18	6	27	18

1. Based on mean of 20-40 bagged-inoculated panicles.
2. ER = Ergot resistant.
3. ICMPES = ICRISAT Millet Pathology Ergot Sib-bulks.

Figure 4. Field screening pearl millet for ergot resistance using inoculation techniques and evaluation procedures developed at ICRISAT Center, ISC, Sadore, Niger, rainy season 1986.

Resistance screening. We screened more than 2600 entries for smut resistance at ICRISAT Center and Hisar, including 266 pathology entries that were evaluated for their reaction to smut following artificial inoculation at ICRISAT Center during the rainy season. Of 26 F_2 lines of crosses between smut-resistant dwarf lines, there was practically no segregation for susceptibility. Based on evaluation of about 200 panicles cross^{-1}, almost all showed < 1 % mean smut severity. Among F_4 progenies of 18 crosses between smut-resistant (SR) accessions, 16 showed mean smut severities of 5% or less.

We also evaluated, following artificial inoculation, 205 SR inbreds, that were selected after several years of testing at ICRISAT Center and Hisar. Over 90% of these were highly resistant (<1% mean smut severity). We also evaluated these inbreds at ISC, Sadore, where again almost 90% were highly resistant. At Sadore, panicles were bagged but not inoculated; however, the mean smut severity on the standard control, BJ 104, was 49%, with smut severity among the many control plots ranging from 37 to 67%. This strongly suggests that smut resistance identified at ICRISAT Center may be effective in West Africa, although in Niger the agronomic performance of materials from ICRISAT Center is generally not so good as that of West African material. We hope to build up a stock of smut-resistant material for our breeding program at ISC.

Multiple Disease Resistance

We screened 724 entries for multiple resistance to DM, ergot, smut, and rust during the 1986 rainy season at ICRISAT Center. These included entries from the all India yield trials (hybrids and populations) and disease nurseries of the All India Coordinated Millets Improvement Project (AICMIP), entries from the international yield trial and disease nurseries of ICRISAT Center, and some ICRISAT inbreds (Table 6).

We conducted our multiple disease evaluations in the DM nursery under natural DM and rust pressures, and artificial ergot and smut pressures applied by hand inoculation. (ICRISAT Annual Report 1985, pp. 97 and 98).

Among the AICMIP hybrid and population trial entries, 94% showed resistance to DM, 17% to smut, but none to ergot. The AICMIP disease nurseries in 1986 included very few entries, all were ICRISAT contributions, and all were resistant to the target disease and to one or more other diseases.

Among the ICRISAT materials we found all 41 entries of the International Pearl Millet Adaptation Trials (IPMAT-10 and -11) resistant to DM, 21 entries had combined resistance to DM and smut, and one entry had combined resistance to DM, smut, and rust. We again found most entries of the international disease nurseries resistant to the target disease. In the International Pearl Millet Downy Mildew Nursery (IPMDMN), 8 of the 18 entries had combined resistance to DM and smut; in the International Pearl Millet Ergot Nursery (IPMEN), 26 of the 31 entries had combined resistance to ergot, DM, and smut; and in the International Pearl Millet Smut Nursery (IPMSN), all 17 entries had combined resistance to DM and smut. However, we only find ergot resistance in genotypes that have been bred for this trait.

We also evaluated 437 disease-resistant inbreds for combined resistance to two or more diseases. A large percentage (77%) of the ER-inbreds were also resistant to DM and smut; 72% of the SR-inbreds had combined resistance to DM and smut; and 51% of the additional SR-lines tested had combined resistance to DM and smut.

Striga hermonthica

During the 1986 rainy season we tested selection 3/4HK-2-2, derived from the 3/4HK population, for its agronomic performance and *Striga* reaction in a *Striga* sick plot at Aourema village in the northern region of Burkina Faso. There were significantly fewer (P < 0.05) *Striga* plants on 3/4HK-2-2 than on the nonselected 3/4HK population. There were a comparable number of *Striga* plants on the local variety (control) to those on 3/4HK-2-2 (Table 7). There were signif-

Table 6. Number of pearl millet lines screened for multiple disease resistance, ICRISAT Center, rainy season 1986.

		Entries found resistant (< 10% infection) to:			
Trial/nursery[1]	Entries screened	Downy mildew	Ergot	Smut	Rust
AICMIP					
Yield trials	132	124	0	23	19
Downy mildew nursery	3	2	1	2	1
Ergot nursery	5	4	5	5	.2
Smut nursery	5	3	0	5	-
Pollinators	26	22	0	13	1
Male steriles	9	5	0	0	0
ICRISAT					
IPMAT-10	20	20	0	13	0
IPMAT-11	21	21	0	8	1
IPMDMN	18	15	0	8	6
IPMEN	31	26	31	31	-
IPMSN	17	17	0	17	-
ER inbreds	257	198	243	255	54[3]
SR inbreds	100	72	-	100	-
SR lines	80	41	-	65	-
Total	724	570	280	545	82

1. IPMAT = International Pearl Millet Adaptation Trial.
   IPMDMN = International Pearl Millet Downy Mildew Nursery.
   IPMEN = International Pearl Millet Ergot Nursery.
   IPMSN = International Pearl Millet Smut Nursery.
   ER = Ergot resistant.
   SR = Smut resistant.
2. - = Not screened.
3. Screened at Aurangabad under natural disease pressure.

Table 7. Comparison of three pearl millet varieties for *Striga hermonthica* resistance and agronomic traits in a *Striga* sick plot Aourema, Burkina Faso, rainy season 1986.

Entry	No. of *Striga* plants (24 m^{-2})	Grain yield (kg ha^{-1})	Panicle length (cm)	Plant height (m)	Time to 50% flowering (days)
3/4HK-2-2	164 (12.8)[1]	520	33	1.86	66
3/4HK	372 (19.3)	710	43	1.28	63
Aourema Local	174 (13.2)	610	33	2.12	79
SE	±(2.04)	±151.9	±0.9	±0.071	±1.1
Mean	(15.1)	614	37	1.75	69

1. Figures in parentheses are square root transformed values.

icant differences among the three varieties for panicle length, plant height, and days to 50% flowering, but not for grain yield. Although 3/4HK-2-2 was significantly less susceptable to *Striga* than its nonselected parent population, it was not superior to the local variety. Its earliness compared to the local should, however, reduce the risk of yield loss due to end-of-season drought. This selection needs further improvement for yield and *Striga* resistance. However, these and similar results from trials in previous years are encouraging because they demonstrate the possibility of selecting genotypes that support fewer emerged *Striga* plants.

At ISC, we grew four trials in the *Striga-sick* plots and three trials in pots (Figure 5). Monthly sowings in pots showed highest infestation of *Striga hermonthica* in June. We tested some promising lines of West African origin in pots and in the field at four locations in Niger. Their performance and tolerance to *Striga* in pots was good, but their establishment and agronomic performance in the field at all sites was poor and needs further improvement.

Insect Pests

Population Monitoring and Insect Biology

Results of soil sampling at ISC for diapausing pupae of the earhead caterpillar, *Raghuva albipunctella* in lm x lm x 0.3 m subplots showed a decline from 10 pupae m^{-3} of soil in November 1985, to 2 pupae m^{-3} in May 1986. Adult moths were first recorded on 23 July, 67 days after a

Figure 5. Evaluating pot-grown pearl millet genotypes for *Striga hermonthica* infestation, ISC, Sadore, Niger, rainy season 1986.

rainfall of 26 mm on 18 May, as against 35 days after a rainfall in 1983, 43 days in 1984, and 49 days in 1985. This prolonged postdiapause period in 1986 is attributed to a dry spell between 24 May and 15 June during which only one rainfall of 37.2 mm was received on 29 May. Based on this observation and earlier studies (ICRISAT Annual Reports 1984, pp. 99-100, and 1985, pp. 98-99), we conclude that continued development during the postdiapause phase and subsequent moth emergence is essentially dependent on non-interrupted favorable soil moisture conditions, within threshold limits necessary for sustained growth.

The level of stem borer, *Acigona ignefusalis* infestation in 1986 was 81 larvae (100 stems)$^{-1}$ at peak infestation in September, similar to that recorded in 1985. Adult moths emerging from diapausing populations were first recorded in light traps on 25 May, and continued appearing for 135 days during the growing season.

Crop Loss Assessment (*Raghuva albipunctella*)

At Chikal, (Filingue Department, northern Niger) a regular pest hot spot, we used three pearl millet cultivars, HKB-Tif (early, improved), CIVT (recommended, improved), and a local landrace (late) to estimate losses due to *R. albipunctella* damage. We used decamethrine (Decis®) as a high-volume spray (0.01% EC) on protected control plots, and made four applications at weekly intervals starting at head exsertion.

Crop damage by *R. albipunctella* was highest in the early-maturing HKB-Tif and corresponded to the highest (41%) loss in grain yield (Table 8). It was lowest (8% yield loss) in the later-flowering local landrace. From our earlier studies on insect biology, we conclude that crop damage in existing varieties is a function of the factors that govern early seasonal growth and development of the pest population (that is, onset of rains and subsequent favorable soil moisture conditions), and the synchronized occurrence of its ecological requirements; which are provided by early sowing or the presence of early-maturing crop varieties.

Testing for Host-plant Resistance

We tested 15 entries of the IMZAT for drier zones for their performance under high natural

Table 8. Assessment of crop loss caused by *Raghuva albipunctella* infestation in three pearl millet cultivars, Chikal, Niger, 1986.

Entry	Treatment	Time to 50% flowering (days)	Panicles with eggs (%)	Damaged panicles (%)	Damage severity[2]	Grain yield (t ha^{-1})	Yield loss (%)
HKB-Tif	Protected control[1]	56	4	9	1.0	1.84	41
	Unprotected	54	54	53	4.2	1.09	
CIVT	Protected control[1]	58	4	9	1.0	2.31	17
	Unprotected	56	33	22	2.8	1.92	
Local	Protected control[1]	69	2	8	1.2	1.65	8
	Unprotected	68	11	15	1.8	1.52	
SE		±3.7		±3.3	±0.10	±0.084	
Mean		59	15	19	2.0	1.72	
CV(%)			4				20

1. Protected with Decis®, 0.01% EC.
2 Measured on a 1-5 scale, where 1 = zero to low severity and 5 = high severity.

Table 9. Performance of 15 entries from the ICRISAT Pearl Millet Zone A Trial (IMZAT) under natural pest infestations, Chikal, Niger, 1986.

	Acigona infestation			*Raghuva* infestation		
Entry	Infested stems (%)	Bored internode (%)	No. of larvae (10 stems)$^{-1}$	Infested panicles (%)	Damage severity[1]	Yield (t ha^{-1})
ICMV 5 (ITMV 8001)	100	87	24	73	4.0	1.46
C12L	100	74	31	75	4.0	1.42
IKMC 1	93	67	25	78	4.3	1.30
HKP	100	83	38	52	3.7	1.29
CT2	97	89	36	68	4.3	1.06
T18L	100	86	44	57	3.3	0.90
ICMV 7 (ITMV 8304)	100	92	35	63	4.7	0.75
IKMV 8201	97	69	22	67	4.7	0.68
INMV 8212	100	73	22	97	4.7	0.60
SE 13	100	88	31	80	5.0	0.57
SE 360	100	67	12	87	4.7	0.42
SE 2124	100	83	18	83	5.0	0.35
IKMV 8501	100	90	27	73	4.3	0.34
INMV 8271	100	79	13	77	5.0	0.28
INMV 8206	93	67	21	80	5.0	0.27
Control						
Local	100	68	27	35	2.5	1.11
SE	±2.4	±9.2	±8.8	±14.3	±0.53	
Mean	99	78	27	71	4.4	0.80
CV(%)	3	19	41	24	13	

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

infestations of stem borers and earhead caterpillar at Chikal. All entries showed high levels of susceptibility to both pests (Table 9). The local control cultivar was least affected by *R. albipunctella.*

Survey of Natural Enemies

In collaboration with the Commonwealth Institute of Biological Control (CIBC) we conducted a survey on the species complex, relative frequencies, and distribution of natural enemies of *A. ignefusalis* and *R. albipunctella* in Niger and Burkina Faso. These field surveys in the Southern Sahelian and Northern Sudanian Zones of both countries covered 53 sites in Niger and 18 in Burkina Faso.

No egg parasites were recorded on *A. ignefusalis.* Larval parasitism was low with only 12% of samples collected either producing parasites or failing to complete their development due to obvious parasitism. Two species of primary parasites, *Euvipio rufa* Szepl. (Braconidae) and *Syzeuctus* sp (Ichneumonidae), occurred throughout the survey area. *Syzeuctus* sp is the main larval parasite of *A. ignefusalis* and was by far the more abundant, occurring in 17 out of 32 sites. *E. rufa* occurred only at 10 sites. A third species, *Goniozus procerae* Risbec (Bethylidae) was occasionally present. Pupal parasitism was much lower with only 3 out of 430 pupae collected producing parasites. *Hyperchalcidia soudanensis* Steffan (Chalcididae) was the only species recorded.

Three groups of egg parasites were recorded on *R. albipunctella,* a Trichogrammatid (*Trichogrammatoidea* sp nv *lutea*) a Saelionid (*Telenomus anares* Nixon) and an unidentified Encyrtid. The overall rate of egg parasitism was less than 10% with a maximum of 40% being recorded only at Sadore. Two egg predators were also recorded, *Orius* sp (Anthocoridae) and *Glypsus conspicus* Westw. (Pentatomidae). Only 4% of larvae collected were parasitized and produced two major species: *Bracon hebetor* Say (Braconidae) and *Litomastix* sp. A third species *Goniophthalmus halli* Mes. (Tachnidae) was recovered from fewer specimens. None of the pupae that developed from larvae we collected yielded parasites. Under field conditions, prepupal larvae pupate in the soil and are therefore largely protected from further parasite attack.

The results of this survey indicate that the parasite and predator complex on both species is poorly developed. However, inventory work on indigenous parasites and predators should continue as part of our studies on pest population dynamics and to assist in the development of pest management strategies.

Microbial Association

Vesicular Arbuscular Mycorrhizae (VAM)

Heterosis for VAM Symbiosis

We had previously reported that VAM colonization is a heritable trait (ICRISAT Annual Report 1983, p. 89). Comparisons of six hybrids and their parents have now confirmed that VAM colonization and phosphorus uptake show heterosis (Table 10). The percentage heterosis calcu-

Table 10. Mycorrhizal colonization, phosphorus uptake, and grain yields of pearl millet parents and F_1 hybrids, Bhavanisagar, India, rainy season 1986.

Genotype	VAM colonization (%)	Phosphorus uptake (g ha^{-1})	Grain yield (t ha^{-1})
Female parent			
ICMA 1 (81A)	18	65	1.83
Male parent and hybrid			
IPC 000155	27	121	1.33
ICMA 1 x IPC 000155	40 (48)[1]	195 (61)	2.33 (75)
ICP 453	32	80	2.00
ICMA 1 x ICP 453	38 (19)	287 (260)	5.00 (150)
SD_2 x ExB-1	22	92	1.00
ICMA 1 x SD_2 x ExB-1	40(82)	160 (74)	2.67 (167)
Controls			
ICMV 1 (WC-C75)	20	241	1.67
MBH 110	15	110	2.17
SE	±3.3	±15.6	±0.250
CV(%)	22	18	22

1. Figures in parentheses indicate percentage heterosis over better parent.

lated over the better parent ranged from 19 to 82% for VAM colonization and from 61 to 260% for phosphorus uptake among the six crosses tested. This result clearly shows that it is possible to breed pearl millet for higher levels of VAM colonization.

Genotypic Differences in Response to VAM Inoculation

During the 1986 rainy season, we field-tested the response to VAM inoculation using 10 genotypes selected for VAM colonization or response to VAM inoculation from our 1983, 1984, and 1985 field experiments. At ICRISAT Center, 3 out of these 10 genotypes, IP 3120, IP 3840, and IP 4382 responded to inoculation with a mixture of *Glomus constrictum, Glomus mosseae,* and *Acaulospora moroweae* with significant (P < 0.05) increases in grain yield by 495 kg ha^{-1} for IP 3120,387 kg ha^{-1} for IP 3840, and 335 kg ha^{-1} for IP 4382. At Bhavanisagar, four genotypes had increased total dry matter (TDM) production, IP 5692 by 660 kg ha^{-1}, IP 5921 by 591 kg ha^{-1}, MBH 110 by 521 kg ha^{-1}, and IP 4382 by 498 kg ha^{-1}. At the same location three genotypes had increased grain yield ICMV 1 (WC-C75) by 308 kg ha^{-1}, IP 4382 by 209 kg ha^{-1}, and IP 3120 by 154 kg ha^{-1}, in response to inoculation with the mixture of three VAM species. IP 4382, among the genotypes tested, has consistently responded to VAM inoculation irrespective of location, cropping season, and year.

We also tested responses to VAM inoculation at different levels of applied phosphorus in a pot experiment using genotypes selected from previous field studies on the basis of relative rates of colonization. We tested six genotypes; two each with high, intermediate, and low rates. We found significant (P < 0.05) interactions for TDM production and phosphorus uptake amongst genotype, the level of phosphorus applied, and inoculation. All six genotypes had increased TDM production due to VAM inoculation; the results for three genotypes are shown in Figure 6. At

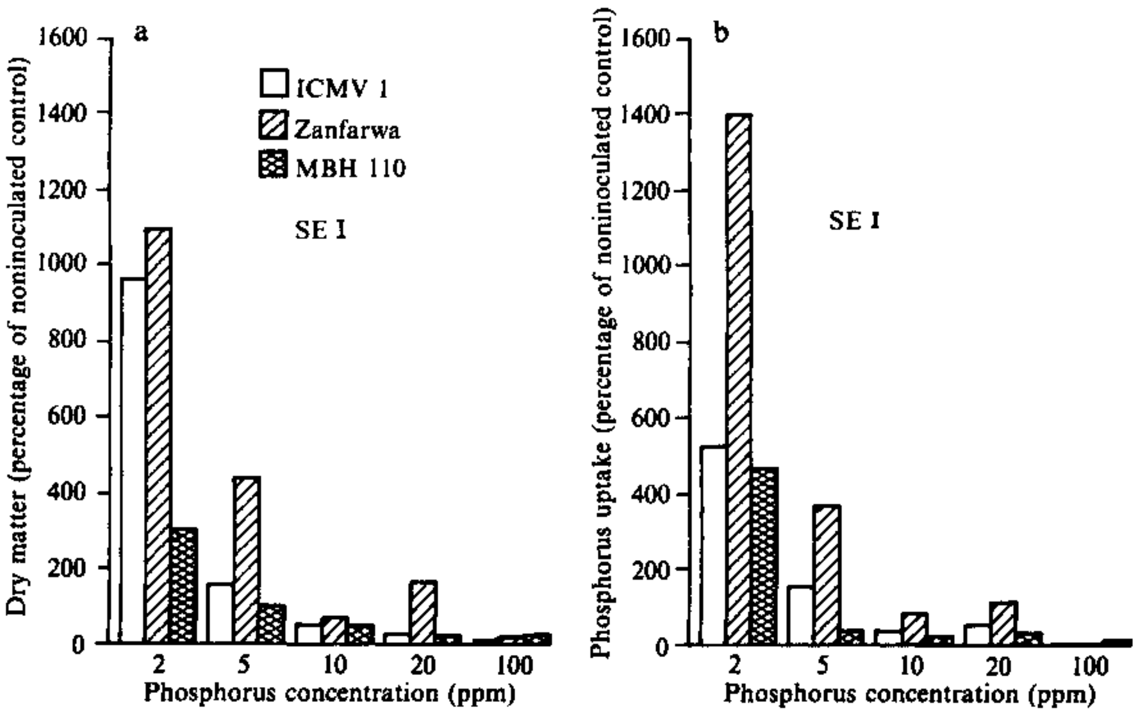


Figure 6. Increases: in a. dry matter, and b. phosphorous uptake in response to VAM inoculation in three pearl millet genotypes grown in pots at five levels of soil phosphorous, ICRISAT Center, 1986.

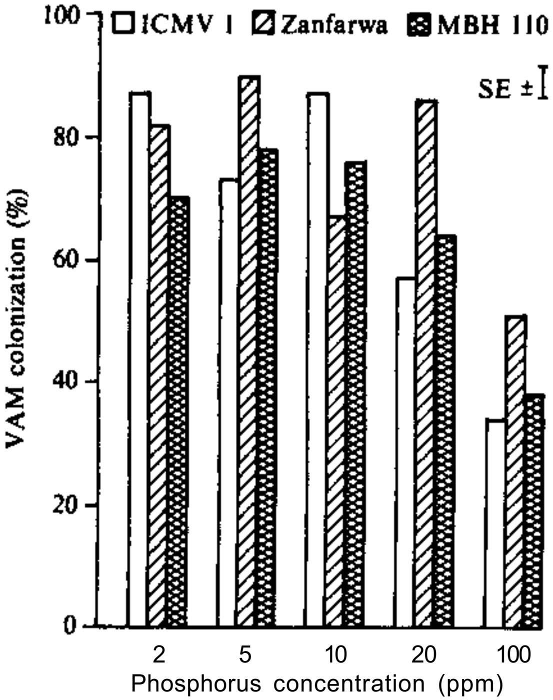


Figure 7. Percentage VAM colonization in three pearl millet genotypes inoculated with VAM, and grown in pots at five levels of soil phosphorous, ICRISAT Center, 1986.

levels of phosphorus above 10 ppm, all genotypes responded less to VAM compared to levels of phosphorus below 10 ppm. Zanfarwa, an accession from Nigeria, was most responsive at very low levels of phosphorus (0-5 ppm P) where the growth of nonmycorrhizal seedlings was severely retarded.

Differences in VAM colonization in response to phosphorus level occurred among the three genotypes (Fig. 7). Zanfarwa and MBH 110 did not show a decrease in VAM colonization even at 20 ppm P, but colonization of ICMV 1 (WC-C75) was greatly reduced by the addition of 20 ppm P. These results will be useful in identifying genotypes that respond better to VAM inoculation at a given phosphorus level, and that maintain a high degree of VAM colonization even at higher levels of phosphorus.

Role of VAM in Sahelian Soils

We earlier reported the distribution of VAM in pearl millet growing areas in western Niger and the increases in plant growth and phosphorus uptake due to VAM inoculation (ICRISAT Annual Report 1985, pp. 103-104). During the 1986 rainy season, we examined the beneficial effect of VAM on pearl millet cultivar Sadore Local. Results of a pot test, comparing different phosphorus levels from 0 to 34 kg P ha^{-1} (as single superphosphate) showed that VAM (G. *constriction)* inoculation enhanced plant growth and phosphorus uptake at all phosphorus levels. In another pot trial with Kodjari rock phosphate (50% acidulated) at 4.3 kg P ha^{-1} equivalent, VAM inoculation doubled the shoot mass and phosphorus uptake compared to the noninoculated control. This indicates that VAM can be exploited to enhance the use of sparingly soluble P from rock phosphate deposits in the Sahel. We also conducted a field experiment with Sadore Local to examine the effects of VAM inoculation and phosphorus application on phosphorus uptake. Without phosphorus application, plants inoculated with VAM took up twice as much phosphorus as noninoculated plants, but the inoculation did not increase phosphorus uptake at 6.4,12.8, or 19.3 kg P ha^{-1}. In another field experiment in which we examined the effect of phosphorus application on VAM colonization, applications up to 19.3 kg P ha^{-1} did not affect VAM colonization of the roots. These results suggest that the benefit of VAM for phosphorus uptake in pearl millet is primarily in soils low in phosphorus, although VAM are present in soils with high phosphorus levels. The reason why pearl millet does not respond to VAM inoculation with phosphorus application in the field, but does so in pots, is not known.

Biological Nitrogen Fixation

Enumeration of N_2-fixing Bacteria using ELISA

We have previously studied serological relationships among nitrogen-fixing bacteria using the enzyme-linked immunosorbent assay (ELISA) (ICRISAT Annual Report 1985, pp. 100-101).

We tested the ELISA technique for the possible enumeration of dead cells. Broth cultures of *Azospirillum lipoferum* were incubated at 32°C, 45°Q and 55°C, and cell numbers were estimated both by ELISA and the dilution and plate counting (DPC) techniques. At 32°C, the counts of cell numbers by both techniques were similar, but at 45°C and 55°C the counts by ELISA were higher than those by DPC. Also the cell numbers counted by the ELISA technique were higher than those counted by the DPC technique in broth or peat inoculants that were either autoclaved at 121° C for 15 min or subjected to a high temperature (65°C) for 1 h. This means that the ELISA technique appears to count both heat-killed and living cells.

Using the ELISA and DPC techniques we examined the persistence of *A. lipoferum* in peat inoculant (commonly used in inoculation trials) incubated at 4°C and 40°C for 9 weeks. Two weeks after incubation at 4°C, the cell counts by ELISA were 6.5 x 10^7 and by the DPC technique were 6.8 x 10^7, and at 40°C the counts were 9.0 x 10^7 by both techniques. Nine weeks after incubation at 4°C, the counts by ELISA were 1.5 x 10^7 and by the DPC technique were 1.3 x 10^7—only a slight decline compared to the 2-week counts. However, at 40°C the counts were 4.6 x 10^6 by ELISA and 9.0 x 10^6 by DPC, a significant decline compared to those at 2 weeks. This indicates that incubation at 40°C causes a decline in the number of viable cells in peat culture. Although both the ELISA and DPC techniques can effectively monitor the decline, the ELISA technique, which is less laborious and less time-consuming, is more feasible.

Response to Inoculation with N_2-fixing Bacteria

For 3 years (1983-1985), we have studied the inoculation response of four pearl millet cultivars BJ 104, ICMV 1 (WC-C75), ICMV 4 (ICMS 7703), and Ex-Bornu, grown in the same plot each year at three N levels (0,20, and 100 kg N ha^{-1}). The cumulative total plant dry matter (above ground parts) and plant N uptake averaged across the cultivars and N levels over 3 years were significantly increased over the noninoculated control by inoculation with *A. lipoferum* (ICM 1001), *A. brasilense(SL33),*and *Azotobacterchroococcum* (ICM 2001) (Fig. 8a). The mean grain yield across the cultivars and N levels was significantly increased only by inoculation with *A. brasilense* (SL 33) and *A. chroococcum* (ICM 2001) (Fig. 8b).

To measure the residual effect on yield of 3 years' continued inoculations, we sowed ICMV 1 (WC-C75) without inoculation in plots in the same field during the 1986 rainy season. The grain yield of ICMV 1 (WC-C75) was significantly higher ($P < 0.05$) in the plots previously inoculated with *A. lipoferum* by 10%, and *A. chroococcum* by 14% over the noninoculated control (Figure 9).

Assessment of Nitrogen Fixation

We measured the nitrogenase activities (C_2H_2 reduction) of BJ 104 and pigeonpea cultivar ICPL 87 to compare the rate of nitrogen fixation by pearl millet to the rate by a legume whose nitrogen fixation is well recognized. BJ 104 was inoculated with a mixture of *A. lipoferum* and *A. chroococcum* to ensure maximum nitrogen fixation. We measured nitrogenase activity on five occasions between 21 to 71 DAS, which corresponded to maturity in BJ 104 and flowering in ICPL 87 (Table 11). Nitrogenase activity fluctuated in BJ 104 with the highest activity at 21 DAS and at maturity (71 DAS). On the other hand, nitrogenase activity in ICPL 87 increased up to the early flowering stage (56 DAS) and then declined. The overall mean nitrogenase activity in BJ 104 was 0.1% of that in ICPL 87. This result suggests that the contribution of nitrogen fixation by pearl millet to nitrogen accumulation in the plant and soil is negligible, compared to that by pigeonpea, estimates of which range from 4 to 70 kg N ha^{-1} depending on the cultivar (ICRISAT Annual Report 1979/80, p. 121).

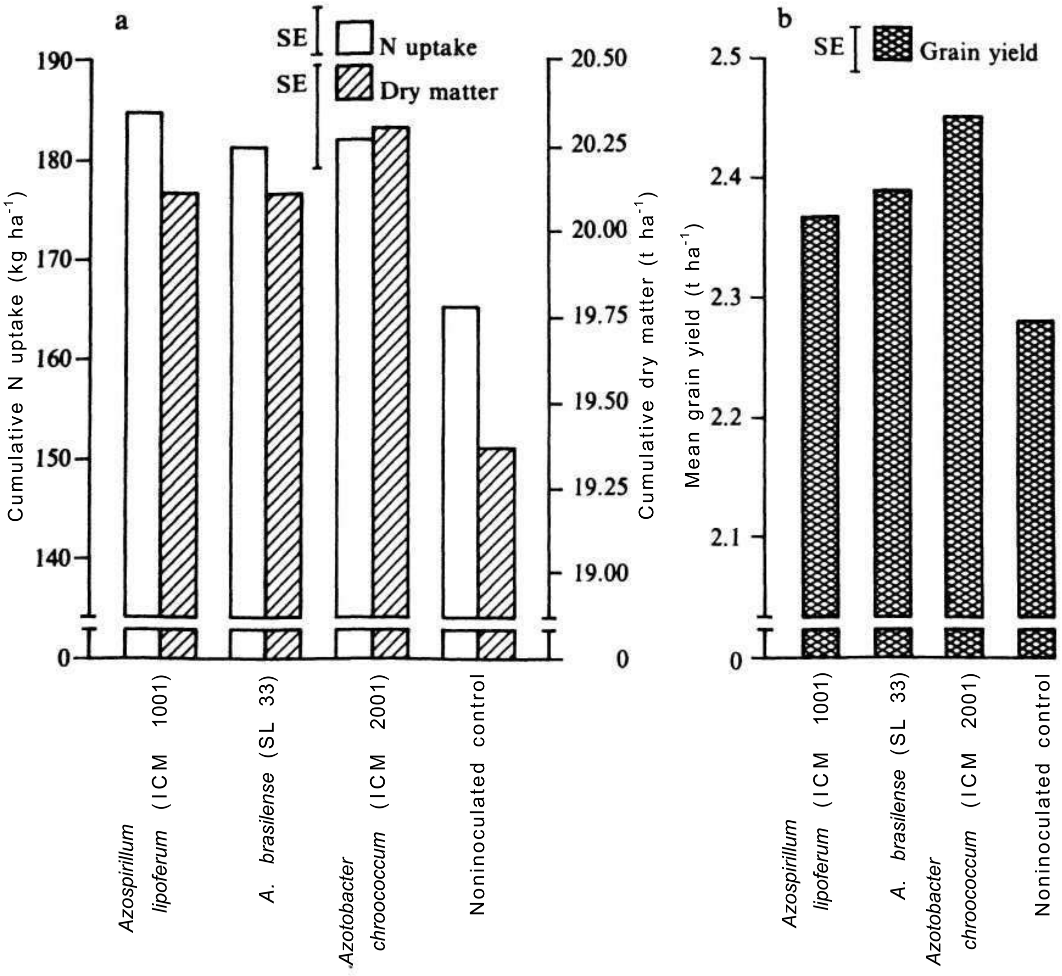


Figure 8. a. Mean cumulative dry matter (t ha^{-1}), and N-uptake (kg ha^{-1}) across pearl millet genotypes and N levels, and b. mean grain yield (t ha^{-1}) of genotypes across years and N levels, as influenced by inoculation with three strains of nitrogen-fixing bacteria in each of three years. ICRISAT Center, rainy seasons 1983, 1984, and 1985.

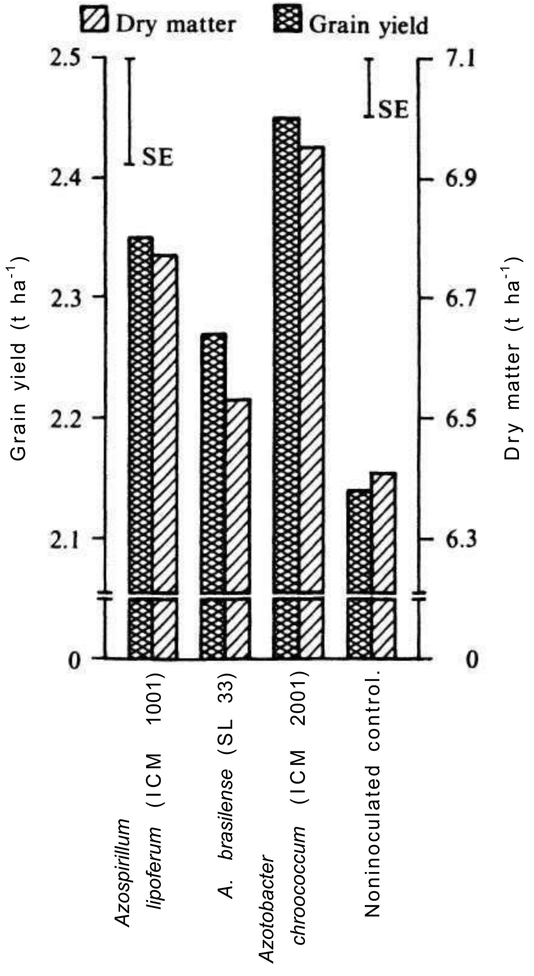


Figure 9. Grain yield and dry matter (t ha^{-1}) of a pearl millet cover crop ICMV 1 (WC-C75) grown in plots inoculated with three strains of nitrogen-fixing bacteria in 1983, 1984, and 1985, ICRISAT rainy season 1986.

Table 11. Nitrogen fixation (C_2H_2 reduction) by pearl millet BJ 104 and pigeonpea ICPL 87[1], greenhouse, ICRISAT Center, 1986.

	Nitrogenase activity[2] (nmole C_2H_4 plant^{-1} h^{-1})					
	Days after sowing					
	21	37	45	56	71	Mean
Pearl millet						
BJ 104	109	2	63	10	107	58
SE	±11.4	±1.0	±8.5	±3.0	±42.1	±23.0
Pigeonpea						
ICPL 87	61	39400	90 200	184000	65 300	75 800
SE	±54.4	±6 590	±12930	±9 980	±11 900	±30780

1. BJ 104 or ICPL 87 were grown in plastic containers each of which held 6 kg of Alfisol.
2. Nitrogenase was measured by intact-plant assay (ICRISAT Annual Report 1979/80, p. 41). Each value is an average of five replications.

Grain and Food Quality

Roti Quality

We evaluated the *roti* quality of four new ICRISAT varieties that have either been released (ICMV 1 (WC-C75), ICMV 4 (ICMS 7703), and ICMH 451) or are in advanced stages of testing (ICTP 8203). *Roti* quality was evaluated by a taste panel at Haryana Agricultural University (HAU), Hisar, as pearl millet *roti* is a common food in Haryana. Twelve persons scored *rotis* made under identical conditions for color and appearance, texture, odor, taste, and general acceptability. *Rotis* from ICMV 1 (WC-C75) and ICMH 451 were rated equal to or better than those from both control varieties for all traits evaluated. (Table 12). *Rotis* from ICMV 4 (ICMS 7703) were generally comparable to those from the controls, except in texture, but *rotis* from ICTP 8203 were rated lower than the controls for most of the evaluated traits.

Table 12. *Roti* quality characteristics of ICRISAT pearl millet cultivars, Hisar 1985.

	Roti characteristics[1]				
Cultivar	Color	Texture	Odor	Taste	General acceptability
ICMV 1 (WC-C75)	3.5	2.9	2.8	3.1	3.2
ICMH 451	3.5	3.0	2.9	3.0	3.0
ICMV 4 (ICMS 7703)	2.9	2.4	2.7	2.9	2.7
ICTP 8203	2.4	3.1	2.4	2.4	2.4
Controls					
Rajasthan local	2.9	2.8	2.8	2.8	2.9
MBH 110	2.6	2.7	2.6	2.5	2.6
SE	±0.19	±0.10	±0.07	±0.11	±0.12

1. Based on a 1-4 scale, where 1 = poor and 4 = good.

Dehulling Quality in Relation to Grain Size and Shape

Dehulling the grain is the first important step in the preparation of many African cereal food products. It is done in households, village market places, and sometimes even in streets by small vendors (Figure 10). Ease of dehulling is an important varietal characteristic. In studies on various aspects of the dehulling quality of pearl millet grains, we have found a wide variation in grain size and shape within and among cultivars. Both factors may influence ease of dehulling and the recovery of dehulled grain.

To test the effects of grain size and shape on dehulling quality, we recorded the variation in grain shape in S_1 or half-sib progenies of four composites (Table 13) and prepared samples of round, intermediate, and long grains by bulking selected open-pollinated panicles in each composite. The compactness of the panicle was used as the main criterion to select for grain shape. Very tightly filled, compact panicles produced (in general) longer grains, whereas loose panicles produced round grains. There was considerable variation among the four composites in the proportion of progenies that showed different grain-shape types. Of 485 New Elite Composite (NELC-C4) progenies, 96 were classed as long grained, 368 as intermediate, and 21 as round, compared to 427 Early Composite II (EC II-C0) progenies, of which 27 were long, 165 intermediate, and 235 round-grain types. As there was little difference between the intermediate and long-grained panicles in MC-C7 only grains of the intermediate and round classes were included in the study.

The physical characters of the grains of long, intermediate, and round types differed. Round

Figure 10. Dehulling pearl millet—a common scene in Senegal.

Table 13. Distribution of grains of different shapes in pearl millet composites, ICRISAT Center, 1984.

Composite[1]	Grain shape	% of sample	Retention on the sieve (%)[2]							
			8/64"	7/64"	6/64"	1/12"	1/13"	1/14"	1/15"	<1/15"
NELC-C4	Long	20	0	1	18	43	18	14	5	(2)
	Intermediate	76	0	4	46	39	6	3	(1)	
	Round	4	0	11	58	26	3	(1)		
MC-C7	Intermediate		0	9	58	28	4	(2)		
	Round		1	29	58	10	(2)			
EC II-C0	Long	6	0	1	16	47	18	13	4	(1)
	Intermediate	39	0	7	51	34	5	(3)		
	Round	55	1	20	60	16	2	(1)		
SRC-C2	Long	15	0	0	15	44	19	14	5	(2)
	Intermediate	82	0	2	41	45	7	3	(1)	
	Round	3	0	10	65	21	9	(1)		
Controls										
ICMV 1 (WC-C75)			0	6	53	32	5	2	(1)	
MBH 110			0	9	45	31	7	5	(3)	

1. NELC = New Elite Composite, SRC = Smut Resistant Composite, MC = Medium Composite, EC II = Early Composite II.
2. Data are means for two determinations made with 500-g samples. Values in parentheses indicate the percentage of grains that passed through different sieves.

grains had higher 100-grain mass than both intermediate and long grains, but the length/thickness and length/breadth ratios were lower for the round than for the long and intermediate types. Grain hardness of round and intermediate types was comparatively higher than that of the longer grain types.

To compare the grain size distribution among grain shape classes, we passed grain lots through a set of graded sieves and calculated the weight of grains retained on each sieve as a percentage of the total. Round grains were generally larger than the other two classes; an average of 60% of the grains in this class was retained on the 6/64 inch sieve, compared to 50% for the intermediate, and less than 20% for the longer grain class (Table 13).

We dehulled grains from each shape class for all cultivars, using the Tangential Abrasive Dehulling Device (TADD), for a fixed time period to estimate completeness of dehulling, and the Scott barley pearler for variable time periods to estimate the dehulling time required. Recovery of dehulled grains using the TADD (Table 14) was generally highest for intermediate grain types (83%) compared to the round (81%) and long types (72%). For the controls, recovery of dehulled grain in ICMV 1 (WC-C75) was 82% compared to 72% for MBH 110.

The time to completion of dehulling using the barley pearler was tested by using a dual staining technique, in which completely dehulled grains stained pink, while partly dehulled grains stained pink and blue. Completeness of dehulling was judged visually by two observers. There were no significant differences in final dehulling percentage among the three grain types, but round grains required the least time to reach a satisfactory level of dehulling (Table 14). It was difficult to dehull long-grain types to the same level of recovery as the round or intermediate types in a similar time. There was variation among individual progenies for both percentage recovery of dehulled grains and time for dehulling, and also

Table 14. Defaulting quality of pearl millet grains of varying shapes evaluated by a tangential abrasive defaulting device (TADD) and a barley pearler, ICRISAT Center, 1984.

		TADD[1]			Barley pearler[2]				
		Recovery (%)			Dehulling time		Recovery (%)		
Composite	Grain shape	Dehulled grain	Broken grain	Loss due to dehulling	min	sec	Dehulled grain	Broken grain	Loss due to dehulling
NELC-C4[3]	Long	80.5	2.0	17.5	4	30	87.1	1.2	11.7
	Intermediate	83.9	1.4	14.7	4	00	87.6	1.3	11.1
	Round	83.6	1.1	15.3	3	30	86.2	2.2	11.6
MC-C7	Intermediate	82.1	1.2	16.7	3	30	82.3	4.9	12.8
	Round	80.9	1.7	17.4	2	50	80.3	6.5	13.2
EC II-C0	Long	78.0	1.4	20.6	4	30	81.5	3.5	15.0
	Intermediate	82.1	1.9	16.0	4	00	78.0	6.2	15.8
	Round	80.0	2.8	17.2	3	00	80.5	5.5	14.0
SRC-C2	Long	79.5	1.3	19.7	4	30	86.3	2.0	11.7
	Intermediate	83.9	1.0	15.1	4	00	86.5	1.9	11.6
	Round	81.5	1.3	17.2	2	50	86.8	2.2	11.0
Controls									
ICMV 1 (WC-C75)		82.0	1.8	16.2	3	45	82.3	3.9	12.8
MBH 110		71.6	2.5	25.9	3	45	73.8	10.0	16.2
SE		±0.90	±0.15	±0.83	-	-	±1.17	±0.72	±0.51

1. Data are means of two determinations made on 20-g samples dehulled for 4 min.
2. Data are means of two determinations made on 100-g samples. Dehulling times are selected treatments judged as the minimum time to complete dehulling.
3. NELC = New Elite Composite, SRC = Smut Resistant Composite, MC = Medium Composite, EC II = Early Composite II.

variation between the different grain shapes within the same progeny. Recovery of dehulled grains was higher for ICMV 1 (WC-C75) than for MBH 110 grains, when dehulled for similar time in the barley pearler (Table 14): this difference may be due to endosperm characteristics rather than grain shape.

In conclusion, round grains not only had a higher seed mass and larger seed size but also dehulled better when tested by two dehulling machines that operate on different principles. Our study therefore points to the desirability of having a much higher proportion of round-shaped grains in pearl millet cultivars.

Plant Improvement—ICRISAT Center

Genetic Diversification

This year we received a range of elite breeding material from ISC (Table 15), most of which originated from National Program/ICRISAT cooperative programs in West Africa. Nine ICRISAT Tarna Millet Varieties (ITMV) came from our cooperative program in Niger (ICRISAT Annual Report 1985, pp. 127-128). In addition, we received four gene pools, i.e., INMG 1

Table 15. Variability in breeding material received from West Africa, at Bhavanisagar (BSR) and ICRISAT Center (IC), rainy season 1986.

Entry	No. of selections from PEQIA	Time to 50% flowering (days)				IC	
		BSR		IC			
		Mean	Range	Mean	Range	Height (m)	Panicle length (cm)
ICMV 5 (ITMV 800!)	55	68	53-76	65	55-70	3.00	43
ICMV 6 (ITMV 8002)	39	63	56-76	62	52-70	2.74	35
ITMV 8003	38	69	56-77	64	52-70	2.95	38
ITMV 8004	40	63	54-70	61	52-70	2.79	32
ITMV 8302	49	61	55-69	58	52-67	2.63	28
ITMV 8303	14	61	56-69	61	55-72	2.74	33
ICMV 7 (ITMV 8304)	76	64	54-78	60	53-72	2.74	25
ITMV 8305	64	65	56-78	58	52-72	2.74	26
ITMV 8306	1	65	-	67	-	2.50	50
INMG I	34	66	56-80	61	53-67	2.81	42
INMG 2	54	64	54-74	59	52-72	2.71	35
INMG 3	47	62	56-76	61	55-72	2.79	35
INMG 5	63	65	52-78	62	55-72	2.75	31
Iniari	118	57	46-70	52	48-62	2.17	18
HKP_3	222	58	46-70	55	48-69	2.35	37
HKB-Tif	125	59	48-69	59	48-72	2.32	35
ICMV 2 (IBV 8001)	162	60	48-70	60	50-72	2.29	27
IBMV 8401	222	64	54-70	63	53-72	1.33	33

(African long headed), INMG 2 (Indian d_1), INMG 3 (tall segregants from d_2 dwarf populations), and INMG 5 (thick headed). Two varieties came from the Senegal/ICRISAT cooperative program, ICMV 2 (IBV 8001) and the dwarf variety IBMV 8401. We received two varieties from the INRAN program in Niger (HKP_3 and HKB-Tif), and a landrace from Burkina Faso called 'Iniari', which is of typical Togo phenotype. In addition to these varieties we received a range of breeding material, some of it for the male-sterile breeding project.

All this material was grown in the Post-Entry Quarantine Isolation Area (PEQIA) in the 1986 dry season. We harvested about 2000 individual panicles from these varieties, and sowed progeny rows and bulks from them at Bhavanisagar and ICRISAT Center in the 1986 rainy season. We recorded data for several characters on these lines (Table 15), and observed great variability between the Sj lines for agronomic desirability. In general pearl millet flowers earlier at Bhavanisagar than at ICRISAT Center. However, this season, there was no marked difference in time to 50% flowering in this material (Table 15). The progenies from ICMV 5 (ITMV 8001) and ITMV 8003 are long-panicled varieties, and progenies from them were the latest to flower at both locations. Among the earliest material were progenies from Iniari, HKP_3, HKB-Tif, and ICMV 2 (IBV 8001) which flowered in less than 60 days at both the locations. Selections from these progenies have been made and they will be intermated in groups according to phenotypic similarity. We then plan to use this material in different breeding projects, in particular for introgression into our advanced composites. We will also make it available to our cooperators.

Breeding Varieties

Pedigree Breeding

We make our synthetic varieties by intermating inbred or partially inbred lines produced by pedigree breeding. In 1986, at ICRISAT Center, Bhavanisagar, Hisar, and Gwalior, we evaluated more than 8400 lines at various stages between F_2 and F_7, and 1620 inbreds, which were beyond the F_7 stage of selfing. We also evaluated 725 F_1s at ICRISAT Center. Most of these were F_1s of plant by plant crosses between high-yielding varieties, Ex-Bornu, ICTP 8202, ICTP 8203, ICMV 4 (ICMS 7703), ICMS 7704, ICMV 81111, ICMV 82132, and ICMV 1 (WC-C75). In addition, we evaluated a 260-entry preinbred nursery at ICRISAT Center, Hisar, and Gwalior. We have also evaluated 61 inbreds in two topcross trials, and 11 inbreds in a diallel trial. We will utilize selected inbreds from these trials to make new synthetics. In 1986 we supplied a 100-entry inbred nursery at 12 locations in 4 countries. This nursery was started 3 years ago to distribute agronomically elite inbreds from this project.

Four synthetics from this project, ICMS 7704, ICMS 8021, ICMS 8010, and ICMS 8283, are in AICMIP trials (Table 25). Synthetic variety ICMS 7704 was proposed for release after 6 years of testing, because of its consistently good grain and fodder yields. In addition, ICMH 83401, which has as its pollinator an inbred from the synthetics project, is also in the AICMIP trials.

Population Improvement

Advancement of existing composites. By the end of the 1986 rainy season we had:

- Completed three to eight cycles of recurrent selection on the Smut Resistant (SRC), New Elite (NELC), Dwarf (D_2C), Inter Varietal (IVC), Medium (MC), and Early (EC) composhes.
- Started the first cycle of selection in two newly formed composites, the Early Composite II (EC II), and the Ergot Resistant Composite (ERC).

Formation of new composites. We have changed the composites in the population improvement project. We have merged composites of similar phenotypes on the basis of their combining ability determined from a trial of the five major composites and the 10 F_1s made between them (Table 16). Amongst the F_1s, NELC-C4 x MC-C7 gave the highest grain yield, exceeding both of the parents (Table 16). Consequently, we have merged MC and NELC to form the Medium Composite II (MC II). The F_1 of the cross IVC-C5 x SRC-C2 outyielded both the parents, so we will merge IVC and SRC to form the Smut Resistant Composite II (SRC II). This merging can be done without adversely affecting resistance to smut as IVC has a good level of smut resistance. We have formed the Elite Composite II (ELC II) from 292 genotypes predominately from NELC, MC, SRC, and IVC, and this will replace NELC. Thus, we will now improve by recurrent selection six composites with distinctly different phenotypes:

- EC II (early-maturing).
- MC II (medium-maturing).
- ELC II (late-maturing, thick-panicled).
- SRC II (smut-resistant, late-maturing, long-panicled).
- D_2C (dwarf).
- ERC (ergot-resistant).

With a view to obtaining new, desirable material for introgression into these composites we are forming two backup composites, one late maturing (LMBC), and the other early maturing (EMBC). The parents of the LMBC are elite genotypes from Africa and other late-maturing material, mainly late varieties from NELC, MC, and IVC. The base material for the EMBC will be the Bold Seeded Early Composite (BSEC) and other early-maturing genotypes mainly derived from ICRISAT composites. We will regularly feed exotic materials into these backup composites and, in turn, superior lines from them will be introgressed, on the basis of phenotype, into the six composites listed above.

Comparative performance of varieties and composite bulks. In order to test the performance of different cycle bulks and the varieties derived

Table 16. Mean performance of two selected pearl millet composites and their F_1s across two locations, rainy season 1985.

	Grain yield						
	Across locations			Bhavanisagar		ICRISAT Center	
Entry	t ha^{-1}	Rank	% of ICMV 1	t ha^{-1}	Rank	t ha^{-1}	Rank
NELC-C4 1 MC-C7	3.72	1	108	4.24	3	3.19	1
NELC-C4	3.63	4	106	4.41	1	2.85	14
MC-C7	3.49	11	102	3.93	13	3.05	6
IVC-C5 x SRC-C2	3.64	3	106	4.24	4	3.03	7
IVC-C5	3.31	15	96	3.94	12	2.69	17
SRC-C2	3.16	16	92	3.57	17	2.75	16
Control							
ICMV 1 (WC-C75)	3.43	12		4.09	8	2.76	15
SE				±0.221		±0.150	
Trial mean (18 entries)	3.46			3.98		2.93	
CV (%)				11		10	

from the respective cycles, we conducted a yield trial at three locations in the 1985 rainy season. Varieties from the advanced cycles of composites were mostly higher-yielding than varieties from the initial cycles, and the highest-yielding composites generally produced the highest-yielding varieties. However, the composite bulks showed a clear trend of increased yield over cycles, whereas the varieties in many cases deviated greatly from their respective bulks in yield (Figures 11 and 12). This may be due to the smaller number of parents involved in forming the varieties as compared to the composites, so that parental choice has a greater effect on the yield of varieties than on composite bulks. In future, we will form varieties from both a small (about 7) or large (20-25) number of progenies to increase the probability of obtaining high-yielding varieties. We will also concentrate more on the higher-yielding composites as parents of varieties.

Performance of varieties. Each year, we make varieties by intermating progenies from the advanced cycles of the composites, and we evaluate these varieties in initial trials. We multiply promising entries from these initial trials by sib-mating before we evaluate them in an advanced trial in the following year. In the 1986 rainy season, we evaluated 20 varieties from six composites, 14 synthetics, and a range of controls in the Pearl Millet Advanced Variety Trial (PMAVT). Varieties from composites yielded better than synthetics, as the highest-yielding synthetic was ranked 24th in the trial. IVC, NELC, MC, and EC II produced higher-yielding varieties which averaged 106-115% of ICMV 1 (WC-C75) (Table 17). The highest-yielding entry amongst these was ICMV 85403 which is a variety from IVC.

Four varieties from this project, NELC-H79, ICMV 81111, ICMV 82132, and ICMV 83118, are currently in the AICMIP trials (Table 25).

A new composite for drought resistance. As mentioned above we recently formed BSEC, to provide a source of early, drought-escaping, and drought-resistant material. We restricted the parental material of this composite to a few parents which combine these traits ICTP 8202 and

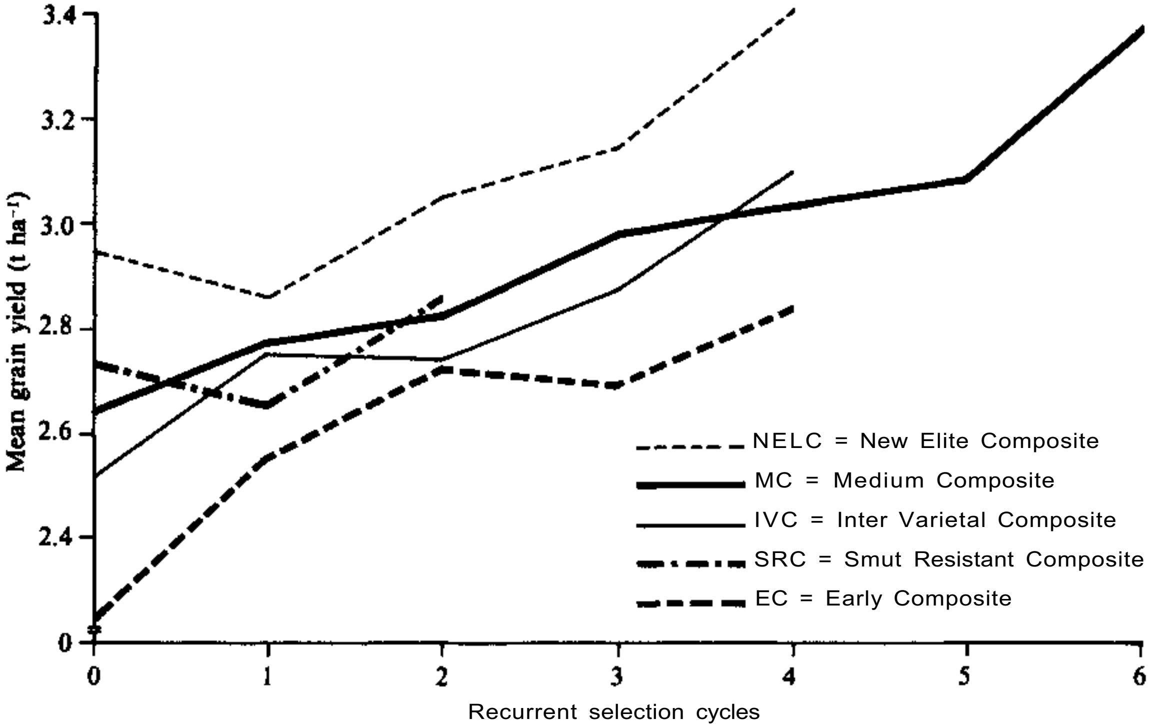


Figure 11. Mean grain yield (t ha^{-1}) in successive cycles of pearl millet composites, ICRISAT Center, Bhavanisagar, and Hisar, rainy season 1985.

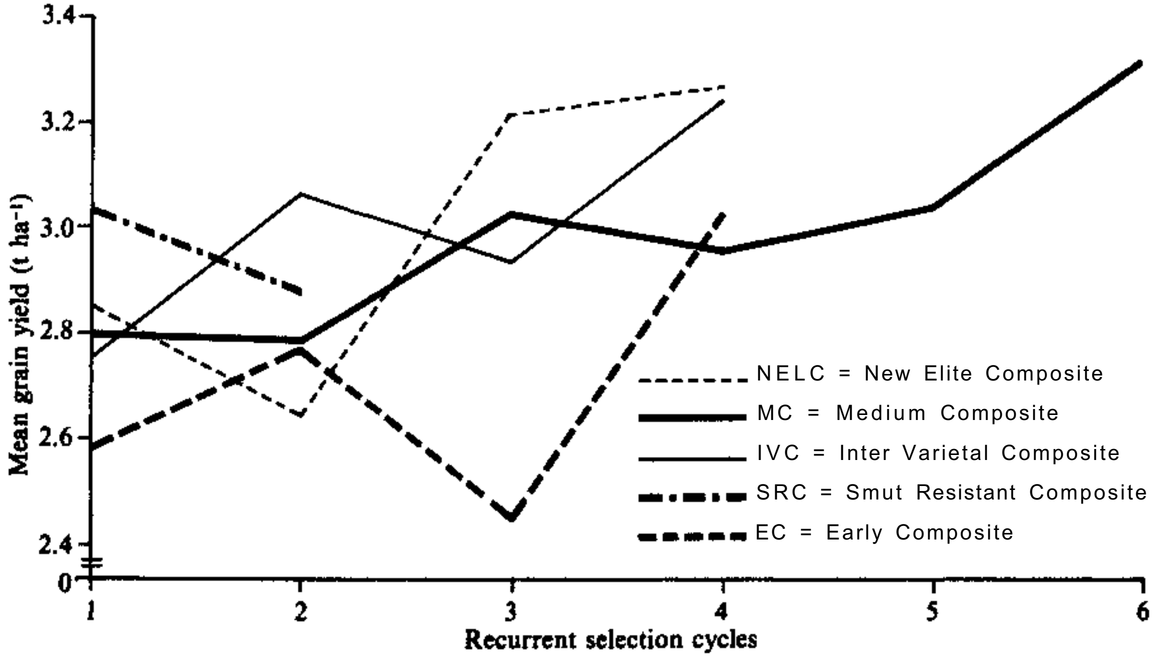


Figure 12. Mean grain yield (t ha^{-1}) of varieties derived from different cycles of pearl millet composites, ICRISAT Center, Hisar, and Bhavanisagar, rainy season 1985.

Table 17. Mean performance of selected pearl millet varieties in the Pearl Millet Advanced Variety Trial (PMAVT), across five Indian locations[1], rainy season 1986.

Entry	Parental composite[2]	Grain yield $t\ ha^{-1}$	Grain yield Rank	Grain yield % of ICMV 1	Time to 50% flowering (days)	Plant height (m)
ICMV 85403	IVC-C6	3.10	1	115	55	2.25
ICMV-D85208	IVC-C6	3.02	3	112	55	2.23
ICMV-D85113	IVC-C6	2.96	5	110	55	2.27
IVC-C6		2.95	6	109	54	2.12
ICMV 83013	MC-C7	3.01	4	111	53	2.11
ICMV 84421	MC-C7	2.94	8	109	52	2.03
MC-C7		2.71	28	100	51	2.09
ICMV 84401	NELC-C4	2.89	11	107	52	2.09
ICMV-F8420	NELC-C4	2.87	15	106	56	2.22
NELC-C4		3.07	2	114	52	2.18
ICMV-B85828	EC II-C1	2.89	13	107	49	2.03
EC II-C1		2.89	10	107	51	2.11
BSEC-C2		2.95	7	109	50	1.98
Control						
ICMV 1 (WC-C75)		2.70	30		51	2.06
SE		±0.163			±0.6	±0.048
Trial mean (49 entries)		2.75			52	2.08

1. Bhavanisagar; ICRISAT Center,high fertility (N 80: P 18); ICRISAT Center, low fertility (N 20: P 9); ICRISAT Center Disease Nursery; and Jalna.
2. Composite bulk from which the varieties are derived.

ICTP 8203 (both derived from a Togo landrace), ICGP 8501 (from Ghana material), ICMV-H85328 (a variety from the EC II), and some selected progenies from a Togo landrace. So far, we have completed four cycles of mass selection, the last under selfing. In the second and third cycles we did the mass selection on plants grown under artificially extended daylength so that late-flowering plants could be removed to reduce the photoperiod sensitivity of the population. We tested the second-cycle bulk in PMAVT; it was the earliest-flowering entry at Hisar in northern India under long-day conditions, and it ranked seventh for grain yield across five other Indian locations (Table 17).

Breeding Hybrids

Breeding Male-Sterile (A) Lines

New male-sterile lines. We contributed three male-sterile lines (861A, 862A, and 863A) of diverse origin and distinct morphological characteristics (Table 18) to the 1986 AICMIP male-sterile lines trial. We identified two additional male-sterile lines, ICMA 87001 and ICMA 87002, which we will contribute to the 1987 AICMIP male-sterile lines trial. Another male-sterile line, ICMA 87003, which is early maturing (50 days to 50% flowering), has large seed (11 g 1000^{-1}),

Table 18. Performance of selected pearl millet male-sterile lines ICRISAT Center, rainy season 1986.

Male-sterile line	Grain yield (t ha^{-1})	Plant height (m)	Panicle length (cm)	Effective tillers $plant^{-1}$	Seed mass (g 1000-0	Time to 50% flowering (days)	Photoperiod response (days)[1]
852A	1.75	1.85	18.7	2.2	9.1	65	17
861A	1.15	1.40	20.7	1.9	5.9	66	12
862A	0.90	1.31	20.8	1.3	6.1	69	15
863A	1.19	1.48	14.7	1.7	11.1	57	12
ICMA 87001	1.25	1.23	20.3	1.3	6.9	71	11
ICMA 87002	1.65	1.71	15.8	2.3	10.1	56	10
ICMA 87003	1.35	1.50	17.7	3.0	11.2	50	10
Controls							
ICMA 1 (81A)	1.18	1.12	20.0	2.3	6.3	60	9
ICMA 4 (834A)	1.40	1.55	19.5	2.2	10.0	52	5
ICMA 2 (843A)	1.16	0.78	13.7	2.6	10.9	43	10
SE	±0.235	±0.057	±0.93	±0.43	±0.07	±1.2	±1.8
Trial mean (25 entries)	1.34	1.42	18.2	2.5	9.1	57	11
CV (%)	18	4	5	18	8	2	16

1. Difference in flowering time between 13.5-h day and 15.5-h day.

and thin stems, had poor general combining ability in our trials. However, because of its earliness, it may be useful for producing early-maturing hybrids, most suitable for dry areas with short growing seasons.

Male-sterile lines 861A, 862A, and ICMA 87001 are of late maturity and are relatively more sensitive than others to increases in daylength. These three male-sterile lines produce late-maturing hybrids that are likely to be more useful in central and southern India or in other locations with an equivalent daylength (<14 h) during the growing season. However, it should be possible to produce high-yielding hybrids having wider adaption on these late-maturing, male-sterile lines. For example, male-sterile line 852A is also highly sensitive to changes in daylength, but a hybrid on this male-sterile, ICMH 85109, was the highest-yielding entry over 13 locations in India in the eleventh International Pearl Millet Adaptation Trial (IPMAT 11) (Table 27). It produced 18% more grain yield than the best control hybrid, MBH 110. Moreover, another hybrid with 852A as the seed parent, ICMH 85231, was top-ranked in the Pearl Millet Advanced Hybrid Trial-1 (PMAHT-1) with 24% more grain than MBH 110. Preliminary results indicate that male-sterile lines 863 A and ICMA 87002 are likely to produce high-yielding hybrids with large seeds, appropriate maturity, and a wider adaptation.

Evaluating new B-lines. High general combining ability is an important characteristic of a male-sterile line. For the first time, we have tested our B-lines (maintainers) for combining ability so that only those with good combining ability will be converted to male-sterile lines. We topcrossed 46 selected B-lines of diverse origin and diverse phenotypic characteristics with four populations, and evaluated the B-lines and top-cross hybrids at ICRISAT Center and Hisar. Based on the average grain yield of B-lines per se, their topcross hybrids, and agronomic eliteness determined by visual scores, we selected 23 B-lines for further evaluation of their performance per se, and general combining ability. Most of these lines are d_2 dwarf, and most have large seeds (8-11 g 1000^{-1}), and are of early to medium maturity (50-56 days to 50% flowering).

We also conducted a multilocational trial of 260 potential B-lines for the first time. Based on visual scores for agronomic eliteness and average grain yield across three locations (Bhavanisagar, ICRISAT Center, and Hisar) we retained 135 genotypes for retesting in the 1987 rainy season. The most useful criteria to reject lines turned out to be delayed flowering and poor seed set at Hisar. In future we will first screen the potential B-lines in a multilocational observation nursery and follow this with a multilocational yield trial the next year. This will allow us to evaluate a larger number of entries and make a preliminary selection of lines with wider adaptation, before obtaining a more precise estimate of their yielding ability. Finally, we will assess the combining ability of the selected potential B-lines before commencing their conversion to A-lines.

New cytoplasmic sources. The utilization of a new source of cytoplasmic male-sterility (CMS) derived from *Pennisetum violaceum* cytoplasm by scientists from Institute francais recherche scientifique pour le developpement en cooperation (ORSTOM) has begun with the incorporation of nuclear genes from maintainer line ICMB 1 (8IB). We have completed two backcrosses and we expect to complete four more by the 1988 rainy season. Isogenic ICMA 1 (81A) and ICMB 1 (81B) lines with this *violaceum* cytoplasm will then be available for comparison with original ICMA 1 (81A) and ICMB 1 (81B) lines that have Tift 23 A_1 cytoplasm. We can then examine the possible effects of these two CMS systems on morphological traits and downy mildew resistance.

Preliminary studies indicate that at least two CMS systems different from that of Tift $23A_1$ have been discovered in the EC II. Investigations are in progress to determine whether these are different from each other and the existing non-A_1 systems.

Breeding for disease resistance. Selecting for downy mildew resistance is an integral part of the male-sterile lines breeding program. We grow at least alternate generations in the downy mildew disease nursery at ICRISAT Center during bulk pedigree selection of new B-lines and when backcrossing them into sterile cytoplasm.

We have also incorporated breeding for resistance to other diseases (rust, smut, and ergot) into the male-sterile program. An S_2 progeny derived from an accession, IP 2696, was found to be rust-resistant due to a single dominant gene. We have completed three backcrosses to transfer this gene into ICMB 1 (81 B). 852B is also highly resistant to rust and has been found to be a very good general combiner. The utilization of 852B in breeding rust-resistant male-sterile lines has just begun with the initial cross made between 852B and ICMB 1(81B).

The inheritance of smut resistance may not be simple, but results indicate that smut-resistant hybrids can be produced even if only one parent is highly resistant. Thus, emphasis has recently been increased on breeding smut-resistant male-sterile lines. Ten elite maintainer progenies derived from crosses involving ICMB 1 (81B), ICMB 2 (843B), BKM 2026, and smut-resistant stocks have shown high levels of resistance to smut as well as downy mildew. We are now converting these into A-lines.

We screened more than 1000 F_3 progenies during the 1986 rainy season. These progenies were from crosses between ICMB 1 (81B), 833B, ICMB 2 (843B) and smut-resistant stocks. Based on smut resistance (<10% incidence), maturity, and agronomic eliteness, we harvested 1000 F_4 progenies from 296 F_3 progenies. We will further evaluate these F_4 progenies for their resistance to downy mildew and smut, and their sterility maintenance ability.

Breeding Pollinators (R-Lines)

Breeding methodology. Pollinators are derived from five main sources:

- Crosses between identified R-lines using bulk pedigree breeding.

- Advanced cycles of composites (see below).
- The restorer composite (RC II) formed in 1984 by random mating 21 lines that were either restorer lines of high-yielding hybrids, or were parents of such lines. This composite is currently at the stage of S, progeny testing.
- Inbreds from our synthetics and genetic diversification projects.
- Inbreds from BxR crosses made in our male-sterile breeding project.

We select among inbred lines from these sources for earliness, height, agronomic desirability,

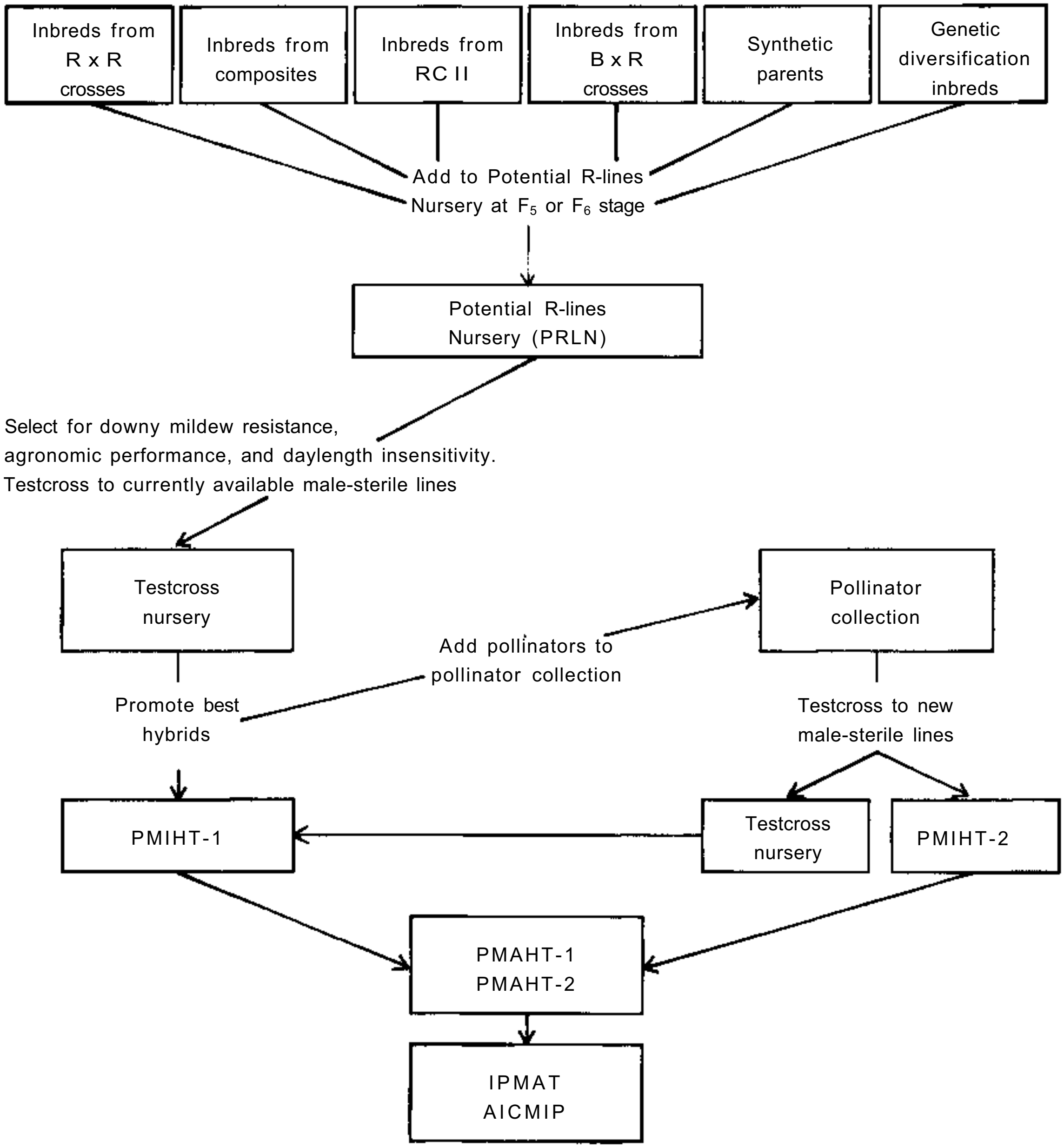


Figure 13. Generalized scheme for flow of genetic material in the pearl millet pollinator project.

and resistance to downy mildew. From 1987, we will do this screening in the Potential R-Lines Nursery (PRLN). We then testcross the selected lines to the currently available male-sterile lines, and evaluate the hybrids in testcross nurseries. We promote the high-yielding, downy mildew-resistant, and fertile hybrids from these testcross nurseries to the Pearl Millet Initial Hybrid Trial-1 (PMIHT-1).

When a hybrid is promoted to this initial trial, we include the pollinator in our pollinator collection. The pollinator collection thus consists of a set of R-lines that we have identified as having restored fertility on at least one male-sterile line. Currently the collection has about 1000 entries that we use to make further testcross hybrids on new male-sterile lines. We first test these hybrids either in a replicated trial, the Pearl Millet Initial Hybrid Trial-2 (PMIHT-2), or in a testcross nursery according to the priority given to the male-sterile line, and the past performance of the pollinator. A schematic diagram of the flow of material is given in Figure 13.

The entries in the pollinator collection are further evaluated for several traits (Figure 14) and the data are computerized. We maintain a computerized record of the crosses that have been made to avoid unnecessary repetition of crosses and to select subsets of the collection for crossing to particular A-lines.

Figure 14. Part of the pearl millet pollinator collection under screening for ergot resistance in the ICRISAT ergot nursery, ICRISAT Center, postrainy season 1986.

Utilization of advanced composites in the pollinator project. We used two composites, IVC and SRC, as source populations for the derivation of inbred lines through rapid generation advance (three generations a year) under selfing. The breeding scheme is shown in Figure 15.

We started with the S_2 bulks of the S_1 progenies that were selected in the multilocational trials of the population improvement project. We then advanced the lines through three generations by selfing using a bulk pedigree method. We used both equal seed descent (ESD) and bulk seed descent (BSD) in the bulk progeny rows to advance the generations. In the BSD method we bulked seed from the selfed panicles of plants in the progeny row, whilst in the ESD method we took equal quantities of seed from each plant before bulking. Thus, BSD may improve the line by allowing natural selection between the plants within the line, while ESD may preserve more

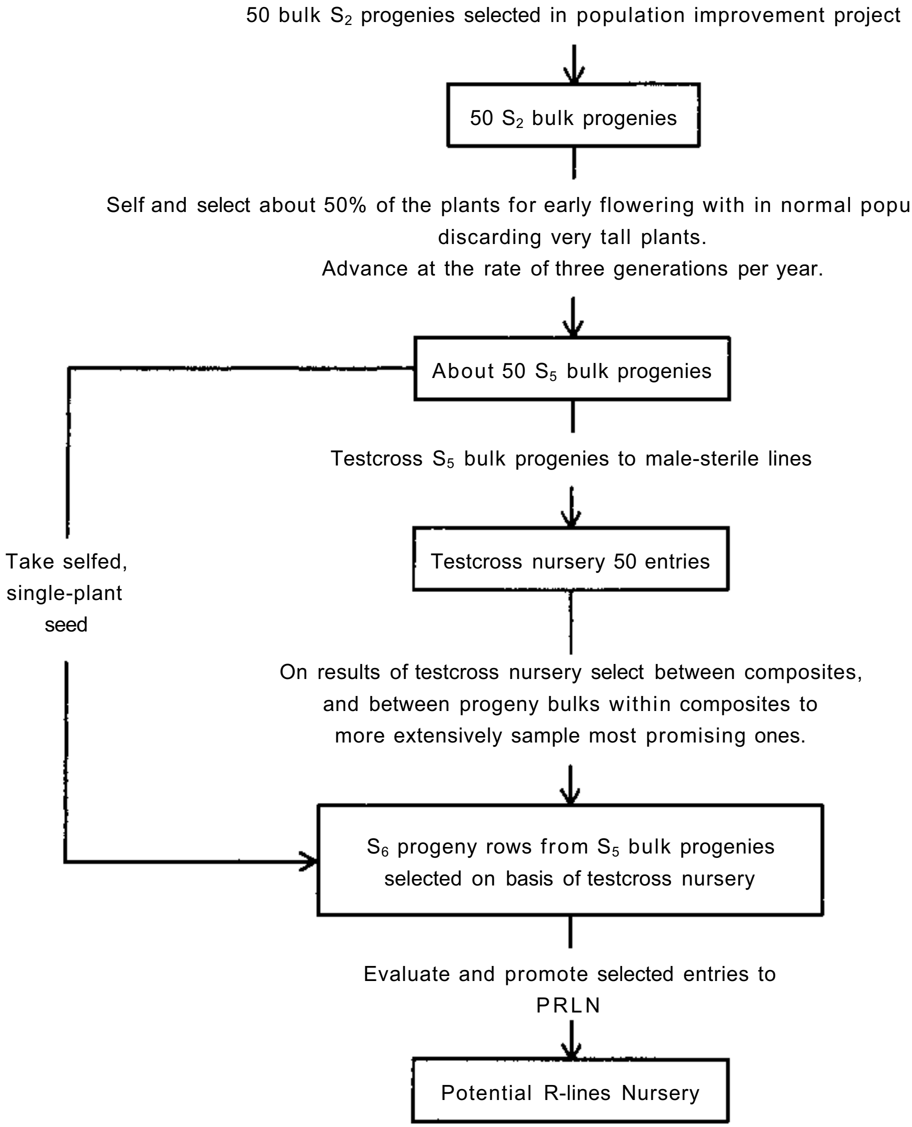


Figure 15. Breeding scheme for the derivation of pearl millet pollinators from advanced composites.

genetic variability within the line by reducing inter-plant selection.

We eliminated only a few lines during the generation advance, i.e., those susceptible to downy mildew, with poor seed set, or those which were obviously agronomically poor. At the S_5 generation we testcrossed the S_5 bulk progenies onto the male-sterile lines ICMA 1 (81A), 852A, 861A, 862A, and 863A and examined the performance of the testcross hybrids in a single year at a single location. These preliminary results indicated that there was no difference between the hybrids of progenies derived by BSD and ESD. Because BSD is simpler we have, pending further results, now uniformly adopted this method in a continuing program to derive inbred lines from all the advanced composites.

Hybrid Testing

We evaluated the entries selected from PMIHT-1 and PMIHT-2 of 1985 at eight locations in India in the PMAHT-1. Hybrid ICMH 85231 on male-sterile 852A yielded 24% more grain than MBH 110, and ICMH 851062 on male-sterile ICMA 1 (81 A) yielded 21% more grain than MBH 110 (Table 19). These two hybrids were significantly superior to all three control entries, MBH 110, ICMS 7704, and ICMV 1 (WC-C75). IPMAT-11 had four ICRISAT-bred hybrids and ICMH 85109 was the highest-yielding entry in the trial (Table 27).

Yield Physiology Studies

The phenotype of medium-maturing (90-110 days) African cultivars has been considered inefficient for the production of grain yield compared to earlier-maturing Indian phenotypes, because African cultivars have a low productive-tiller number (those tillers that produce grain) and low harvest index. We had shown in earlier studies at ICRISAT Center that later panicle initiation (i.e., a longer vegetative phase and later crop maturity) resulted in increased leaf area, radiation interception, and dry-matter

Table 19. Performance of two selected pearl millet hybrids from the Pearl Millet Advanced Hybrids Trial-1 (PMAHT-1), at four Indian locations, and downy mildew (DM) incidence, ICRISAT Center Downy Mildew Nursery, rainy season 1986.

	Grain yield ($t\ ha^{-1}$)						Time to 50% flowering	Plant height	DM inci-dence
Entry	Mean	Rank	ICHF[1]	ICLF[1]	BSR[1]	HSR[1]	(days)	(m)	(%)
ICMH 85231	3.41	1	3.82	1.98	4.81	3.02	56	2.21	0.0
ICMH 851062	3.31	3	3.62	1.55	5.21	2.87	57	2.05	0.0
Controls									
MBH 110	2.74	43	3.03	1.55	3.44	2.93	48	1.87	0.0
ICMV 1(WC-C75)	2.70	44	2.47	1.64	4.09	2.61	53	2.08	0.0
ICMS 7704	2.59	48	2.96	1.63	3.67	2.12	59	2.17	0.0
SE			±0.207	±0.119	±0.312	±0.253			
Trial mean (49 entries)	2.99		2.96	1.76	4.40	2.86	53	2.02	0.4
CV (%)			14	14	14	18			

1. ICHF = ICRISAT Center high fertility (N 80: P 18); ICLF = ICRISAT Center low fertility (N 20: P 9); BSR = Bhavanisagar; HSR = Hisar.

accumulation (ICRISAT Annual Report 1981, p. 81). However, in that study increased dry matter accumulation did not result in increased grain yield, as this was associated with a reduced productive-tiller number.

In order to understand the relationship between phenotype and duration of the vegetative phase, and to identify the constraints to increased yield potential in medium-maturing African millets, we made a detailed study of yield physiology in two daylength environments that gave either a short duration of the vegetative phase (SVP) or a long duration (LVP), at ICRISAT Center in the 1985 rainy season. We grew two hybrids, 841A x J 104 with high productive-tiller numbers, and ICMA 1 (81 A) x Souna B, with low productive-tiller numbers, under normal (13.5-h) and extended (15.5-h) daylengths to vary the duration of the vegetative phase. There were adequate water and nutrients, and the plant population was 9 plants m^{-2}.

There were no differences between the two hybrids in crop development (Table 20) or in crop growth (Table 21) over the season in either the SVP or LVP treatment, and at maturity total shoot dry matter and grain yields were similar (Table 21). Differences in productive-tiller number between the hybrids had no effect on grain

Table 20. Mean time to panicle initiation, flowering, and maturity in two pearl millet hybrids, grown under daylength treatments resulting in a short or long vegetative phase, ICRISAT Center, rainy season 1985.

Hybrid Duration of vegetative phase	Time to 50% panicle initiation (days)	Time to 50% flowering (days)	Time to 50% maturity (days)
841A x J 104			
Short[1]	20	48	77
Long[2]	32	59	87
ICMA 1 (81 A) x Souna B			
Short[1]	22	50	78
Long[2]	32	59	87
SE		±1.2	±2.5

1. Normal daylength 13.5 h. 2. Extended daylength 15.5 h.

Table 21. Grain yield and yield components in two pearl millet hybrids, grown under daylength treatments resulting in a short or long vegetative phase, ICRISAT Center, rainy season 1985.

	Duration of vegetative phase				
	Short		Long[2]		
Grain yield and yield components	841A x J 104	ICMA 1 x Souna B	841A x J 104	ICMA 1 x Souna B	SE
Grain yield (g m^{-2})	430	411	448	422	±33.9
Stem mass (g m^{-2})	496	501	1112	972	±78.4
Total shoot mass (g m^{-2})	1010	1010	1690	1510	±101
Harvest index (%)	42	41	27	28	±2.3
Productive tillers $plant^{-1}$	3.9	1.9	3.2	1.8	±0.47
Grain yield $panicle^{-1}$ (g)	13.7	23.6	14.3	27.8	±1.90

1. Normal daylength 13.5 h. 2. Extended daylength 15.5 h.

yield, since a lower productive-tiller number was compensated for by increased grain yield panicle^{-1} (Table 21). We have previously observed similar yield component compensations (ICRISAT Annual Report 1981, p. 81).

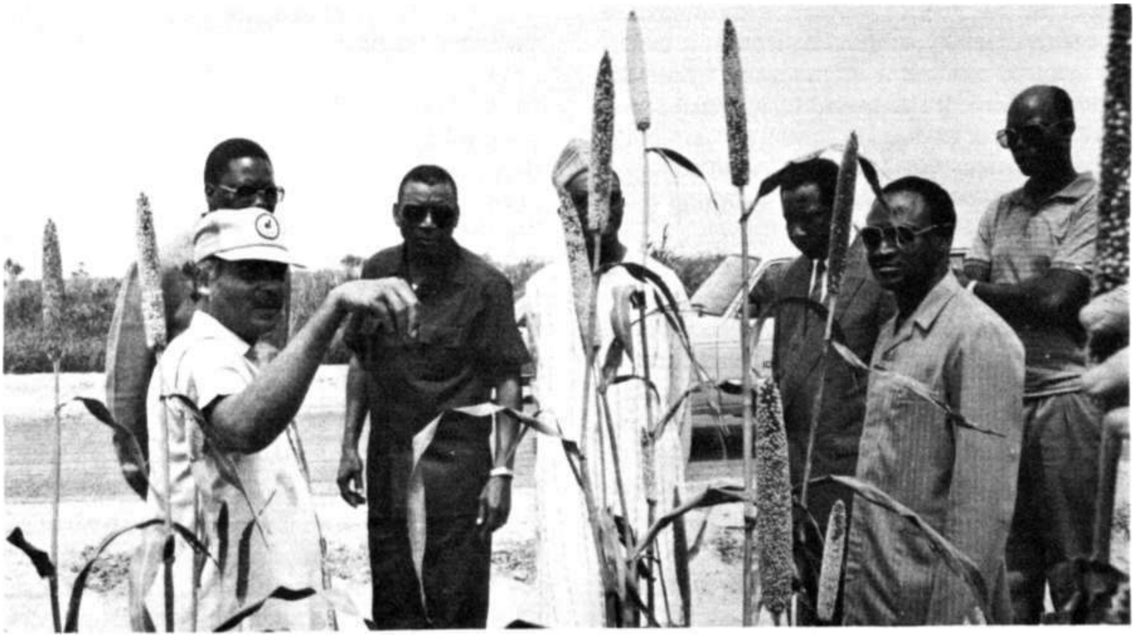
Increasing the duration of the vegetative phase did have effects on crop development and crop growth. Maturity was delayed (Table 20), and the total shoot dry matter at maturity was increased (Table 21). This confirmed our earlier observations (ICRISAT Annual Report 1981, p. 81). However, grain yield was not increased with an increase in the vegetative phase since all the additional dry matter accumulated was partitioned to increased stem growth, rather than to increased panicle or grain growth (Table 21).

The major constraint to increased yield potential in medium-maturity millets compared to early ones is the failure to translate the extra dry matter accumulated into reproductive growth Our detailed studies of dry-matter accumulation and partition indicate that this is due to the early onset of stem growth relative to panicle growth in the LVP treatment, and to a higher stem growth rate. This suggests that increases in grain yield potential can only be achieved by reducing the proportion of dry matter partitioned to the stem. Reducing stem growth, by using dwarfing genes, does not look very promising at present as a means of reducing the proportion of dry matter in the stem (ICRISAT Annual Reports 1981, p. 81; 1985, p. 118). Reducing the duration of stem growth, by searching for genotypes with a later start to stem growth relative to the start of panicle growth would be worth investigating. Alternatively, variation in panicle growth rate or, more likely, panicle growth duration should be examined for the same purpose.

Plant Improvement—ICRISAT Sahelian Center

Our main aims are to breed adapted varieties and improved genetic material with high and stable yield potential for use by the national research programs (Figure 16). These objectives

Figure 16. Ministers of West African countries visiting pearl millet breeding fields at ISC, Sadore, Niger, rainy season 1986.



are based on the recommendations made by participants from Africa at the International Pearl Millet Workshop held at ICRISAT Center in April 1986, and specifically include: to breed for good emergence and seedling survival, for maturity slightly earlier than the existing local landraces, for regional adaptation, and for increased and stable yield.

In January 1986, pearl millet breeding at ISC was reorganized to enlarge the scope of the research and better serve the national research programs in the region. The breeding program currently operating at Kamboinse (Burkina Faso) is now responsible for developing varieties and improved parental material for the transition zone (600-900 mm annual rainfall). This includes the breeding of full season (120-150 days to maturity), photoperiod-sensitive varieties for sowing with the onset of the rainy season, and medium-maturing varieties (80-110 days) suitable for early- (May) and late- (July) sowing conditions. In addition, a regional breeder, responsible for coordinating cooperative activities with the national programs, is now located at ISC.

Genetic Diversification

One of the ISC's major activities is the utilization of genetic diversity, originating from elite breeding material received from programs within the region, to generate improved plant phenotypes. This includes evaluation both of variability received from within the region, and of segregating populations and progenies resulting from crosses with such material.

We received over 380 inbred lines in 1985 from the Institut Senegalais de recherches agricoles (ISRA)/ICRISAT cooperative program (ICRISAT Annual Report 1985, p. 107) and reevaluated them in 1986. We visually rated as agronomically superior 21 of the 97 lines initially identified in 1985 and we will now use these as parents of varieties. We evaluated 50 entries from this nursery for smut reaction after inoculating the panicles; 19 entries had less than 50% incidence and will be used to breed hybrid parents.

We derived 10 F_2 populations from specific crosses made to broaden the available genetic variation in the dwarf background. These crosses were between two dwarf parents and various tall genotypes possessing desirable panicle characteristics. In addition, we have made 120 selections in a 380-entry nursery to diversify the dwarf phenotype. These selections along with several others identified in the segregating progenies, will be put into a dwarf nursery.

From a set of new crosses generated in 1985, using improved and adapted landrace varieties from within the region as parents (ICRISAT Annual Report 1985, p. 107), we have evaluated over 200 F_2 populations and made 2590 individual plant selections for further inbreeding. Following evaluation of over 600 F_3 and F_4 bulk progenies we have identified groups of parental material to recombine into varieties, and we selected 440 of the progenies for further evaluation. We have also selected 10 F_4 bulk progenies for large panicle circumference (>12 cm). This character was found in the progeny of crosses between Bazame and Ankoutess landraces from Niger, and Souna, a landrace from Mali.

Breeding Varieties

Pedigree Breeding

In the 1986 dry season, we made 18 varieties from groups of progenies we had selected during the previous rainy season. We yield-tested these in two initial trials grown at ISC and Bengou. The highest yields of test entries, ranged between 110-130% of the respective location mean yield (Table 22). On the basis of grain yield, downy mildew incidence recorded at Bengou, and visual assessment we have selected five entries from these two trials, to be evaluated in an advanced trial in 1987.

From the advanced yield trial, constituted from 13 entries selected from two preliminary yield trials of 1985, we have selected two varieties (ICMV 8524 SC and ICMV 8526 SC) on the basis of grain yield and visual ratings at each location, and downy mildew incidence at Ben-

Table 22. Mean grain yield and rank of selected entries of Pearl Millet Initial Variety Trials (PMIVT) -1 and -2, at three locations, Niger, rainy season 1986.

Entries	ISC I[1]		ISC 2[2]		Bengou	
	Yield (t ha^{-1})	Rank	Yield (t ha^{-1})	Rank	Yield (t ha^{-1})	Rank
PMIVT-1						
ICMV 8533 SC	2.18	2	1.76	7	1.70	3
ICMV 8604 SC	2.01	7	1.84	4	1.69	4
ICMV 8605 SC	2.14	3	1.85	3	1.48	12
ICMV 8606 SC	2.09	4	1.79	5	1.44	13
ICMV 8607 SC	2.02	5	1.66	12	2.19	1
Controls						
ICMV 5 (ITMV 800!)	2.26	1	1.76	7	1.40	14
CIVT	1.77	12	2.03	1	1.67	5
Local[3]	1.94	9	1.73	8	1.53	9
SE	±0.220		±0.101		±0.157	
Trial mean (16 entries)	1.90		1.73		1.57	
CV(%)	26		13		22	
Efficiency (%)[4]	-		113		-	
PIVMT-2						
ICMV 8526 SC	2.40	2	2.22	2	1.95	10
ICMV 8621 SC	2.34	3	2.15	4	1.88	13
ICMV 8628 SC	2.13	6	1.71	13	1.68	15
ICMV 8629 SC	2.16	5	2.12	5	2.29	1
ICMV 8630 SC	1.94	10	1.73	12	2.04	2
Controls						
ICMV 5 (ITMV 8001)	2.02	9	2.06	6	2.00	6
CIVT	2.18	4	2.31	1	1.99	8
Local[3]	1.15	15	2.16	3	1.87	14
SE	±0.210		±0.152		±0.097	
Trial mean (16 entries)	1.90		1.90		1.93	
CV(%)	25		18		11	
Efficiency	-		-		108	

1. First sowing at ISC (29 May, 1986) received 13 mm supplemental irrigation.
2. Second sowing at ISC (17 June, 1986), no supplemental irrigation.
3. Sadore Local at ISC and Haini-Khirei de Bengou at Bengou.
4. 4 x 4 balanced lattice, net plot size 18 m^2 to 19.2 m^2.

gou. We will evaluate these two varieties in cooperative trials with national programs in Niger and Mali in 1987.

In the transition zone millet breeding program, we selected 21 out of 68 F_2 populations derived from crosses between full-season, photoperiod-sensitive lines and early-maturing, low-photoperiod-sensitive lines. We selected a further 200 F_3 and F_4 progenies from different breeding nurseries. We will recombine them in groups to form varieties for evaluation in 1987.

Population Improvement

In 1985, we constituted four varieties from selected S_1 progenies derived from genepools and varieties from the INRAN/ICRISAT program. We yield-tested these in the Pearl Millet Initial Variety Trial-2 (PMIVT-2) (Table 22) and retained two (ICMV 8628 SC and ICMV 8629 SC) for evaluation in an advanced trial in 1987. Of the three varieties tested in the advanced yield trial that were derived from populations, we retained two (ICMV 8532 SC and ICMV 8534 SC) for evaluation in cooperative trials in 1987.

We completed the second random mating of the ISC Composite 851, constituted from 193 intervarietal crosses involving 40 varieties and adapted landraces. We will random mate this composite for the third time in the 1987 dry-season.

Several varieties from the transition-zone breeding programs have been recommended for cultivation in Burkina Faso (see Cooperation with National Programs). Three-year multilocational trial results from Burkina Faso are now available for several newer varieties, from which two, IKMP 1 and IKMC 1, with stable and superior performance were identified. Variety IKMP 1 was derived by recombining selected progenies of several local cultivars; its mean grain yield (over locations and years) was 1380 kg ha^{-1}, whilst that of Kapelga (a local cultivar grown in central Burkina Faso) was 970 kg ha^{-1}. A second variety, IKMC 1, is suitable for late-sowing conditions; its average grain yield over locations and years was 930 kg ha^{-1}, compared to the local control cultivar's 330 kg ha^{-1}.

Selection for Downy Mildew Resistance

In collaboration with the Institut national d'etude et recherche agronomique (INERA) Cereal Pathologist, we screened 49 entries from our transition-zone yield trials for downy mildew reaction at Kamboinse and Fada N'Gourma. In addition we screened 190 advanced breeding lines at Kamboins6. Two entries were disease free, and 11 were classified as highly resistant or resistant (Table 23). These included varieties IKMP 2, IKMV 8201, and IKMC 1. Results obtained this year, and observations made in past years, confirm that we have succeeded in both identifying sources of, and in breeding varieties with, stable downy mildew resistance.

Table 23. Rating for downy mildew of some selected entries evaluated at two locations, Burkina Faso[1], rainy season 1986.

Entry[3]	Rating[2] Kamboinse	Rating[2] Fada N'Gourma
IKM/CVP 39/83/84/351	F	F
IKM 85/86/116	F	F
IKM 85/86/128	HR	F
IKMP 2	HR	HR
7/8 SRMP 4	HR	HR
IKMV 8101	HR	HR
IKMV 8201	HR	HR
IKMV 8501	HR	HR
IKM 85/86/133	HR	R
IKML 8404	HR	R
IKM 85/86/304	HR	R
IKM/CVP 186/83/84/356	R	HR
IKMC 1	R	HR
Susceptible controls		
Kapelga	S	HS
NHB 3	S	HS
7042	HS	HS

1. Data from the INERA/ICRISAT collaborative screening project carried out by INERA cereal pathologist.
2. F = Free of disease; HR = Infection Index (II) < 5%; R = II 5-10%; S = II 11-50%; HS = II >50%.
3. IKM denotes ICRISAT entries from Burkina Faso.

Breeding Hybrids

We evaluated 22 of the 96 A and B pairs selected in 1985, in the downy mildew nursery during the 1986 rainy season. These 22 pairs came from five genetic backgrounds but the incidence of downy mildew was low only in the pairs with Souna genetic background (range 0-78% with a mean of 21%, based on an average of 20 plants $plot^{-1}$). We retained six pairs from four of the five genetic backgrounds for further evaluation, and for selection for downy mildew resistance in collaboration with the national programs.

The ORSTOM/ICRISAT collaborative program identified several maintainers (B-lines) for the *violaceum* cytoplasm. These include Tiotande (from Mauritania), several accessions from India and southern Africa, and ICMB 1 (81B). The latter lines, however, are not adapted to the harsh environment of the Sahel, and another maintainer Hombori (from Mali) has lost much of its vigor following inbreeding. As a first step in obtaining an improved maintainer for the *violaceum* cytoplasm, we made crosses between Hombori and other B-lines. Progenies from the cross Hombori x ICMB 1 (81B) appear promising.

The collaborative program also studied the geographic distribution of *P. violaceum* maintainers by observing restoration in 160 testcrosses between a *violaceum* male-sterile line and early-maturing landraces. Accessions from India and southern Africa displayed a much lower frequency of fertility restoration than those from the Sahel. Fifteen accessions from West Africa were identified as potential maintainers, and will be used to breed maintainer lines with desirable agronomic characters.

We evaluated 370 testcrosses in small plots (4.5 m^2) with repeating controls, CIVT and HKP. Nearly half of the testcrosses were on ICMA 1 (81 A). The mean yield of the testcrosses was 2.4 ± 0.04 t ha^{-1}, with a range of 0.6 to 5.0 t ha^{-1}. The mean of the best-yielding control, CIVT, was 2.7 ± 0.24 t ha^{-1} (20 observations). Forty-three testcrosses gave yields ranging from 125-170% of CIVT. Based on downy mildew incidence, yield, and visual assessments, we selected 20 testcrosses for further evaluation in a preliminary hybrid trial in 1987.

Cooperation with National Programs

ICRISAT Center

Supply of Breeding Materials

We supply an increasing number of trials, nurseries, and breeding materials to national and regional programs each year. This year we sent more than 8400 samples to 20 different countries (Table 24). The majority of these lines were entries in our trials and nurseries. Apart from seed sent within India, the biggest recipient of seed was the SADCC/ICRISAT regional program in Zimbabwe.

In 1986, we sent the Uniform Progeny Nursery (UPN 86) to 30 cooperators in seven countries, i.e., Cameroon, India, Niger, Pakistan, Sudan, Zambia, and Zimbabwe. This nursery consists of 90 partially inbred lines selected from the entire pearl millet breeding program plus a repeated control. It is intended for use as parental material by our cooperators. We sent another nursery, the Elite Products Nursery (ELPN 1986), to 12 locations in six countries, i.e., India, Kenya, Mexico, Sudan, USA, and Vietnam. The ELPN is primarily intended to provide a preliminary evaluation of pearl millet varieties and hybrids in countries that do not cultivate a large area of pearl millet. It consists of 21 entries of elite hybrids and open-pollinated varieties from the ICRISAT Center breeding program. All the entries are either released in India, or are in AICMIP trials.

Varieties for National Trials

Eighteen varieties, synthetics, and hybrids from ICRISAT were tested in various AICMIP trials in 1985, where ICMV 1 (WC-C75) was used as one of the standard controls. We contributed ICGP 8501, a white-seeded progeny variety, to the AICMIP white-grain trials. ICRISAT entries

Table 25. Performance of ICRISAT pearl millet entries presently in All India Coordinated Millets Improvement Project (AICMIP) trials across years in the trial, through the rainy season, 1985.

Entry	Male-sterile or parental composite	Years trial	Grain yield (t ha⁻¹)	Grain yield % trial mean	Grain yield % controls mean[1]	% of controls mean: Fodder yield	% of controls mean: Time to 50% flowering	% of controls mean: Plant height (m)	DM[2]	Status[3]
Hybrids										
ICMH 423	841A	3	2.04	109	114	114	107	1.01	35 (3.5)[4]	Ret
ICMH 451	ICMA 1 (81A)	2	2.20	114	121	117	110	1.05	17 (1.8)	Rel
ICMH 501	ICMA 4 (834A)	2	2.09	109	115	118	107	1.10	10 (1.1)	Rel
ICMH 83202	ICMA 1 (81A)	1	1.93	101	106	108	111	1.01	28 (3.5)	Pro
ICMH 82601	ICMA 1 (81A)	1	2.01	106	110	112	105	1.01	20 (2.4)	Wit
ICMH 83506	ICMA 1 (81A)	1	2.08	109	114	112	107	1.03	17 (2.1)	Pro
ICMH 83401	ICMA 1 (81A)	1	2.16	113	118	110	113	1.05	15 (1.9)	Pro
ICMH 837129	ICMA 1 (81A)	1	1.97	103	107	101	107	1.04	25 (3.1)	Wit
Open-pollinated varieties										
ICMS 7704		6	1.84	107	103	125	110	1.16	25 (2.6)	Com
ICMS 8021		3	1.64	113	110	114	105	1.10	17 (2.4)	Ret
NELC-H79	NELC	3	1.59	109	107	129	109	1.14	17 (2.4)	Dro
ICMS 8010		2	1.69	112	105	102	103	1.08	30 (4.8)	Ret
ICMV 81111	IVC	2	1.75	116	109	127	107	1.14	28 (4.5)	Ret
ICTP 8203		2	1.63	108	102	90	103	1.05	32 (5.0)	Ret
ICMV 82132	SRC	1	1.79	113	101	134	110	1.13	11 (1.3)	Pro
ICMV 83118	MC	1	1.74	109	98	112	110	1.09	32 (3.9)	Pro
ICMS 8283		1	1.69	106	95	94	104	1.11	28 (3.5)	Pro

1. For calculating % of test entries over controls means, BJ 104, MBH 110, and ICMV 1 (WC-C75) are the controls, except for the open-pollinated varieties in APMPTV where BJ 104 and ICMV 1 (WC-C75) are the controls.
2. DM = downy mildew incidence.
3. Pro = Promoted from the initial to the advanced trial, Rel = Released for cultivation in India, Ret = Retained in the trial, Wit = Withdrawn by ICRISAT, Dro = Dropped from the trial, Com = Testing completed.
4. Figures in parentheses are the actual % incidence over the years in the trial.

Table 24. Pearl millet seed samples dispatched from ICRISAT Center, 1986.

Country	Breeder seed	No. of trials	Trial entries	Breeding lines	Total samples
Brazil				70	70
Cameroon		1	100	34	134
Colombia				5	5
Ghana				6	6
India	177	49	3 276	1390	4843
Kenya		1	20	76	96
Mexico		1	16	13	29
				7	7
Niger		8	250	128	378
Pakistan		4	604	7	611
Senegal				11	11
Sudan		3	249	24	273
Sultanate of Oman		1	21	2	23
Thailand				5	5
Tonga				3	3
USA				57	57
Vietnam		3	63		63
Yemen Arab Republic		2	42	4	46
Zambia	3	3	130	2	135
Zimbabwe		6	350	1295	1645
Total	180	82	5121	3139	8440

continued to perform very well (Tables 25 and 26). In 1985 we had three entries in the advanced hybrid trial, and two of these are now released, while the third, ICMH 423, has been retained for further testing. Of the five hybrids in the initial trial, all of which are on male-sterile line ICMA 1 (81 A) three have been promoted to the 1986 Advanced Hybrid Trial. It is of note that all our hybrid entries, in both the initial and advanced trials, are on ICRISAT-bred male-sterile lines. Our open-pollinated varieties continue to perform well, and of the six varieties in the advanced trial, four were retained, one was dropped, and one completed six years of testing. All three varieties in the initial trial were promoted. Amongst the varieties, ICMV 82132 and ICMS 8283 are highly resistant to smut. ICTP 8203 is an early, bold-seeded variety that yields relatively well under drought conditions. It is in the prerelease (state minikit testing) stage in Maharashtra. It may also be recommended for the drier pearl millet-growing areas of Andhra Pradesh.

Two of our hybrids, ICMH 451 and ICMH 501, were released for general cultivation in India in January 1986. These are the first ICRISAT-bred pearl millet hybrids to be released in India. This is in addition to two ICRISAT-bred open-pollinated varieties, ICMV 1 (WC-C75) and ICMV 4 (ICMS 7703) already released for cultivation in India.

Organization of International Trials

The eleventh International Pearl Millet Adaptation Trial of 1986, IPMAT 11, had 20 entries (9 hybrids, 8 population varieties, and 3 synthetic varieties) and was sent to 27 locations in India, Niger, Pakistan, and the Yemen Arab Republic.

Table 26. Performance of ICRISAT pearl millet entries in All India Coordinated Millets Improvement Project (AICMIP) trials, rainy season 1985.

AICMIP trial	Entry	Grain yield ($t\ ha^{-1}$)	Grain yield Rank	Top test entry	Grain yield ($t\ ha^{-1}$)
APMHT II[1]	ICMH 423	2.07	12	MBH 136	2.32
	ICMH 451	2.25	4		
	ICMH 501	2.00	16		
IPMHTII[2]	ICMH 83202	1.93	24	MBH 143	2.24
	ICMH 82601	2.01	17		
	ICMH 83506	2.08	9		
	ICMH 83401	2.16	3		
	ICMH 837129	1.97	21		
APMPT V[3]	ICMS 7704	1.50	10	ICMS 8010	1.65
	ICMS 8021	1.63	3		
	NELC-H79	1.48	11		
	ICMS 8010	1.65	2		
	ICMV 81111	1.60	5		
	ICTP 8203	1.51	9		
IPMPT IV[4]	ICMV 82132	1.79	3	ICMV 82132	1.79
	ICMV 83118	1.74	5		
	ICMS 8283	1.69	9		

1. Advanced Pearl Millet Hybrid Trial II.
2. Initial Pearl Millet Hybrid Trial I.
3. Advanced Pearl Millet Population Trial V.
4. Initial Pearl Millet Population Trial IV.

This year 6 of the 20 entries were from five of our cooperators.

Across thirteen locations, hybrid ICMH 85109, which has 852A as the seed parent, was the highest-yielding entry (Table 27). The best open-pollinated variety was ICMV 84108, a variety from NELC.

International Disease Resistance Nurseries

In cooperation with a number of national programs, we conducted multilocational nurseries for each of the four major diseases. These nurseries provide national programs with an opportunity to evaluate resistance under their own conditions, give information on stability of resistance, and indicate differences in the aggressiveness/virulence of pathogen populations over locations. In 1986 these nurseries included the 18-entry IPMDMN for which data were received from Aurangabad, Bhavanisagar, Cuddalore, ICRISAT Center, and Mysore (India), and from Kamboinse (Burkina Faso), Bengou and Sadore (Niger), Samaru (Nigeria), and Bambey (Senegal). The 18-entry IPMSN for which data were received from Hisar and ICRISAT Center (India), and from Sadore (Niger), Samaru (Nigeria), and Bambey (Senegal); the 32-entry IPMEN for which data were received from Aurangabad, ICRISAT Center, and Mysore; and the 45-entry International Pearl Millet Rust Nursery (IPMRN) for which data were received from Aurangabad, Bhavanisagar, ICRISAT Center, and Mysore.

Over many years of multilocational testing we have identified a number of lines with stable resistance to disease. Those with the highest

Table 27. Performance of selected entries in International Pearl Millet Adaptation Trial (IPMAT-11), across 13 Indian locations, rainy season 1986.

Entry	Male-sterile or parental composite	Grain yield (t ha^{-1})	Grain yield Rank	Time to 50% flowering (days)	Plant height (m)	DM[1] (%)
ICMH 85109	852A	2.86	1	55	1.90	1
ICMH 82205	ICMA 1 (81A)	2.58	4	56	1.93	0
ICMH 83506	ICMA 1 (81A)	2.50	5	56	1.86	0
ICMV 84108	NELC	2.40	7	56	2.01	0
ICMV 84423	MC	2.39	9	55	1.94	1
ICMH 85409	ICMA 2 (843A)	2.32	10	55	1.48	1
ICMV 85404	IVC	2.31	11	57	2.06	2
Controls						
MBH 110		2.40	8	50	1.81	0
Local		2.15	17	53	1.77	3
ICMV 1(WC-C75)	WC	2.06	18	54	1.91	0
ICMS 7704		2.03	19	59	2.08	0
SE		±0.073		±0.3	±0.025	
Trial mean (21 entries)		2.32		54	1.88	

1. Data on DM incidence from ICRISAT Center Downy Mildew Nursery, rainy season 1986.

resistance in 1986, that also performed well in one or more previous years include: P 1591, D 332/1/2-2, and P 1449-3 for downy mildew; ICMPS 100-5-1, ICMPS 700-1-5-4, and ICMPS 1800-3-1-2 for smut; ICMP 1 (ICMPES 1), ICMP 2 (ICMPES 2), and ICMPES 34 for ergot; and P 24-2 and 7042-1-4-4 for rust. Many of these entries also possess resistance to more than one disease.

Adoption of ICRISAT Material in India

We now have two released hybrids, and four open-pollinated varieties in the release or prerelease (state minikit testing) stage in India. We have distributed considerable quantities of breeder seed to many institutions in India (Table 28)

Breeder seed is the essential base for the multiplication of certified seed for farmers (Figure 17). Demand for breeder seed of our varieties has been high. There has been continuing demand for breeder seed of ICMV 1 (WC-C75) which now occupies a considerable hectarage in India, and an increasing demand for ICMV 4 (ICMS 7703), and ICMS 7704.

With the release of two hybrids and two open-pollinated varieties the hectarage that will be occupied by ICRISAT pearl millet material in India is likely to be greatly increased. From data on seed multiplied by the public sector alone at least one million ha could be sown to hybrid ICMH 451 in the 1987 rainy season. When data on seed produced by the private sector is also considered, the area sown to ICMH 451 could be well in excess of two million ha. When the considerable planned production of ICMV 1 (WC-C75) in the public sector is considered (more than 4670 t of certified seed, enough to sow more than one million ha), then a significant proportion of the pearl millet hectarage of India will be occupied by ICRISAT-bred hybrids and varieties.

The Department of Plant Breeding, HAU, Hisar have proposed HHB-50 for release in Haryana. This hybrid has ICRISAT male-sterile line ICMA 1 (81A) as the seed parent; the polli-

Table 28. Breeder seed of released hybrids, and released and prerelease varieties supplied in India from ICRISAT Center, 1985 and 1986.

	ICMH 451			ICMH 501						
	ICMA 1 (81A)	ICMB 1 (81B)	ICMP 451	ICMA 4 (834A)	ICMB 4 (834B)	ICMP 501	ICMV 1 (WC-C75)	ICMV 4 (ICMS 7703)	ICMS 7704	ICTP 8203
Quantity dispatched in 1985[1] (kg)	21	11	0.5	15	3	3	30	93	10	12
Number of organizations	1	1	1	1	1	1	3	8	1	2
Quantity dispatched in 1986 (kg)	207	116	34	13	42	45	200	97	95	22
Number of organizations	37	37	34	8	8	9	16	15	9	4

1. From June 1.

Table 29. Farmers' perceptions of ICMV 1 (WC-C75) in comparison to competing cultivars, selected districts of Maharashtra, 1986.

	Superiority/inferiority of ICMV 1 (WC-C75) compared to competing cultivars (% of farmers interviewed)															
	Local (69)[1]				BJ 104 (43)				BK 560 (89)				MBH 110 (43)			
Character	Superior	Inferior	Same	Don't know	Superior	Inferior	Same	Don't know	Superior	Inferior	Same	Don't know	Superior	Inferior	Same	Don't know
Grain yield	86	10	4	0	46	40	14	0	42	45	13	0	19	72	9	0
Fodder yield	64	19	17	0	86	9	5	0	82	11	7	0	88	5	7	0
Grain price	4	44	33	19	40	14	30	16	38	21	25	16	2	74	7	16
Fodder price	14	6	52	28	32	5	44	19	39	10	30	20	58	0	16	26

1. Figures in parentheses are the number of farmers interviewed.

nator, H90/4-5, was bred at HAU. The hybrid is highly resistant to downy mildew and is the first hybrid proposed for release that has an ICRISAT male-sterile line and a national program pollinator.

In addition, many of the private sector hybrids are on ICRISAT male-sterile lines and pollinators, or have ICRISAT material in their parentage.

Farmers' Perceptions of ICMV 1 (WC-C75)

We conducted a survey to examine how the ICRISAT released variety, ICMV 1 (WC-C75), compared to hybrids and the local varieties, since there was little information on the acceptance and adoption of this variety by farmers. The survey was conducted in Maharashtra in 1986 by economists in the Resource Management Program. Farmers were asked to evaluate specific characteristics of ICMV 1 that they know as WC-C75 relative to those of the four main competing cultivars—local varieties, and the hybrids BK 560, BJ 104, and MBH 110. The competing cultivar was considered to be what the farmer was growing before he tried ICMV 1; this varied from district to district, and farmer to farmer. Farmers were questioned about several characters of the cultivars including yield, price, maturity, and disease resistance. In assessing each character farmers were given four options: ICMV 1 was 1. superior to, 2. inferior to, 3. about the same as the competing cultivar, or 4. farmers' had insufficient information on which to make a comparative evaluation.

Farmers were also asked if they exploited the advantage of being able, if their ICMV 1 crop had been cultivated in reasonable isolation from other varieties, to resow their own seed without a visible yield loss in the subsequent crop.

Yield, price, and disease reaction. Farmers' comparative perceptions on grain and fodder yields and prices of ICMV 1 differed sharply across the competing cultivars (Table 29). Farmers saw ICMV 1 as yielding more than the local varieties, yielding about the same as hybrids BK 560 and BJ 104, and yielding less than hybrid

Figure 17. Panicles of pearl millet ICMP 451, the pollinator of released hybrid ICMH 451, in a breeder seed production plot, ICRISAT Center, postrainy season 1986.

MBH 110 (Table 29). The advantage in grain yield over the local was to some extent eroded by the farmers' view of a lower grain price for ICMV 1 compared to the local. However, ICMV 1 was more often considered superior in grain price to BJ 104 and BK 560. About 75% of the interviewed farmers also felt that ICMV 1 fetched a lower price than MBH 110, reinforcing MBH 110's perceived yield advantage. Farmers cited the smaller and elongated grain shape of ICMV 1 and its nonuniformity in grain size relative to MBH 110 as factors contributing to its lower price.

An overwhelming majority of farmers perceived that ICMV 1 gave higher fodder yields than all three hybrids. Most farmers thought that ICMV 1 also produced more fodder than the local cultivars. Perceptions on comparative performance in fodder price were not so sharp, but the data on fodder price (Table 29) suggest that ICMV 1 does enjoy an advantage in fodder quality over all the hybrids and particularly over MBH 110.

With regard to the incidence of major pearl millet diseases, such as downy mildew, ergot, and smut, almost all the interviewed farmers reported that disease incidence had not been high enough, during the last 3 cropping years, to significantly reduce pearl millet yields. Farmers did observe, however, that either there was no disease attack on ICMV 1 or that ICMV 1 was less susceptible to disease than the competing cultivars. Nonetheless, because of the negligible incidence of the major pearl millet diseases in the districts surveyed, this potential advantage of ICMV 1 was not realized.

These results show that ICMV 1 has competed well against hybrids. It is superior in several ways, including grain price, to the public-sector hybrids BK 560 and BJ 104, where the advantage of ICMV 1 is perhaps unexpected. The success of ICMV 1 is illustrated by the fact that 60% of the farmers interviewed responded that they would sow ICMV 1 again next season.

Seed costs and seed production. The cost of producing certified seed of ICMV 1 is less than that of hybrids, but this was not much of an advantage. The lower price of certified ICMV 1 seed (Rs 6 kg^{-1} compared to Rs 12-14 kg^{-1} for hybrid seed) caused farmers to suspect that the quality of ICMV 1 seed was either not good, or the cultivar itself was not very promising. Most farmers viewed ICMV 1 as a hybrid. They did not know that they could sow their last year's harvest without suffering a visible reduction in yield in the following year. The few farmers who were aware of the varietal nature of ICMV 1 preferred to purchase seed from the market instead of using home-produced seed. They thought that their home-produced seed was not of good quality and believed purchased seed to be superior. Thus, the perceived advantage by plant breeders of a farmer being able to resow his own seed of an open-pollinated variety without significant yield loss was not realized. Nevertheless, the easier seed production of ICMV 1 was an advantage when the hybrid BJ 104 became susceptible to downy mildew; ICMV 1 could be multiplied very rapidly, and it soon replaced BJ 104 over large areas.

Although the inferiority of ICMV 1 to MBH 110 in grain yield and quality is marked, the area devoted to ICMV 1 is still high, almost certainly because seed production difficulties in MBH 110 have limited the supply of its seed. These difficulties are caused by poor seed set on the male-sterile line of MBH 110, which is derived from Serere, Uganda, material. ICRISAT has had similar problems with male-sterile lines in this genetic background. For a good hybrid to compete well with an open-pollinated variety it requires not only a superior agronomic performance, but also freedom from major seed production problems.

Assistance to Sudan National Program

We continued to provide some assistance to the Sudan National Program, primarily in the evaluation of varieties and segregating materials bred/selected during the 1977-85 period when an ICRISAT plant breeder was stationed in the Sudan supported by United Nations Development Programme (UNDP) funding. A series of trials of promising materials were conducted at four locations in Western Sudan. Location mean yields were generally low (200-400 kg ha^{-1}) over a range in rainfall of 300-360 mm. Under these conditions there were only a few instances where new selections significantly outyielded the control variety Ugandi.

Two hundred kilograms of Ugandi seed was supplied to the Global 2000 Program for demonstration plots on farmers fields in Northern Kordofan Province. Nine tonnes of seed of the same variety that was multiplied by a private seed company in 1985 was distributed to farmers in Northern Kordofan by the Department of Agriculture.

ICRISAT Sahelian Center

Supply of Breeding Materials

During the year we supplied elite breeding material to three countries in the region, and we provided dry-season breeding facilities for the Malian and Nigerien programs. We recombined four groups of selected progenies of the Malian program to form varieties. For the program in Niger, we recombined parents to make four varieties and increased seed of three elite lines.

We supplied to Mali 123 breeding lines, representing F_2 populations (17), F_3 and F_4 progenies (98), and d_2 sources (8) and an A- and B-line nursery containing 26 pairs of potential male-sterile lines. We also supplied 32 advanced breeding lines and varieties to the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) program in Ghana, and 32 to the National Program in Ivory Coast from our transition-zone breeding program.

Organization of Regional Trials

This year we coordinated one regional trial and five joint trials with national programs. The trials have entries contributed by the national research programs and the National Program/ ICRISAT cooperative programs. Data from most of the locations are due and a detailed report of the overall performance of the entries will be made in the next Annual Report.

The regional trial, IMZAT contained 14 test entries and two controls. The test entries were contributed by INRAN (3), Institute of Agricultural Research (IAR), Nigeria (3); and by National Program/ ICRISAT cooperative programs in Burkina Faso(3), Niger(2), and Nigeria(3). The trial—to be sown in a randomized-block design (RBD), was sent to 15 locations in 10 countries in Africa. In addition, this trial was also evaluated for downy mildew at Bengou, smut and *Striga hermonthica* at ISC, and infestation by *Raghuva albipunctella* at Chikal in Niger.

Three joint IAR/ICRISAT trials each containing 15 test entries that were contributed by IAR (5 entries), and national program/ICRISAT cooperative programs in Burkina Faso (3), Niger (2), and Nigeria (27). These trials were conducted at locations in Ghana (1), Niger (1), Nigeria (3), and The Gambia (1). In addition, we coordinated two INRAN/ICRISAT cooperative trials, one each for the northern and southern zones in Niger. The former contained nine test entries and was grown at seven locations, and the latter contained 11 test entries and was evaluated at six locations. Test entries in these trials were from INRAN and ICRISAT.

We also evaluated three trials from ICRISAT Center and have selected 12 entries for revaluation in 1987 in the ICRISAT Sahelian Center-Pearl Millet Initial Variety Trial (ICSC-PMIVT).

Regional Disease Nurseries

We initiated two regional downy mildew nurseries in West Africa in 1986 and received data from four of the five locations. The West African Downy Mildew Observation Nursery (WADMON) offers national programs the possibility to test their best varieties at different sites in West Africa. The objective of the second nursery, the West African Downy Mildew Variability Nursery (WADMVN), is to study variability in virulence of downy mildew in West Africa over a period of three years.

The highest downy mildew incidence across both nurseries was at Bengou (Niger) followed by Kamboinse (Burkina Faso), Bambey (Senegal), and Samaru (Nigeria), in descending order. One entry, CVP39/83/84/351, remained downy mildew free at all locations. Evidence for virulence differences in *S. graminicola* among the four locations was especially noticeable for NBH 3, ICMB 1 (8IB), ICMV 3 (IBV 8004), ICMV 5 (ITMV 8001), and Souna III.

Varieties for National Trials

Several varieties of different maturity groups from the transition-zone breeding program have shown sufficiently improved yield potential in multilocational trials in previous years (ICRISAT Annual Report 1985, p. 124) to merit large-scale testing on farmers' fields and in preextension trials. Evaluation data on these varieties were presented to the Sorghum, Millet, and Maize Committee of INERA of Burkina Faso at its meetings held in Ouagadougou (21 February 1986) and Bobo Dioulasso (11 March 1986). The Committee accepted four varieties, IKMV 8201, IKMP 2, IKMP 3, and IKMP 5, for large-scale testing and for addition to the INERA catalog of recommended varieties.

Variety IKMV 8201 is early maturing (90 days) and was recommended for late-sowing situations. The long-term average trial yield of IKMV 8201 is 870 kg ha^{-1} compared to the local control variety yield of 390 kg ha^{-1}. The Organisme regional de developpement (ORD) in Ouahigouya has recommended this variety for general cultivation in the region. In collaboration with the Food and Agriculture Organization of the United Nations (FAO), ORD has produced foundation seed of this variety on 1.5 ha, and plans further large-scale seed multiplication by groups of farmers in different villages. Varieties IKMP 2 and IKMP 5 are of intermediate maturity (110-120 days) and were recommended for normal sowing in the 500-650 mm rainfall zone of Burkina Faso. The long-term average yields of IKMP 2 and IKMP 5, are 560-570 kg ha^{1} compared to the local control yield of 150 kg ha^{-1}. The late-maturing (130 days) variety, IKMP 3, was recommended for normal sowing situations in the 700-900 mm rainfall zone. The long-term average yield of IKMP 3 is 1570 kg ha^{-1} compared to the local control yield of 1100 kg ha^{-1}.

We have supplied 50 kg of seed of ICMV 5 (ITMV 8001) and 50 kg of ICMV 7 (ITMV 8304) to the Semi-Arid Food Grain Research and Development (SAFGRAD)/ Benin (Unite de recherche et production) for evaluation on research stations and tests on 40 farmers' fields in Karimama District. We supplied IKMV 8201 to the National Cereals Research and Extension Program of the Institut de la recherche agronomique de Cameroun for multiplication and on-farm tests. Fifty kg of ICMV 5 (ITMV 8001) were supplied to the Chadian National Program/ FAO for on-farm tests and multiplication. This variety was recommended for Chad by l'Institut du Sahel (INSAH) of Comite permanent interetats de lutte contre la secheresse dans le Sahel (CILSS), following a 4-year evaluation in regional trials. To the ICRISAT program in Mali, we supplied varieties ICMV 7 (ITMV 8304) and 3/4HK-B78 for intercropping trials.

SADCC/ICRISAT Regional Program for Southern Africa

Evaluation and Supply of Breeding Material

Evaluation of the Zimbabwe collection. We evaluated 339 accessions orginating from Zimbabwe for possible use in the breeding program. These accessions were, on average taller and 10 to 15 days later than introductions from ICRISAT Center. Twenty-five of the accessions were selected for future use.

Evaluation of ICRISAT Center material. We grew eight trials from ICRISAT Center consisting of composite varieties, hybrids, synthetics, and composite bulks at Matopos. ICMH 83401, ICMH 83507, ICMV 83104, ICMV 83205, ICMV-D85111, ICMV-I84228, ICMS 8330, ICMS 8413, ICMH 83506, NELC-H79, ICMH

837127, ICMH 837130, ICMH 8439, ICMH 84306, ICMH 85430, ICMS 8359, and ICMV-E84425 were the highest yielding. The two dwarf hybrids ICMH 8439 and ICMH 84306 produced over 35% more grain yield than the best dwarf control NC(d_2). The selected hybrids and varieties will be entered in the Pearl Millet Introduced Varieties Trial for regional evaluation in 1986/87.

Identification of pollinators. We selected 27 out of 204 pollinators from nurseries supplied by ICRISAT Center. There was particular interest among SADCC scientists in the bold-grain types. We also retained 14 inbreds from the ICRISAT Center Pearl Millet Inbred Nursery, with a panicle length of more than 40 cm for the breeding program.

We crossed a total of 471 introduced inbreds onto a set of male-sterile lines during the dry-season for evaluation in the 1986/87 season.

Introduction nursery. We supplied an introduction nursery of 191 entries from Brazil, Nigeria, Senegal, Sudan, and Zimbabwe to seven locations in the region. Selected entries were from Senegal (IBMV 8502, ICMH 8413 SN), Nigeria (ICNMV 43, ICNMV 134), and from the Sudan (BI-ST-47, and Acc 932).

Development of Composites

We random-mated four composites for the fourth time: early maturing (184 entries), medium maturing (174 entries), dwarf (39 entries), and bristled (63 entries). We selected over 4000 S_1s from each composite for evaluation in the 1986/87 rainy season.

We formed a late-maturing (photosensitive) population by random-mating 302 entries tested in the dry-season. This population is primarily for Tanzania and will be grown there during the main cropping season.

Organization of Regional Trials

We supplied tall and dwarf variety trials to seven locations in the region. In the tall variety trial, IVS-P78 gave the highest grain yield followed by IVC-A82, ICMH 83507, IBMV 8501, IVS-P8204 and IBMV 8402. In the dwarf trial IBMV 8504 (medium tall) produced the highest yield. NC(d_2), and IVC(d_2) were the best dwarf genotypes.

Regional Disease Nursery

We grew a 20-entry nursery of diverse genotypes at 10 locations in the SADCC region to monitor the occurrence of diseases and to determine whether resistances previously identified elsewhere are effective in the SADCC region. Although disease levels were generally low, false mildew and rust commonly occurred at a number of locations. Rust resistance previously identified in India was effective in the SADCC region. Entries had not previously been evaluated for false mildew, but we did find variation among entries for reaction to this disease.

Varieties for National Testing

The Malawian and Zambian National Programs selected dwarf varieties IVC(d_2) and NC(d_2) for their national demonstrations. The Zambian program also selected 1CMV 82132 and ICMV 83104 for the same purpose.

Breeding Finger Millet (*Eleusine coracana*)

We evaluated the germplasm collection from Zimbabwe (396 entries) at Matopos, Mzarabani, and Gwebi in Zimbabwe and retained 68 entries for further testing. We have now received 667 lines of the world germplasm collection from the USA, 20 from Zambia, and 27 from Uganda. Seeds of all these have been increased to support regional trials in the 1986/87 season.

Workshops, Conferences, and Seminars

International Pearl Millet Workshop

A major International Workshop on pearl millet was held at ICRISAT Center on 7-11 April. It brought together 109 key scientists (excluding those from ICRISAT Center) from 22 countries to address major areas of research, production, and utilization of pearl millet on a global basis. The main areas covered were: production and utilization in Asia and Africa, food quality, genetic resources and their utilization, breeding techniques and progress in breeding varieties and hybrids, disease and insect problems, potential for and exploitation of beneficial microbiological associations with roots to improve plant nutrition, and climatic and edaphic factors affecting pearl millet growth and use. Other areas considered as special topics included the production and utilization of hybrids in Africa, the production of pearl millet as a crop for intensive agriculture, its importance as a forage/fodder crop, studies relating to quantitative genetics, and the analysis of multilocational trials. Recommendations on priorities for future research were drawn up by four committees: breeding for Africa, breeding for India, crop protection, and agronomy. The proceedings, to be published in 1987, will include the texts of 19 major papers, 54 abstracts of short presentations, summaries of 13 paper/discussion sessions, workshop recommendations, and summary data on pearl millet production and utilization by country, and within India by state.

ICRISAT Center Pearl Millet Scientists' Day

The Cereals Program organized a Pearl Millet Scientists' Day at ICRISAT Center on 20-21 August 1986. This meeting provided an opportunity for the participating scientists to see and discuss ICRISAT's research on pearl millet in agronomy, microbiology, and physiology. Seventeen scientists from the Indian Council of Agricultural Research (ICAR), Indian agricultural universities, and Indian private seed companies participated in the Scientists' Day, as well as eight in-service trainees and fellows from Chad, Guinea, India, Italy, Nigeria, Swaziland, and Zambia.

The Scientists' day was a joint project of the Cereals, Genetic Resources Unit (GRU) and Resource Management Program (RMP). It included visits to experiments on cropping systems, agroforestry, and crop modeling in RMP; to studies on nonsymbiotic nitrogen fixation (Figure 18) and VAM effects in Cereal Microbiology; studies on effects of crop duration and the d_2 dwarfing gene on growth and yield in Millet Physiology; and the variability in the germplasm collection in GRU. The results were followed by discussions with ICRISAT scientists on ICRISAT's present and future research on the topics shown to the participants.

West African Regional Pearl Millet Workshop

The annual Regional Pearl Millet Tour/Workshop was held in Niger from 7-11 September 1986. This workshop brought together pearl millet scientists in the region and provided an opportunity to visit different national millet improvement programs, as well as ISC, and to discuss important research topics.

Twenty-nine scientists from the national programs of Burkina Faso, The Gambia, Ghana, Ivory Coast, Niger, Nigeria, and Senegal; from the University of Reading, UK; ICRISAT Center; and ISC participated. The program included visits to INRAN's research station at Tarna, (Maradi), and the ISC at Sadore to observe material in the field. Sessions were held to discuss soil-agroclimatological zonation and its implications for millet improvement, germplasm collection and evaluation in West Africa, ISC's research on stand establishment and on characterization of variability in *S. graminicola,* and on-farm testing of improved varieties. The workshop also discussed reorganization of ICRISAT's millet research in West Africa, and cooperative activities. National programs of Niger

Figure 18. ICRISAT Scientists Day participants discussing field responses of pearl millet to inoculation with nitrogen-fixing bacteria, ICRISAT Center, rainy season 1986.

and Nigeria offered to assist ISC in food quality evaluation of advanced varieties. Responses of participants indicated that the workshop was extremely useful, particularly in the opportunity it offered for interaction between scientists from national programs and ICRISAT.

Looking Ahead

Physiology. With work on techniques for screening for seedling emergence establishment now nearly complete, efforts in this area will concentrate on improving the emergence/establishment ability of breeding materials. Particular effort will be placed on this at ISC where products of crosses with exotic materials have often had inferior stand establishment capability compared to the local landraces.

We will increase our efforts on physiological studies of varieties with differential ability to set and fill grain under terminal stress, in order to determine the reasons for such differences.

We shall continue our studies on the effects of the dwarfing genes in pearl millet, particularly on the differences in grain size between tall and dwarf materials, and the effects of drought on dwarf hybrids.

Pathology. Studies of pathogenic variability in the downy mildew pathogen will continue in collaboration with the University of Reading, and limited studies on variability will be initiated at ICRISAT Center. A sprinkler system to improve DM field screening will be installed and used at Bengou, Niger, and more emphasis will be given to mass screening of breeding material for resistance to DM at the seedling stage in the greenhouse at ICRISAT Center. We will continue to study recovery resistance to DM and conduct experiments which provide more information on DM infection and symptom expression, and the implications of these aspects for DM screening.

We will screen selected material for ergot resistance, and continue to study the mechanism of ergot resistance in collaboration with Imperial College, and the biology of rust, to improve our screening procedures.

Research on *Striga hermonthica* will be conducted in West Africa on methods of screening for promising materials for resistance, and on gaining information related to improving the reliability of screening procedures.

In collaboration with National Programs, we will grow multilocational disease nurseries in India, West Africa, and southern Africa to determine stability of identified resistance and to ascertain possible pathogenic differences among locations.

We will continue to try to improve the reliability of disease resistance screening, especially in West Africa. In southern Africa we hope to gain a better understanding of the major disease problems and to develop new techniques, or modify existing ones for resistance screening.

We will continue inheritance studies for DM, smut, and rust at ICRISAT Center, in collaboration with breeders.

Entomology. Our emphasis will be on the development of techniques for artificial rearing and infestation of the earhead caterpillar (*Raghuva albipunctella*) and the stem borer (*Acigona ignefusalis*) which should make possible more reliable screening of pearl millet for resistance or tolerance to these pests. We shall undertake studies on the biology of these insects relating to laboratory culture. These will include ways to control diapause formation, determination of optimum environmental conditions for culture, identification of preferred ovipositional surfaces, and adult space, fecundity, and food requirements. Studies relating to artificial infestation will include methods to augment natural field populations of the insects and to precisely measure host-plant response.

Microbiology. We will screen germplasm and advanced breeding materials, with VAM inoculation to select genotypes with more efficient VAM symbiosis for improved phosphorus uptake and plant growth.

At ISC, we will investigate the relationship between VAM status and phosphorus uptake by pearl millet plants to assess the benefits of VAM, and to exploit VAM in using phosphorus fertilizer more efficiently. We will continue efforts to quantify associative nitrogen fixation.

Breeding at ICRISAT Center. We will place increasing emphasis on our genetic diversification project and reduce activity on synthetics breeding. In our population improvement project the process of merging old composites and creating new ones will be continued.

Our male-sterile project will place increasing emphasis on breeding for multiple disease resistance, and the diversification of the cytoplasmic base.

In our pollinator project we will continue to improve the pollinator collection, and in future we will add new pollinators to the collection only after they have been screened in PRLN.

We will continue to conduct IPMAT, participate in the AICMIP testing system, multiply breeder seed, and distribute trials, nurseries, and breeding material worldwide.

Breeding at ISC. We will increase our efforts to evaluate accessions in their area of origin in collaboration with the national programs and the GRU.

Appropriate crosses will be made with agronomically superior accessions from Nigeria and with local and improved local cultivars. Recurrent selection will be initiated on the newly formed composites. Elite progenies identified will be screened for DM resistance and maintenance reaction.

Male-steriles currently identified will be further evaluated for DM resistance. A preliminary hybrids trial will be initiated. Elite progenies and varieties will be screened for stand establishment capability in collaboration with the agronomist and for DM resistance in collaboration with the pathologist.

Varieties identified in initial and advanced trials will be further tested in advanced and National Program/ICRISAT cooperative trials. Our regional cooperative activities involving national program scientists, such as seed supply, provision of dry-season nurseries, training, and field tours/workshops will be extended.

Breeding at SADCC. Emphasis in breeding pearl millet will be on grain size, grain yield, and resistance to diseases, particularly ergot, using both population improvement and hybrid breeding. We will develop genetic materials for different zones of maturity, and dwarf types for more intensive agriculture. We will initiate a crossing program for finger millet to develop high-yielding lines of early as well as late-maturing types.

Publications

Institute Publications

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-111-9. (CPE 037)

Journal Articles

Giller, K.E., Wani, S.P., and Day, J.M. 1986. Use of isotope dilution to measure nitrogen fixation associated with the roots of sorghum and millet genotypes. Plant and Soil 90:255-263. (JA 493)

Henson, I.E., Mahalakshmi, V., Alagarswamy, G., and Bidinger, F.R. 1986. Regulation of abscisic acid concentration in leaves of field-grown pearl millet (*Pennisetum americanum* [L.] Leeke): the role of abscisic acid export. New Phytologist 102:249-259. (JA 508).

Mahalakshmi, V., and Bidinger, F.R. 1986. Water deficit during panicle development in pearl millet: yield compensation by tillers. Journal of Agricultural Science. 106:113-119. (JA 517)

Ramaiah, K.V. 1985. Hand pulling of *Striga hermonthica* in pearl millet. Tropical Pest Management 31(4):326-327. (JA 505)

Subramanian, V., Jambunathan, R., and Ramaiah, C.D. 1986. Physical and chemical characteristics of pearl millet grains and their relationship to roti quality. Journal of Food Science 51(4): 1005-1008 and 1020. (JA 498)

Thakur, R.P., Subba Rao, K.V., Williams, R.J., Gupta, S.C., Thakur, D.P., Nafade, S.D., Sundaram, N.V., Frowd, J.A., and Guthrie, J.E. 1986. Identification of stable resistance to smut in pearl millet. Plant Disease 70(1):38-41. (JA 471)

Willingale, J., Mantle, P.G., and Thakur, R.P. 1986. Postpollination stigmatic constriction, the basis for ergot resistance in selected lines of pearl millet. Phytopathology 76:536-539. (JA 551)

Conference Papers

Krishna, K.R. 1986. Vesicular-arbuscular mycorrhiza for efficient use of fertilizer phosphorous. Pages 167-177 *in* Soil biology: proceedings of the National Symposium on Current Trends in Soil Biology, 25-27 Feb 1985, Hisar, Haryana, India. Hisar, Haryana, India: Haryana Agricultural University. (CP 253)

Soman, P., Bidinger, F.R., and Jayachandran, R. 1986. Evaluation of genotypic differences in seedling emergence through soil crusts under field conditions. Pages 270-277 *in* Assessment of soil surface sealing and crusting: proceedings of the Symposium, 23-27 Sep 1985, Ghent, Belgium. Ghent, Belgium: Flanders Research Centre for Soil Erosion and Soil Conservation. (CP 220)

Upadhyaya, M.N., Hegde, S.V., Rai, P,V., and Wani, S.P. 1986. Root-associated nitrogen fixation in finger millet. Pages 93-102 *in* Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 330)

Walker, T.S., and Witcombe, J.R. 1986. ICRISAT presentation: yield variability in sorghum and millet. Pages 167-175 *in* Summary Proceedings of a Workshop on Cereal Yield Variability, 26-29 Nov 1986, Feldafing, Federal Republic of Germany. Washington, D.C., USA: International Food Policy Research Institute. (CP 284)

Wani, S.P. 1986. Nitrogen fixation associated with cereals and forage grasses. Page 227-240 *in* Soil biology: proceedings of the National Symposium on Current Trends in Soil Biology, 25-27 Feb 1985, Hisar, Haryana, India. Hisar, Haryana, India: Haryana Agricultural University. (CP 229)

Wani, S.P. 1986. Measurement of nitrogen fixation. Pages 215-218 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.). Hisar, Haryana, India: Haryana Agricultural University. (CP 236)

Wani, S.P. 1986. Cereal nitrogen fixation: problems and potentialities. Pages 7-21 *in* Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 258)

Wani, S.P. 1986. Research on cereal nitrogen fixation at ICRISAT. Pages 55-68 *in* Cereal nitrogen fixation: proceedings of the Working Group Meeting, 9-12 Oct 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. (CP 259)

Wani, S.P., and Lee, K.K. 1986. Developments in nonlegume N_2-fixing systems. Pages 163-166 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.). Hisar, Haryana, India: Haryana Agricultural University. (CP 235)

Thesis

Carberry, P.S. 1986. Development and construction of a simulation model of the growth of pearl millet (*Pennisetum americanum* (L.) Leeke). Ph.D. thesis, University of Sidney, Sidney, Australia. 219 pp.

LEGUMES

CHICKPEA

Contents

Cover photo: Comparing chickpea genotypes for their response to irrigation on a Vertisol. Rows of nonirrigated plots (with two lighter plots) are in the center, on either side are buffer plots, and at the extreme left and right are irrigated plots (with perfo-irrigation pipes). ICRISAT Center, postrainy season 1985/86.

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CHICKPEA

There are two main types of chickpea: desis, which constitute about 85% of the total production, and kabulis, which form the remaining 15% of seed produced. The kabuli type is of particular importance in countries of the Mediterranean region, and most of our research on it is therefore concentrated at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria. However, the demand for kabuli chickpeas is strong in other countries as well, and ICRISAT Center is increasing its efforts to serve countries with agroclimatological conditions similar to those in India interested in the kabuli types.

During the 1985/86 cropping season our activities were concentrated at four main locations: ICRISAT Center (18°N, 78°E, 764 mm mean annual rainfall) on short-and medium-duration types; Hisar (29° N, 75° E, 450 mm mean annual rainfall) in cooperation with the Haryana Agricultural University (HAU) on medium- and long-duration types; at Islamabad, Pakistan (34°N, 73° E, 1116 mm mean annual rainfall) in cooperation with the National Agricultural Research Center (NARC), mainly on long-duration chickpeas with emphasis on breeding for ascochyta blight resistance and at Aleppo, Syria (36° N, 37°N, 340 mm mean annual rainfall) in cooperation with ICARDA on extra-long duration chickpeas, which are suitable for spring or winter sowing. Subsidiary testing centers are at Gwalior (26°N, 78°E) in central India and, for off-season advancement at Tapperwaripora (34°N, 75°E) in Kashmir, northern India, Dharwad (15°N, 75°E) in southern India for the first time; Sarghaya (36°N, 36°E) in Syria, and Terbol (34°N, 36°E) in Lebanon. National scientists at many other locations in different countries participated in testing ICRISAT materials, and we gratefully acknowledge their contribution to our research effort.

In the 1985/86 season, yields were good in West Asia and northern India, but rather disappointing in peninsular India and Ethiopia where the rainfall distribution was far from optimal.

Physical Stresses

We are currently focussing our research efforts to understand the effects of drought stress on chickpea yield, and to evaluate management and genetic improvement options to alleviate these effects. This year we report some of our results on screening for drought tolerance. We continue to seek a better general understanding of climatic adaptation of chickpea and have increased our research efforts in northern India; by stationing a Pulse Agronomist at Gwalior. We are continuing efforts to identify chickpea genotypes better able to set pods during the cold winters of northern India and thus escape the deleterious effects of high temperature in late spring, as maturity approaches. We are also assessing the extent of variation in salinity response among chickpea genotypes obtained in previous studies, in order to determine the scope for genetic improvement of salinity tolerance.

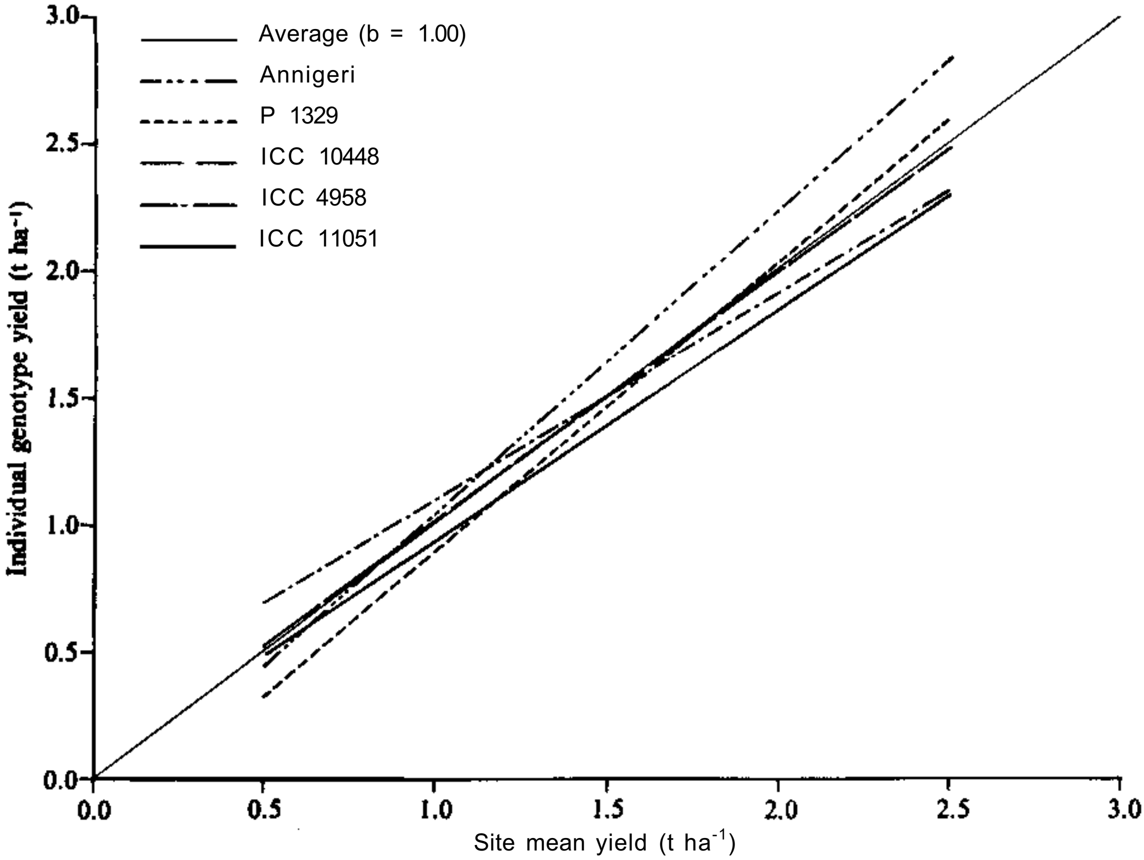
Yield Stability across a Range of Soil Moisture Environments

For several years we have been trying to identify short-duration chickpea genotypes tolerant to drought in the peninsular Indian environment (ICRISAT Annual Report 1982, pp. 110-111). This has involved growing a range of genotypes with and without irrigation and accounting for drought escape effects by either extending the daylength to synchronize flowering or by using multiple regression analysis (ICRISAT Annual Report 1979/80, pp. 82-84). To verify genotypic differences found so far we grew five contrasting genotypes in nine soil environments during the 1984/85 season at ICRISAT Center. These environmental differences were created by growing the plants on Alfisols and on Vertisols differing in soil depth, with and without irrigation.

We determined yield stability across the different soil moisture environments by regressing yield of individual genotypes against the average yield for the environment (Fig. 1). The results demonstrate that:

- selection of genotypes for a greater degree of drought tolerance is possible (e.g., ICC 4958);
- drought-tolerant genotypes may not be able to capitalize on favorable moisture conditions that occur in some years (e.g., ICC 4958);
- genotypes with a high yield potential in favorable environments may not perform well in drought environments (e.g., P 1329); and
- Annigeri performs reasonably well under drought but can also positively respond to improved soil-moisture conditions.

It now seems feasible to attempt genetic improvement of drought tolerance in short-duration chickpea as we now have appropriate



Annigeri	y = -151	+ 1.1921x	r^2 = 0.99
P 1329	y = -235	+ 1.1297x	r^2 = 0.97
ICC 10448	y= 44	+ 0.9733x	r^2 = 0.97
ICC 4958	y= 299	+ 0.8046x	r^2 = 0.96
ICC 11051	y = 42.7	+ 0.9002x	r^2 = 0.99

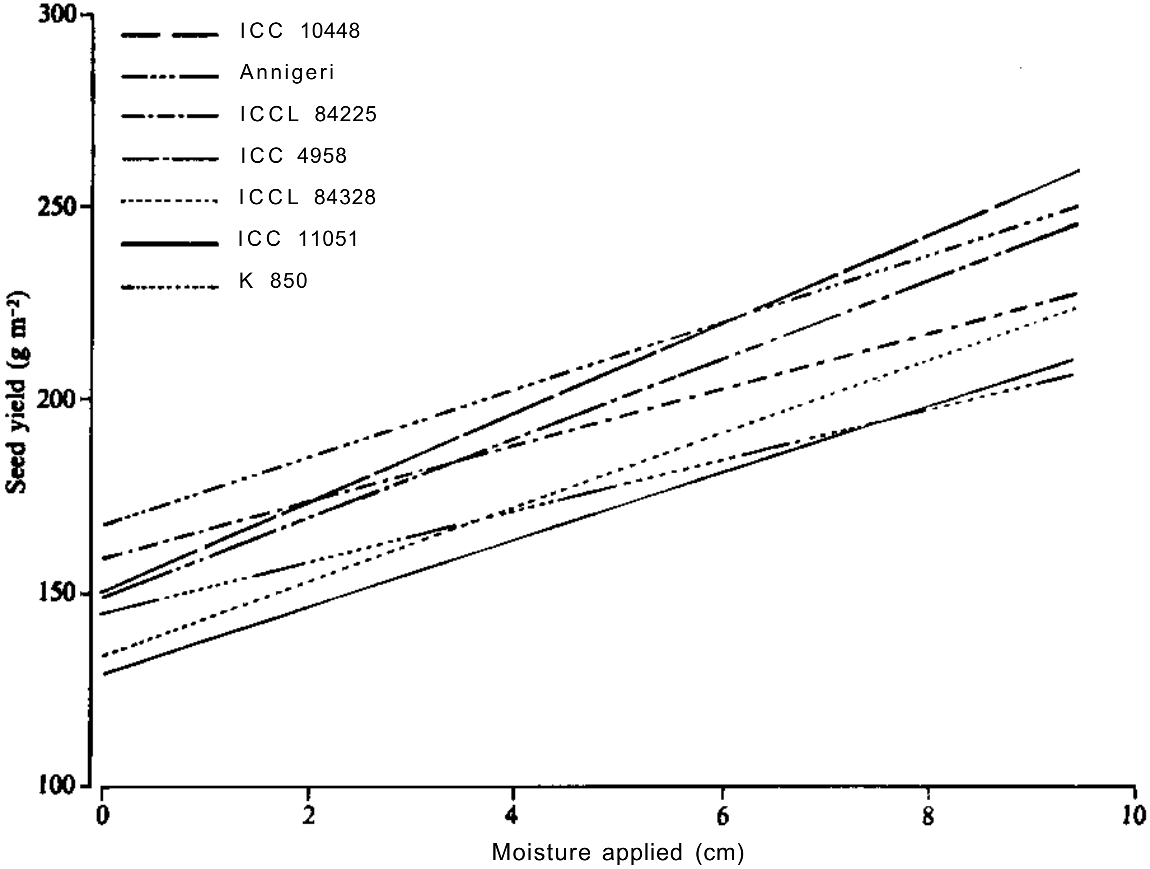
Figure 1. Response of five chickpea genotypes across a range of soils differing in moisture availability, ICRISAT Center, 1984/85.

donor parents (e.g., ICC 4958) and reproducible drought environments under which selection pressure can be exercised.

Use of Line-Source Sprinklers to Determine Moisture Response

Drought screening of chickpea has usually been done using just two moisture treatments, with and without irrigation. However, in order to compare genotypes more precisely in their response to moisture, it is necessary to develop moisture response relations. In 1985/86 we used a line-source sprinkler system to create a moisture gradient (Fig. 2). We grew four replications of 20 genotypes in 1-m wide strips from 0 to 15 m from the sprinkler line. We applied sprinkler irrigation at 28 and 52 days after sowing (DAS). However, heavy rain during the pod-filling stage (53 mm in late January, and 39 mm in mid-February) revived plants at the drier end of the gradient. We harvested 1.5 m subplots across each strip and plotted yields against moisture applied by the sprinklers. Responses of both total above-ground biomass and seed yield (Fig. 3) to moisture were linear over the moisture range used; we expected a reduction in seed yields at the highest moisture levels due to excessive vegetative growth. Linearity indicates that the two treatments, with and without irrigation, would suffice for genotypic comparisons over this moisture range. It is encouraging to note that the response patterns of Annigeri, ICC 10448, ICC 4958, and ICC 11051 in Figure 3 follow a similar trend to that obtained in Figure 1 over a similar yield range. In 1986/87, we are repeating this study using more genotypes and will, hopefully, obtain a wider range of moisture levels, particularly towards the drier end.

Figure 2. Layout of the line-source sprinkler irrigation experiment with chickpea. The sprinkler line runs vertically through the center of the photograph (indicated by arrow), and positions of the l-m wide and 15-m long strips for each test genotype are indicated by plot markers left and right. Vertisol, ICRISAT Center, postrainy season 1985/86.



ICC 10448	y = 151.3 + 11.67x	r^2 = 0.95
Annigeri	y = 168.2 + 8.85x	r^2 = 0.85
ICCL 84225	y = 149.4 + 10.23x	r^2 = 0.96
ICC 4958	y = 159.1 + 7.36x	r^2 = 0.74
ICCL 84328	y = 134.4 + 9.57x	r^2 = 0.93
ICC 11051	y = 129.0 + 8.69x	r^2 = 0.93
K 850	y = 145.2 + 6.57x	r^2 = 0.89

Figure 3. Response of several chickpea genotypes to differential moisture application by line-source sprinklers. ICRISAT Center, postrainy season 1985/86.

Adaptation Studies at Gwalior

In 1985/86, we conducted growth analyses on a range of genotypes growing on an Inceptisol at Gwalior, a site supposedly suitable for medium-duration chickpea. It was found that a group of genotypes that flowered over a narrow range of 60-75 DAS showed a wide range in seed yield, from 1.76 to 2.58 t ha^{-1}. ICCV 6 (ICCC 32) was the top yielder and a distinct outlier. It flowered at 74 DAS, as compared with 68 DAS for G2 and 61 DAS for JG 315, the two best-adapted local cultivars. However, ICCV 6 (ICCC 32) matured 5 days earlier than the other two cultivars. Yields of cultivars such as JG 315 and C 235 were similar despite their flowering dates being 25 days apart. Further growth analysis studies are in progress to determine the reasons for the differences in yield performance, particularly the high yield of ICCV 6 (ICCC 32).

Responses of Late-sown Chickpea to Agronomic Inputs

It may be necessary for various reasons, for instance when sowing in rice fallows, to sow chickpea later than its optimum sowing date in various parts of northern India. To determine the optimum agronomic conditions for late sowings in the Gwalior environment we studied the effects of fertilizer, irrigation, and plant density on the growth of chickpea cultivar K 850 at two sowing dates. A delay in sowing from 29 November to 9 December caused a yield reduction of 20-28% but neither increasing diammonium phosphate application from 100 to 200 kg ha^{-1} nor plant density from 33 to 50 plants m^{-2} enhanced yields of late-sown chickpea. The effects of irrigation were probably atypical because of the above-normal rainfall throughout that growing season. This study is continuing.

Improving the Growth of *Cicer* Plants in Pots

For breeding programs that require careful supervision and frequent observation—for instance, when interspecific crosses are attempted—it is convenient to grow potted plants. But under the conditions prevailing at ICRISAT Center, chickpeas often do not grow well in pots. It was expected that soil type, soil composition, and soil temperature may be responsible. In a 2^4 factorial experiment, we tested two different *Cicer* species: *C. arietinum* and *C. judaicum;* the effect of two mixtures of black and red soils; two soil compositions prepared by adding 0 and 50% vermiculite; and two different pot colors: black with a soil cover of black polypropylene granules, and white with a soil cover of white polypropylene granules. The difference in pot color, which caused differences in temperatures of up to 4°C 15-cm deep in the soil resulted in significant differences in growth and yield of both species. The effect of the other factors was insignificant. Under the experimental conditions at ICRISAT Center, painting pots white and covering the soil surface with white polypropylene granules doubled the biomass and seed production of chickpea genotypes grown in such pots.

Biotic Stresses

Diseases

Disease Situation in Chickpea

Observations at research stations in India during the crop season showed incidence of chickpea stunt disease (caused by bean leaf-roll virus, BLRV) to be relatively high in the peninsular zone. The incidence of foliar diseases such as ascochyta blight (*Ascochyta rabiei*) and botrytis gray mold (*Botrytis cinerea*) in northern India was negligible, mainly due to the dry weather that prevailed in the 1986/87 postrainy season. The incidence of ascochyta blight was also negligible in Pakistan. In Ethiopia, fusarium wilt (*Fusarium oxysporum*) and root rots (*Rhizoctonia* spp) appear to be the main problems but the extent of damage they cause needs to be determined.

Purification of the causal agent of stunt. BLRV that causes stunt of chickpea is a phloem-specific virus and under field conditions is transmitted mainly by *Aphis craccivora.* The virus is known to occur in low concentration in its host tissue and therefore, to obtain a workable quantity of virus for purification, a large quantity of chickpea tissue, preferably of roots, is required.

Using root tissue from infected plants, we consistently obtained spherical particles, about 25 nm in diameter, typical of BLRV (Fig. 4).

Development of a medium for *Botrytis cinerea.* The fungus which causes gray mold of chickpea grows profusely on potato-dextrose broth; however, few or no conidia are produced. To develop an efficient screening technique, we tried to prepare a medium on which the fungus could pro-

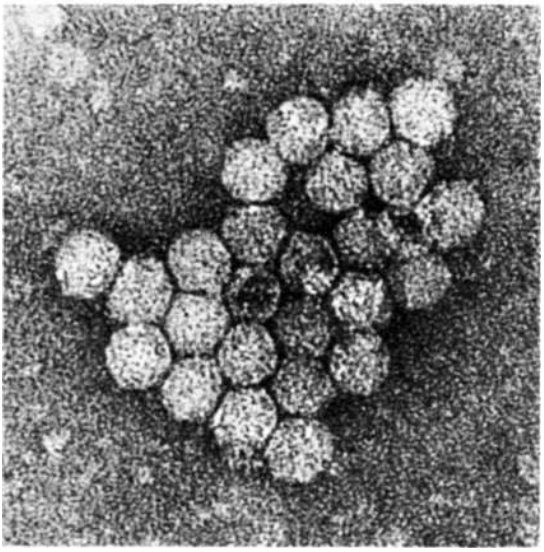


Figure 4. Purified preparation of bean leaf roll virus (BLRV) particles. This virus is responsible for stunt disease in chickpea. (Electron micrograph, magnification x 3 000 000).

duce many conidia. We used several conventional media, and others reported as successful elsewhere. We used autoclaved tissues of different plant species and nutrient media, with combinations of dextrose, ammonium nitrate, and asparagine. However, we observed heavy sporulation only on desi chickpea (DCP) meal broth (extract from 40 g broken desi seed in 1 L distilled water). After a 15-day incubation period, the fungal growth contents from each flask were macerated in a blender, filtered through a strainer, and the number of conidia estimated using a hemocytometer.

The fungus produced very few conidia on DCP meal broth when exposed to fluorescent light, but the number of conidia increased when it was exposed to 12 h rather than 8 h near-UV light (Table 1).

Lower temperatures enhanced sporulation. There was no sporulation at 30° C. The fungus produced more conidia (308×10^4 mL^{-1} suspension) on DCP meal broth when incubated at 15°C than at 20°C (144×10^4 mL^{-1}) and 25°C (77×10^4 mL^{-1}).

Fusarium wilt and grafting. We grafted chickpea genotypes to study the disease reaction of graft-hybrids to *Fusarium oxysporum* f. sp *ciceri* race 1. The reciprocal grafts involving wilt-resistant and wilt-susceptible genotypes were subjected to disease stress soon after the establishment of root and scion. Successful establishment of the reciprocal grafts in wilt-infested soil suggests the involvement of certain anti-

Table 1. Effect of media composition and photoperiod length on sporulation of *Botrytis cinerea*, laboratory test, ICRISAT Center, 1986.

Treatment		Number of conidia x 10^4 mL^{-1} suspension[2]	
Photoperiod (near-UV light)	Broth medium[1]	Trial 1	Trial 2
8 h	Desi chickpea meal	27.5	20.4
8 h	Desi chickpea flour	8.7	8.3
12 h	Desi chickpea meal	40.9	24.6
12 h	Desi chickpea flour	4.2	4.3
SE		±3.25	±2.85
CV (%)		32	40

1. 50 mL autoclaved medium in 250 mL flask, incubated at 25 °C.
2. Average of four replications.

fungal substances produced by plants in imparting resistance.

Use of ICRISAT Chickpea Wilt and Root Rot Resistance Sources by National Programs

Wilt (*Fusarium oxysporum* f. sp *ciceri*) and root rots (mainly *Rhizoctonia bataticola* and *R. solani*) are the major disease problems of chickpea in countries in lower latitudes (0-25° N) where the growing season is warm and dry. Though crop rotations and agronomic management practices such as adjustment of sowing date and use of irrigation can help to minimize the losses caused by these diseases, growing resistant/ tolerant cultivars is the most effective and practical means of control. ICRISAT has been engaged in extensive screening of germplasm and breeding materials in wilt-sick plots at ICRISAT Center for the past 10 years to develop wilt-and root-rot resistant/tolerant varieties of chickpea. In order to identify chickpea lines with broadbased resistance to wilt and root rots and to share the seed of such lines with scientists in national programs, two multilocational cooperative disease nurseries are currently being organized. The Indian Council of Agricultural Research (ICAR)/ICRISAT Uniform Chickpea Root Rots and Wilt Nursery (IIUCRRWN) in India is conducted in collaboration with the All India Coordinated Pulses Improvement Project (AICPIP). The International Chickpea Root Rots and Wilt Nursery (ICRRWN) is conducted in other chickpea-growing countries.

ICRRWN. From 1984 to 1986, 160 entries were evaluated at 12 locations in 9 countries. The lines that showed 0-20% mortality at 6-7 locations are listed in Table 2. Lines that showed resistance in so many locations possibly have durable resistance and could therefore be used in resistance breeding programs in such countries as Bangladesh, Chile, Ethiopia, India, Mexico, Nepal, Spain, Tunisia, and the USA.

IIUCRRWN. From 1984 to 1986,172 entries in this nursery were evaluated at 17 different

Table 2. Chickpea lines with broadbased resistance to wilt and root rot diseases in the major chickpea-growing countries, 1984-86.

	Incidence of wilt and root rots (%)												Number of locations where found resistant
				India		Mexico						USA	
Cultivar	Bangladesh	Chile	Ethiopia	ICRISAT Center	Hisar	Bajio	Sonora	Sinaloa	Nepal	Spain	Tunisia	San Luis Obispo	
ICC 1435	17	85	44	2	14	46	23	7	2	30	15	0	7
ICC 1437	15	100	19	2	8	70	24	0	0	33	55	1	7
ICC 2595	13	74	21	8	0	61	29	1	4	17	35	5	7
ICC 9029	35	87	19	4	2	69	30	4	1	100	28	0	6
ICCL 83127	18	61	19	12	3	47	11	0	21	96	35	20	7
Control													
JG 62[1]	35-98	48-90	10-20	100	100	50-94	100	100	34-99	84-85	30	98-100	1

1. Susceptible to wilt and root rots.

Table 3. Chickpea lines with broadbased resistance to wilt and root rots at 14 locations in India, 1984-86.

	Wilt incidence (%)														Number of locations where found resistant
Cultivar	Akola	Badna-pur	Berham-pore	Da-hod	Dholi	Farid-kot	Gwa-lior	Gurdas-pur	Hi-sar	Ludh-iana	Pant-nagar	ICRISAT Center	Ra-huri	Se-hore	
ICC 2664	6	10	11	20	5	27	8	60	6	48	44	10	5	20	10
ICC 6440	13	6	17	15	17	14	4	55	6	26	25	16	36	83	9
ICC 6815	1	9	11	17	0	8	-	62	6	27	53	3	0	20	10
ICC 9112	8	8	61	11	8	8	15	75	17	33	40	7	3	29	9
ICC 9127	11	12	70	7	0	9	5	63	14	30	42	8	0	67	9
ICC 10384	2	16	20	10	8	9	7	41	13	36	41	20	2	0	11
ICC 10399	8	16	13	12	1	9	36	60	25	34	54	11	17	23	8
ICC 10630	12	4	32	31	10	4	16	47	9	16	45	6	26	36	8
ICC 10809	7	4	43	9	5	13	55	46	12	28	37	11	14	25	8
ICC 11224	4	2	9	1	3	2	13	20	10	6	37	7	18	50	12
ICC 11314	28	7	36	8	4	9	6	20	16	17	40	9	41	42	9
ICC 11322	4	5	33	31	5	7	15	50	8	20	36	7	12	21	9
ICC 11324	11	54	85	8	2	5	24	64	4	13	40	100	11	12	8
ICCL 81004	9	6	5	49	43	1	7	58	18	20	57	16	28	60	8
ICCL 81006	8	6	49	84	8	4	17	16	15	18	61	15	2	55	10
ICCL 81010	6	7	35	75	8	8	10	11	13	38	49	41	3	31	8
Control															
JG 62[1]	82-100	100	98	28	99	78-100	36	100	100	100	25-45	25-100	100	25-94	0

1. Susceptible to wilt and root rots.

locations in India. At most of the locations screening was carried out in wilt-sick plots. The lines that showed a broad resistance to wilt and dry root rot (*R. bataticola*) are listed in Table 3. The line ICC 11224 was resistant (less than 20% mortality) at 12 out of 17 test locations and can be used in resistance breeding programs in various regions of India.

Effect of Solarization on Chickpea Wilt

Last year we reported that soil solarization (covering the soil with transparent polythene to increase surface soil temperature) largely overcame the adverse effects of fusarium wilt on a wilt-susceptible cultivar, ICCV 1 (ICCC 4), growing in a wilt-sick field (ICRISAT Annual Report 1985, pp. 145-147). In the 1985/86 season we reimposed solarization treatments on the 1984/85 experimental plots to measure residual and cumulative effects of solarization. Plant growth was relatively poor, probably due to low rainfall in 1985 and lack of irrigation during crop growth. Despite this, a large response to solarization was still obvious in the wilt-susceptible cultivar and there was a strong residual effect from the previous year (Fig. 5). No significant effects were measured in the wilt-resistant cultivar, JG 74.

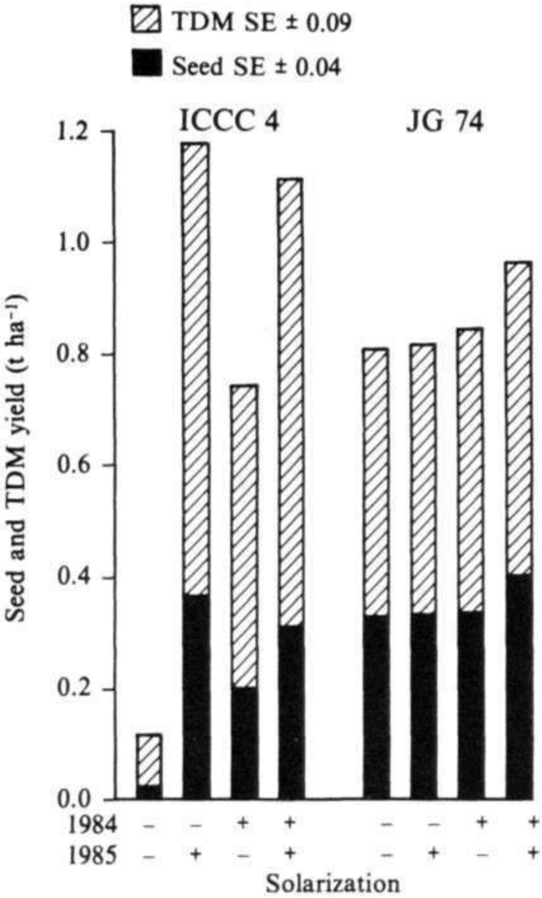


Figure 5. Residual and cumulative effect of soil solarization (+ = solarized, - = nonsolarized) on seed and total dry matter yields (t ha^{-1}) of wilt-susceptible (ICCC 4) and wilt-resistant (JG 74) chickpea genotypes on a wilt-sick Vertisol plot, ICRISAT Center, postrainy season 1985/86.

Solarization decreases pathogen population and increases the activity of antagonistic microorganisms. We studied the soil microflora in solarized and nonsolarized soils. The fungal population was generally reduced in solarized soil but the population of some antagonistic fungi remained high. One of them, *Penicillium pinophilum* Hedgcock identified by the Commonwealth Mycological Institute (CMI), UK was found to be antagonistic to the chickpea wilt pathogen in laboratory studies.

We conducted two screenhouse pot experiments to study the interaction of *P. pinophilum* with the chickpea wilt pathogen (*Fusarium oxysporium* f .sp *ciceri*). In one experiment seeds of the wilt-susceptible genotype JG 62 were sown in fusarium-infested soil that had been inoculated separately with the two strains of the antagonistic fungus, *P. pinophilum.* In another experiment, 7-day-old test seedlings of the same cultivar grown in sterilized sand were root-inoculated with *F. oxysporum* f. sp *ciceri* and either of the two strains of *P. pinophilum,* that had been multiplied on potato-sucrose broth. The seedlings were then transplanted into a sterilized Vertisol in plastic pots. The six treatments in both experiments were: fusarium alone, each antagonist alone, fusarium in combination with each antagonist, and the control (sterilized soil with no fungi). The chickpea plants were observed for wilt incidence after 60 and 90 days. While there was 100% wilting in the fusarium-inoculated treatments in both the experiments, the plants remained free from wilt where the antagonist was present along with fusarium. Inoculation with the antagonist fungal strains alone did not adversely affect the plants.

Solarization can also adversely affect beneficial soil microorganisms. Where the soil was irrigated prior to solarization there was a 1000-fold reduction in numbers of chickpea rhizobia, to <10 g^{-1} dry soil. By chickpea sowing time, some 4 months later, rhizobial numbers in solarized plots had increased to about 100 g^{-1} of dry soil. The low rhizobial numbers resulted in low nodule number and mass $plant^{-1}$ in 47-day-old JG 74 but shoot mass was not adversely affected. Although solarization can reduce rhizobial populations in the soil they are able to recover especially if chickpea is grown. Further, the reduction in nitrogen fixation appears to be compensated by an increased release of soil nitrate from 4 to 15 ppm following solarization.

Insect Pests

Pest Incidence

The pod borer, *Heliothis armigera* was again the major insect pest of chickpea in all areas that we surveyed in India in 1986. This insect attacks the plant from the seedling stage and can completely defoliate young plants, but most genotypes quickly recover from such damage. The greatest yield loss is caused by the larvae feeding on the pods, because compensation for such damage is usually limited by plant senescence, that occurs with the onset of the hot, dry season. In 1985/86, the populations of *H. armigera* moths recorded in the light and pheromone traps at ICRISAT Center were unusually low for most of the season. However, substantial populations of larvae developed on chickpea before and after they flowered. The catches of this moth at Hisar, in both light and pheromone traps, were higher than usual, and there was substantial damage to chickpea crops that were not protected by insecticides.

Few other pests were very harmful in this year. *Aphis craccivora,* the vector of BLRV that causes the stunt disease of chickpea, was more common than in the previous year. At Hisar, few plants (<1%) were killed by termites (*Odontotermes obesus*). Cutworms (*Agrotis* spp) were locally damaging in central India. *Spodoptera exigua* was recorded as a minor pest at ICRISAT Center. Reports from Ethiopia indicated that *H. armigera* was particularly destructive to chickpea crops there. In the Mediterranean region the leaf miner (*Liriomyza cicerina*) was a widespread pest. In Mexico *Heliothis zea* was the major pest in the northwest region and a leaf miner (*Liriomyza* sp) was common in the central region.

Heliothis armigera

Host-plant resistance. We grew 1162 new germplasm accessions in unreplicated plots in an augmented design in the pesticide-free Vertisol area at ICRISAT Center, and we recorded their pod damage and yields. Some appeared to be less susceptible or tolerant when compared with the control cultivars. These will be tested in replicated trials in the coming season.

Major attention was paid to screening material being bred for resistance to both *Heliothis* and wilt. This material was screened at both ICRISAT Center and at Hisar. Our previous selections were retested to confirm resistance in 12 m^2 test plots.

In this year for the first time we offered the International Chickpea *Heliothis* Resistance Nursery (ICHRN) comprised of short-, medium-, and long-duration genotypes to 10 cooperators in India and to 13 in eight other countries.

We developed field cages that appear to encourage *H. armigera* moths to lay their eggs (Fig. 6) on the plants within the cages rather than on the cages themselves. These 2-m high cages are constructed of 5-mm mesh nylon fishnet; they retain the moths, but have little effect on

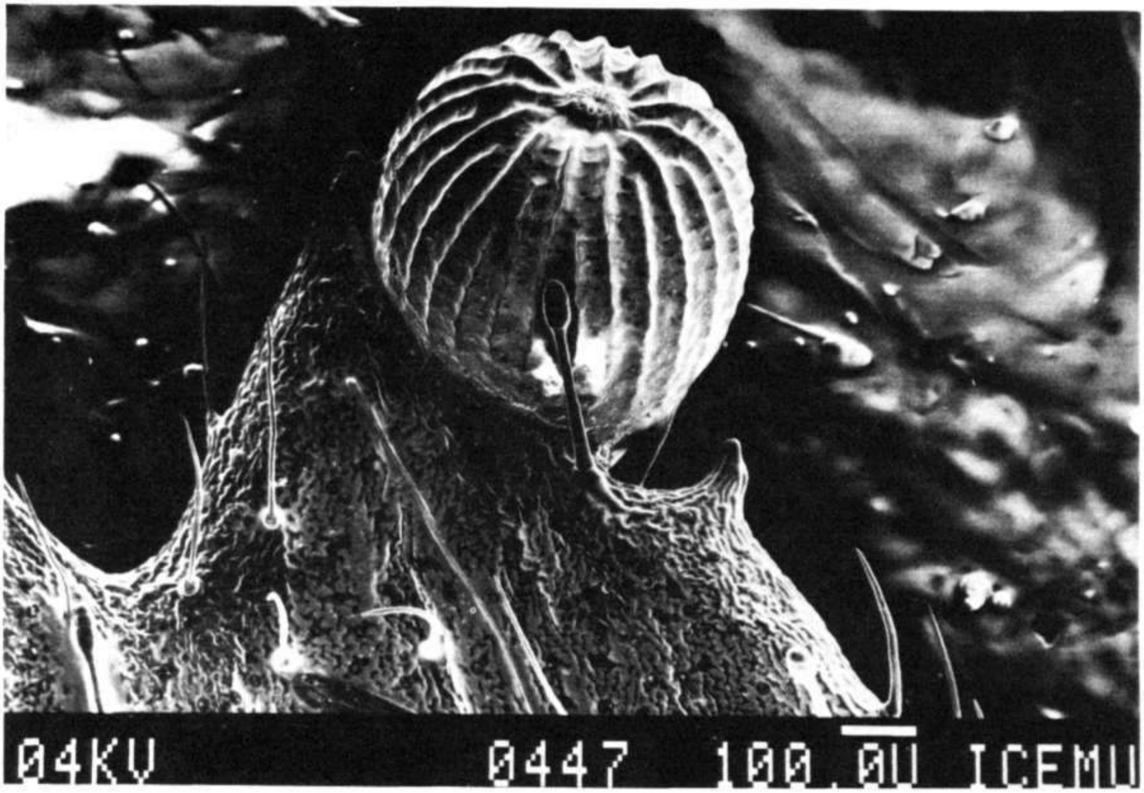


Figure 6. Scanning electron micrograph of a *Heliothis armigera* egg laid in a typical position on the margin of a chickpea leaflet. A glandular trichome which secretes acid can be seen in front of the egg.

light or other environmental factors. Such cages are expected to allow us to use laboratory-reared moths to screen chickpeas for oviposition non-preference throughout the year.

Mechanisms of resistance. We again tested for mechanisms of resistance in trials that were carried out in the open fields and in screenhouses and laboratories.

We reported earlier (ICRISAT Annual Report 1985, pp. 150-151) that chickpea genotypes differ in susceptibility to *H. armigera* due to differences in oviposition, larval retention, and antibiosis. This year we compared some of our resistant genotypes with control cultivars in a three-replicate trial in a pesticide-free field. Each plot consisted of two 9-m rows, 60 cm apart. Eggs and larvae of *H. armigera* were counted on five tagged plants in each of these rows at 3-day intervals from 19 November to 13 December (8 counts). All eggs and larvae were removed from one of the rows after each count, the other row was left undisturbed. Pod damage and yield were recorded from all the tagged plants in each row at maturity. The two resistant selections had much less pod damage than the susceptible control (Annigeri). However, the mechanisms of resistance clearly differed. The selection ICCL 86102 (ICCX 790197-23PLB-11PLB-BPLB), which had been specifically bred for *H. armigera* resistance, was infested by far fewer eggs and larvae than the control, Annigeri (Table 4). ICCV 7 (ICCX 730008-8-1-1P-BP-8EB), a cross that was not specifically made for *H. armigera* resistance, was infested with as many eggs and larvae as the control, but suffered far less pod

Table 4. Counts[1] of eggs and larvae *of Heliothis armigera* and the percentages of pods damaged by this pest on chickpea genotypes[2], ICRISAT Center, postrainy season 1985/86.

	On rows where eggs and larvae were removed after each count			On undisturbed rows		
Genotypes	Eggs	Larvae	Pod damage (%)	Eggs	Larvae	Pod damage (%)
ICCL 86102	57	60	8	58	189	13
ICCV 7 (ICCX 730008)	121	99	10	108	354	12
Control						
Annigeri	139	102	32	126	345	27
SE (mean)	±12	±10	±3.2	±18	±22	±1.2
Trial mean (8 entries)	106	87	16.4	97	296	18
CV (%)	19	21	34	32	13	12

1. Data shown are totals from eight counts at 3-day intervals from 19 November 1985. All eggs and larvae were removed from one row in each plot 3 days before the first count and after each count.
2. Randomized block design with three replicates.

damage. We suspect that the resistance of the latter selection may result from antibiosis. This will be further studied in laboratory tests.

Oviposition on wild legumes. Wild relatives of crop species may contain resistance genes that can usefully be transferred to the cultivated crop. In cooperation with our Genetic Resources Unit (GRU), we screened, in laboratory tests, eight wild *Cicer* spp for oviposition nonpreference. In each test, flowering and podding twigs of two wild species and of resistant and susceptible chickpea genotypes were exposed to egg laying moths in plastic cages. All of the wild species (*Cicer bijugum, C. chorassanicum, C. cuneatum, C. echinospermum, C. pinnatifidum, C. reticulatum,* and *C. yamashitae*) attracted more egg-laying than the resistant chickpea genotype, ICC 506, so there was no oviposition nonpreference resistance in these species.

TDRI/ICRISAT Cooperation

Scientists from the Tropical Development and Research Institute (TDRI), UK are collaborating with ICRISAT in studies of the population dynamics of *H. armigera.* In this year we studied the population build up of this pest in pesticide-free chickpea (cv Annigeri) at ICRISAT Center. We monitored the adult populations with a 6-watt portable light trap set in the crop and all females caught were dissected to determine if they had mated. We also monitored eggs and larvae by twice-weekly counts on 80 plants in the field. Over the same period, plants were uprooted and taken to the laboratory, where they were examined for eggs and small larvae, to ascertain the efficiency of our field counts. Adult emergence was monitored using 1-m^2 metal gauze interception traps that were set in the crop. Collections of larvae were reared to determine parasitism. We also conducted field experiments to estimate pupal mortality.

The highest number of mated females trapped coincided with the peak of egg numbers on the crop. The numbers of females, the proportion mated, and number of eggs on the crop all declined sharply from standard week 49, in early December, when the chickpea flowered. After first converting the data to numbers m^{-2} and correcting for undersampling of eggs and small larvae, we calculated the mortality of the different stages, or age groups, using a life-mortality budget, to identify key mortality factors. The

Table 5. Life mortality budget for *Heliothis armigera* in chickpea, ICRISAT Center, postrainy season 1984/85.

Development stage	Estimated number m^{-2}	Log estimated nos. m^{-2}	K value[1]	Observed mortality factors
Eggs	257	2.410	0.222	
Small larvae	154	2.188	0.389	
Small-medium larvae	63	1.799	0.007	*Campoletis chlorideae* (16.6%)
Medium larvae	62	1.792	0.190	*Carcelia illota* (54.3%)
Large larvae	40	1.602	0.959	
Emerged adults	4.4	0.643	0.643	Pupal mortality (74.3%)

1. K value = Mortality rate calculated as difference between the logs of estimated number nr^2 of the successive development stages.

correction factors were derived from the regressions of field sample counts on those from the detailed observations on plants in the laboratory. The mortality rates were expressed as K values, these being the differences in log numbers between successive developmental stages. The greatest mortality rate occurred between the large larvae and adult emergence (Table 5). This was confirmed by other experiments that showed considerable parasitism by *Carcelia illota* in the large larvae, and heavy predation of pupae in the soil. Mortality of early instar larvae was next in importance. This was probably associated with establishment failure by the newly hatched larvae and with deaths caused by virus.

Insecticide Use

Insecticide use on chickpea at ICRISAT Center in the 1985/86 season gave a yield increase of about 37%, with 1.3 t ha^{-1} being harvested from the insecticide-treated plots. This was the 10th year of such trials; the data are summarized in Table 6.

Table 6. Pods damaged by *Heliothis armigera* in nonprotected plots, grain yields from protected plots, and differences in yield from insecticide-protected and nonprotected plots (avoidable loss), ICRISAT Center, 1976-1986.

Year	Pods damaged in nonprotected plots (%)	Mean grain yield of plots protected with insecticide (t ha^{-1})	Avoidable loss (kg ha^{-1})	Avoidable loss (%)
1976-77	9.4	1.20	209	17.6
1977-78	24.8	0.43	101	23.4
1978-79	14.6	0.94	179	19.1
1979-80	11.8	1.73	510	29.5
1980-81	11.2	1.28	181	14.1
1981-82	14.9	1.56	190	12.2
1982-83	14.6	2.16	400	18.5
1983-84	10.4	0.86	100	11.6
1984-85	8.0	0.95	160	16.8
1985-86	28.3	1.34	360	37.4
Average	14.8	1.24	239	19.3

In most years, two sprays of endosulfan have been sufficient to give adequate protection against *H. armigera.* As the cost ha^{-1} of each spray is roughly equivalent to the sale value of 45 kg of chickpea, insecticide use would have been a good investment in all the years when the crop potential exceeded 1 t ha^{-1}.

In some years (e.g., 1979/80) the percentage of avoidable loss exceeded the percentage of pods damaged. This can be explained because *H. armigera* larvae not only reduce yields by damaging the pods, but also damage vegetative parts and flowers reducing the numbers of pods $plant^{-1}$. In one year, 1981/82, the percentage of avoidable loss was less than the percentage of pods damaged, and the damaged plants obviously compensated for the losses by prolonged growth. In most years the pesticide-treated plots senesced a few days before the untreated plots.

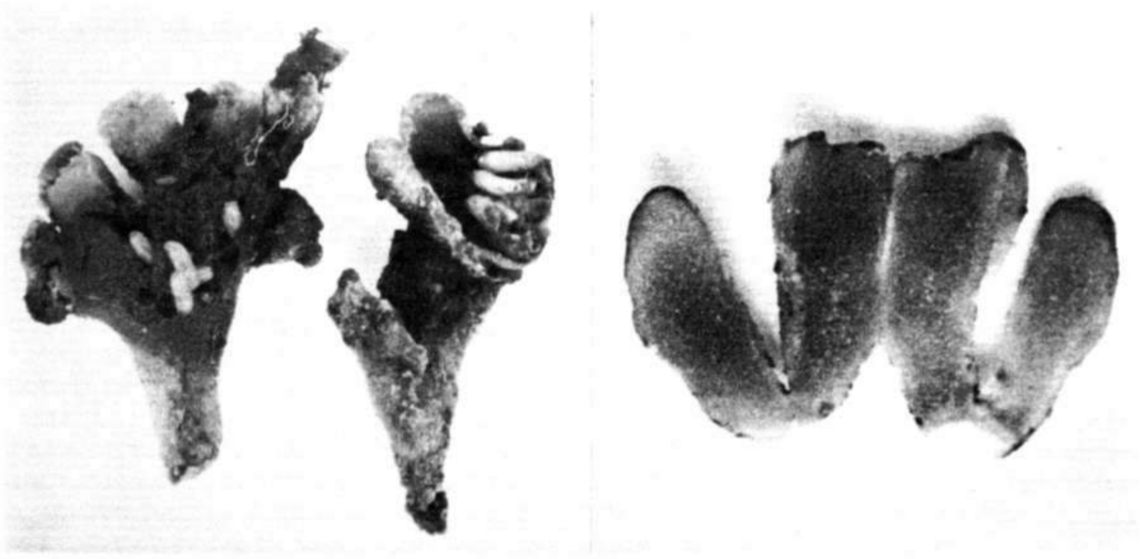
Susceptibility of *H. armigera* to Insecticide

As part of our TDRI/ICRISAT collaboration, we sent samples of *H. armigera* collected from chickpea at ICRISAT Center, to Reading University, UK for insecticide toxicity tests. Compared with controls, from a long-established laboratory culture, these were found to be highly resistant (70 fold) to DDT but equally susceptible to both endosulfan and cypermethrin. As endosulfan has been intensively used to control this pest at ICRISAT Center for the last 10 years, this result was encouraging but rather surprising. It suggests that the *H. armigera* populations on chickpea at ICRISAT Center migrate from areas where DDT has been intensively used for many years.

Nodule-damaging Insects

Over several years, we have recorded insect damage in up to 25% of the nodules on chickpea roots. The extent of such damage varies with years and locations. This year we succeeded in collecting samples of the insect that is responsible for most of the damage. It has been identified as a new species of *Metopina* (Diptera: Phoridae) by a specialist taxonomist at Cambridge University, UK. The effect of the damage (Fig. 7) on the nitrogen-fixing ability of the plants is still to be assessed.

Figure 7. Chickpea nodule (left) dissected to show tissue damaged by *Metopina* sp, compared to healthy nodule in longitudinal section (right). ICRISAT Center, 1986.



Plant Nutrition

We are trying to develop the most appropriate methods for identifying and correcting mineral nutrient imbalances in chickpea. Our major emphasis is on enhancement of symbiotic nitrogen fixation. We are hosting a Government of Japan Special Project that is examining interactions between mineral nutrition and soil moisture availability in chickpea. We are continuing studies on the identification of mineral nutrient deficiencies in chickpea by the use of a pot culture technique, and we are measuring residual effects of chickpea genotypes that differ in nodulation capacity, on subsequent rainy-season crops; the results will be reported in detail next year.

Response to Rhizobial Inoculation Rate

Responses to rhizobial inoculation in chickpea are often inconsistent in soils with a native chickpea *Rhizobium* population. We thus wondered whether the usually recommended inoculation rate of 10^4-10^5 rhizobia seed^{-1} was indeed sufficient to improve nodulation. In 1985/ 86, we conducted a field trial on an Alfisol containing chickpea rhizobia in which we measured the effect of different rates of inoculation of strain IC 2091 on nodulation of chickpea cultivar K 850. Rhizobia were applied as a peat inoculant suspension in water below each seed at sowing. Although an increased inoculation rate did not significantly increase the nodule number, according to serological identification it markedly increased nodule occupancy by the inoculant strain (Fig. 8). Plant growth was not improved

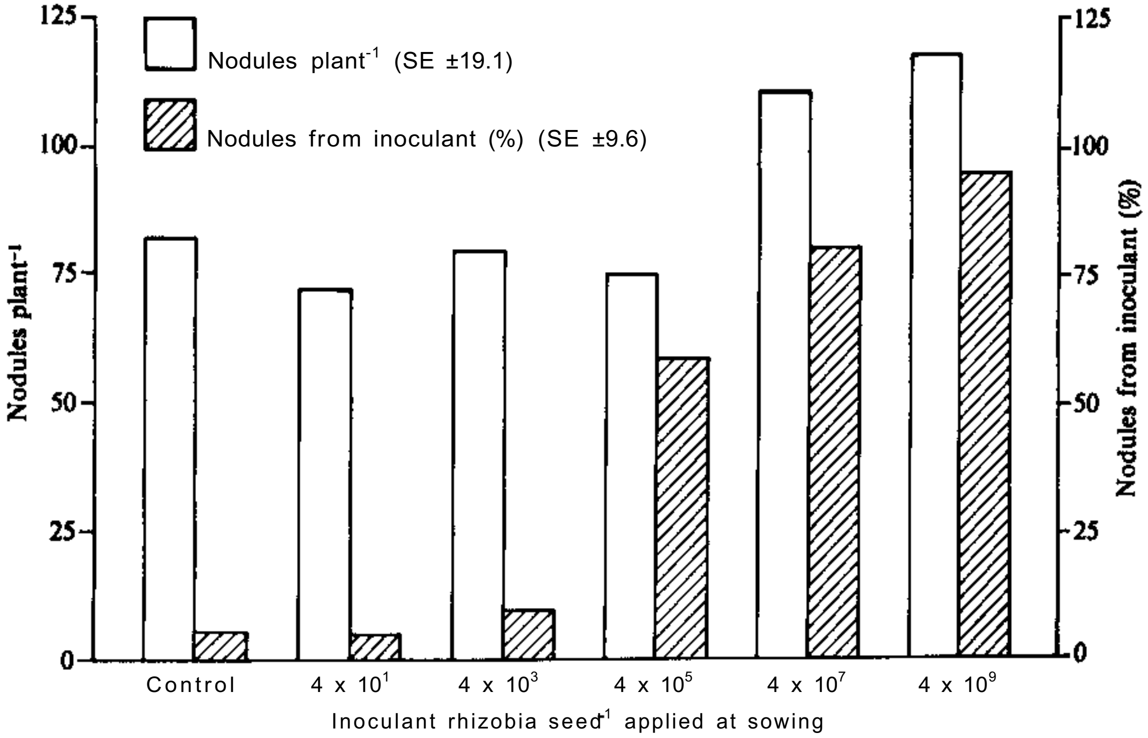


Figure 8. Effect of increasing rates of rhizobial inoculation at sowing on nodule number plant^{-1}, and percentage of nodules formed by inoculant rhizobia at 53 DAS on the roots of chickpea genotype K 850 grown on an irrigated Alfisol, ICRISAT Center, postrainy season 1985/86.

by increased inoculation rate, as the native rhizobia were sufficiently effective, but the present results demonstrate that an improved strain of *Rhizobium* would have to be inoculated at high rates if it is to compete successfully with native rhizobia in forming nodules.

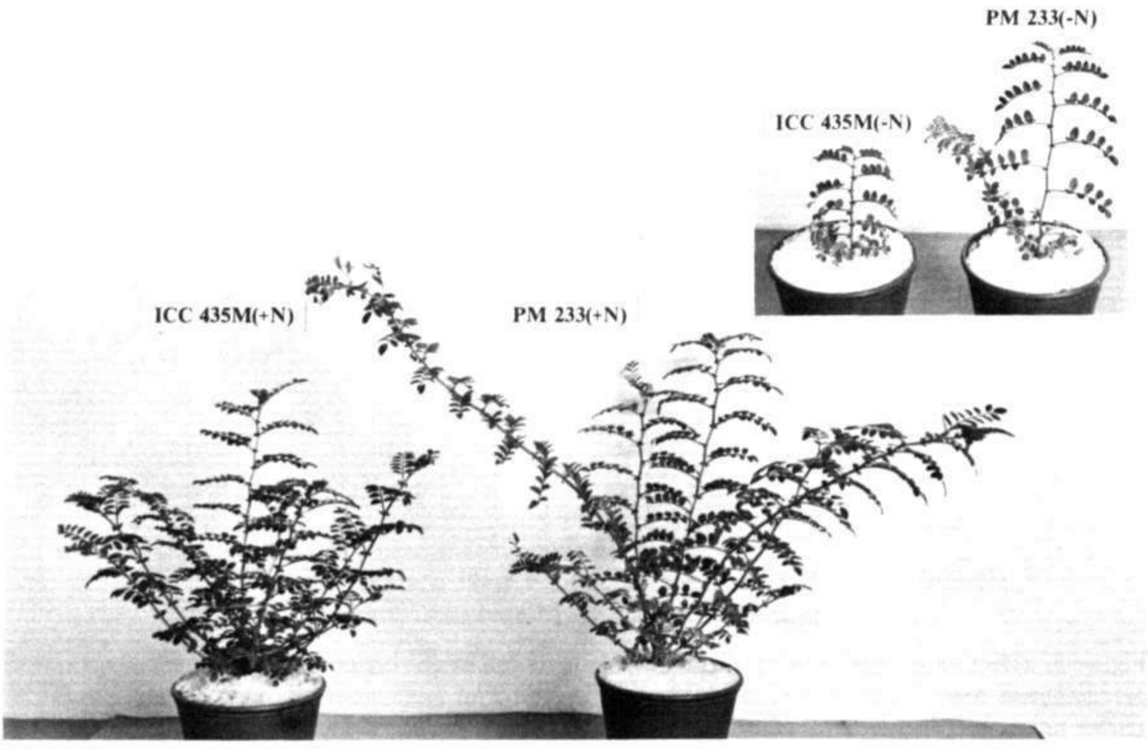
Identification of a Nonnodulating Chickpea Mutant

During a routine nodulation observation in 1985/86 in a Vertisol field with abundant chickpea rhizobia, we noticed a nonnodulated plant of ICC 435. This plant was potted and grown in a greenhouse to produce seeds. In subsequent studies the progenies of this plant were truly nonnodulated in the presence of abundant rhizobia of strain IC 59. This naturally occurring mutant (ICC 435M) was compared with a previously known induced (gamma-irradiation) mutant PM 233 (received from Dr. T.M. Davis, University of New Hampshire, USA) in a pot trial, along with the parents of both mutants. In the absence of nitrogen both the mutants grew poorly and did not flower but plants fed on 100 ppm N grew very well (Fig. 9). The mutants were distinctly different from one another in flowering and growth patterns.

Root Development Patterns and Phosphorus Accumulation

In the 1984/ 85 postrainy season, we followed the time course of root growth, shoot dry matter accumulation, and phosphorus (P) uptake in chickpea cultivar K 850 growing in a Vertisol

Figure 9. Chickpea plants (44 DAS) of nonnodulating mutants ICC 435M and PM 233 grown in pots containing sand watered with quarter-strength Arnon nutrient solution without N (insert) and with 100 ppm N as KNO_3, greenhouse trial, ICRISAT Center, 1986.



under receding soil moisture conditions. A post-sowing irrigation was given to ensure even emergence, and 1.8 mm of rain fell at 53 DAS. Moisture in the 0-90 cm soil profile was 30-35% (w/w) at 10 DAS and gradually declined to 10% near the surface and 20% at 90 cm depth at 83 DAS.

Two phases of active root development were observed, one during the vegetative growth period prior to 60 DAS and another during the grain-filling period (Fig. 10). Before the grain-filling period, the roots had attained 87% of their maximum dry mass and 76% of their maximum

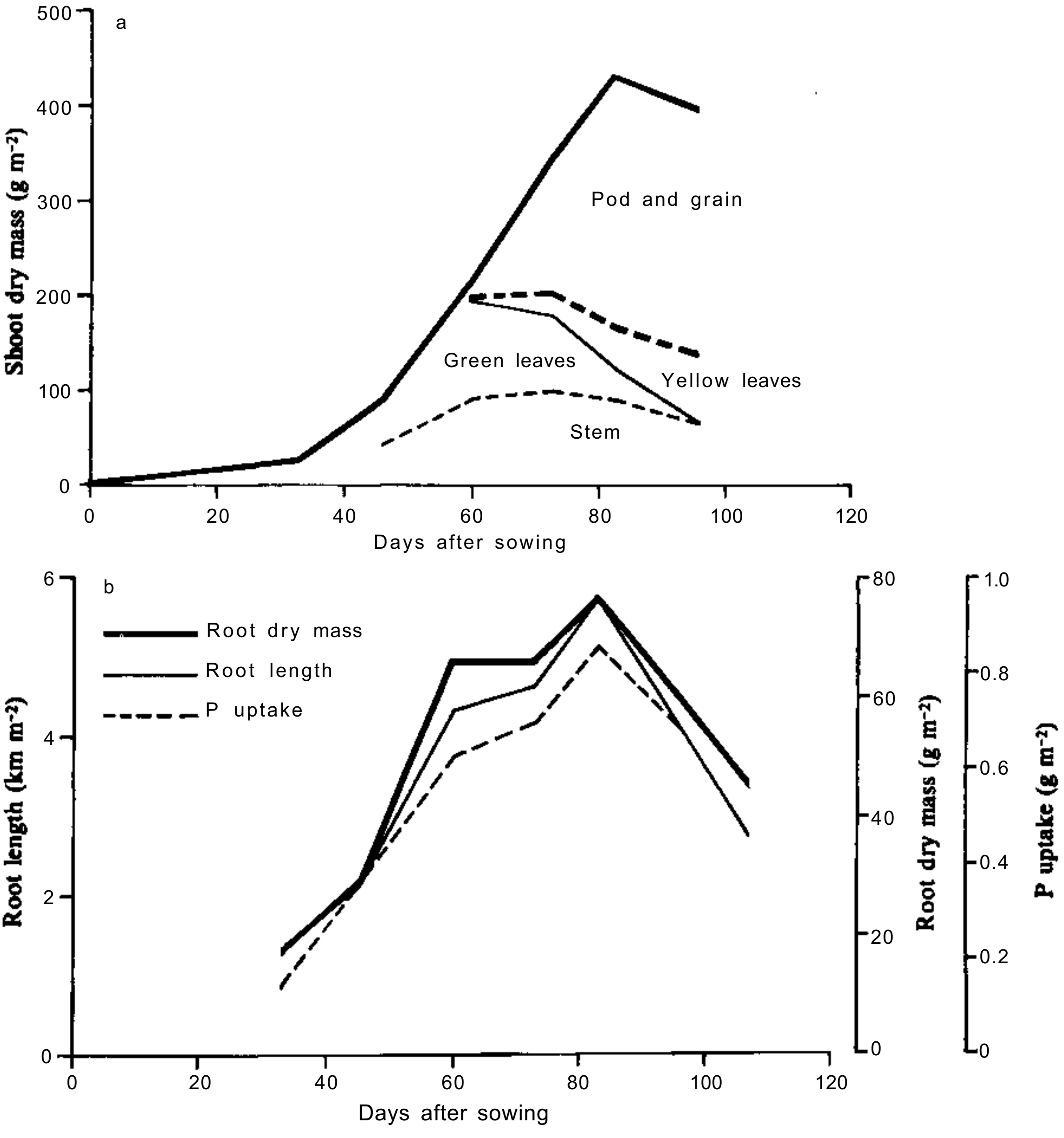


Figure 10. Changes with time in: a. shoot dry mass, and b. root length, root dry mass, and phosphorus uptake in chickpea genotype K 850 growing under receding soil moisture conditions on a Vertisol, ICRISAT Center, postrainy season 1984/85.

length. During this period, the shoot accumulated only 50% of its maximum dry matter and 73% of its P. In this respect chickpea differs from other crops, such as maize or soybean, where dry matter and P accumulate in the shoot almost in parallel.

The increased root development during the grain-filling period (Fig. 10) occurred at a time when soil moisture was low and gradually decreasing. Root length increased to a greater extent than did root dry mass, indicating an efficient use of carbohydrates in increasing root surface area. Phosphorus uptake to shoots increased in a manner similar to root growth during this period.

These data demonstrate that chickpea can take up the bulk of its P requirement for shoot growth in its early growth stages, while the soil is still moist. However, the ability of this crop to produce roots and absorb P when the soil is relatively dry, during the grain-filling period, indicates a possible special adaptive mechanism of chickpea that permits absorption of nutrients under conditions of receding soil moisture. This is being further studied.

Grain and Food Quality

During this year, we concentrated our efforts in the areas of chemical composition, dehulling quality, consumer acceptance, protein digestibility, and biological evaluation. In addition, we obtained information on the effect of fertilizer, irrigation, field conditions [soil pH and electrical conductivity (EC)], and location on chickpea protein content.

Chemical Composition

To study the nutrient profile of lines developed by ICRISAT, we analyzed seed of several genotypes including commonly grown cultivars for protein, starch, sugars, ash, fat, fiber, minerals, and trace elements. As shown in Table 7, we observed significant differences in protein, starch, calcium, and iron contents of dhal (decorticated split seed) samples of these genotypes. ICCV 1 (ICCC 4) contained the highest amounts of protein, confirming results of sample analysis for the 1984/85 season. Results of the analysis of whole-seed samples substantiated this observation. The nutrient profiles of genotypes developed by ICRISAT were comparable with those of local cultivars, and for some constituents they were better (Table 7). We examined the effect of growing season by analyzing seed samples from eight genotypes ICCV 1 (ICCC 4), ICCV 2 (ICCL 82001), ICCV 6 (ICCC 32), ICCC 37, K 850, P 1329, Annigeri, and L 550 grown during 1984/85 and 1985/86 at ICRISAT Center.

Table 7. Chemical composition[1] of dhal samples of chickpea genotypes, ICRISAT Center, 1985/86.

Genotype	Protein (N x 6.25) (%)	Starch (%)	Soluble sugars (%)	Fat (%)	Fiber (%)	Calcium (mg 100g^{-1})	Iron (mg 100g^{-1})	Zinc (mg 100g^{-1})
ICCV 1 (ICCC 4)	29.0	50.0	5.5	5.7	1.0	73.2	8.8	5.8
ICCV 2 (ICCL 82001)	22.6	57.9	5.3	5.8	1.2	93.4	6.3	4.0
ICCV 5 (ICCL 83009)	20.7	56.3	5.6	6.8	1.1	58.4	6.3	4.6
ICCV 6 (ICCC 32)	21.9	54.1	5.3	4.3	1.4	74.9	7.6	6.0
ICCC 37	22.9	54.6	5.7	6.1	1.2	52.9	6.4	4.2
Annigeri	23.3	54.0	5.8	6.7	1.1	50.5	6.1	4.0
L 550	22.7	54.2	5.7	5.3	1.2	73.2	6.5	4.7
SE	±0.25	±0.82	±0.12	±0.13	±0.07	±5.59	±0.29	±0.07

1. Expressed on moisture-free basis.

Whole-seed and dhal samples were analyzed for protein, starch, soluble sugars, fat, fiber, ash, and minerals. Of the various constituents, protein and starch were significantly (P = 0.05) influenced by the growing season. Mean protein content of the 1985/86 season was significantly (P=0.05) higher than that of the 1984/85 season and the reverse trend was true for starch content. Genotype x environment interaction was significant (P< 0.01) for protein and starch contents of both whole-seed and dhal samples. Further analysis indicated that the calcium content of the whole-seed was significantly (P = 0.01) higher than that of the dhal. On an average, about 60% of the calcium in the grain was lost by removing the seed coat during dhal preparation which confirmed our earlier findings.

Protein Content as Influenced by Environment

The large variability in chickpea protein content has become a matter of great concern because as yet we are unable to determine all the causes for the observed variations. We conducted experiments to study the effects of location, fertilizer, irrigation, and field conditions (soil pH and EC) on protein content. The application of nitrogen fertilizer significantly (P = 0.01) increased the protein content in chickpea (19.3% with 120 kg N ha^{-1} and 16.9% without nitrogen). On the other hand, irrigation had no significant (P = 0.05) effect on protein content. The protein content of Annigeri whole-seed samples grown in different fields at ICRISAT Center varied from 13.9 to 23.8%. In alkaline and saline soils (soil pH readings of 8 and above and EC readings of 2 and above) the protein content was reduced.

To confirm our earlier results, (ICRISAT Annual Report 1984, p. 145) we studied the effect of location on protein content by analyzing seed samples of 16 genotypes of ICCT-DL grown with three replications each at Faridkot, Hisar, and Kanpur. The mean protein content of these genotypes was 18.8% at Faridkot, 23.3% at Hisar, and 18.9% at Kanpur. Statistical analysis of these data revealed significant (P = <0.01) genotype differences and genotype x location interaction. The genotypic differences found in this study confirmed our earlier observations, but we had not previously found significant interactions between locations and genotypes.

Cooking Quality and Consumer Acceptance

A considerable proportion of chickpea produced in India and many other countries of the world is consumed as whole seed. Information on cooking quality and consumer acceptance is therefore important and we studied these for five genotypes each of desi (C 235, G 130, H 75-35, H 208, ICCV 1 (ICCC 4) and kabuli (L 144, L 550, ICCC 25, ICCV 6 (ICCC 32), and ICCC 33) chickpeas grown during 1985/86 at Hisar. We tested whole seed samples for their seed color, texture, flavor, taste, and general acceptability with the help of 10 panel members. The results indicated no significant differences between desi and kabuli types for all the characters studied. In addition, the cooking time of whole seed and dhal samples of 14 elite ICRISAT lines (ICCC 14, 25, 33, 34, 36, 38-43, and 46-48) was determined. For whole seeds it varied from 54 min for ICCC 25 to 98 min for ICCC 42, whereas for dhal it ranged from 25 to 46 min, the mean being 34.3 min. The cooking time for whole seed and dhal of 25 genotypes, including the 14 mentioned earlier, did not show a singificant correlation (r = 0.13). Further, we observed that 100-grain mass was positively and significantly correlated with cooking time of whole seed (r = 0.45, P= <0.05) and dhal (r = 0.53, P= <0.01). The protein content of these genotypes was not correlated with the cooking time of whole seed and dhal.

Dehulling Quality

In cooperation with the Home Science College, Hyderabad, we evaluated nine chickpea genotypes for their dehulling quality using the Prairie Regional Laboratory (PRL) mini dehuller. The dhal yields varied from 67.7 to 84.8% (Table 8).

Table 8. Dehulling quality of chickpea genotypes, ICRISAT Center, 1985/86.[1]

Genotype	100-grain mass (g)	Recovery of dehulled material (%)				
		Whole seed	Dhal	Broken	Powder	Husk
ICCV 1 (ICCC 4)	15.0	6.9	67.7	1.8	4.8	11.2
ICCV 2 (ICCL 82001)	23.8	1.4	84.8	1.0	6.2	4.5
ICCV 6 (ICCC 32)	17.5	1.1	84.3	1.5	6.8	3.6
ICCC 37	18.2	7.6	72.1	4.7	5.3	7.3
K 850	29.4	2.4	83.5	2.1	4.0	9.4
P 1329	18.7	2.6	80.5	2.5	1.7	10.2
Annigeri	21.6	12.5	72.9	1.1	3.6	9.7
H 208	11.3	7.6	70.2	5.0	3.9	9.9
L 550	19.7	1.0	84.7	0.8	7.1	3.3
SE	±0.33	±0.87	±2.59	±0.23	±0.21	±0.46

1. Using PRL mini dehuller.

In general the dhal yield was higher for kabuli than desi types which might be due to the former's lower seed coat content. However, we noticed that the powder fraction was relatively higher in the kabuli types, suggesting that kabulis might incur greater nutrient losses on dehulling. Among the desi types, the dhal yield ranged from 67.7 to 83.5%.

Effect of Cooking on Protein Digestibility

As the digestibility of legume protein is reported to be low even after heat treatment, we studied the digestibility of raw and cooked (15 lb pressure for 15 min) whole seed and dhal samples of chickpea Annigeri. We determined the biological value, true protein digestibility, and net pro-

Table 9. Effect of cooking on biological value, protein digestibility, and net protein utilization in chickpea (cv Annigeri), ICRISAT Center, 1986.

Treatment	Food consumed (g)	Biological value (%)	True protein digestibility (%)	Net protein utilization (%)
Annigeri whole seed				
Raw	45.8	78.9	80.8	63.7
Cooked	46.8	73.2	81.9	60.0
SE	±1.53	±2.78	±0.90	±2.52
Annigeri dhal				
Raw	47.9	79.3	87.6	69.5
Cooked	49.0	80.7	86.9	70.1
SE	±0.62	±1.34	±1.22	±1.16

tein utilization of whole seed or dhal samples using Wistar strain rats. These parameters were not changed significantly by cooking (Table 9).

Plant Improvement

Breeding Short- and Medium-duration Desi Types

The details of breeding materials of short- and medium-duration desi types evaluated at ICRISAT Center and Hisar are presented in Table 10. Replicated yield tests of medium-duration materials were also conducted at Gwalior.

The F_1s were advanced to obtain sufficient F_2 seeds for screening against diseases and *Heliothis* and to meet the demands of our cooperators. The F_2 to F_4 populations, and F_3 to F_8 plant progenies/families were evaluated in normal or wilt-sick fields with or without insecticide protection to identify materials combining high yield and resistances to diseases and *Heliothis.* All the resistant F_2 and F_3 plants were bulk harvested and over 4200 single plants with desired characters were selected for further progeny tests. Based on actual seed yield, percentage increase in yield over the moving average of controls, and scores for diseases and pests, 686 progenies were selected for replicated yield tests in 1986/87. Some of these combined high seed yield with resistance to fusarium wilt, dry root rot, and *Heliothis*, a combination hitherto not available in short-duration backgrounds.

We conducted preliminary (PYT) and advanced yield trials (AYT) of 667 advanced-generation breeding lines at ICRISAT Center and Gwalior. The most adapted local controls were included for comparison. These lines were also screened for resistance against wilt, root rots, and *Heliothis.* Forty-seven short-duration and 25 medium-duration lines that outyielded the controls and showed resistance to wilt and *Heliothis* were contributed to International Chickpea Screening Nurseries (ICSNs). In addition, we selected 104 lines for advanced yield tests in 1986/87.

Breeding Long-duration Desi Types

We are now breeding for resistance/tolerance to biotic and abiotic stresses prevalent in specific regions. We aim to incorporate resistance to the major diseases and *Heliothis.* In the environments where long-duration chickpeas are grown, resistance to the following stress factors is considered important: wilt, root rot, stunt, ascochyta blight, botrytis gray mold, *Heliothis,* salinity, and low temperatures.

We made 150 crosses during the year, mostly to incorporate resistance to two or more stress factors mentioned above into high-yielding genotypes. Some single crosses will be used as parents in three-way crosses to add more resistances. In addition we made ten crosses to increase levels of resistance to botrytis gray mold and 45 crosses to increase levels of resistance to ascochyta blight and to study the inheritance of resistance.

About 9500 progenies and 850 bulks were evaluated in normal, wilt-sick, and nonsprayed fields at Hisar. Based on visual evaluations, yield, and wilt resistance, selections were made both of single plants and progenies (Table 10).

In collaboration with HAU, we screened 8 F_2 bulks and 1082 F_3 progenies and selected 155 single plants from a joint ascochyta blight nursery. At Pantnagar, where we collaborate with G.B. Pant University of Agriculture and Technology, 405 bulks and progenies were screened in the botrytis gray mold nursery and we selected 471 plants that showed resistance.

High-yielding, wilt-resistant, and uniform progenies (two hundred and seventy six) were bulked and included in replicated PYTs, while the six most promising lines were entered in AYTs to be conducted during 1986/87.

The results of the 1985/86 PYTs with 622 lines and AYTs with 92 lines were analyzed. Table 11 presents data of four representative trials. Based on this performance data we selected 50 lines for ICSN-DL, 12 lines for ICSN-DM, six lines for the International Chickpea Cooperative Trial-Desi Long-duration (ICCT-DL), and 101 lines for AYTs. Two promising entries were contributed to AICPIP trials as ICCV 11 and 12.

Table 10. Numbers of chickpea populations and progenies evaluated at ICRISAT Center and Hisar, 1985/86.

	Materials grown in:				Materials selected	
Generation	Normal field	Wilt-sick field	Non-sprayed field	Nonsprayed wilt-sick field	Single plants	Bulks
ICRISAT Center						
Desi short and medium duration						
F_1 Crosses	294					232
F_2 Populations		258		27	423	258
F_3 Populations		104				100
F_3 Progenies	279	755		588	390	371
F_4 Populations	56				2538	
F_4 Progenies	499	390	203	174	304	12[1]
F_5 Progenies	2005	3352	1994	68	466	269[1]
F_6 Progenies	828	1681	1150	43	361	277[1]
F_7 Progenies	690	671	398	398	163	111[1]
F_8 Progenies	157	141				17[1]
Total	4808	7352	3745	1298	4645	1647
Hisar						
Desi long duration						
F_1 Crosses	144					120
F_2 Populations	6	18	15		618	77
F_3 Progenies	1024	541	60		311	354+21[1]
F_4 Progenies	1076	894			4030	16+16[1]
F_5 Progenies	3317	3058	266		865	112[1]
F_6 Progenies	1906	1983	143		378	59[1]
F_7 Progenies	647	926	349		154	60[1]
F_8 Progenies	284	513	233		31	18[1]
Total	8404	7933	1066		6387	853
Hisar and ICRISAT Center						
Kabuli						
F_2 Populations	47				437	
F_3 Progenies	51	51			9	
F_4 Progenies	279	261			34	9[1]
F_4-F_5 Progenies	55				13	
F_5 Progenies	515	315			9	32[1]
F_5-F_6 Progenies	342	342				12[1]
F_6 Progenies	276	231			63	25[1]
F_7-F_{10} Progenies	227	228				31[1]
Total	1792	1428			565	109

1. Selected for replicated yield trials during 1986/87.

Table 11. Performance of the three highest-yielding entries in chickpea Preliminary Yield Trials (PYTs), Hisar, India, 1985/86.

Line/cultivar	Time to 50% flowering (days)	100-seed mass (g)	Seed yield ($t\ ha^{-1}$)
Desi long-duration lines trial			
ICCX 800138-BH-BH-35H-BH	92	12.2	3.8
ICCX 800135-BH-BH-47H-BH	87	12.1	3.7
ICCX 800161-BH-BH-9H-BH	96	13.8	3.7
Controls			
H 208	87	12.5	2.9
K 850	83	23.9	2.8
SE	±1.9	±0.46	±0.21
Trial mean (25 entries)	93	14.3	3.2
CV(%)	4	6	13
Mid-tall lines trial			
ICCX 770913-BH-6H-BH	72	13.6	3.6
ICCX 770382-BP-1H-1H-1H-2H-BH	83	18.2	3.6
ICCX 770918-BH-11H-2H-1H-2H-BH	89	11.9	3.2
Controls			
K 850	85	24.0	2.9
H 208	90	12.3	2.9
SE	±1.6	±0.53	±0.21
Trial mean (25 entries)	88	14.3	2.7
CV(%)	4	8	15
Multiseeded lines trial			
ICCX 780359-4H-1H-1H-BH	93	14.1	3.0
ICCX 800461-4H-1H-BH	98	10.6	3.0
ICCX 780351-5P-1H-1H-BH	95	17.2	2.8
Controls			
K 850	85	25.3	2.4
HMS 8	96	13.5	2.1
H 208	90	12.1	2.1
SE	±2.7	±0.72	±0.22
Trial mean (36 entries)	94	15.6	2.3
CV(%)	5	8	17
Heliothis-resistant lines trial			
ICCX 800771-22PLB-5PLB-6HLB-BHLB	80	*11.6*	4.4
ICCX 800771-22PLB-3PLB-1HLB-BHLB	82	16.2	3.7
ICCX 800771-22PLB-3PHB-2HLB-BHLB	85	11.6	3.3
Controls			
ICCX 730020-11-2-EB	86	10.1	3.0
H 208	85	11.2	3.0
SE	±1.6	±0.92	±0.41
Trial mean (25 entries)	84	11.9	2.7
CV(%)	4	15	30

Breeding Kabuli Types

For the kabuli crossing program 45 single crosses were made among parents with good agronomic backgrounds, resistance to diseases such as wilt, stunt, ascochyta blight, and botrytis gray mold, *Heliothis* resistance, large seed size, and with different countries of origin. In addition 34 multiple crosses were made mainly among single crosses mutually compensating for the missing component/characters required in the region.

Table 10 lists the breeding materials, F_2 through F_7, grown in normal and wilt-sick fields and together with a few F_2s grown in the blight nursery at HAU, Hisar. It also shows the number of single plant selections made, and the progenies individually bulked for PYTs. A high selection pressure was applied for larger seed size through all the generations.

Five PYTs and one AYT were conducted at Hisar. The AYT was also repeated at Gwalior. L 550 and ICCV 6 (ICCC 32) were included as controls in all these trials.

A number of lines exceeded the control cultivars in yield and many had larger seeds (Table 12). The most promising entries in these trials were contributed to the International Chickpea Cooperative Trial Kabuli (ICCT-K) which was initiated this season and sent on request to 7 non-ICRISAT locations. It comprised 15 entries of short-, medium-, and long-duration types with L 550 as control. Some trial entries were selected for further testing in AYTs. From the advanced trial we selected two entries that performed well at both Hisar and Gwalior, and were contributed to the AICPIP as ICCV 13 and ICCV 14.

Short-duration kabuli cultivars are in increasing demand in peninsular India. Two varieties, ICCV 2 (ICCL 82001) and ICCV 5 (ICCL 83009), are early maturing and wilt-resistant and were sent to cooperators at Lam, Coimbatore, Bijapur, Gulbarga, Akola, Badnapur, and Rahuri for testing. Unfortunately the crops failed because of the severe drought.

Because of the growing interest in kabulis, we started a small-scale breeding program with 12 crosses involving short-duration kabulis with *Hehothis* and wilt resistance, and large seed. We also grew 55 F_4 progeny rows, selected 30 plants from these, and bulked 6 progenies for inclusion in PYTs.

Breeding for Drought Resistance

Following the identification of drought-tolerant parents we have initiated a breeding program that follows the diversified bulk population breeding approach.

In this scheme, an adapted parent will be crossed with a drought-tolerant parent ICC 4958. The resulting F, then will be crossed with wilt and dry root rot-resistant parent ICC 12237. The F_2 population of the three-way cross will be screened in the disease nursery. The wilt and dry root rot-resistant plants thus harvested will then be evaluated under both drought-stressed and nonstressed conditions in the F_3, F_4, and F_5 generations. Single plants selected in F_5 will be grown as F_6 progenies and the best progenies will be evaluated again in yield tests under both environmental conditions. The top-yielding 20-25 lines will be further screened for drought resistance by the line-source sprinkler technique to identify elite lines for multilocational trials.

We envisage that this approach will integrate disease resistance, drought resistance, and yield potential, and may also give us information about environments suitable for drought screening.

Breeding for *Heliothis* Resistance

We continued our efforts to incorporate *Heliothis* resistance into high-yielding genotypes of short duration at ICRISAT Center, and of long duration at Hisar, by screening the breeding materials in pesticide-free areas. Our major thrusts were to combine wilt and *Heliothis* resistance, to identify breeding lines with consistently low *Heliothis* damage, and to increase the level of resistance by combining resistant sources. At ICRISAT Center we developed a wilt-sick plot in the pesticide-free area so that we

Table 12. Seed yield (t ha^{-1}) and 100-seed mass (g) of the two highest-yielding kabuli chickpea lines in four Preliminary Yield Trials, Hisar, India, 1985/86.

Line/cultivar	100-seed mass (g)	Seed yield (t ha^{-1})
Trial 1		
ICCX 780670-BH-BH-24H-BH	31.0	3.7
ICCX 780670-BH-BH-22H-BH	30.4	3.3
Control		
L 550	22.1	2.8
SE	±0.59	±0.20
Trial mean (25 entries)	26.9	2.9
CV(%)	4.3	14
Trial 2		
ICCX 770198-BH-7H-BH-BH-BH	25.5	3.0
ICCX 790476-BH-BH-27H-2H-BH	31.7	3.0
Control		
L 550	25.1	2.6
SE	±0.88	±0.15
Trial mean (25 entries)	27.5	2.7
CV(%)	6.4	11
Trial 3		
ICCX 790506-BH-BH-29H-2H-BH	30.3	3.2
ICCX 790265-9H-BH-BH-1H-BH	32.3	3.1
Control		
L 550	21.1	2.7
SE	±0.60	±0.18
Trial mean (25 entries)	26.7	2.8
CV(%)	4.5	13
Trial 4		
ICCX 790280-BH-1H-BH-BH	25.7	3.1
ICCX 761293-5H-4H-1H-BH	23.6	3.0
Control		
L 550	23.2	2.6
SE	±0.75	±0.20
Trial mean (25 entries)	25.6	2.7
CV(%)	5.9	15

can screen for *Heliothis* and wilt resistance at the same time. Kabulis are generally more prone to *Heliothis* damage, so we started to incorporate resistance into these types.

From segregating breeding materials in various generations grown in wilt-sick and pesticide-free fields, we selected 617 plants that survived wilt attack and also showed low *Heliothis* damage, and 198 plants from the pesticide-free areas. Seventy-nine advanced generation breeding lines that had low *Heliothis* incidence and/ or good yield levels were bulk harvested individually for PYTs next year. In addition, we bulked 23 lines that showed low *Heliothis* damage and resistance to fusarium wilt for tests in replicated trials next year.

At Hisar, 15 desi and 24 kabuli F_2 populations, and 963 F_3 to F_8 progenies were grown in pesticide-free plots; 1274 desi and 228 kabuli plants were selected.

Sixty-nine lines were tested in PYTs and AYTs in the pesticide-free areas at ICRISAT Center and 92 were tested in similar trials at Hisar. We identified lines that gave good yields and were resistant to *Heliothis,* the best 4 lines, ICCL 86101 to 86104 in these trials were contributed to the AICPIP multilocational trial for *Heliothis* resistance. Besides these, two more lines, ICCL 86105 and ICCL 86106, were contributed to ICRISAT's ICHRN.

We compiled the data of the last 4 years and identified lines that showed consistently low *Heliothis* damage. We are crossing these with lines that have both wilt- and *Heliothis*-resistance.

Two lines (ICCL 84501 and ICCL 84502) contributed to AICPIP multilocational trial for *Heliothis* resistance in 1984/85 maintained their performance in 1985/86 and were retained for further testing.

Offseason Nurseries

The major offseason activity was at Tapperwaripora in Kashmir where we grew around 3000 rows of different materials. About 80% were F_1s and the rest were male steriles, and materials for backcross studies, interspecific crosses, breeding methodology, mutation breeding, and multilocational testing. A wet spell during the early stages of the crop favored the development of ascochyta blight. However, the crop recovered after frequent fungicidal sprays and warm weather later in the season. Production was not satisfactory and we continue to search for a better offseason site.

Exploring possible sites for chickpea offseason work, we conducted trials at Dharwad. Six varieties of different maturities and types were tested on three sowing dates: 15 May, 1 June, and 15 June. The same set was sown at Tapperwaripora and at 5 locations at ICRISAT Center in the 3rd week of June in red and black soils, under permanent shelter, and in a movable shelter (Table 13). The data suggest that we may be able to produce a fair crop at Dharwad by sowing in the 3rd week of June, if the weather conditions later during harvest are relatively dry so that the crop can avoid colletotrichum blight and excessive vegetative growth. At ICRISAT Center, the crop grown under the movable shelter produced the highest yield. The red and black soil crops require full protection against colletotrichum blight.

In the rainout shelters at ICRISAT Center we made crosses for aschochyta blight and botrytis gray mold resistance, grew breeding materials to study the inheritance of the nonnodulating character, continued a backcross program, increased seed for double-podded and wilt-resistant tall lines, conducted an allelism test for male sterility, and multiplied seed for mutation breeding. We made 55 crosses for disease resistance, backcrosses for incorporating disease resistance in adapted genotypes, and a three-way cross for drought resistance.

In the multiple disease sick plot we screened 4 F_2 populations for a diversified bulk population breeding program.

Extending Chickpea Adaptation

Early sowing at lower latitudes. Sowing chickpeas early, i.e., in mid-September, gave higher

Table 13. Seed yield (kg ha^{-1}) in contrasting genotype trials conducted in the off-season, ICRISAT Center, Dharwad, and Tapperwaripora, 1986.

	ICRISAT Center locations[1]					Dharwad sowing date			Tapperwaripora sowing date		
Genotype	1	2	3	4	5	15 May	1 June	15 June	25 May	10 June	Mean
Annigeri	610	330	710	780	1690	440	470	500	490	720	670
K 850	510	320	660	810	1130	1090	730	840	900	870	790
Pant G 114	710	470	760	700	1580	470	700	660	530	740	730
ICCV 2 (ICCL 82001)	340	240	440	640	1310	280	340	320	280	350	450
ICCV 6 (ICCC 32)	510	290	1020	780	1410	760	670	1120	600	1110	830
Rabat	190	80	730	930	1360	710	460	930	550	720	670
SE	±86	±49	±77	±116	±158	±98	±100	±117	±117	±154	
Mean	480	290	720	770	1410	620	560	730	560	750	
CV (%)	31	29	18	26	19	27	31	28	36	35	

1. Locations
   1 = Vertisol.
   2 = Alfisol.
   3 = Medium black soil, reduced sunlight, full exposure to rains.
   4 = Fixed rain-out shelter.
   5 = Mobile rain-out shelter, covered only during rains and at night.

yields than sowing at the normal time, i.e., in October at ICRISAT Center (ICRISAT Annual Report, 1983, p. 136; 1985, p. 161). This year we selected the 23 highest-yielding lines screened for early sowing and tested these together with two controls in an early versus normal sowing comparison. In addition we sowed four more early-sown screening trials in September. One of these comprised of F_5 progeny bulks of crosses involving parents which yield well when sown early. The remaining three trials contained germplasm lines grouped according to their time to 50% flowering. Twenty-six crosses were made between lines adapted to early sowing, and sources of resistance to wilt, dry root rot, black root rot, colletotrichum blight, and *Heliothis.* Under early-sown conditions, 1331 F_3 to F_5 progenies were evaluated and 954 of these were also screened in a wilt-sick plot. We advanced 629 progeny bulks, and included 46 progeny bulks in replicated trials.

The season was unusually dry and the crop suffered from drought. The medium-maturing lines that yielded well in the previous years suffered most due to limited soil moisture, and their crop duration was curtailed. The early-sown crop took slightly more time to flower; and in the case of the high-yielding lines also took more time to mature than the normal-sown crop (Table 14). The early-sown crop was taller, and had more pods plant^{-1}. Seed size was not affected by sowing date. Despite the prevailing drought conditions, the early-sown crop yielded 1.1 t ha^{-1} compared to 0.7 t ha^{-1} for the normal-sown crop, thus confirming the advantage of early sowing.

Late sowing at higher latitudes. There is a growing interest in introducing legumes into new areas and cropping systems, particularly in late-vacated cotton (late November to early December) and rice fallows in South and Southeast Asia. We continued our efforts at Hisar and Gwalior to identify and develop genotypes adapted to late-sown conditions.

For that purpose 50 single crosses were made between parents adapted to late sowing and lines

Table 14. Performance of chickpea lines in an early vs normal[1] sown trial, ICRISAT Center, postrainy season 1985/86.

Line/cultivar	Time to 50% flowering (days)		Time to maturity (days)		Plant height (cm)		Pod number plant^{-1}		100-seed mass (g)		Seed yield (t ha^{-1})	
	Early	Normal	Early	Normal	Early	Normal	Early	Normal	Early	Normal	Early	Normal
1-209-15	43	39	91	88	27	24	37	29	15.7	16.2	1.5	1.1
NEC 2820	48	44	93	90	31	26	35	23	17.5	17.7	1.4	1.0
P6099-2	47	45	95	92	30	29	33	28	14.9	14.5	1.4	1.0
63-1	43	43	92	89	29	25	30	23	18.5	17.6	1.4	0.8
P4197-2	47	45	91	90	30	26	32	24	17.9	17.5	1.4	1.0
Controls												
Annigeri	45	41	96	95	27	24	27	25	19.3	20.6	1.2	0.9
P 1329	58	59	123	127	32	32	15	23	19.5	19.6	0.4	0.3
SE	±0.7	±0.6	±1.7	±1.7	±0.7	±0.6	±2.2	±1.8	±0.6	±1.0	±0.08	±0.07
Trial mean (25 entries)	50	48	103	103	30	28	25	22	20.8	20.8	1.1	0.7
CV (%)	4	3	4	4	5	5	22	20	7	11	17	23

1. Early = sown on 14 September 1985, normal = sown on 12 October 1985.

with resistance to wilt, ascochyta blight, and *Heliothis.* In northern India, chickpea is generally sown from late October to mid November. We sowed 312 germplasm lines and 566 F_3 to F_7 progenies, derived from earlier crosses, with appropriate controls in the first week of December in normal fields. These progenies were simultaneously screened for resistance to wilt at ICRISAT Center or Hisar. Based on visual scores for agronomic performance and increase in seed yields over the moving averages of controls, 173 single plants, 23 germplasm lines, and 34 progeny bulks were selected for progeny tests and replicated yield trials.

We evaluated 46 advanced-generation desi and 23 kabuli lines in late-sown PYTs. Several lines outyielded the controls (Table 15) and 16 desi and 7 kabuli lines were selected for AYTs in 1986/87.

Sets of 23 desi and 10 kabuli elite lines were evaluated in advanced yield tests at Hisar and Gwalior. One wilt-tolerant desi line, ICCV 15, produced a mean seed yield of 2.0 t ha^{-1} and one kabuli line, ICCV 16, produced 1.9 t ha^{-1} against 1.7 t ha^{-1} produced by the control, H 208 and 1.5 t ha^{-1} produced by the control, L 550. ICCV 15 and ICCV 16 were contributed to the AICPIP late-sown trials.

Breeding and Genetic studies

Recombination breeding. We continued our efforts to recombine the desirable characteristics of Annigeri, K 850, JG 62, ICC 506, and ICCL 83151 through single, double, and biparental crosses (ICRISAT Annual Report 1985, pp. 157). We made 51 biparental crosses among the selected F_3 progenies from earlier double crosses. Twenty-four F_2s from biparental crosses, 33 F_3 progenies from double crosses, and 132 F_5 progeny bulks from initial single crosses were evaluated in normal or wilt-sick fields. The F_2s were bulk harvested for one more screening against wilt; 70 single plants were selected in F_3 progenies; and the 20 highest-yielding F_5 progenies were bulked for replicated yield tests in 1986/87.

Early generation bulk yield testing. We were

Table 15. Hundred-seed mass (g) and seed yields (t ha^{-1}) of three highest-yielding desi and kabuli chickpea lines, in late-sown trials, Hisar, India, 1985/86.

Line/cultivar	100-seed mass(g)	Seed yield (t ha^{-1})
Preliminary Yield Trial — Desi		
ICCX 790518-49H-BH-1H-1H-BH	12.9	3.1
ICCX 790519-BT-BH-BH-14H-1H-BH	25.1	3.1
ICCX 790519-BT-BH-BH-7H-1H-BH	26.8	3.1
Control		
H 208	11.4	2.6
SE	±0.41	±0.18
Trial mean (25 entries)	18.9	2.6
CV (%)	4	14
Preliminary Yield Trial—Kabuli		
ICCX 790525-15H-BH-1H-1H-BH	26.7	3.2
ICCX 790525-2H-BH-1H-1H-BH	24.7	2.8
ICCX 790525-19H-BH-1H-1H-BH	20.3	2.7
Control		
L 550	21.0	1.4
SE	±0.82	±0.24
Trial mean (25 entries)	24.7	1.8
CV (%)	7	26

following the classical pedigree breeding procedures prior to 1978/79 when the modified bulk pedigree procedure was initiated (ICRISAT Annual Report 1978/79, p. 117). This method involved replicated yield testing of F_2/F_3 bulks multilocationally to select potentially good crosses. The F_4 derived F_5 progenies from selected bulks were evaluated for yield and their high-yielding progenies were individually bulked. We included selected progenies in ICSNs that are distributed to cooperators through out the chickpea-growing areas of the world.

We evaluated the usefulness of early-generation testing after the 1984/85 season. For this, we drew information on F_2/F_3 bulks, and F_5/F_6 progenies grown at ICRISAT Center and elsewhere, and worked out the following correlations:

- between yields of F_2 and F_3 bulks, and F_5 and F_6 progenies;
- between yields of F_3 bulks, and F_5 and F_6 progenies; and
- between yields of F_2 and F_3 bulks and their derived lines in ICSNs.

We did not observe any consistent correlations between F_2 and F_3 yields in multilocational trials. The number of high-yielding progenies bulked in the F_5 generation showed a significant positive correlation with the F_3 bulk yield at some locations during some years; but the correlation with the mean yields of such progenies was low or negative (Table 16). The mean yields of derived lines in ICSNs in 1983/84 showed a negative correlation with the F_2 yields; while the lines in the ICSNs in 1984/ 85 showed no correlation with the F_2s. The best lines that we selected in F_5 and F_6 and included in ICSNs had no correlation with their early generation perfor-

Table 16. Correlation coefficients between F_3 yield in the 1982/83 chickpea multilocational trial with other parameters in F_4-F_5 generations, ICRISAT Center, 1984/85.

	Parameters in later generations		
Locations	No. of plants selected in F_4 bulk	No. of lines bulked in F_5	Mean yield of F_5 bulked lines
Akola	-0.52	-0.63*	-0.32
Gulbarga	-0.66*	0.66*	0.30
ICRISAT Center	0.24	0.40	0.38
Rahuri	0.87**	0.64*	-0.14

mance. There may be several reasons for the lack of relationship between early and later generations, but the main reasons seem to be: large genotype x environment (locations and years) interactions; the occurrence of crosses with low mean yield but high variability; and the specific adaptation pattern in chickpea that tends to eliminate crosses involving parents that are unadapted to a zone.

Consequent to this finding, and also due to our present emphasis on screening for multiple disease resistances in early generations we have discontinued the early-generation testing.

Studies on desi-kabuli introgression. Desi chickpeas are distributed throughout the world, and are adapted to winter sowing in the subtropics and in hilly areas of the tropics. The kabulis on the other hand, are distributed mainly in the West Asian and Mediterranean regions, and are adapted to spring sowing at higher latitudes.

Useful characters can be transferred (introgressed) from one type to the other. For example, the resistance to fusarium wilt in desi has been transferred to kabuli types; and the resistance to ascochyta blight in kabulis is being transferred to the desi type. Having been geographically separated, these two types may have different gene blocks for important yield components and therefore, yield improvement may be achieved by introgression.

The first ICRISAT Quinquennial Review Panel (1977) recommended desi x kabuli introgression studies. We initiated these studies in 1979 with the following objectives: 1. to introgress desirable characters from desi types to kabuli types and vice-versa, and 2. to study variability generated in desi x desi, desi x kabuli, and kabuli x kabuli crosses. We chose three desi (CPS 1, BG 203, and Pant G 114) and three kabuli varieties (C 104, K 4, and P 9800), and made a diallel cross. A wide range of segregants was obtained in the F_2 of desi x kabuli crosses for seed shape, size, and color. Overall, the proportion of desi type seeds was higher (Table 17) than those of the kabuli type. Apart from these two types, a range of intermediate seed types was also obtained, the proportion of which was higher than that of the kabulis but less than that of the desi types. The actual ratios however varied from cross to cross. For example, the kabuli line K 4 produced a relatively high proportion of desi and intermediate seed types, while the opposite was observed for C 104. We studied F_2 single plants, and F_3 randomly derived progenies to assess the variability generated in different crosses. In general the extent of variability generated by a desi x kabuli cross was similar to that of a desi x desi or kabuli x kabuli cross. The variability in a cross was more related to the divergence of the parents involved than to the seed type. The desi parents increased the variability for pod number per plant and number of seeds per pod, while the kabulis increased variability for plant height and 100-seed mass.

The replicated test of F_3 bulks was vitiated, hence it was repeated as an F_4 bulk trial to select high-yielding bulks. We chose the highest-yielding

Table 17. Desi, intermediate, and kabuli seed type chickpea plants in F_2 populations of desi x kabuli crosses, ICRISAT Center, 1981/82.

Cross	Total plants	Seed types (%)		
		Desi	Intermediate	Kabuli
CPS 1 x K 4	810	71.9	9.9	18.2
CPS 1 x P 9800	684	50.0	26.5	23.5
CPS 1 x C 104	724	30.8	51.9	17.3
Pant G 114 x K 4	779	63.8	19.8	16.4
Pant G 114 x P 9800	734	61.1	26.4	12.5
Pant G 114 x C 104	720	25.0	57.5	17.5
BG 203 x K 4	856	75.1	9.9	15.0
BG 203 x P 9800	713	58.5	25.8	15.7
BG 203 x C 104	743	32.3	49.7	18.0

desi (D), kabuli (K), and intermediate (I) bulks based on replicated F_4 bulk tests. Each of the three bulks was crossed to a fourth desi (WR 315) and kabuli variety (No. 501) to initiate a second cycle of introgression. In the F_2 of the second cycle, we observed that the recovery of kabuli seed type segregants is higher than D or I types when kabuli or intermediate seed type bulks were crossed with the fourth kabuli parent. The recovery of kabuli type segregants in desi bulk x kabuli parent was similar to the desi x kabuli cross F_2 of first cycle of crossing.

We evaluated cycle I and cycle II F_3 bulks to compare the variability. It appeared that cycle II F_3 bulks have reduced variability for many of the characters studied. But reduction in variability for seed yield is only found at Hisar and not at ICRISAT Center. There is a very clear reduction in range for number of pods at both locations. The comparison will be repeated for one more year to confirm these findings.

Inheritance of resistance to fusarium wilt (*Fusarium oxysporum* f. sp *ciceri*) race 1. We evaluated the F_1, F_2, and F_3 progenies of wilt susceptible JG 62 crossed with wilt-resistant P 165 and P 289, in pots with wilt-infested soil. The F_1s were late wilting and the F_2 segregated in a ratio of 3 susceptible: 1 resistant in both crosses. The susceptible phenotypes classified as late and early wilters gave a good fit to 3 late: 1 early. As in the case of recessive epistasis, the locus for late wilting failed to express in the absence- of another dominant gene for early wilting, to give rise to 9 late: 3 early: 4 resistant phenotypes. Segregation among 50 F_3 families for each of the two crosses supplemented the results obtained from F_2 studies. In another set of trials involving progenies of late x late wilters, we used the F_1 and F_2 populations of K 850, H 208, and C 104 crossed with GW 5/7 as a common parent. The F_1s of all the three crosses were late wilting and in F_2 digenic segregation ratios of 15 susceptible: 1 resistant in the crosses with K 850 and C 104, and 13 susceptible: 3 resistant with H 208 were observed. The results suggest that the alleles for genes governing late wilting in GW 5/7 are different from those identified in K 850, C104; and that H 208 differs from K 850 and C104 in one or two of the resistance genes.

Inheritance of resistance to dry root rot (*Rhizoctonia bataticola*). We studied the inheritance of dry root rot resistance in the crosses C 104 x P 165 and H 208 x P 165 using a blotting paper technique developed at ICRISAT. The inheritance appeared to be simple with resistance dominant over susceptibility (Fig. 11). We also measured the primary root length of the seedlings before inoculation to correlate this with their disease reaction. The simple correlation coefficient (r = 0.23) between primary root length and

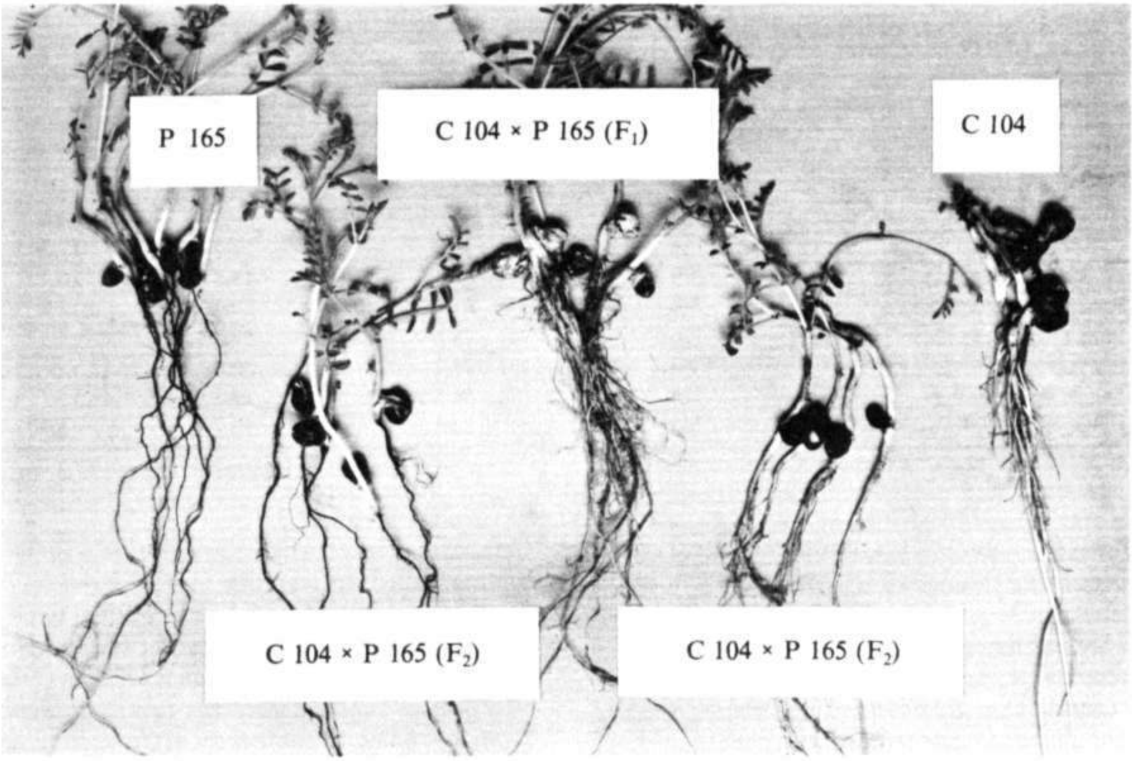


Figure 11. Inheritance of resistance to dry root rot (*Rhizoctonia bataticola*) in chickpea. P 165 = susceptible parent; C 104 = resistant parent; F_1 = resistant; F_2 = segregating in 3 resistant: 1 susceptible ratio, laboratory trial, ICRISAT Center, 1986.

disease score in F_3 families of the cross C 104 x P 165 was not significant. Hence it may not be possible to select resistant genotypes from segregating populations based on their root length alone. We successfully transferred seedlings showing resistance from blotting paper to wilt-infected soil in plastic pots and thus succeeded in screening for both wilt and dry root rot resistance using the same material.

Cooperative Activities

Asian Grain Legumes Network

The Asian Grain Legumes Network (AGLN), known until 17 December 1986 as the Asian Grain Legume Program (AGLP), was initiated at the beginning of 1986 to strengthen the collaboration between ICRISAT's Legumes Program and scientists in Asia working on ICRISAT's three mandate legume crops; groundnut, chickpea, and pigeonpea. The concept for this Network came from two meetings held at ICRISAT Center, the Consultative Group Meeting for Asian Regional Research on Grain Legumes, 11-15 December 1983, (ICRISAT Annual Report 1983, p. 148) and the Review and Planning Meeting for Asian Regional Research on Grain Legumes, 16-18 December 1985, (ICRISAT Annual Report 1985, p. 173).

The Coordinator of the Network was appointed on 1 January 1986 with an Office in the Legumes Program at ICRISAT Center. The Network has a special relationship with India because of the many cooperators associated with ICRISAT through ICAR. The Coordinator visited the People's Republic of China in late 1985 and will visit again early in 1987. During 1986 the Coordinator visited all the other countries that are presently in the Network (Bangladesh, Burma, Indonesia, Nepal, Pakistan, The Philippines, Sri Lanka, and Thailand). Contact has been made with other countries in Asia and visits made to the Republic of Korea, Japan, and Taiwan.

These visits have been used to carry through the recommendations put forward by the Review and Planning Meeting mentioned above. Contacts were made to integrate AGLN activities with those of regional and international organizations. Preliminary surveys were made to determine disease and pest incidence as a basis for recommending appropriate research activities. Enquiries were made on the need to collect germplasm of the three legume crops in each country. Plans were made with the Regional Co-ordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber crops in the Humid Tropics of Asia and the Pacific (CGPRT) in Bogor, Indonesia, to conduct a socioeconomic survey of groundnut in Indonesia and Thailand. The need for joint special projects with national programs for basic studies were ascertained. Training requirements and personnel requiring training were identified. An indication of the agroclimatological data available in each country was obtained. These data can be used to identify agroecological zones, within which specific legume genotypes can be recommended. A genotype x environment study, in conjunction with the Australian Centre for International Agricultural Research (ACIAR), was planned.

The Director General of ICRISAT signed a Memorandum of Understanding (MOU) in Dhaka, Bangladesh on 9 September 1986 with the Director General of the Bangladesh Agricultural Research Institute and another in Rangoon, Burma on 10 September 1986 with the Managing Director of the Agriculture Corporation. These MOU's indicate the interest these countries have in collaborating with ICRISAT on research on grain legume crops, and will facilitate the movement of scientists and material between ICRISAT and these countries. ICRISAT already has MOU's with Pakistan, The Philippines, and Thailand.

International Trials and Nurseries

During 1985/86 we sent 15 different types of international trials and nurseries to collaborators. Table 18 lists these and shows how many of each type were dispatched. The ICRRWN and the IIUCRRWN were most in demand, followed by the ICHRN-desi medium-duration and the ICSN, while the International Chickpea Adaptation Trials (ICAT) were not so popular. Unlike earlier seasons, no F_3 trials were supplied, but those who had received F_2 trials during 1984/85 could conduct F_3 trials from the harvested seed. The ICSNs were duplicated instead of nonreplicated augmented designs as before and also twice the previous plot sizes to increase accuracy. The trials and nurseries were distributed over 24 different countries (Table 19). There was increased interest particularly in Mexico, and in Bangladesh, Burma, and Nepal. Material was sent to Zimbabwe for the first time.

Large location and variety differences were observed as expected. The highest average location yield, 4.6 t ha^{-1}, was from Sriganganagar. The most stable trial entries across locations are shown in Table 20 with their average increase in yield over the controls.

Adaptation trials. This year the ICATs were sent only to Tunisia, the West Indies, and Zambia in response to requests from local scientists who wanted to determine the type of material that might suit their environmental conditions.

Distribution of breeders' material. We supplied 892 samples of breeding material to cooperators in 16 countries including India. Of these, 712 went to Pakistan's Chickpea Improvement Program.

Cooperation with AICPIP

We contributed six new desi lines (ICCV 8-12,

Table 18. Types of international chickpea trials and nurseries sent to collaborators in 1985/86.

Trial / Nursery	Number of sets dispatched
Breeding	
F_2 Multilocational Trial Desi Short Duration (F_2-MLT-DS)	19
F_2 Multilocational Trial Desi Medium Duration (F_2-MLT-DM)	12
F_2 Multilocational Trial Desi Long Duration (F_2-MLT-DL)	13
International Chickpea Screening Nursery Desi Short Duration (ICSN-DS)	24
International Chickpea Screening Nursery Desi Medium Duration (ICSN-DM)	17
International Chickpea Screening Nursery Desi Long Duration (ICSN-DL)	13
International Chickpea Cooperative Trial Desi Short Duration (ICCT-DS)	21
International Chickpea Cooperative Trial Desi Medium Duration (ICCT-DM)	15
International Chickpea Cooperative Trial Desi Long Duration (ICCT-DL)	15
International Chickpea Adaptation Trial (ICAT)	3
Pathology	
International Chickpea Root Rot and Wilt Nursery (ICRRWN)	25
ICAR/ICRISAT Uniform Chickpea Root-Rot Wilt Nursery (IIUCRRWN)	25
Entomology	
International Chickpea *Heliothis* Resistant Nursery Desi Short Duration (ICHRN-DS)	12
International Chickpea *Heliothis* Resistant Nursery Desi Medium Duration (ICHRN-DM)	24
International Chickpea *Heliothis* Resistant Nursery Desi Long Duration (ICHRN-DL)	17

and 15) and two new kabuli lines (ICCV 13,14, and 16) to the AICPIP coordinated variety trials for testing in the 1986/87 season. In addition 13 ICRISAT varieties entered in previous years were tested during 1985/86. As best entries from the 1985/86 experiments, ICCC 37, 43, and 47 were promoted to the Gram Coordinated Varietal Trial (GCVT) 1986/87.

In the late-sown trials, ICCC 41 was ranked second in the Central Zone of India, while ICCV 6 (ICCC 32) took the second place in the North West Hill Zone and ICCC 49 did the same in the North East Plain Zone. These lines along with five other ICRISAT contributions (ICCC 14,36, 38, 42, and 48) have been retained for further testing.

Kabuli cultivar ICCV 6 (ICCC 32), identified for release in the Central and North West Plains Zone was tested in 100 prerelease minikit trials in farmers'fields in the states of Haryana, Punjab, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Bihar, and Uttar Pradesh.

We supplied 1560 kg of ICCV 6 (ICCC 32) seed for minikit trials to be conducted during 1986/87 in the same states, and 360 kg of ICCC 37 seed for minikit trials in Tamil Nadu, Andhra Pradesh, and Karnataka. An additional 100 kg seed of ICCV 2 (ICCL 82001) was dispatched to Guntur, Andhra Pradesh for State Minikit Trials. For seed multiplication 300 kg seed of ICCV 1 (ICCC 4) and 600 kg seed of ICCV 6 (ICCC 32) were sent to the Central State Farm at Hisar. We supplied on request a total of 170 kg seed of ICCC 37, 20 kg of ICCV 5 (ICCL 83009), 5 kg of ICCV 2 (ICCL 82001), and 5 kg of P 1329 to the Director of Extension, Andhra Pradesh Agricultural University (APAU); to the Andhra Pradesh Seed Development Corporation (APSDC); and to the Indian Farmers Fertilizer Cooperative Organisation (IFFCO). In cooperation with AICPIP scientists we continued demonstration trials of the short-duration, wilt-resistant kabuli cultivars ICCV 2 (ICCL 82001) and ICCV 5 (ICCL 83009) in peninsular India to popularize

Table 19. Countries to which chickpea trials and nurseries were distributed from ICRISAT Center, 1985/86.

Country	Number sent
Argentina	1
Bangladesh	12
Burma	8
Chile	1
Ethiopia	4
Egypt	1
Greece	1
India	154
Kenya	4
Mexico	16
Nepal	9
Pakistan	25
Peru	1
Philippines	1
Spain	I
Sudan	1
Syria	3
Tunisia	4
Turkey	1
USA	1
West Indies	1
Yemen Arab Republic	1
Zambia	1
Zimbabwe	3
Total	255

the cultivation of kabuli chickpeas. Additionally the advantage of early sowing in peninsular India was further investigated in cooperation with five national research stations. Interest arose in practical chickpea production in Kashmir and sowing date and variety trials were initiated at two locations—Tapperwaripora and Zainopora. Ascochyta blight resistance is an important requirement for successful chickpea cultivation in this part of India.

Cooperation with ICARDA

The objective of the ICARDA/ ICRISAT Kabuli Chickpea Program is to develop stable high-yielding kabuli varieties for different ecological conditions. An ICRISAT chickpea breeder is stationed at ICARDA in Syria, and scientists of other disciplines from ICRISAT Center visit ICARDA occasionally to assist with the Program.

Major improvement goals are to increase yield by introducing winter sowing in the Mediterranean region and by developing irrigation-responsive cultivars for the Nile Valley, the Indian subcontinent, and Central America and to stabilize chickpea production by developing genotypes resistant to physical stresses, such as cold tolerance in winter-sown crops and drought, and biotic stresses such as ascochyta blight, the

Table 20. Average yield of best-performing ICRISAT entries in international trials, 1985/86.

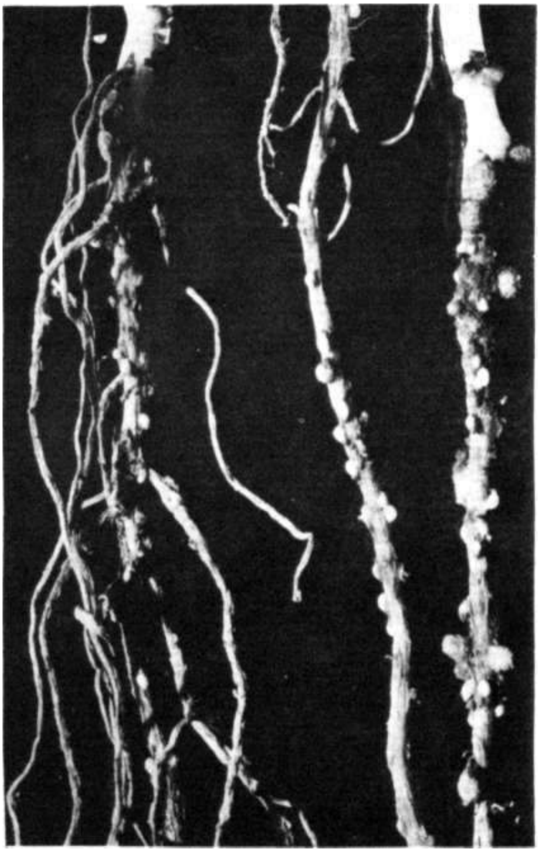
Type of trial	Highest-yielding entry	Highest yield ($t\ ha^{-1}$)	Average yield as percentage of control
International Chickpea Screening Nursery:			
Desi Short Duration	ICCL 82104	1.2	110
Desi Medium Duration	ICCL 85319	1.8	157
Desi Long Duration	ICCL 84438	3.0	130
International Chickpea Cooperative Trial:			
Desi Short Duration	ICCL 83224	1.6	116
Desi Medium Duration	ICCL 83228	1.8	127
Desi Long Duration	ICCL 85446	2.5	103

major limiting factor to production in West Asia and northern Africa, leaf miner that can reduce yields by 20%, and the cyst nematode *Heterodera ciceri* that causes sporadic damage (Fig. 12).

Physical Stresses

Cold tolerance. We have evaluated 2433 germplasm lines in the past 6 years and have found 11 cold-tolerant lines and 36 moderately tolerant lines in two cold seasons. Of these, 17 originated from India, 8 from Pakistan, 17 from the Mediterranean region, and 5 from Chile. The 11 cold-tolerant lines are ILC 668,794,1071,2487,2505, 3081, 3287, 3470, 3598, 3599, and 3789.

Figure 12. Chickpea roots damaged by the cyst nematode (*Heterodera ciceri*), ICARDA, 1985/86.



Response to irrigation. In order to cater for the needs of areas where chickpeas are irrigated, for the first time this year we began screening for response to irrigation. We evaluated 151 genotypes that were grown rainfed and with supplemental irrigation.

Of the 151 lines, 92 produced significantly higher yields when irrigated. Nineteen lines produced more than 3 t ha^{-1} on irrigation, the highest yield being 3.7 t ha^{-1}. Under rainfed conditions only two lines yielded more than 3.01 ha^{-1} and the highest yield was 3.1 t ha^{-1}. The mean yield of all the 151 lines with irrigation was 2.7 t ha^{-1} against 1.9 t ha^{-1} without irrigation. Thus 0.8 t ha^{-1} or 41% more yield was produced by irrigation. The irrigated plants had a longer reproductive period, higher total biomass, and more pods per plant. Irrigation however reduced the 100-seed mass, harvest index, number of primary and secondary branches, and protein content in the seed.

Biotic Stresses

Though many diseases can infect the chickpea crop, only ascochyta blight (*Ascochyta rabiei*) causes substantial damage in West Asia and northern Africa. The control of the disease through fungicides is uneconomical, and the most effective and practical method of control is through the use of resistant cultivars. Therefore, ascochyta blight resistance work receives major emphasis. The other diseases of some importance are fusarium wilt (*Fusarium oxysporum*) and root rots (*Rhizoctonia* spp). They are important in Tunisia, Spain, and Mexico. We are continuing our collaborative work on wilt with the national program. In view of the demand from Syria we have begun screening genotpes for resistance to the cyst nematode in collaboration with the Instituto di Nematologia Agraria, Bari, Italy.

Epidemiology of ascochyta blight. The relationship of temperature and relative humidity

(RH) with the development of ascochyta blight was examined in the field for the third year in 1985/86. The 1985/86 season was not favorable for blight, even the susceptible line was not completely killed. The disease epidemic started late with temperature and RH conditions in the first week in April similar to those during the first week in February 1984. The results were similar to those of 1982/83 and 1983/84 (ICRISAT Annual Report 1984 p. 159).

Screening for ascochyta blight. During 1985/86,690 germplasm accessions were screened and 18 lines were found promising. These will be evaluated in the advanced screening nursery next season. With these, about 15000 germplasm accessions have been evaluated for their reaction to blight.

Screening for resistance to different races of *A. rabiei.* Six races (1 to 6) have been identified from Syria and Lebanon. Races 1 to 3, the less virulent ones, were most widely distributed and races 4 to 6, the more virulent ones, were least common. We evaluated a total of 1069 lines, including 943 kabuli types, 76 desi types, and 50 newly bred FLIP lines, against the six different races in the greenhouse. Twelve genotypes are resistant to at least three races (Table 21). Three lines, ILC 202, ILC 3856, and ILC 5928, had resistance to five races. These will be particularly useful to breeding programs.

Combined resistance to ascochyta blight and cold. During 1985/86, 355 newly bred lines were evaluated for resistance to ascochyta blight and cold. Ninety lines were found resistant to ascochyta blight and 91 to cold but 10: FLIP 83-7, 83-49, 84-109, 83-112, 85-47, 85-79, 85-83, 85-86, 85-99, and 85-124 were resistant to both. In most years only 'tolerance' to both stresses is adequate. Lines found resistant to both stresses will be used extensively in our hybridization program as they also have large seeds and some mature early and are medium-tall.

Estimation of yield loss due to ascochyta blight. Yield losses due to ascochyta blight were determined in a set of 20 lines, including resistant, tolerant, and susceptible genotypes. A split-plot design was adopted with blight-protected and blight-inoculated treatments as main plots and genotypes as subplots with three replications. No disease was noticed in plots protected by chlorothalonil (Bravo 500®), whereas disease developed in epiphytotic form in plots which were artificially inoculated with a mixture of races 1 to 4.

In another experiment, yield loss due to blight was estimated in a set of resistant or moderately resistant lines. A susceptible control, ILC 1929, was included for comparison. The design and treatments were the same as in the previous experiment. The fungicide spray and blight inoculation were also similar, as were the results (Table 22) . Yield loss in the resistant kabuli types was virtually nil, whereas there was some yield loss in the resistant desi types. Resistance in the desi type is known to be weak at podding which results in yield loss. There was considerable yield reduction in moderately resistant types, especially in desis, and heavy losses occurred in

Table 21. Chickpea lines showing resistance to three or more races of *Ascochyta rabiei,* Tel Hadya, Syria, 1985/86.

ICARDA accession/ line	Reaction to races[1]					
	1	2	3	4	5	6
ILC 72	R	R	R	R	S	S
ILC 190	R	S	R	S	R	S
ILC 201	R	R	S	R	R	S
1LC 202	R	R	R	R	R	S
ILC 482	R	R	S	S	R	S
ILC 2506	R	R	S	R	S	R
ILC 2956	R	S	R	S	R	R
ILC 3279	R	S	R	R	R	S
ILC 3856	R	R	R	R	S	R
ILC 5928	R	R	S	R	R	R
FLIP 83-48C	R	R	R	S	R	S
ICC 3996	R	R	R	S	S	S

1. R = resistant; S = susceptible.

Table 22. Estimation of yield loss due to ascochyta blight in resistant, moderately resistant, and susceptible chickpea lines, Tel Hadya, Syria, winter season 1985/86.

Blight reaction	Seed type	No. of entries	Average yield (t ha^{-1}) Blight-protected	Blight-inoculated	Increase/ decrease (%)
Resistant	Kabuli	11	2.7	2.7	+ 3.3
	Desi	6	2.4	2.8	+ 14.8
Moderately resistant	Kabuli	2	2.6	1.9	-26.5
Susceptible	Kabuli	1	2.5	0.1	-97.0
SE levels of protection			±0.67		
CV (%)			16		

susceptible types. This year's results are in accordance with those obtained during 1982/83 and 1983/84 (ICRISAT Annual Report 1984, p. 158-159).

Control of ascochyta blight. Earlier studies have shown that chemical control of ascochyta blight in susceptible lines is uneconomical, but it could be useful in a tolerant line that is resistant at the vegetative stage and susceptible at the podding stage. To investigate this further, two field trials were conducted, one during the winter and the other during the spring using the blight-tolerant cultivar ILC 482. The disease was created by spreading debris from diseased plants and spraying with spore suspensions of *A. rabiei.* One and two sprays of chlorothalonil (Bravo 500®) were given at different stages of crop growth. One spray at either the preflowering, flowering, or early podding stage was sufficient to eliminate pod infection in the spring-sown crop; this is highly desirable for the production of disease-free seed. Two sprays at the preflowering and flowering stage, or flowering and early podding stage were required for the winter-sown crop. This year's findings are in close conformity with the earlier findings (ICRISAT Annual Report 1984, pp. 159-160).

Leaf miner (*Liriomyza cicerina*). Of 340 new germplasm lines screened, two were rated 4 on a 1-9 scale (1 = free, 9 = most of the leaf area affected), 10 rated 5 and the remainder between 6 and 9. Sixty-three lines found tolerant or resistant in previous seasons were sown during 1985/86 for reconfirmation. During this season leaf miner damage was relatively severe, but we found 22 resistant and 41 tolerant lines.

Plant Improvement

Winter sowing compared to spring sowing. Common trials were sown at three sites (Tel Hadya, Jindiress, and Terbol) in winter and spring seasons, for 3 years (1983/84, 1984/85, and 1985/86). The spring of 1983/84 was the driest and the 1984/85 winter was one of the coldest in the last 50 years. The winter-sown trials over the three seasons produced a mean yield of 2.0 t ha^{-1} and the spring-sown trials 1.2 t ha^{-1}. Thus the winter-sown trials yielded 57% more than the spring-sown trials.

Yield trials for winter and spring sowing. A large number of lines which had been developed in the past year were evaluated for yield at 3 locations in two seasons (Table 23). Some lines exceeded the yield of the control cultivars significantly except at Terbol during winter sowing. There has been better progress for spring sowing as shown in this year's trials. Early-maturing lines seem to perform well during spring.

Table 23. Yield performance of newly developed chickpea lines sown in winter and spring at Tel Hadya and Jindiress, Syria, and Terbol, Lebanon, 1985/86.

Location	Entries tested	Entries exceeding controls	Entries significantly exceeding controls (P=0.05)	Range of highest yields (t ha^{-1})	Range for CV (%)
Winter sowing					
Tel Hadya	306	120	2	1.3-2.7	10.5-40.3
Jindiress	196	54	6	2.2-2.9	8.9-16.6
Terbol	240	43	0	3.0-3.8	5.9-16.3
Spring sowing					
Tel Hadya	218	46	35	1.7-2.4	7.3-17.5
Jindiress	152	93	5	1.0-2.2	13.7-21.3
Terbol	174	75	13	1.6-2.0	12.0-19.7

Large-seeded types. Twenty-two newly bred lines were evaluated for yield and other traits during 1985/86. Of these, only two lines produced as much as the medium-seeded control (30 g (100 seeds)$^{-1}$), but their seed size was 45% greater than that of the control. It is necessary to improve the lines for resistance to ascochyta blight, earliness, and yield. Many cooperators will accept these large-seeded lines even if they yield as much or somewhat lower than the medium-seeded genotypes because of strong consumer preferences and a higher selling price.

Tall types. The chickpea plant commonly has a bushy growth habit. The tall types were first grown as a commercial crop in the Central Asian Region of the USSR. They were generally late in maturity and had pea-shaped, light cream to light pink seeds. The tall types are easy to machine harvest.

During 1985/86,44 newly bred tall types were evaluated for yield and other traits at Tel Hadya and Terbol. The lines FLIP 84-22, 84-86, 85-16, 85-18, and 85-19 gave as much yield as that of ILC 3279 the original germplasm collection but with an improved seed size (36-44 g(100 seed)$^{-1}$ as compared to 28 g (100 seed)$^{-1}$ in ILC 3279). But their disease resistance was slightly lower and needs improvement.

Cooperation with National Programs

We have developed different types of nurseries to meet specific demands of national programs. During the 1986/87 season 497 sets of 11 different trials were supplied to 48 countries to strengthen their breeding efforts. Demands have increased almost 15-fold in eight years. So far 10 lines had been selected and released as cultivars in four countries (Table 24). Of these, ILC 482

Table 24. Lines selected from ICRISAT/ ICARDA international chickpea nurseries and released as cultivars by national programs by October 1986.

Country	ICARDA accession/ line	Name of released cultivar	Year of release
Syria	ILC 482	Ghab 1	1982-1986
	ILC 3279	Ghab 2	1986
Cyprus	ILC 3279	Yialousa	1984
Spain	ILC 72	Fardon	1985
	ILC 200	Zegri	1985
	ILC 2548	Almena	1985
	ILC 2555	Alcazaba	1985
	ILC 200	Atalaya	1985
Tunisia	ILC 3279		1986
	FLIP 83-46C		1986

(Ghab 1), ILC 3279 (Ghab 2), and FLIP 83-46C were released during 1986.

Syria. The on-farm chickpea trials were started jointly by the Agriculture Research Center (ARC), Ministry of Agriculture and Agrarian Reform, Syria, and ICARDA during 1979/80 to compare the performance of winter sowing with traditional spring sowing. The major achievement of collaborative effort has been the release of ILC 482 named Ghab 1 and ILC 3279 named Ghab 2 (Fig. 13). Winter-sown Ghab 1 produced 100% more yield (1.61 ha^{-1}) than Syrian landrace sown during the spring on an average of 114 tests between 1980 and 1986, and Ghab 2 produced 60% more yield (1.4 t ha^{-1}), than the Syrian landrace sown during the spring on an average of 75 tests between 1982 and 1986.

Other countries. On-farm trials have been adapted by several national programs, including those of Algeria, Egypt, Lebanon, Morocco, Oman, Tunisia, and Turkey where we provide seed and advice. The results are being used when they consider the release of the component cultivars. We are continuing to screen germplasm lines for cold tolerance in cooperation with the Turkish National Program.

Cooperation with Pakistan

ICRISAT has stationed one chickpea breeder/pathologist as Resident Scientist at the National Agricultural Research Center (NARC) in Islamabad to work on the development of high-yielding chickpea varieties with a high level of

Figure 13. Right ILC 482 (Ghab 1), and left ILC 3279 (Ghab 2), these two chickpea cultivars have recently been released in Syria. Large-scale demonstration, Food Legume Improvement Program, ICARDA, Syria, May 1986.

resistance/ tolerance to ascochyta blight. The program has facilities for offseason nurseries in the Kaghan Valley.

Segregating Populations

Screening for resistance to blight. Following our major objective, we screened all available segregating populations and some established lines, against this disease. The test materials included varying numbers of F_2 through F_6 populations, either developed locally, brought from ICRISAT Center, ICARDA, the Nuclear Institute of Agriculture and Biology (NIAB) in Faisalabad, Pakistan, and as single plant selections from ICRISAT Hisar and HAU.

Each of the test entries was sown in October in one or more 4-m rows at NARC at a spacing of 30 x 10 cm. A susceptible control (C 727) was sown after every fifth test entry. Diseased plant debris (collected from previous year's nurseries) were chopped and spread over the field during January. Once in February and four times thereafter spore suspensions of *Ascochyta rabiei* (5×10^4 mL^{-1} spores) were sprayed at different time intervals during cloudy and rainy weather to create a high inoculation concentration. Blight reactions were recorded every 2 weeks until the control (C 727) had a rating of 9 on a 1-9 scale.

Out of 1166 populations we selected 94 bulks and 969 single plants, and 75 bulks and 524 single plants from 233 F_3 progenies. Most of the selections that had ratings of 3 (resistant) were the progenies of six crosses: PK 51832 x CM 72, PK 51832 x ILC 195, PK 51835 x CM 72, PK 51863 x NEC 138-2, PK 51825 x CM 72, and CM 72 x ILC 195.

Screening for agronomic characteristics. Four nurseries with 46 segregating populations (F_2-F_5) were established at NARC to select for good agronomic characteristics. Despite repeated spraying of Daconil® (0.2%), many of the entries were killed by ascochyta blight or had disease ratings (susceptible). Among the survivors with ratings of 1-5, about 500 single plants were selected for various characteristics such as earliness, good plant type, and apparent high biological and/or seed yield. These plants were individually harvested and threshed. Further selections based on seed infection due to blight, seed color, and texture were made in the laboratory.

Agronomic trials

Three agronomic experiments were conducted to study the genotype $\times$ environment interaction on blight reactions, yield components, and yield of a number of genotypes. In one experiment, we examined the effect of three levels of P_2O_5 (0,20, and 50 kg ha^{-1}) on time to 50% flowering, 100-seed mass, and seed yield. Four desi genotypes were used in the trial. Phosphorus increased the time from sowing to flowering, 100-seed mass, and seed yield. All genotypes reacted similarly.

In another experiment we studied the effect of plant geometry on time to 50% flowering, and seed number and seed yield. The three spacings used (20 x 20 cm, 30 x 10 cm and 30 x 20 cm) had significant influence on time to 50% flowering and seed yield but had little influence on seed number. The genotypes reacted similarly to the spacings used.

In the third experiment the effect of the two sowing dates (10 October and 10 November) on blight reactions, seed yield, and main yield components was examined on 50 genotypes. Despite frequent spraying of Daconil® many genotypes were badly affected by blight. Delayed sowing had an adverse effect yield per plant but it increased the harvest index in most varieties.

Workshops, Conferences, and Seminars

Chickpea Scientists' Meet

The 1986 Chickpea Scientists' Meet, the first one outside India, was held from 5-8 April 1986 at NARC in Islamabad, Pakistan. There were 32 participants from different countries: India, Nepal, Pakistan, Syria, UK, and USA. The theme of the meet was 'Genetic improvement of chickpeas for the control of ascochyta blight'. The devastation caused by ascochyta blight from 1980 to 1983 and the success of identifying and using resistant germplasm was emphasized.

Field visits were made, to enable participants to see chickpea experiments and breeding material at NARC, Islamabad, at the Barani (Dryland) Agricultural Research Institute at Chakwal, the Ayub Agricultural Research Institute at Faislabad, and the Nuclear Institute of Agriculture and Biology, also at Faislabad.

Looking Ahead

Studies to pinpoint the major factors determining environmental adaptation in chickpea will continue. Of prime importance is the reaction of chickpea to limited amounts of available soil moisture; so the search for more drought-resistant genotypes will proceed. We also hope to confirm our preliminary findings of genotypes able to set flowers and pods during the cold winter periods of the northern Indian environment. This will facilitate escape of heat damage during maturation in late spring. We hope to document our findings to date on ideal plant types for specific environments, particularly in relation to excessive vegetative growth in the northern Indian environment.

We continue to explore ways of maximizing symbiotic nitrogen fixation in chickpea. We will be screening a range of genotypes for symbiotic efficiency in a low-nitrogen soil. Studies on the interactions between mineral nutrition of chickpea and soil moisture availability will continue, primarily under the Government of Japan Special Project.

We intend to devote more time to botrytis gray mold of chickpea that has become a serious problem in northern India, Bangladesh, Nepal, and Pakistan. Laboratory inoculation techniques will be standardized. Better sources of resistance will be sought and studies on epidemiology will be initiated. Work on ascochyta blight resistance at ICRISAT Center will be strengthened by developing facilities under controlled conditions, and our studies on the epidemiology of this disease will continue. Work on identification of broadbased resistance and multiple disease resistance to such other major diseases as wilt, dry root rot, and stunt will receive continued attention.

We expect to clarify our understanding of the population dynamics of *Heliothis armigera*, by analyses of the data from the pheromone trap network and from radar and other studies, in cooperation with TDRI. We hope to complete our research on the economic thresholds for insecticide use on this crop.

We intend to make increased use of our newly developed field cages to screen genotypes for resistance to *Heliothis*, in more than one crop generation each year. The efforts to combine resistance to this insect and to wilt disease in a high-yielding background will be further intensified. Our studies on the mechanisms of resistance to *Heliothis* will also receive increased attention.

The quality of food products prepared from ICRISAT mandate crops has been receiving increasing attention in recent years. In addition to evaluating the cooking quality of whole seed, our efforts will concentrate on food products such as *pakoda* and parched chickpeas, and on the use of chickpea as a composite flour in making *roti.* The nutritional quality of germinated and fermented products of chickpea will also be studied.

The genetic improvement of chickpeas to achieve yield stability will increasingly be an integrated team effort. In addition, collaboration with national programs in multilocational breeding projects will add stability by adaptation to different environments. Adaptation breeding for particular situations such as early sowing in locations of lower latitudes, late sowing in areas of higher latitudes, and high input cropping where more advanced farming is feasible, will continue to receive due attention. Studies to support chickpea breeding will deal with the inheritance of disease resistance, seed size, time to flowering and other characters of interest. More attention will be given to tissue culture techniques for rapid clonal propagation and for rescue of embryos from interspecific crosses. Also mutation breeding will have its place among the different chickpea improvement programs.

Our cooperative activities with ICARDA will continue to aim at the development of stable, high-yielding material for spring and winter sowing in West Asia, the Mediterranean area and regions of similar crop adaptation.

In Pakistan our main goal will be to support the national breeding program especially in its efforts to produce ascochyta blight resistant material. In other areas also, where resistance to wilt and root rots is required, we will attempt to share useful material, and interact regularly with our cooperators.

Publications

Institute Publications

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. International Chickpea Newsletter nos. 14 and 15. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2508.

Journal Articles

Chalam, T.V., Reddy, M.V., Subbayya, J., Nene, Y.L., and Beniwal, S.P.S. 1985. Narrow leaf disease of chickpea (*Cicer arietinum* L.) caused by bean yellow mosaic virus. Indian Phytopathology 38(4):708-713. (JA 418)

Chalam, T.V., Reddy, M.V., Nene, Y.L., Beniwal, S.P.S., and Subbayya, J. 1986. Some properties of a strain of cucumber mosaic virus isolated from chickpea in India. Plant Disease 70(2): 128-130. (JA 417)

Onkar Singh, Singh, K.B., Sethi, S.C., Jain, K.C., Gowda, C.L.L., Jagdish Kumar, and Smithson, J.B. 1986. Registration of ICCV 1 chickpea. Crop Science 26(5):1081-1082. (JA 501)

Smithson, J.B., Thompson, J.A., and Summerfield, R.J. 1985. Chickpea (*Cicer arietinum* L.). Pages 312-390 *in* Grain legume crops (Summerfield, R.J., and Roberts, E.H., eds.). London, UK: Collins.

Conference Papers

Gowda, C.L.L. 1986. The potential of chickpea after rice. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 270)

Pa war, C.S., Srivastava, C.P., and Reed, W. 1986. Some aspects of population dynamics of *Heliothis armigera* at ICRISAT Center. Pages 79-85 *in* proceedings, Oriental Entomology Symposium, 21-24 Feb 1984, Trivandrum, Kerala. Trivandrum, Kerala: Association for Advancement of Entomology, University of Kerala. (CP 177)

Reddy, D.V.R., Nene, Y.L., and McDonald, D. 1986. Virus disease problems of groundnut, chickpea, and pigeonpea in Asia. Pages 67-75 *in* Virus diseases of rice and leguminous crops in the tropics: proceedings of an International Symposium, 1-5 Oct 1985, Tsukuba, Japan. Tropical Agricultural Research Series No. 19. Tsukuba, Ibaraki, Japan: Tropical Agriculture Research Center, Ministry of Agriculture, Forestry and Fisheries. (CP 237)

Rupela, O.P. 1986. *Rhizobium* inoculant production system for developing countries. Pages 219-222 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.). Hisar, Haryana, India: Haryana Agricultural University. (CP 240)

Thesis

Desai, S. 1986. Studies on identification of physiologic races of chickpea wilt-Fusarium. Ph.D. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 115 pp.

LEGUMES
PIGEONPEA

Contents

Cover photo: Prolific podding on a medium-duration indeterminate pigeonpea genotype, ICRISAT Center, rainy season 1986.

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PIGEONPEA

Pigeonpea, *Cajanus cajan,* is extremely versatile, both in its uses and in the range of environments across which it can be usefully grown. Although more than 80% of the world's recorded production and consumption is in India, it is also an important crop in several countries in Africa, in Burma, and in the Caribbean region. In many more countries it is popular as a backyard hedge, from which pods are harvested for family use.

In India, and other countries to which people of Indian origin have migrated, the pods are harvested when mature and the dried seeds are processed into dhal (decorticated, split seed), that is used in a wide range of food preparations. In the Caribbean islands and in many other countries, most of the pods are harvested while still green and the seed, or sometimes the whole pods, are used as green vegetables. The green plants are used for grazing or harvested as fodder. The woody stems are used for a variety of purposes, e.g., in basket making, thatching, and construction, but are of increasing importance and value as fuel. Pigeonpea is known to improve soil structure and fertility, giving substantial benefit to subsequent crops.

Pigeonpea is a perennial shrub, and is grown as such in several countries in Africa and the Caribbean. However, it is most commonly used as an annual intercrop with shorter-duration crops, especially cereals. A very wide range of plant types and durations are grown, most as unimproved landraces. Our research at ICRISAT Center and elsewhere has shown that improved short-duration genotypes that mature in as little as 100 days can be very high-yielding when grown as close-spaced, sole crops. Such crops appear to have great potential in a wide range of cropping systems. Our research is now particularly focussed on the improvement of short-duration types.

Our research activities are concentrated at three locations in India: 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.

At ICRISAT Center most of our field trials are with the short-duration types intended for sole cropping, and medium-duration types that are commonly used as intercrops with cereals. At Hisar we concentrate on short-duration types that can be sown in the rainy season and harvested in time to allow timely sowing of winter crops, particularly wheat. At Gwalior we work on the long-duration types that are extensively used as intercrops in northern India and in several other countries, particularly those in Africa.

Physical Stresses

We are attempting to quantify factors of the physical environment that limit growth and yield of pigeonpea and are seeking the alleviation of these constraints through both management and genetic improvement. We are particularly concerned with drought stress. We are continuing to screen medium-duration genotypes for tolerance to terminal drought stress, and have initiated drought-screening studies on short-duration genotypes. We are conducting a series of multilocational growth analyses to help us understand how best to improve adaptation to particular environments and enhance pigeonpea production in various cropping systems. We are continuing work on appropriate plant types for intercropping and on fitting short-duration genotypes into rotations with wheat in northern India. We are beginning collaborative studies on accommodating pigeonpea in rice-based cropping systems. Studies on screening genotypes for tolerance to salinity and waterlogging are continuing but in this case, we are giving much attention to assessing the exploitable genetic variation in response to these stresses.

Screening Medium-duration Pigeonpea for Terminal Drought Tolerance

Medium-duration pigeonpea, when grown as a rainfed crop in southern and central India, normally faces increasing moisture shortage during the reproductive growth phase. We are attempting to identify genotypes better able to tolerate this terminal drought stress. In 1985/86 we evaluated 100 genotypes, originating from regions with different rainfall, by imposing irrigation treatments after the end of the rainy season. The experiment was conducted on an Alfisol in a split-plot design, with three replications, with irrigation treatments in main plots and genotypes in subplots.

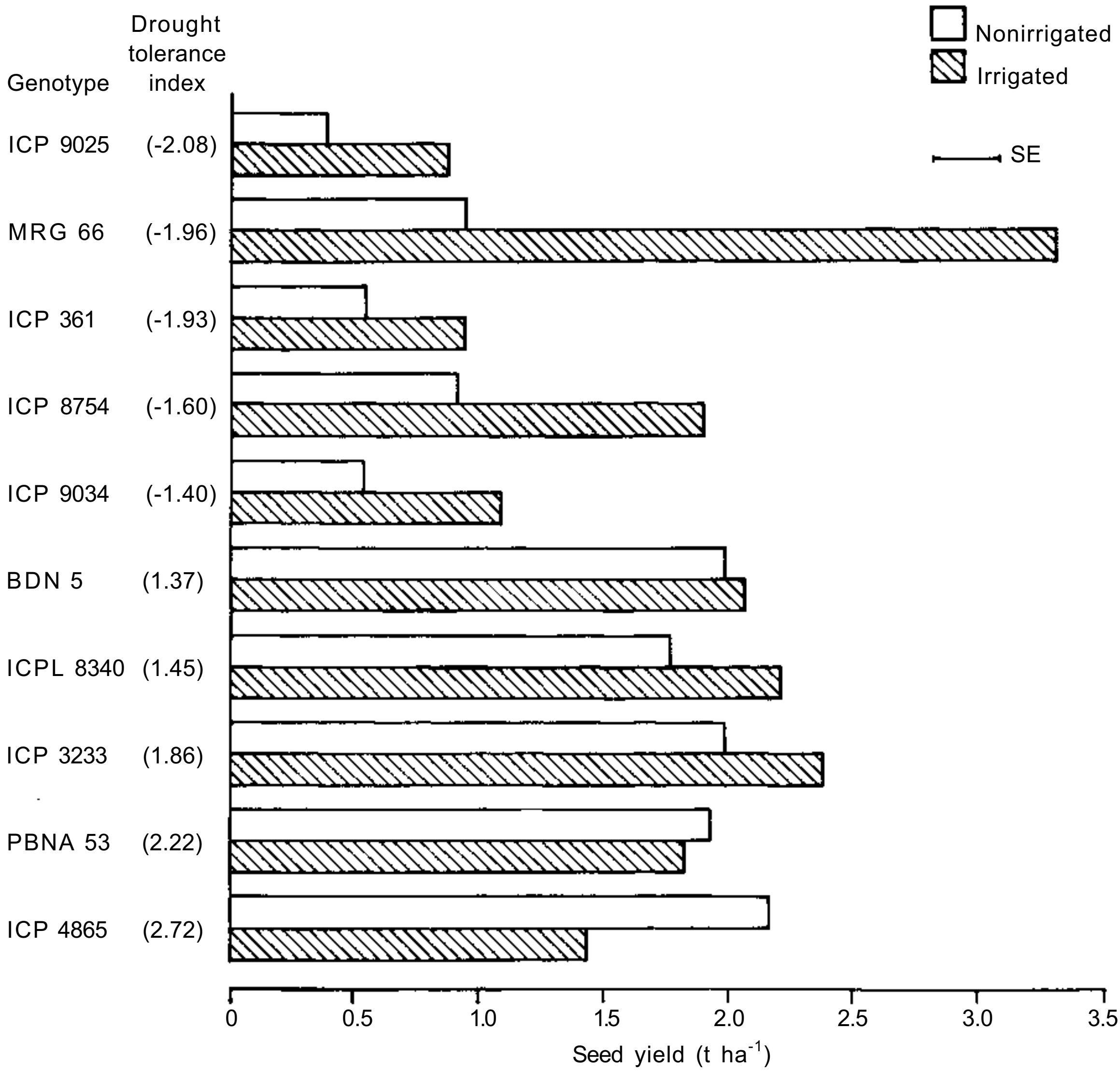


Figure 1. Seed yield (t ha^{-1}) with and without irrigation, and drought tolerance indices of several medium-duration pigeonpea genotypes grown on an Alfisol, ICRISAT Center, postrainy season, 1985/86.

Mean seed yield with irrigation was 1.89 t ha^{-1} as compared to 1.27 t ha^{-1} without. There were large genotypic differences in response to irrigation as illustrated by examples in Figure 1. Some genotypes could yield up to 2.10 t ha^{-1} without irrigation. Part of the variation in yield in the stressed treatment could be attributed to drought escape as days to 50% flowering had a significant negative correlation (r = -0.46) with stress yield. Stress yield was positively correlated (r = 0.46) with irrigated yield. Together these factors accounted for 42% of the variation in yield under stress. The remaining 58% of variation could thus be attributed to experimental error and drought tolerance.

To estimate the relative drought tolerance of a genotype, we adopted a similar approach to that used for pearl millet (ICRISAT Annual Report 1982, p. 66). This eliminates the effects of escape and yield potential from the performance of genotypes under stress. The drought tolerance index (standardized residual) was calculated from the difference between measured and predicted yield divided by the standard error of the predicted yield. Indices ranged between -2.54 (susceptible) and 2.73 (tolerant). We classify genotypes having an index > 1.0 as drought-tolerant and 13 genotypes fell into this category. There were 14 susceptible genotypes (index < 1.0). We are repeating this screening procedure in the current season to reconfirm the reaction of some of these genotypes and to test a new set.

Biotic Stresses

Diseases

Fusarium Wilt (*Fusarium udum*)

Eradication of *Fusarium udum* from pigeonpea seed. The pigeonpea wilt pathogen (*F. udum*) was found to be internally seedborne (ICRISAT Annual Report, 1984, p. 169). Although the fungus could not be detected from seeds of such highly susceptible genotypes as ICP 2376 and LRG 30, it was detected in the seeds of wilt-tolerant cultivars such as BDN 1 and Hy 3C. We confirmed the internal seedborne nature of this pathogen by repeated laboratory studies and 'growing on' tests.

Seed treatment with a fungicide mixture effectively controlled seedborne *F. udum.* We found that wet seed treatment with a mixture of benomyl and thiram at equivalent rates completely eradicated the fungus, as shown by testing the seed in Nash and Spyder's fusarium-specific medium, and a 'growing on' test in the greenhouse.

Soil solarization. Last year we reported the dramatic effects of soil solarization, covering the soil with transparent polythene to increase temperatures in the upper soil layer, on reducing fusarium wilt in a susceptible pigeonpea genotype (LRG 30) and even enhancing growth and yield in a wilt-resistant genotype ICPV 1 (ICP 8863) (ICRISAT Annual Report 1985, pp. 183-184). In 1985/86 we repeated the experiment on an adjacent wilt sick area and obtained essentially similar results.

We reimposed solarization treatments on the 1984/85 experimental plots to measure the residual and cumulative effects of solarization. Only for ICPV 1 (ICP 8863) (Fig. 2) was there a slight residual effect of the 1984 solarization. There was no cumulative effect of solarization for this cultivar, since solarization only in the current year was as effective as solarization in both years. However, for LRG 30, a single solarization treatment in the current year was superior; the reason for this is not clear. There were no significant effects of these treatments on rhizobial populations in this experiment, with most probable number (MPN) estimations for the different treatments being in the range 3.6-4.9 $\log_{10}$ g^{-1} dry soil. Consequently there were no effects of solarization on nodulation parameters but we found that ICPV 1 (ICP 8863) nodulated better than LRG 30.

We are continuing these studies in the current season to further examine residual effects, and to determine solarization effects on pigeonpea growth and yield at different locations, including Hisar and Gwalior.

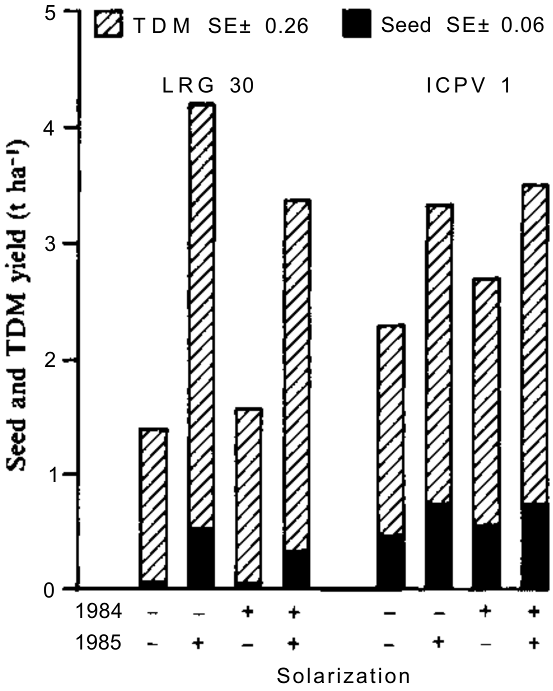


Figure 2. Residual and cumulative effect of soil solarization in the 1984 and 1985 dry seasons (+ = solarized, - - nonsolarized) on seed and total dry matter (TDM) yield (t ha^{-1}) of a wilt-susceptible (LRG 30) and a wilt-resistant (ICPV 1) pigeonpea genotype on a wilt sick Vertisol, ICRISAT Center, postrainy season 1985/86.

Our studies of the microflora in soil sampled from the solarized and nonsolarized plots showed a general reduction in the fungal population of the former. However, one species, identified by the Commonwealth Mycological Institute (CMI), Kew, UK as *Penicillium pinophilum* was relatively abundant in the solarized soil and was found to be antagonistic to *F. udum* in the laboratory. In pot tests in the greenhouse, the addition of *P. pinophilum* to *F. udum*-inoculated soil allowed over 90% of wilt-susceptible seedlings (LRG 30) to grow without wilt symptoms, while only 21% of the seedlings survived in pots to which the antagonistic fungus had not been added.

Wilt and pod borer screening nursery. Fusarium wilt and pod borer (*Heliothis armigera*) are two of the major biotic constraints to pigeonpea production in the Indian subcontinent and Africa. Control of these pests through the use of resistant varieties would greatly increase and stabilize pigeonpea production. Our work on host-plant resistance has resulted in the identification of good sources of individual tolerance to wilt and pod borer. However, we found that many lines tolerant to *Heliothis* were highly susceptible to wilt. In order to initiate a breeding program to produce pigeonpea genotypes with combined tolerance to wilt and pod borer, we have developed a screening nursery at ICRISAT Center.

A 1-ha Vertisol field adjacent to the pesticide-free area at ICRISAT Center was selected for this purpose. In the first fortnight of June 1985, just before sowing, about 1.5 t of chopped wilt-infected pigeonpea material collected from other ICRISAT fields in the previous season was distributed in this field. Every fifth row of the plot was sown with a highly susceptible cultivar (LRG 30). In order to promote a high incidence of wilt, early sowing, and good weed control (through preemergence application of herbicides and hand weeding) were undertaken. At the end of the season (March 1986), the susceptible control showed very high and uniform wilt incidence (98%).

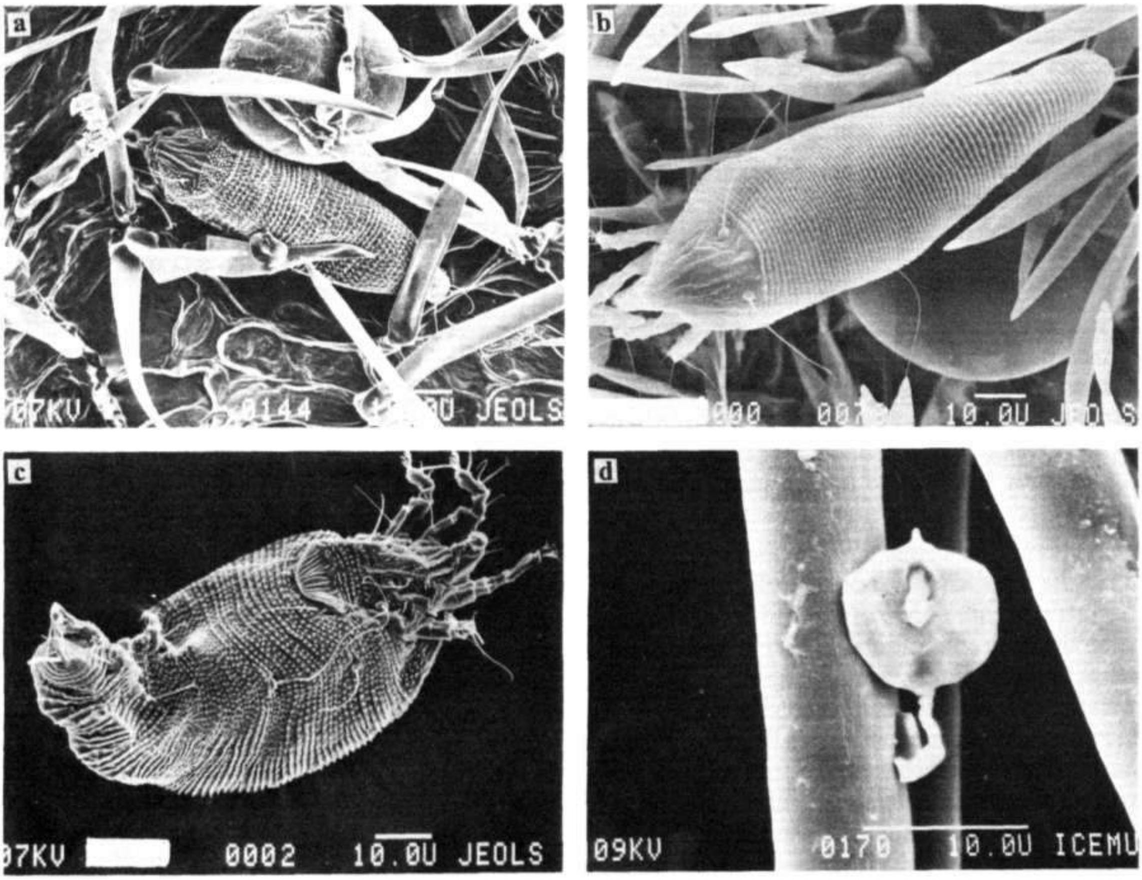
During the 1985/86 season, three wilt- and *Heliothis*-tolerant germplasm accessions, 15 F_2, and 3 F_3 bulks involving wilt- and *Heliothis*-tolerant parents were screened. Though the screening for wilt resistance was effective, adequate screening for *Heliothis* resistance was not possible, because of the low natural incidence of the insect. The three germplasm accessions, ICP 4769, ICP 6831, and ICP 7198 showed less than 10% wilt. The wilt incidence in the F_2 and F_3 bulks ranged from 12 to 98%. The wilt-resistant plants have been advanced by the single-pod descent method, and will be tested in a similar nursery in the coming season.

Sterility Mosaic

Nature of the causal agent. In continued attempts to determine the causal agent of sterility mosaic, we extracted flexuous rod-shaped, virus-like particles (VLP) from infected leaves collected from Pudukkottai in Tamil Nadu. These were similar to the VLP from ICRISAT Center that we reported earlier (ICRISAT Annual Report 1985, pp. 184-185). However, both the VLPs, from Pudukkottai and from ICRISAT Center did not appear to contain nucleic acid as they failed to show maximum absorption at 260 nm.

Morphology of *Aceria cajani*. We have previously found differences in the range of pigeonpea genotypes that are susceptible or resistant to sterility mosaic disease across different locations in India. We postulated that such differences may be the result of variability in either the pathogen or the vector, an eriophyid mite (*Aceria cajani*). In this year we initiated studies on the morphology and biology of the mites, using a scanning electron microscope installed at ICRISAT Center. The morphological characteristics of *A. cajani* adults, nymphs, and spermatophores collected from pigeonpea at ICRISAT Center can be seen in Figure 3. We intend to

Figure 3. Scanning electron micrographs of the eriophyid mite, *Aceria cajani,* the vector of sterility mosaic disease; a. dorsal view of the nymph among the simple leaf hairs and next to a spherical oil-filled gland on a pigeonpea leaf, b. dorsal view of an adult, c. ventro-lateral view of female adult, showing the genital coverflap distinguished by longitudinal striations, and d. spermatophore adhering to a simple pigeonpea leaf hair, ICRISAT Center, 1986.



compare these with the morphological characteristics of mites collected from locations where the range of pigeonpeas that are susceptible or resistant to sterility mosaic differs from that at ICRISAT Center.

Yellow Mosaic

Experimental host range. The yellow mosaic disease of pigeonpea is particularly common on postrainy-season crops in many areas of India. This disease is widely assumed to be caused by the mung bean yellow mosaic virus, a gemini virus carried by white fly (*Bemisia tabaci*). In this year, using adult white flies as vectors, we succeeded in transmitting the pathogen from yellow mosaic infected pigeonpea to other pigeonpea plants (ICP 1) and to mung bean *(Vigna radiata),* lima bean (*Phaseolus lunatus*), and horse gram (*Macrotyloma uniflorum*). However, the rate of transmission of the pathogen to pigeonpea was poor, for only 30% of the pigeonpea plants expressed symptoms when 30 to 50 white flies, bred on infected plants, were released on each plant.

Phytophthora Blight (*Phytophthora drechsleri* f. sp *cajani*)

New sources of resistance. We have previously reported many sources of resistance to the P2 isolate of *P. drechsleri* f.sp *cajani.* However, we have so far failed to identify sources of resistance to the P3 isolate of this fungus. During the last 5 years, 5989 pigeonpea germplasm accessions and a large number of breeding materials were pot-screened against the P3 isolate in the greenhouse by the soil drench method of inoculation. No line was found uniformly resistant and most showed more than 50% diseased plants. In an attempt to develop sources of resistance to this isolate, we reinoculated the surviving plants of the most-promising lines, using the stem inoculation method, and collected selfed seed from the surviving plants. This screening/reinoculation cycle was then repeated. Twenty-four selections from such screening have so far been developed and the seed is being multiplied in the field. The blight resistance of these selections will be tested through both field and pot screenings during 1987.

Two wild relatives of pigeonpea, *Atylosia goensis* (accession JM 3501) and *A. platycarpa* (accession PR 4557) were found to have a higher degree of resistance to the P3 isolate than the best of our resistant pigeonpea selections, and showed less than 20% blight. At some stage we may be able to utilize these sources of resistance, if it becomes possible to make crosses between these wild species and cultivated pigeonpea.

Breeding for Disease Resistance

We started a backcross program to develop high-yielding and disease-resistant lines using adapted genotypes as recurrent parents. Cultivars C 11 and BDN 1, that are highly susceptible to sterility mosaic (SM), were crossed with an SM-resistant F_6 line from ICPX 73054. After three backcrosses with recurrent parent BDN 1 and two backcrosses with C 11, we screened the F_2 and later generations in the SM nursery. In the 1985 rainy season, we screened 122 progenies of BDN 1 BC_3F_4 and 16 progenies of C 11 BC_2F_4. Nineteen progenies from the BDN 1 backcross were free from SM and we selected 49 plants from these for further screening. From the C 11 backcross, we selected nine plants from four SM-resistant progenies.

Cultivar LRG 30 has many desirable characteristics but is highly susceptible to wilt. To incorporate wilt resistance LRG 30 was crossed with 15-3-3 as a donor parent in 1978. The first backcross was made in 1982, and the BC_1F_2 and BC_1F_3 were screened in a wilt nursery. This year 17 BC_1F_4 progenies were grown in wilt sick nurseries. Only three progenies showed resistance, these had a wilt incidence of 6-14%. We will retest the wilt resistance of these progenies and evaluate them for grain yield.

In 1984 we irradiated dry seed of LRG 30 with gamma-rays (5-40 kR) in the hope of producing wilt-resistant mutants. In the 1985 rainy season, the M_2 generation was grown in a wilt sick nursery, and 156 resistant plants were identified and selfed for evaluation in the M_3 generation.

We also screened several populations, single-plant progenies, and advanced lines derived from crosses between disease-resistant and high-yielding parents, in wilt, SM, and SM and wilt nurseries. Advanced lines from these crosses have shown stability for yield and disease resistance over the last three years (Table 1). Four of these lines combine wilt and SM resistance. The yield potential of the three wilt-resistant lines (ICPL 8356, 8357, and 8358) compared favorably with that of control cultivar C 11. An SM-resistant line, ICPL 343, produced 2.19 t ha^{-1} compared with 2.18 t ha^{-1} from the control cultivar. Two of these advanced lines, ICPL 227 (wilt- and SM-resistant), and ICPL 8357 (wilt-resistant), will be evaluated in multilocational trials.

Insect Pests

Pest Incidence

The pod borer (*Heliothis armigera*), the major pest of pigeonpea, was much less abundant in the 1985/86 season than in previous years at ICRISAT Center. The borer populations increased as usual in August/ September and the short-duration pigeonpea that flowered then was severely damaged. But from then onwards, the populations which we monitor by counts on the crops and in pheromone and light traps, were much lower than expected. In most years *Heliothis* populations on our farm reach a peak in November/ December but our moth catches over that period in 1985 were the lowest in our 10 years' records and our medium-duration pigeonpea suffered much less damage than usual.

Table 1. Mean performance of wilt- and sterility mosaic-resistant lines in the Medium-duration Pigeonpea Sterility Mosaic Wilt Resistant Yield Trial (MPSMWRY) grown in a disease-free field, ICRISAT Center, rainy seasons 1983-1985.

					In disease nursery	
Entry	Time to 50% flowering (days)	Time to maturity (days)	100-seed mass (g)	Grain yield (t ha^{-1})	Wilt (%)	Sterility[1] mosaic (%)
Wilt-resistant						
ICPL 8357	118	177	9.9	2.25	9	100
ICPL 8358	118	176	9.0	2.18	7	100
ICPL 8356	111	169	9.7	2.13	8	92
Sterility mosaic (SM)-resistant						
ICPL 343	107	165	9.8	2.19	100	0
Wilt- and SM-resistant						
ICPL 227	122	181	11.0	1.93	9	2
ICPV 1 (ICPL 8363)	129	186	8.5	1.89	8	0
ICPL 8362	128	189	8.4	1.85	8	0
ICPL 335	121	181	9.2	1.75	8	0
Control						
C 11	114	174	10.3	2.18	75	100
SE	±0.3	±0.6	±0.2	±0.13		
Trial mean (20-23 entries)	116	175	10.0	1.98		
CV(%)(range)	0.4-0.6	0.5-1.0	3.5-5.6	9.4-18.6		

1. SM data from 1984 and 1985 seasons.

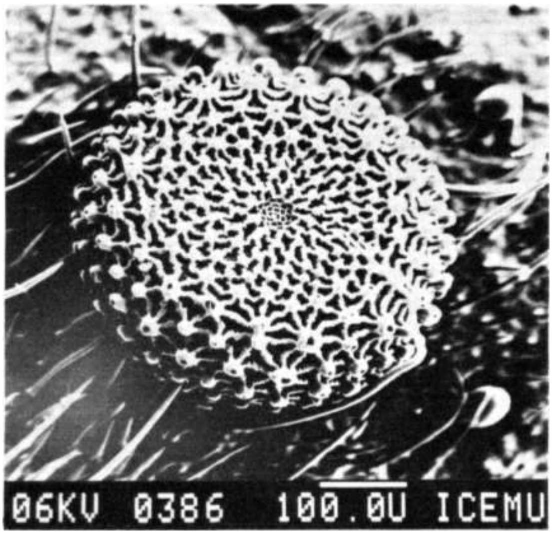


Figure 4, Scanning electron micrograph of the egg of the blue butterfly, *Lampides boeticus,* laid on a pigeonpea leaf, ICRISAT Center, 1986.

Of the other lepidopteran pests, the leaf webber (*Cydia critica*) was more common than usual at ICRISAT Center but relatively rare at Hisar in northern India. There, almost all of the flower and pod webbing that occurred was caused by *Maruca testulalis.* This pest was also seen to be very common on experimental crops of pigeonpea in Thailand. As in previous years at ICRISAT Center we found many eggs but few larvae of the blue butterfly (*Lampides boeticus*) on pigeonpea (Fig. 4).

The podfly (*Melanagromyza obtusa*), the second most damaging pest of pigeonpea throughout India, built up to large, damaging populations in our long-duration genotypes, particularly at Gwalior. The hymenopteran pest (*Tanaostigmodes cajani*) was again a major pest on our research farm but rare in farmers' fields. The unusually dry rainy season provided ideal conditions for the sucking pests. *Aphis craccivora* was very common on the seedlings and several species of pod-sucking bugs, particularly *Clavigralla gibbosa,* caused substantial crop damage from September onwards. The blister beetle (*Mylabris pustulata*) was very common at ICRISAT Center from August through November and we received reports from several areas of India that this pest destroyed many of the flowers of pigeonpea and other legumes. The bruchids (*Callosobruchus* spp) were commonly found in pods, particularly where harvesting was delayed and were, as usual, the main pests in stored pigeonpea.

The jewel beetle (*Sphenoptera indica*), whose larva tunnels below the bark at the base of pigeonpea stems and promotes a prominent gall, was evident in several fields. An unusually heavy infestation of the red spider mite (*Schizotetranychus cajani*) developed in a field where we had applied soil insecticides in an attempt to control the nodule-damaging fly (*Rivellia angulata*). This outbreak may have been a result of natural enemy destruction and served as yet another warning that insecticide use may promote unusual pest attacks.

Heliothis armigera

Populations and migration. Since it is commonly found that the populations of several lepidopteran pests are enhanced by high humidity and rainfall, and overcast conditions, it is tempting to attribute this year's low populations of *Heliothis* at ICRISAT Center to the unusually dry rainy season. However, studies of the *Heliothis* populations over the last 9 years reveal no obvious correlation with the rainfall in each year, the highest populations ever recorded being in 1977, when the annual rainfall was also unusually low!

We are anxious to understand the factors that promote damaging *Heliothis* populations and are cooperating with scientists from the Tropical Development and Research Institute (TDRI), UK in studies of populations and their movements. Similar studies are also being conducted by TDRI scientists in eastern Africa.

We monitor populations by counting eggs and larvae on the many host plants of this insect and by recording catches of moths in pheromone and light traps. The network of pheromone traps that was described earlier (ICRISAT Annual Report 1985, p. 191) continued to operate, and we received data from 98 traps operated by cooperators in India, Pakistan, and Sri Lanka. We now have data for more than 4 years from many locations which we are analyzing in relation to climatic and crop factors.

We have light-trap data from far fewer locations, for light traps are much more difficult to operate, and good, reliable sources of electricity are seldom available in the fields of most research stations. However, TDRI has developed a battery-operated light trap that has proved to be very useful for monitoring insects in individual fields, since its attractive range is much smaller than the larger mains-dependent, Robinson-type traps used as general monitoring tools at ICRISAT over several years. Instructions for the construction of the battery-operated traps, and for a modification that separates catches from differing periods of the night, can be obtained from ICRISAT Legumes Program Office.

We monitored the moth populations in a 6-ha field of medium-duration pigeonpea using battery-operated light traps, placed 5 m into the crop on each side of the field, and two pheromone traps nearer the center of the field. We counted the number of eggs and larvae on samples from sections of the field at weekly intervals. We estimated adult emergence by recording moths that emerged in 15 cages of 9 x 9 m that were placed over the crop after the second period of egg laying in mid-November. Radar, operated by a team of TDRI scientists, was used to scan over the crop in an attempt to monitor the extent and direction of flight of potentially migrant moths leaving this field.

The first invasion, which took place in early October before the flower buds started to show their petal color, was mainly of male moths. The numbers of female moths peaked in the following week, but numbers dropped sharply before 50% flowering. This indicated that the crop was attractive before flowering began, and that the female moths had fed elsewhere before egg laying. Few larvae resulted from this oviposition, possibly because it was too early, relative to the flowering period, to ensure adequate survival of the young larvae. Oviposition in the second generation in November, which in most years is responsible for the greatest number of damaging larvae, was very low in this year. This may have been because only a small proportion of the females had mated. Moth emergence peaked at the end of December, but even at the peak the nightly emergence was estimated to be only 3500 moths from the whole field. The radar was operated from late November to mid-December but the numbers of moths emerging from the field were insufficient to give rise to a definite, detectable plume of departing moths. The overall second generation moth emergence was calculated to approximate to 10% of the eggs that had been laid.

The pheromone trap catches corresponded only approximately with those of the light and emergence traps and, in contrast to the light traps, catches of moths at first flowering were very much lower than at other times. This suggests that the pheromone traps were less efficient in monitoring the important invading population than the subsequent generation that emerged in the crop. This may have been a result of a higher proportion of competing females in the invading population, even though most had already mated.

The numbers of moths in the emergence cages peaked a week later than those in the light traps, and about 2 weeks later than those in the pheromone traps. This may have been because a high proportion of the moths captured originated from outside the field, or because competing females reduced the earlier pheromone catches. Emergence in the cages continued for longer than expected indicating prolonged pupal development periods in some individuals.

Flight studies. Our studies of the movement and migration of *Heliothis* moths require a knowledge of the flight potential of the moths that originate from various host plants. We examined the flight potential of 1-day-old moths at ICRISAT Center using flight mills developed at TDRI. A flight mill (Fig. 5) consists of a light, balanced rotating arm, to the end of which a moth is attached by means of a fine wire glued to the thorax. Flight performance was measured as the distance flown (number of rotations re-

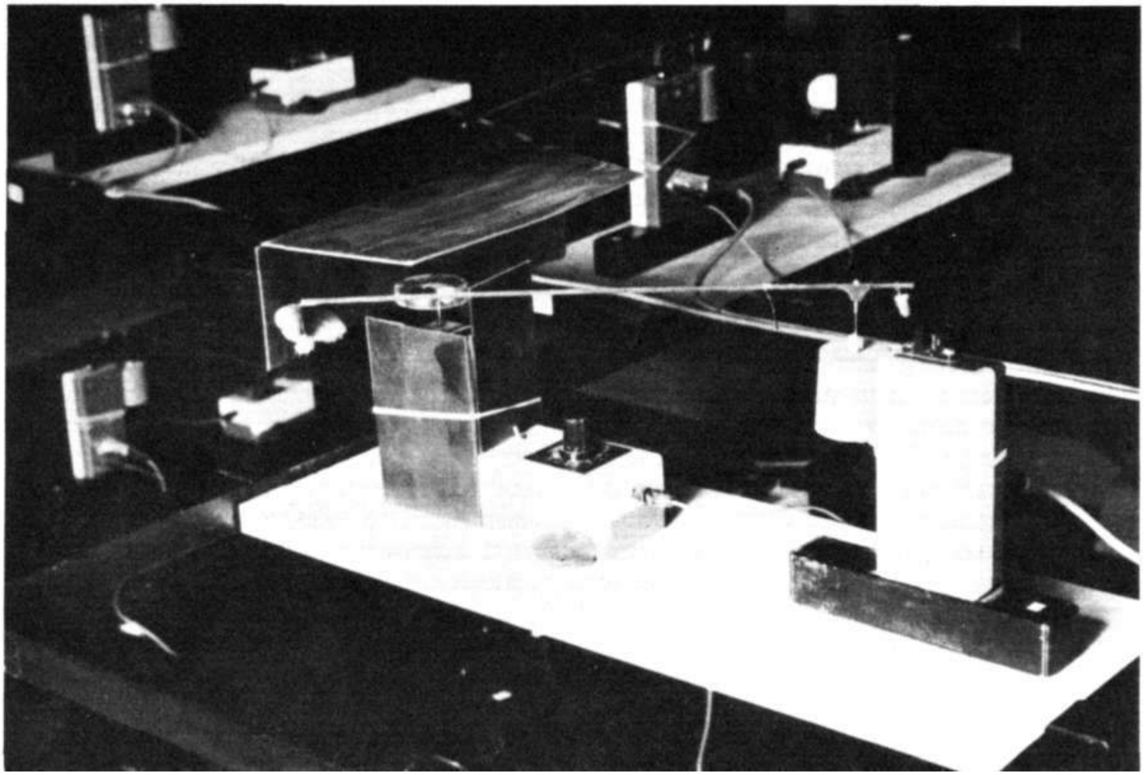


Figure 5. A flight mill that is used by TDRI scientists in laboratory studies on the flight of *Heliothis armigera* moths, ICRISAT Center, 1986.

corded), and as flight duration. Both flight and reproductive potential were compared for moths fed on water, on a sucrose diet, and unfed, and for moths that had fed as larvae on sorghum, pigeonpea, and the weed, *Gompherena celosioides.*

Flight performances were very variable. Some moths did not fly at all, while others flew an equivalent of up to 60 km in a night. Unfed male moths from sorghum made the most prolonged flights. Those from pigeonpea did not fly far unless fed with water or sucrose, but tended to fly more frequently for shorter periods. Moths fed on *Gompherena* generally flew less well than those fed on sorghum and pigeonpea.

Larval diet affected pupal mass and fecundity, with moths fed on sorghum being the largest and laying most eggs. Sucrose was found to be essential for ovary development and successful mating in moths from all hosts.

Host-plant resistance. We resumed screening the pigeonpea germplasm collection for resistance and tolerance to *Heliothis* and other pests. We compared 560 new accessions with control cultivars in an augmented design in our pesticide-free Vertisol area. Single-plant selections, from accessions that suffered less damage than the controls, will be advanced to replicated testing next season. In our pesticide-free fields we screened breeding materials, particularly those lines developed for *Heliothis* and podfly resistance in large-scale trials. The paucity of *Heliothis* made adequate screening difficult in some trials. However, we successfully tested new field cages (9 x 9 x 2 m) covered with 5-mm mesh nylon fishnet. Laboratory-reared moths released inside these cages laid eggs on the plants, with fewer being laid on genotypes that had previously shown oviposition nonpreference in open field and laboratory tests. Such nets are expected to facilitate our resistance screening. Previously we had tested a variety of cages and nets that gave unsatisfactory results because most of the eggs were laid on the cages themselves.

We continued to screen short-duration genotypes for pod borer resistance at both ICRISAT Center and Hisar. Evidence that there are genotypic differences in susceptibility to borers has been obtained from a series of trials conducted from 1983 to 1985, that are summarized in Table 2. Single-plant selections have been made and used as parents in crosses, with the objective of obtaining genotypes with enhanced resistance and other desirable traits, such as acceptable seed size.

Mechanisms of resistance. We have conducted field and laboratory studies over several years to determine the mechanisms of resistance in our selections. We have found oviposition nonpreference, (ICRISAT Annual Report 1985, pp. 194-195), and a reduction in the number of larvae retained on some genotypes. We have also selected tolerant genotypes, that show much greater compensation for flower and pod damage than others (ICRISAT Annual Report 1983, p. 164).

Table 2. Pod damage (%) caused by lepidopteran borers and mean yields (t ha^{-1}) from short-duration pigeonpea tested under pesticide-free conditions, ICRISAT Center and Hisar, 1983-1985.

	ICRISAT Center		Hisar	
Genotype[1]	Mean pod damage (%)	Mean yield (t ha^{-1})	Mean pod damage (%)	Mean yield (t ha^{-1})
ICPL 1	37.9	0.58	17.1	2.47
ICPL 2	51.9	0.65	14.1	2.66
ICPL 187-1	32.6	0.86	20.8	2.45
ICPL 269	35.0	0.80	19.2	1.94
Control				
Pant A1	56.6	0.99	28.5	2.09
SE	±3.30	±0.07	±2.70	±0.13

1. Numbers of genotypes tested in each trial ranged from 12 to 36.

This year we conducted several laboratory tests in which we studied the development of larvae, fed on various plant parts taken from field-grown resistant and susceptible genotypes. The major difficulty with such tests is that mortality caused by virus and other diseases tends to ruin most of the experiments. An example of the results from one test is shown in Table 3. In this test larvae were fed on artificial diets containing powder from ground seeds of resistant and susceptible pigeonpea genotypes, and compared with those fed on our standard diet, that contains powder of kabuli chickpea seed. It was evident that inclusion of the seed coat, particularly that from brown-colored seeds, had an antibiotic effect on the larvae. Most larvae that were fed on the diets containing seed coats died; although a few survived for over 70 days they were still small and in the third instar at the end of that period. The white-seeded genotype showed the least antibiosis, confirming field observations that most such types are very susceptible. The diets containing powder from seeds that were boiled for 40 min were intended to test whether heat-degradable feeding deterrents, such as trypsin inhibitors, were involved in the antibiosis. Survival on this treatment was very low, so some essential nutrients may have been destroyed by boiling. An attempt to remove the polyphenols from the seeds by soaking in 1% sodium bicarbonate for 16 h did not reduce the antibiotic effect. A repeat of this test gave very similar results, with the greatest survival, shortest development time, and largest pupae on the standard diet, followed closely by those fed on the dhal diet and on the whole white-seed diet. However, in this test virus killed over 40% of the larvae in the controls.

The Max-Planck Institute for Biochemistry, Munich, Federal Republic of Germany is collaborating with us by studying the chemicals involved in resistance. In the Munich laboratories it has been shown that a volatile signal (kairomone) is involved, since moths laid eggs preferentially on nets covering susceptible plants. The

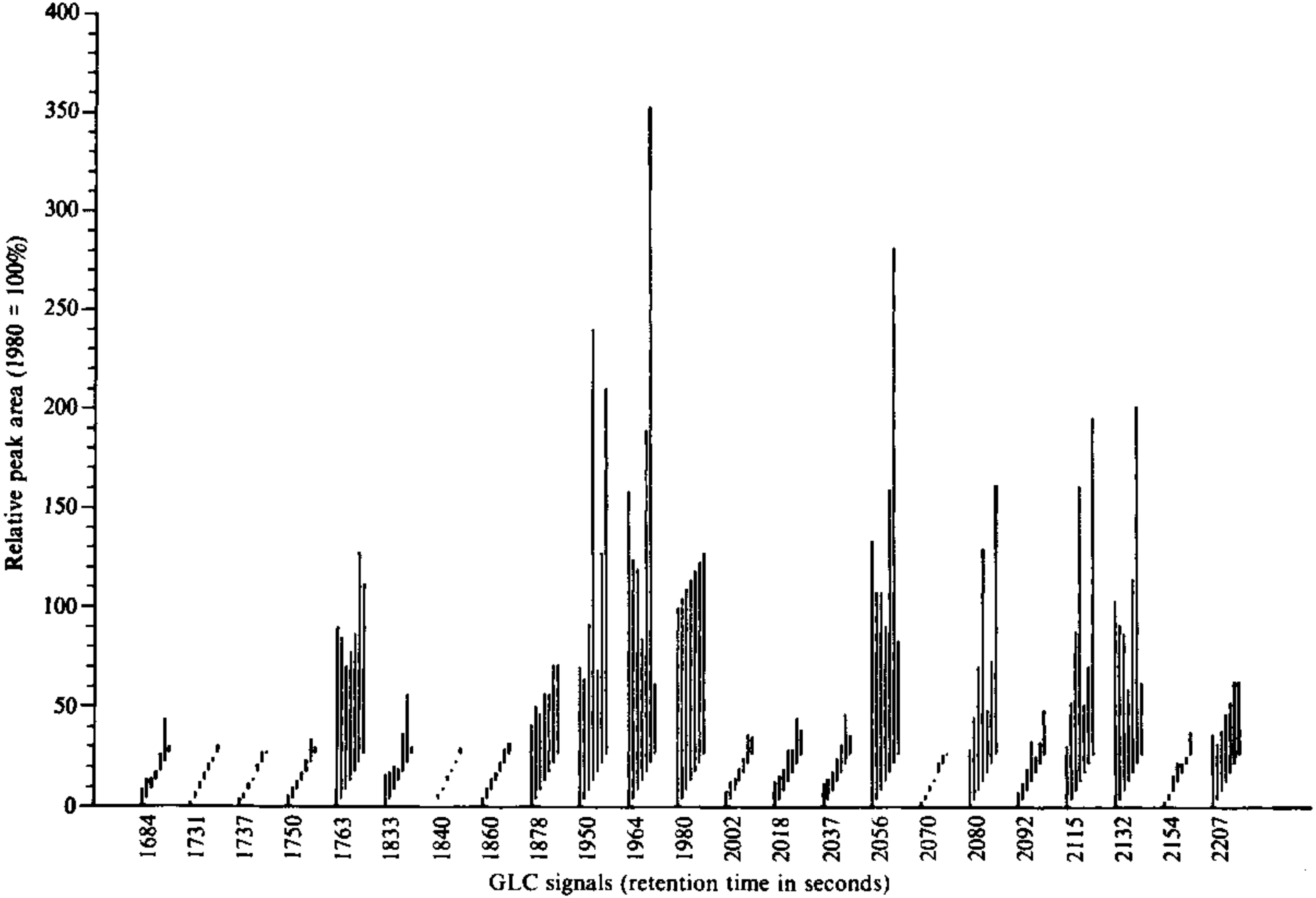


Figure 6. Aromagrams of seven pigeonpea genotypes in order of increasing oviposition preference by *Heliothis armigera* (front to rear). Bars represent the relative amounts of the components related to signal 1980 (100%). Means of two replications, from extracts of leaves sampled from the Max-Planck Institute collaboration plot at ICRISAT Center.

Table 3. Survival, mean larval period, and pupal mass of *Heliothis armigera* larvae fed on artificial diets containing powdered seeds or dhal of resistant and susceptible pigeonpea genotypes in the laboratory, ICRISAT Center, June 1986.

Diet ingredient	Number of larvae surviving to pupation (out of 32)	Mean larval period (days)	Mean pupal mass (g)
ICP 1903, brown-seeded, borer-resistant			
Seed	0		
Boiled seed	0		
Soaked seed	3	38 (± 2.0)[1]	0.23 (± 0.02)
Dhal	18	16 (± 1.8)	0.30 (± 0.01)
PPE 50, brown-seeded, borer-susceptible			
Seed	0		
Boiled seed	0		
Soaked seed	0		
Dhal	23	14 (± 0.7)	0.31 (± 0.01)
ICP 1691, white-seeded, borer-susceptible			
Seed	22	26 (± 0.7)	0.27 (± 0.01)
Boiled seed	3	30 (± 2.0)	0.26 (± 0.02)
Soaked seed	10	33 (± 1.1)	0.22 (± 0.01)
Dhal	23	14 (± 0.7)	0.32 (± 0.01)
Control			
Kabuli chickpea seed	30	13 (± 0.6)	0.33 (± 0.01)

1. Figures in parentheses are SE values.

oviposition attractant has been shown to be located in the sesquiterpenoid fractions. Characteristic varietal differences have been detected in the fractions derived from resistant and susceptible genotypes and further separated by capillary gas chromatography in a Sichromat 11 double oven gas chromatograph. An example of such "chemical fingerprints" is shown in Figure 6. Peak areas were integrated and are displayed as bars labelled by their retention time (in seconds). The peaks in each chromatogram are given in relative amounts in proportion to the signal at 1980 (homulene), which is set at 100% as an internal standard. The aromagrams of seven medium-duration pigeonpea genotypes are shown. Only a section of the chromatograms from the hexane extracts (hydrocarbon sesquiterpenes) from leaves is presented, similar fractions were also found in flower extracts and steam distillates. This fraction induced a positive reaction by *Heliothis* females in the oviposition assay. The components in the aromagram have partly been identified by mass spectroscopy and nuclear magnetic resonance spectroscopy.

Breeding for resistance. Our breeders and entomologists work together on a well-established project to breed for resistance to insect pests. Lines that showed reduced susceptibility to pests over several years of screening have been used in the crossing program to develop genotypes that give reasonable yields in fields where little or no pesticide is used. For example, two selections that have some resistance to *Heliothis* (ICP 3193-12 and ICP 1900-11) were crossed with cultivars Prabhat and BDN 1. The segregating populations were screened every year in pesticide-free conditions to select desirable types. In

1985/86, we conducted 9 replicated yield trials with these selected advanced lines under pesticide-free conditions at ICRISAT Center. Although the *Heliothis* incidence during the season was unusually low, some of these lines showed reduced pest susceptibility and produced better yields than the control cultivar. These genotypes also had larger seeds than the resistant control, ICPL 332. One advanced line (ICPX 80321-E34-E1-EB) significantly outyielded the resistant control and was higher-yielding than C 11 (Table 4).

Podfly (*Melanagromyza obtusa*)

Host-plant resistance. In most years, podfly is the most damaging insect pest of long-duration pigeonpea, a crop of major importance in central and northern India. We previously reported (ICRISAT Annual Report 1984, p. 180) several selections that have some resistance to this pest. This year we devoted more of our resources to the search for improved resistance to podfly, at the expense of our biological control studies.

Screening for resistance to podfly is very tedious. The egg is laid through the pod wall (Fig. 7) and the subsequent development of the larva and pupa takes place inside the pod, with no external symptoms. Thus, infestations can only be detected and quantified by destructive sampling of the pods. Almost all of the resistance that we have detected so far has been attributed to oviposition nonpreference, which may be of little value in the no-choice situations in farmers' fields for this insect is oligophagous. In previous years we found no evidence of antibiosis in any genotype for the ratio of pupae to eggs was at least as great in the resistant genotypes as in the susceptible ones. However, this year we recorded a reduction in the larval-pupal survival in one of our resistant selections; that has given us an incentive to continue our search for antibiosis.

In our studies of the mechanisms of resistance we have consistently recorded that our resistant selections tend to be small-seeded and small-podded. The only other characteristic that appears to be consistent is a reduced sugar content in the pod walls of resistant selections when compared with the susceptible types.

Table 4. Performance of some entries in a pigeonpea insect-resistant lines yield trial grown in a pesticide-free field, ICRISAT Center, rainy season 1985/86.

Entry	Time to 50% flowering (days)	Time to maturity (days)	100-seed mass (g)	Borer-damaged pods (%)	Grain yield (t ha^{-1})
ICPX 80321-E34-E1-EB	98	147	7.0	9.8	1.62
ICPX 76239-B-1-17-EB-EB	114	165	7.9	8.1	1.49
ICPX 76239-B-12-E1-EB-EB	113	164	7.9	8.7	1.47
ICPL 84060	114	165	8.0	9.8	1.45
ICPX 80322-E1-E1-EB	109	160	7.4	8.5	1.37
Resistant control					
ICPL 332	115	168	6.7	8.2	1.17
Susceptible control					
C 11	121	179	10.8	18.0	1.34
SE	±0.5	±0.8	±0.17	±2.1	±0.13
Trial mean (30 entries)	116	174	8.7	17.5	1.19
CV (%)	0.8	1	4	24	22

Figure 7. Scanning electron micrograph of the egg of the podfly, *Melanagromyza obtusa,* that is laid through the pigeonpea pod wall into a pod locule, ICRISAT Center, 1986.

Nodule-damaging Fly (*Rivellia angulata*)

Quantifying the effects of nodule damage. We have regularly observed that larvae of the fly, *Rivellia angulata,* cause substantial damage to pigeonpea nodules, particularly in Vertisols where up to 90% of the nodules may be destroyed. During 1985/86 we began collaborative trials involving entomologists and agronomists to quantify the effects of this damage on growth and yield of pigeonpea. In a field experiment on a Vertisol, we applied insecticide treatments (aldrin and BHC) to genotype ICPL 87. However, insecticide applied to the soil did not substantially reduce nodule damage and, although there appeared to be some advantage in early growth, plant size and yield at maturity were not affected by insecticide application. The insecticide applications may not have been sufficiently effective to control nodule damage, or the ability of pigeonpea to extract mineral nitrogen from deeper soil layers may have compensated for effects of nodule damage in the field.

We therefore conducted a pot experiment during 1986 using a Vertisol previously treated in three ways; depleted of N by first growing sorghum and then mixing in rice straw, left undisturbed, and with 20 kg ha^{-1} N as urea added at sowing of the test genotype, ICPL 87. Nodule damage was induced by caging adult *Rivellia* flies on half of the pots (ICRISAT Annual Report 1985, p. 195) at weekly intervals from 3 to 7 weeks after sowing. Sixty-eight days after sowing (DAS), nodule damage was significantly greater in all insect-infested treatments than in the noninfested controls (Table 5). Insect damage caused an average loss of about 30% in acetylene reducing activity of the nodules, 36% in leaf area, and 25% in shoot dry matter. The magnitude of loss was greatest in the N-depleted soil (Fig. 8), where the plants had to be more reliant on symbiotic nitrogen fixation. These results demonstrate that nodule damage by *Rivellia* can severely impair nitrogen fixation by pigeonpea grown in Vertisols, and further investigations of how best to alleviate this problem seem warranted.

Plant Nutrition

We are concerned with understanding and optimizing the mineral nutrition of pigeonpea particularly in relation to plant genotypic differ-

Table 5. Effect of infestation by *Rivellia angulata* on percentage nodules damaged pot^{-1} of pigeonpea genotype ICPL 87 grown in pots containing a Vertisol, 68 DAS, ICRISAT Center 1986.

	Soil nitrogen			
Treatment	Low[1]	Normal[2]	Added[3]	Mean
Infested with *Rivellia*	91	64	55	70
Noninfested	28	10	9	16
SE		±6.6		±3.8
Mean	60	37	32	43
SE		±4.7		

1. Available N was depleted by growing sorghum followed by mixing rice straw with the soil.
2. No extra N added.
3. The equivalent of 20 kg ha^{-1} N as urea added at sowing.

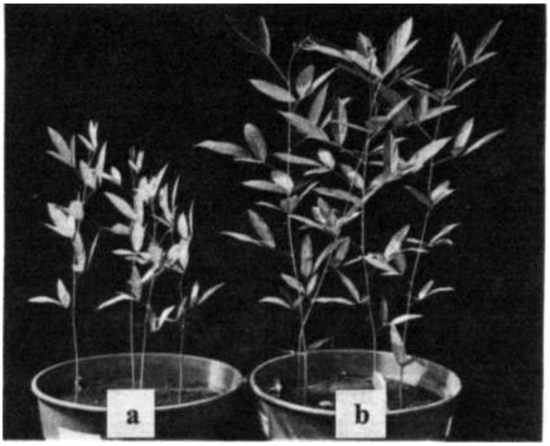


Figure 8. Effect of the nodule-damaging fly, *Rivellia angulata,* on shoot growth of pigeonpea genotype ICPL 87 grown in a Vertisol low in available N, 68 days after sowing (a. infested with *R. angulata,* b. noninfested), ICRISAT Center, 1986.

ences. Our major research emphasis is on optimizing nitrogen nutrition, which implies enhancement of symbiotic nitrogen fixation. We are hosting a Government of Japan Special Project that is examining interactions between mineral nutrition and soil moisture availability in pigeonpea.

Screening Soils for Potential Nutrient Limitations

We are adapting pot culture techniques to determine the ability of soils to provide each of the essential elements for pigeonpea growth. Essentially, this involves optimizing all plant growth factors to the extent possible and testing the effect of presence or absence of each of the essential elements that could possibly limit growth on a particular soil type. We have been using a half-factorial design ($1/2x2^7$) and, as an example, for neutral to alkaline soils we test the effect of P, S, K, Zn, Fe, B, and a combined treatment of Mo + Co + Mn + Cu. This method supplements soil analysis in identifying potential mineral nutrient problems; and the magnitude of the responses obtained in pots guide formulation of appropriate treatments for field fertilizer experiments.

We have so far tested two Vertisols and an Alfisol from ICRISAT Center, an Entisol from Hisar, and an Inceptisol from Gwalior. The only nutrients that we found to be potentially limiting in these soils are P and S, with a strong P x S interaction on the Vertisols (Table 6); no significant responses were measured on the Entisol.

We were concerned at the poor growth of pigeonpea on the Vertisol in 1985, compared to that on the Alfisol, and suspected that field capacity—the soil water content normally main-

Table 6. Effect of phosphorus and sulfur application on shoot dry matter (g $plant^{-1}$) of pigeonpea genotype ICPL 87 in nutrient screening trials in pots containing soils from ICRISAT Center (Vertisol, Alfisol) and Gwalior (Inceptisol), ICRISAT Center greenhouses, 1985 and 1986.

Treatment	Vertisol 1985		Vertisol 1986		Alfisol 1985		Inceptisol 1986	
S↑ P→	-P	+P	-P	+P	-P	+P	-P	+P
-S	0.19	0.77	0.32	1.05	4.23	5.32	4.00	4.86
+S	0.17	1.67	0.30	2.08	4.42	5.47	4.84	5.32
SE	±0.092		±0.055		±0.246		±0.087	
Response[1]	P***,S***,PxS**		P***,S***,PxS***		P***		P***, S***	

1. The significance of responses to application of phosphorus (P), sulfur (S) and their interaction (P x S), are indicated as ** for *P* <0.01, and *** for *P* <0.001 probability levels.

tained in such studies—was suboptimal for maximum growth. Thus, in 1986, we conducted a pot experiment where we maintained soil water content at different levels. We recorded large and almost linear increases in plant growth with increasing soil water contents from 15 to 30% (w/w), and a small but insignificant increase between 30 and 40%; the field capacity of this soil was 26%. The ability of pigeonpea to grow well for 52 DAS, at moisture levels as high as 40% was surprising, because pigeonpea is generally considered susceptible to waterlogging conditions. The reason for the generally observed poorer growth of pigeonpea on Vertisols, when compared with growth on soils of lighter texture, remains unexplained.

Nitrogen Requirements at Different Growth Stages of Short-duration Pigeonpea

To assess the scope for genetic improvement of symbiotic nitrogen fixation in pigeonpea we need to know the extent to which nitrogen is limiting growth in the field, and the growth stages at which this limitation occurs. We previously observed that pigeonpea genotypes ICPL 87 (short-duration) and ICPL 304 (medium-duration) responded to fertilizer N applied at sowing on a Vertisol but not on an Alfisol (1CRISAT Annual Report 1985, p. 198).

In the 1985/86 season we applied urea to ICPL 87 (Pragati), grown in both an Alfisol and a Vertisol field, at different growth stages; namely, sowing, mid-vegetative, 50% flowering, mid-pod filling, and after harvesting the first flush of pods. Apart from one treatment, we applied irrigation whenever we thought moisture deficit was limiting growth, and to ensure that the urea applied at different times was available for uptake by roots. We harvested three flushes of pods from crops on both soils. On the Vertisol, although urea application at any growth stage soon caused a darkening of leaf color, only treatments that received N at 50% flowering or later had significantly higher grain yields (up to 20%) than the treatment without any fertilizer N (Table 7). No significant differences in responses to fertilizer N were obtained on the Alfisol, although application of 100 kg N ha"[1] at sowing led to seedling mortality and consequently reduced yield. Withholding irrigation reduced yield on

Table 7. Effect of fertilizer N and its time of application on grain yield[1] (t ha^{-1}) of pigeonpea genotype ICPL 87 grown on a Vertisol and an Alfisol, ICRISAT Center 1985/86.

Treatment	Vertisol	Alfisol
ON	2.63	3.21
20 kg N ha^{-1} at sowing	2.83	2.98
20 kg N ha^{-1} at sowing without *Rhizobium*[2]	2.79	3.45
20 kg N ha^{-1} at sowing without irrigation[2]	2.67	2.04
100 kg N ha^{-1} at sowing	2.61	2.37
20 kg N ha^{-1} at sowing + 50 kg N ha^{-1} at 40 DAS	2.70	3.02
20 kg N ha^{-1} at sowing + 75 kg N ha^{-1} at 50% flowering	3.10	3.12
20 kg N ha^{-1} at sowing + 80 kg N ha^{-1} at pod filling	2.92	2.72
20 kg N ha^{-1} at sowing + 80 kg N ha^{-1} at first harvest	2.80	2.89
20 kg N ha^{-1} at sowing + 50 kg N ha^{-1} at 40 DAS + 75 kg N ha^{-1} at 50% flowering + 80 kg N ha^{-1} at pod filling + 80 kg N ha^{-1} at first harvest	3.10	3.11
SE	±0.07	±0.25
CV (%)	5	18

1. Total of three harvests.
2. Treatments omitting either *Rhizobium* inoculation or irrigation were also included for comparison.

the Alfisol but not on the Vertisol. In this and other studies we have observed that symbiotic nitrogen fixation activity in pigeonpea is better on Alfisols than on Vertisols, provided soil moisture is adequate.

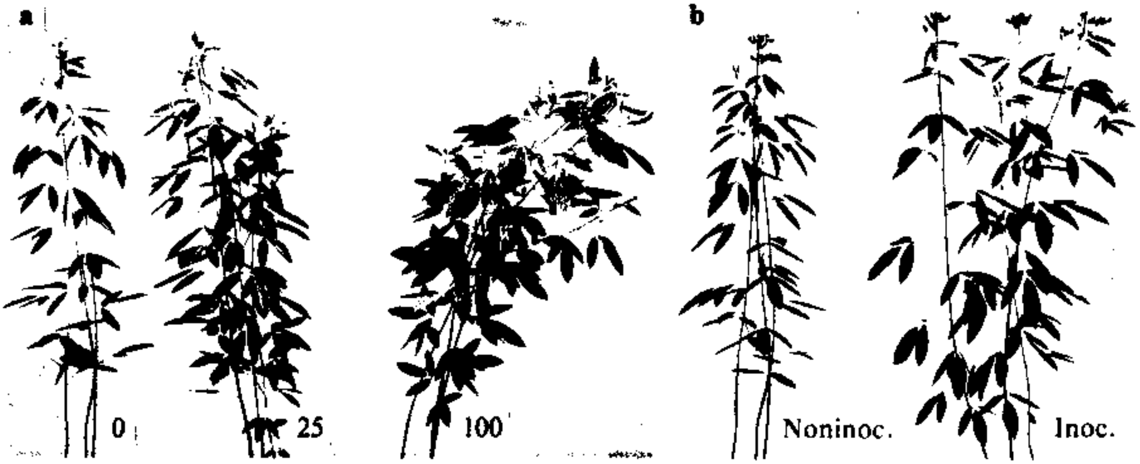
Although symbiotic activity appears adequate to meet the crop's nitrogen needs throughout its growth on Alfisols, this is not the case on Vertisols where nitrogen becomes limiting at later growth stages. Thus, there is scope for genetic enhancement of symbiotic nitrogen fixation capability in such heavy soils. To confirm these findings we are repeating this experiment at different locations in 1986/87.

Mycorrhizal Response in Nonsterilized Soil

Last year we reported large responses of pigeonpea genotype ICPL 87 to inoculation with vesicular arbuscular mycorrhizae (VAM) in a sterilized Alfisol (ICRISAT Annual Report 1985, pp. 197-198). In the 1985 rainy season we repeated the study using a nonsterilized Alfisol. We used nine mycorrhizal strains that had performed well in sterilized soil, together with sterilized and nonsterilized controls without inoculation, in a factorial combination with 5 rates of P application (0, 10, 25, 50, 100 kg P ha^{-1}). There was a significant response to fertilizer P in terms of shoot dry matter (Fig. 9a), nodule number, nodule mass, and N and P uptake. The response to mycorrhizal inoculation was not significant but there was a significant interaction between VAM and P level. For example, *Glomus caledonium* significantly increased shoot dry matter over the control in the absence of applied P (Fig. 9b).

The large responses to VAM inoculation in sterilized soil suggest that pigeonpea depends on mycorrhizal associations to enhance at least its P nutrition on natural, nonsterilized soils. However, the lack of response to inoculation by a wide range of VAM strains on nonsterilized soil suggests that there is little scope to enhance pigeonpea growth by VAM inoculation in natural soils. Nevertheless, the response to *Glomus caledonium,* as well as various other responses of pigeonpea to VAM inoculation in nonsterilized soils that have been reported from other laboratories, needs to be further examined before we can reasonably assess the prospects for improving pigeonpea growth in the field by manipulation of VAM associations.

Figure 9. Effect of a. 0, 25, and 100 kg P ha^{-1}, and b. inoculation with *Glomus caledonium* on shoot growth of pigeonpea ICPL 87 in a nonsterilized Alfisol, 88 days after sowing, ICRISAT Center, 1985.



Estimation of Soil Phosphorus Availability

Previous studies at ICRISAT Center have demonstrated that pigeonpea is much less responsive to P application than pearl millet or sorghum (ICRISAT Annual Report 1979/80, pp. 182-185) and that responses to sorghum are only obtained at Olsen-P levels (extraction with bicarbonate at pH 8.5) less than 2.5 mg P kg^{-1} on Vertisols (ICRISAT Annual Report 1984 pp. 256-258). Such levels are usually considered to indicate soils with low P availability to plants, but it must be questioned as to whether this method of extraction is really appropriate to pigeonpea.

With this in mind we conducted a pot experiment to compare the ability of six crop plants—pigeonpea, chickpea, soybean, sorghum, pearl millet, and maize—to extract P from soils low in available P, and to which no fertilizer P was added. We used a Vertisol with 1.5 mg P kg^{-1} and an Alfisol with 3.0 mg P kg^{-1} extracted by Olsen's method. All of the crops except pigeonpea produced more dry matter, and could extract more P (Table 8) up to the grain-filling stage in the Vertisol than in the Alfisol. With the exception of pigeonpea this result suggested that the ability of these crops to acidify the rhizosphere may contribute to greater P availability in the Vertisol.

We tried to fractionate soil associated with the roots of these crops when they were 2 months old. The fraction termed "Rhizosphere a" comprised the soil attached to the root mass that could be removed by gentle shaking. "Rhizosphere b" referred to soil removed by vigorous shaking. The pH of rhizoplane-attached soil was determined by soaking vigorously shaken roots in 20 mL distilled water and measuring the pH of the suspension. Even with these crude methods the pH of the soil adjacent to the root was found to be markedly lower than in the bulk soil (Table 9). We are refining these methods to be able to more precisely measure rhizosphere pH.

We then studied the effect of extractants of different pH on P availability from these soils. Figure 10 illustrates the results, showing the

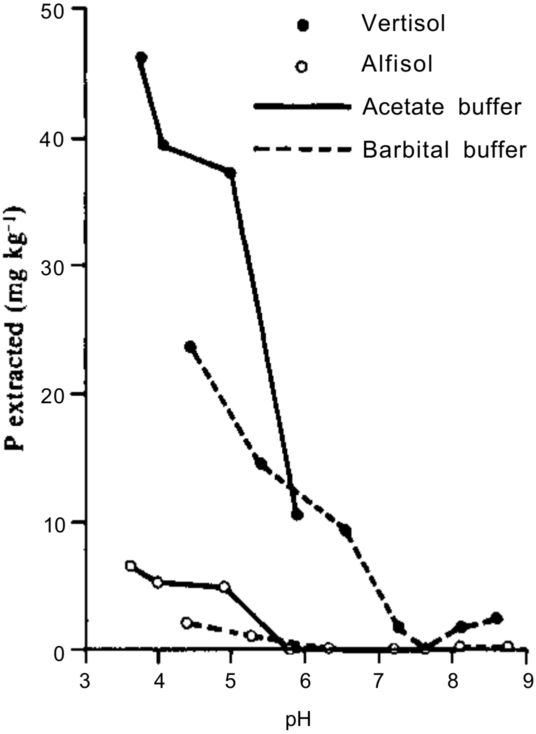


Figure 10. Phosphorus extraction from an Alfisol and a Vertisol in acetate and barbital buffers at various pH levels.

Table 8. Shoot phosphorus content (mg P pot^{-1}) of plants at the grain-filling stage after growth in low-P soils, pot trial, ICRISAT Center, 1986.

Soil	Pigeonpea	Chickpea	Soybean	Sorghum	Pearl millet	Maize
Alfisol	5.72	4.73	1.40	0.59	0.64	0.51
Vertisol	2.34	6.79	6.53	3.91	5.38	6.13
SE	±0.82	±0.77	±0.20	±0.39	±0.34	±0.25

Table 9. pH of bulk, rhizosphere, and rhizoplane-attached soil for six crop species grown for 2 months, in pots containing an Alfisol or a Vertisol, ICRISAT Center, 1986.

		pH				
Crop	Soil type	Bulk[1]	Rhizosphere a[1]	Rhizosphere b[1]	Rhizoplane-attached soil[2]	SE
Pigeonpea	Alfisol	8.46	7.14	6.88	6.82	±0.195
	Vertisol	9.27	8.13	8.11	7.60	±0.176
Chickpea	Alfisol	8.44	7.13	6.80	6.68	±0.203
	Vertisol	9.20	8.17	8.61	7.51	±0.180
Soybean	Alfisol	8.87	6.81	6.56	6.29	±0.296
	Vertisol	9.24	8.20	8.69	7.53	±0.182
Sorghum	Alfisol	8.59	7.66	7.61	7.22	±0.146
	Vertisol	9.17	8.44	8.80	7.99	±0.127
Pearl millet	Alfisol	8.73	7.57	7.82	6.82	±0.200
	Vertisol	9.06	8.65	8.55	7.77	±0.134
Maize	Alfisol	8.79	7.19	7.00	6.99	±0.220
	Vertisol	9.19	8.50	8.62	7.76	±0.149

1. Bulk and rhizosphere soil pH measured in a ratio of 1 soil: 2 water.
2. Roots with rhizoplane-attached soil soaked in 20 mL water, pH measured in resulting suspension.

increase in P availability as pH declines. For example, 39.3 mg P kg^{-1} could be released at pH 4 whereas only 1.5 mg P kg^{-1} could be extracted by Olsen's method in the same Vertisol at pH 7 and above.

These data demonstrate that Olsen's method may not be sufficiently sensitive or appropriate to estimate available P in alkaline soils for crops that acidify the rhizosphere. However, these results cannot explain the better growth of pigeonpea on Alfisols than Vertisols and alternative explanations for this must be sought.

Grain and Food Quality

Protein Content and Amino acids

We analyzed the protein content of 1573 dhal and 752 whole-seed samples received from ICRISAT pigeonpea breeders. It ranged from 18.8 to 34.5% for the dhal samples and from 16.3 to 22.8% for the whole-seed samples. The analyses of the dhal samples confirmed our earlier results that some of the lines developed by the ICRISAT breeding program have particularly high protein contents. In addition, we determined the protein content of 865 whole-seed samples from our Genetic Resources Unit; these ranged from 17.2 to 24.8%.

We have been studying the variability in amounts of sulfur-amino acids in pigeonpea. These are at inadequate levels in genotypes so far tested and we hope to identify genotypes with adequate levels. We estimated methionine in 105 defatted dhal samples of a progeny raised from gamma-irradiated material. The methionine content of these samples ranged from 0.82 to 1.38 g 100 g^{-1} protein and their protein content varied from 21.4 to 30.4%. Our pigeonpea breeders grew 22 accessions of *Atylosia scarabaeoides* in the postrainy season 1985/86 at ICRISAT Center and we analyzed defatted dhal samples of these for their methionine + cystine content.

Values ranged between 2.37 and 3.03 g $(100\ g)^{-1}$ protein with the mean being 2.50 g $(100\ g)^{-1}$ protein. This indicated only a small variation in the sulfur-amino acid contents of these accessions.

Cooking Quality

We continued to study the cooking quality of pigeonpea genotypes developed by ICRISAT that may be released. This year we evaluated the cooking quality of dhal samples of six short-duration and six medium-duration genotypes, by determining their cooking time, water absorption, and solids dispersion. The cooking time of all these genotypes was similar to that of the controls, except for ICPL 186 which took significantly longer to cook (Table 10). The protein content of ICPL 151 was lower than that of all the other genotypes. We did not find consistent differences between the short- and medium-duration genotypes in the characteristics that we measured.

Multiple harvesting of short-duration pigeonpea may become a common practice, so we determined the cooking quality of samples harvested twice, at intervals of about 60 days, from ICPL 81, ICPL 87, and ICPL 151 grown during 1985 at ICRISAT Center. No significant differences were apparent in the cooking time, water absorption, and solids dispersion of the samples of dhal from the two harvests. However, the protein content was significantly (P < 0.01) higher in the second harvest.

In some African countries, pigeonpea is consumed as whole seeds cooked to a soft consistency. However, it is frequently said that pigeonpea is less popular than cowpea because it takes much longer to cook. We compared the cooking time of pigeonpea and cowpea, with and without 16-h presoaking treatments using either water, or a sodium bicarbonate solution (1% w/v). Although the pigeonpea genotypes we tested took longer to cook than the cowpea when the seed had not been presoaked, this was reversed after presoaking (Table 11).

Table 10. Evaluation of cooking quality of dhal samples from pigeonpea genotypes developed by ICRISAT, laboratory tests, ICRISAT Center 1986.

Genotypes	Protein (%)	Cooking time (min)	Water absorption ($g\ g^{-1}$)	Solids dispersion (%)[1]	Texture (force, kg)[1]
Short-duration					
ICPL 87	20.2	17	1.19	31.3	125
ICPL 151	17.9	17	1.09	24.6	184
ICPL 186	23.2	22	1.06	23.3	222
ICPL 8324	19.5	19	1.22	33.0	170
Control					
UPAS 120	21.3	17	1.07	28.9	150
Medium-duration					
ICPL 270	20.7	17	1.27	38.9	100
ICPL 304	20.1	17	1.06	25.4	184
ICPL 333	20.1	16	1.29	37.9	90
ICPL 84060	21.0	16	1.05	28.0	127
Control					
C 11	20.4	17	1.04	25.5	165
SE	±0.21	±0.8	±0.043	±0.77	±8.8

1. Sample cooked for 15 min before estimation.

Table 11. Effect of presoaking with water and sodium bicarbonate solution (1% w/v) for 16 h, on the cooking time of whole seeds of cowpea and pigeonpea, ICRISAT Center, 1986.

		Cooking time (min)		
			Presoaked (16 h) with	
Genotype	100-seed mass (g)	Control	Water	Na HCO_3 (1% w/v)
Cowpea				
Russian	17.1	38	20	18
Local 1	22.7	36	18	15
Local 2	11.0	34	15	12
Pigeonpea				
T 21	7.0	46	15	13
C 11	9.2	52	15	12
BDN 1	9.3	54	14	10
ICPL 87	9.3	48	12	10
SE	±1.31	±1.9	±0.7	±0.8
Mean (20 pigeonpea genotypes)	9.7	53	15	12

Germinated and fermented preparations of pigeonpea may enhance its utilization in some Asian and African countries. We have initiated efforts to develop and test such preparations. We prepared products of germinated pigeonpea, in combination with rice flour, that were cooked in oil (uttapa), and in water (porridge), and a fermented product (dhokla) of pigeonpea flour in combination with rice and urd bean flours. Our tasting panels found all these products acceptable. We also found that both the germination and fermentation processes removed, or masked, a perceived "off-flavor" from the pigeonpea.

Dehulling Quality

Methods of dehulling pigeonpea and associated nutrient losses received considerable attention. We tested a tangential abrasive dehulling device (TADD), a barley pearler, and a manually operated stone chakki (mill) to determine a reliable method for evaluating the dehulling quality of differing pigeonpea genotypes. Using C 11, we compared the dhal yield, and the broken pieces, powder, and husk quantities produced by the three methods. Our results indicated that both the TADD and barley pearler could be used to determine the dehulling quality. However, it is more convenient to use the TADD for small quantities of seed.

We studied the influence of dehulling on nutrient losses by analyzing the dhal and powder fractions obtained by dehulling C 11 in the TADD for different periods (0, 2, 4, 8, and 12 min). The protein content of the dhal decreased as the dehulling time increased (Table 12). We also observed significant losses ($P < 0.01$) in calcium and iron contents even after dehulling for only 2 minutes. This indicated that these constituents are concentrated in the outer layers of cotyledons, that are removed as a result of abrasive dehulling. However, the levels of the essential amino acids (lysine, methionine + cystine, and threonine) did not significantly change even after extended abrasion. It was apparent that unlike protein, calcium, and iron, these amino acids are uniformly distributed in the cotyledons and that their concentrations are not reduced by dehulling.

Table 12. Effect of dehulling, using the Tangential Abrasive Denuding Device (TADD) for various times, on the protein, calcium, and iron contents of the dhal and powder fractions of pigeonpea genotype C 11 seeds, ICRISAT Center, 1986.

	Dhal			Powder		
Dehulling time (min)	Protein (%)	Calcium (mg 100 g^{-1})	Iron	Protein (%)	Calcium (mg 100 g^{-1})	Iron
0[1]	21.4	58.2	5.1	-	-	-
2	20.8	46.5	3.7	31.2	149.7	15.4
4	20.3	46.0	3.6	29.7	107.5	11.0
8	19.6	41.0	3.2	27.1	86.3	8.4
12	19.6	40.8	2.5	24.9	82.6	7.8
SE	±0.17	±2.34	±0.19	±0.17	±2.03	±0.53

1. This treatment was dehulled by hand and not subjected to abrasion in the TADD.

Vegetable Pigeonpeas

We studied texture (hardness), moisture content, and 100-grain mass of green seeds of vegetable-type pigeonpea, since these are characteristics likely to affect their consumer acceptability. We determined the texture of single seeds of ICP 12005 using a compression probe, a piercing probe, and a cutting blade in the Instron food tester. We used a back-extrusion cell to determine the texture of 30-g green seed lots of 16 genotypes. We also analyzed these genotypes for protein, starch, soluble sugars, crude fiber, and fat content. We found greater variation in texture between seeds within a genotype than between the seed lots of differing genotypes. This heterogeneity in texture among seeds is probably a result of differences in their maturity stages. Based on the analysis of 16 genotypes using the back-extrusion cell, textures showed significant positive correlations ($r = 0.73$, $P < 0.01$) with 100-grain mass and significant, and negative correlations ($r = -0.81$, $P < 0.01$) with moisture content, thus demonstrating the importance of these parameters in the texture measurement of vegetable pigeonpea. We also found that the variation in soluble sugar contents (2.6-6.4%) was greater than that in crude fibre contents (7.9-9.9%) in these genotypes.

Plant Improvement

Short-duration Pigeonpea

Short-duration pigeonpea genotypes mature 90 to 150 DAS and are becoming popular in a number of cropping systems. The incorporation of such genotypes into cropping systems under rainfed, supplemental, and full irrigation conditions can lead to increased cropping intensity. With the availability of a wider range of short-duration genotypes, commercial pigeonpea cultivation can be extended to regions where either the crop is not grown, or is grown as a minor component with cereals, or as a backyard crop. Traditional, long-duration, tall, photosensitive genotypes have little potential outside the intercrop systems and regions where they are currently grown. With short-duration genotypes we are dealing with a virtually new crop requiring different agronomy and with potential for mechanized farming. Such genotypes are relatively photoinsensitive and so have wider adaptation, across both geographic regions and seasons. In this year we intensified our breeding efforts in this maturity group, at the expense of our work on longer-duration types. We also undertook a series of adaptation trials in new areas at higher

Table 13. Performance of some newly developed short-duration pigeonpea lines, ICRISAT Center, 1985.

	Time to 50% flowering (days)	Time to maturity (days)	100-seed mass (g)	Grain yield (t ha^{-1})		Sterility mosaic (%)[2]
				Hisar[1]	ICRISAT Center	
Determinate						
ICPL 85016	63	106	8.2	3.54	2.65	65
ICPL 85017	62	105	9.6	3.25	2.58	80
ICPL 85012	60	95	10.0	3.32	1.89	47
ICPL 85005	55	95	9.2	3.75	1.81	3
ICPL 83008	63	105	9.8	3.58	2.50	7
Control						
Prabhat	60	92	5.5	2.56	1.78	87
SE	±0.6	±1.0	±0.23	±0.15	±0.20	
Trial mean (36 entries)	62	104	9.3		2.09	
CV (%)	2	2	4	10-21	18	
Indeterminate						
ICPL 84048	58	103	9.3	2.78	1.25	29
ICPL 85049	74	117	12.8	3.12	I.I9	87
ICPL 84044	54	102	10.7	3.01	1.13	24
Control						
UPAS 120	57	104	7.8	2.43	1.09	89
H 77-216	56	102	7.9	2.78	1.23	100
SE	±1.4	±1.0	±0.17	±0.13	±0.11	
Trial mean (36 entries)	59	105	9.3		1.11	
CV (%)	4	2	3	11-15	17	

1. 1984 data from different tests (ICRISAT Annual Report 1985, p. 203).
2. Disease incidence recorded from the sterility mosaic disease nursery at ICRISAT Center.

latitudes. Further, we initiated multi-disciplinary nurseries to screen for photoinsensitivity and adaptation to rice fallows and arid areas.

ICPL 87. In 1986 our short-duration, determinate cultivar ICPL 87 was officially released as Pragati (meaning progress) by the Central Varietal Release Committee (CVRC) for cultivation in peninsular India and notified for the whole country. Following recommendations by an All India Coordinated Pulses Improvement Project (AICPIP) workshop, and in collaboration with the Directorate of Pulses Research, of the Indian Council of Agricultural Research (ICAR), Kanpur, a release proposal for another short-duration cultivar ICPL 151 was submitted to the CVRC.

ICPL 87 has shown wide adaptation in diverse agroclimatic conditions across India. It has wilt tolerance, high yield potential, and good ratoonability (ICRISAT Annual Report 1984, pp. 167-

168). These characteristics were amply exploited and demonstrated in on-farm adaptation trials conducted by the Andhra Pradesh State Department of Agriculture in Rangareddy District. The farmers who grew the trials were enthusiastic about the crop, that looked very attractive and grew to a height of less than 90 cm, enabling them to easily spray it with insecticides. In two harvests they recorded dry seed yields of up to 5.20 t ha^{-1} in 180 days. The Government of Maharashtra State took further steps to release ICPL 87 because of its relatively large seed (100-seed mass = 9g) and superior yield performance in multilocational and on-farm trials. It gave a mean yield of 1.24 t ha^{-1} in 1985 in eight on-farm trials as compared to 0.88 t ha^{-1} for the control. In 12 on-farm trials in three northern districts of Madhya Pradesh, where ICPL 87 is intended to be double cropped with wheat, this variety gave a mean yield of 1.45 t ha^{-1}, compared to 1.20 t ha^{-1} by the control cultivar UPAS 120.

Following requests from the Departments of Agriculture and agricultural universities associated with the states of Madhya Pradesh, Gujarat, Maharashtra, and Andhra Pradesh we organized a number of short-duration adaptation trials. We supplied about 500 kg of pure seed of ICPL 87 to national and state seed corporations and to universities in India for further multiplication.

Improved genotypes. Our work on the improvement of short-duration pigeonpea was continued at Hisar and ICRISAT Center in 1985. Unfortunately, most yield tests at Hisar were lost because of severe water-logging and soil salinity problems.

During 1985 two of our extra-early-pigeonpea lines, ICPL 317, and ICPL 8306, were reported by AICPIP to have good potential at Samba in the Northwest Hill Zone, and at Imphal in the Northeast Hill Zone of India. In these areas pigeonpea is virtually a new crop, but shows considerable potential. At Samba, ICPL 317 gave a mean yield of 2.67 t ha^{-1} compared to 1.43 t ha^{-1} by the control cultivar, UPAS 120. At Imphal, ICPL 317 gave a mean yield of 3.20 t ha^{-1} against 2.35 t ha^{-1} by UPAS 120.

Large-seeded, short-duration lines which yielded very well at Hisar in 1984 were tested at ICRISAT Center in 1985. They again produced much larger seeds than the control cultivars, and several gave greater mean yields (Table 13). Some of these lines also had greater tolerance/resistance to sterility mosaic disease than the controls.

Short-duration lines from ICRISAT were also tested in nontraditional production systems at Pusa, Bihar, India where we evaluated a set of determinate and indeterminate lines in the 1985/86 postrainy season in collaboration with ICAR. Some of our lines gave better yields and had larger seeds than the control cultivar and will be tested further (Table 14).

Table 14. Performance of short-duration pigeonpea lines in trials at Bihar, India, postrainy season 1985/86.

Genotype	Time to maturity (days)	100-seed mass (g)	Grain yield (t ha^{-1})
Determinate			
ICPL 84029	150	8.5	2.99
ICPL 8322	148	7.5	2.93
ICPL 151	148	10.5	2.78
Control			
UPAS 120	165	7.0	2.48
SE			±0.14
Trial mean (19 entries)			2.39
CV (%)			10
Indeterminate			
ICPL 314	159	8.5	2.78
ICPL 292	159	9.5	2.51
ICPL 84052	160	8.0	2.45
Control			
UPAS 120	162	6.5	2.16
SE			±0.13
Trial mean (18 entries)			2.13
CV (%)			10

Medium-duration Pigeonpea

Composite populations. In 1981 we made five composite populations using MS3A and ICPM 1 (MS4A) male-sterile sources to improve the levels of salt tolerance, pod borer resistance, podfly resistance, combined resistance to sterility mosaic and wilt, and wilt resistance. Every year, 5000 plants from each population are grown in isolation. At the flowering stage male-sterile plants are identified and the seeds collected from these plants are bulked to reconstitute the populations. After four cycles of random mating, these populations will be tested for progress in the attributes for which they were constituted. Such testing will commence in the 1987/88 season, and then, selected populations will be tested for yield and other characteristics, and new genetic variability will be incorporated for further improvement.

This year we developed a new composite population to combine wilt, sterility mosaic, and phytophthora blight resistance using two male-sterile lines, and diverse disease-resistant parents.

Long-duration Pigeonpea

We continued to breed long-duration pigeonpea at Gwalior. Our main aim is to develop lines resistant to diseases and insect pests so as to stabilize crop productivity. An alternaria blight- and sterility mosaic-resistant line ICPL 366, entered in the 1985 AICPIP Late Maturity, Arhar Coordinated Trial (ACT 3), has performed well over the past 4 years (Table 15). In 1986 another high-yielding line, tolerant to sterility mosaic, was also entered in the multilocational ACT 3.

Table 15. Performance of an alternaria blight- and sterility mosaic-resistant pigeonpea line ICPL 366 in trials at Gwalior and Morena, India, 1982-1985.

		Grain yield (t ha^{-1})	
Year	Number of trials	ICPL 366	Control GW 3
1982	5	2.67	2.61
1983	4	2.53	2.24
1984	7	2.57	2.29
1985	5	2.17	1.27
Mean		2.49	2.11
Alternaria blight (%) in greenhouse		0.0	100
Sterility mosaic (%) in sterility mosaic nursery		0.0	100

Hybrids

The short-duration hybrid ICPH 8 that has recorded high yield levels (ICRISAT Annual Report 1985, pp. 205-206) continued to perform well in 1985 (Table 16). This hybrid has now been entered in the AICPIP Extra-early Arhar Coordinated Trial (EACT). We also compared four other new short-duration pigeonpea hybrids with three national control cultivars at 10 locations in India using 3 x 4-m plots in replicated trials. In the six trials that had a coefficient of variation (CV) less than 25%, the yield increase of ICPH 13 over the best national control cultivar (T 21) ranged from 8 to 91% with an average of 30% (Table 16). We plan to produce enough seed of ICPH 13 in isolation for multilocational testing in the coming season.

High-Protein Lines

For the first time we tested agronomically superior, medium-duration, high-protein lines with the national control cultivar, BDN 1. Most of the test lines flowered and matured at the same time as BDN 1 (Table 17). The high-protein lines were also similar to BDN 1 in plant height, number of seeds per pod, and seed size. Some of the lines in this trial exhibited a similar yield potential to that of BDN 1 but their protein content was significantly higher. The best high-protein line, HPL 40-5, yielded over 20% more protein per hectare than the control.

Table 16. Grain yield t ha^{-1} of short-duration pigeonpea hybrids and national control cultivars at six Indian locations, rainy season 1985.

Entry	ICRISAT Center	Secund-erabad	Jalna	Baroda	Gulbarga	Sriganga-nagar	Mean	Increase over T 21 (%)
ICPH 13	2.59(1)[1]	2.65(1)	1.70(1)	1.79(2)	0.80(1)	3.02(3)	2.09	30
ICPH 14	1.83(4)	2.47(2)	1.33(5)	1.55(4)	5.30(5)	3.53(1)	1.87	16
ICPH 16	1.95(3)	2.47(2)	1.64(2)	1.46(6)	0.66(4)	2.94(4)	1.85	15
ICPH 8	1.45(6)	2.39(4)	1.58(3)	1.47(5)	0.74(3)	3.09(2)	1.79	11
ICPH 15	2.43(2)	2.11(8)	1.19(6)	1.91(1)	0.79(2)	2.25(8)	1.78	11
Controls								
T 21	1.42(7)	2.29(5)	1.16(7)	1.56(3)	0.42(7)	2.78(5)	1.61	
UPAS 120	1.22(8)	2.17(7)	1.37(4)	0.85(8)	0.53(6)	2.33(6)	1.41	
H 77-216	1.57(5)	2.19(6)	1.03(8)	1.02(7)	0.37(8)	2.25(7)	1.41	
SE	±0.22	±0.10	±0.15	±0.18	±0.09	±0.21		
Trial mean (8 entries)	1.81	2.34	1.38	1.45	0.61	2.72		
CV (%)	21	7	19	21	25	13		

1. Numbers in parentheses indicate the ranking of the entry in the trial.

Table 17. Performance of high protein pigeonpea lines, ICRISAT Center, rainy season 1985.

Line	Time to 50% flowering (days)	Time to maturity (days)	Plant height (m)	Seeds pod^{-1}	100-seed mass (g)	Grain yield (t ha^{-1})	Protein	
							(%)[1]	(t ha^{-1})
HPL 40-5	115	169	1.70	3.6	9.6	2.10	26.9	0.47
HPL 40-17	117	169	1.61	3.6	8.5	2.07	26.5	0.45
HPL 40-23	116	168	1.64	3.6	9.4	1.94	26.4	0.42
HPL 40-6	116	168	1.67	3.6	9.9	1.91	26.4	0.41
HPL 40-15	121	171	1.60	3.3	9.1	1.82	27.2	0.40
Control								
BDN 1	115	168	1.68	3.4	9.6	2.02	23.2	0.39
SE	±1.0	±0.9	±0.05	±0.13	±0.18	±0.18	±0.46	±0.04
Trial mean (25 entries)	117	170	1.66	3.6	9.1	1.81	26.3	0.40
CV (%)	1.5	0.9	4.7	6.6	3.4	17	3.0	17

1. Estimated in dhal.

The high-protein character, transferred to pigeonpea from its wild relatives, *Atylosia albicans, A. sericea,* and *A. scarabaeoides,* has shown a high level of stability over years. The mean percentage of dhal protein in our high-protein selection for each of 4 years (1982-85) ranged from 28.8 to 31.2%, compared with 22.6 to 23.6% in the control BDN 1. To determine its

Table 18. Protein content (%) of dhal from high protein pigeonpea lines compared to the national control cultivar C 11 in 10 environments in India, rainy season 1985.

Location	HPL 24	HPL 25	HPL 28	HPL 31	Control C 11	SE	CV (%)
ICRISAT[1]	31.3	28.5	27.8	30.1	23.3	±0.26	1.7
ICRISAT[2]	33.6	29.0	28.6	28.5	22.1	±0.32	2.4
ICRISAT[3]	29.6	29.8	26.8	NT[5]	22.9	±0.54	4.2
ICRISAT[4]	NT	31.2	26.4	29.9	22.6	-	-
Jalna	32.2	28.9	30.4	30.9	23.1	±0.69	5.0
S.K.Nagar	30.9	28.4	27.3	28.8	21.4	±0.36	2.0
Gulbarga	32.1	29.9	27.6	29.2	23.0	±0.49	3.7
Gwalior	32.3	30.4	27.3	30.1	22.0	±0.71	4.5
Hisar	31.1	29.6	29.2	NT	24.5	-	-
Sabour	32.8	29.1	29.3	NT	23.9	-	-
Mean	31.8	29.5	28.1	29.6	22.9		

1. ICRISAT Center Vertisol, irrigated.
2. ICRISAT Center Vertisol, rainfed.
3. ICRISAT Center Alfisol, rainfed.
4. ICRISAT Center Vertisol, September sowing.
5. Not tested, seed not available.

stability over environments, we conducted replicated tests of the high-protein lines and a control cultivar in diverse environments. The protein content (Table 18) in the seed received from 10 environments was higher in the high-protein lines than in the control.

The sulfur-containing amino acids of the high-protein lines were found to be similar to those of the control cultivar. The mean methionine + cystine values for the high-protein lines was 2.61 $g(100g)^{-1}$ of protein compared with 2.53 $g(100g)^{-1}$ for the control. This indicated that protein quality in terms of essential amino acids did not decrease as the protein content increased. These results clearly show that characters such as high-protein content, large seed size, and high yield can be successfully combined in pigeonpea. We have entered one of the selections for evaluation in the Medium-duration Pigeonpea Adaptation Yield Trial (MPAY). High-protein lines may have potential as a nutritious food component in areas where pigeonpea is not presently popular as a food. We have now made crosses to develop high-protein, high-yielding, short-duration lines.

Wood Production from Pigeonpea

In view of the increasing demand for wood as a source of fuel or construction material in semi-arid areas, we are assessing the potential of different pigeonpea genotypes in different cropping systems to provide this product. Wood from pigeonpea (Fig. 11) has been traditionally used by subsistence farmers but there has been little biological or economic quantification of this product. At Gwalior, long-duration lines (e.g., ICPL 360) yielded up to 7.5 t ha^{-1} air-dried sticks $season^{-1}$. At ICRISAT Center, medium-duration lines have produced more than 10 t ha^{-1} oven-dried sticks $season^{-1}$ from a monocrop grown at a population of about 6.6 plants m^{-2}. Short-duration pigeonpea monocrops, from which multiple grain harvests are taken, can yield up to 8 t ha^{-1} of oven-dried sticks.

At Hisar, we recorded air-dried stick yields of more than 20 t ha^{-1} from a short-duration pigeonpea crop sown in late June. However, when short-duration pigeonpea was sown in this environment in early April and the crop was

Figure 11. Threshing pigeonpea; the woody stems have many uses, but are particularly valuable as a source of fuel, ICRISAT Center, 1986.

given adequate irrigation, stick yields exceeded 30 t ha^{-1}. Thus, a changeover from longer duration to short-duration pigeonpea should not reduce the mass of sticks, but more, smaller sticks will be produced and these may not be so useful for some purposes as the larger sticks from the longer-duration crops.

Plant Regeneration from Immature Pigeonpea Embryos

Atylosia platycarpa is of potential value to pigeonpea improvement programs because it carries genes for photoinsensitivity, earliness, and resistance to fusarium wilt, phytophthora blight, and salinity. Despite repeated attempts, we failed to hybridize *A. platycarpa* with pigeonpea. The cause of cross-incompatibility between *A. platycarpa* and pigeonpea was found to be associated with the abnormal growth of pollen tubes of *A. platycarpa* on pigeonpea stigmas. Bridge crosses have been used as a means of combining the genomes of species that are cross-incompatible by normal hybridization methods. In such cases, a third related species (usually a cross-compatible wild type) is used in the primary hybridization and the resulting hybrid is then crossed with the intended recipient species. Experiments at ICRISAT Center have shown that *A. platycarpa* will form pods when crossed as a female with *A. acutifolia, A. cajanifolia,* and *A. scarabaeoides,* and as a male with *A. scarabaeoides.* However, these pods contained shrivelled, nonviable seeds. Dissections showed that the embryos formed in these seeds ceased to grow when 0.5-1.0 mm long. This was linked to the degeneration of the endosperm tissue in the hybrid ovule.

We developed a method to raise plantlets from these immature embyros. The technique involved dissecting the embryos from the hybrid ovules and placing them under sterile conditions on B5 medium containing *2%* sucrose, 0.8% agar, 0.25 mg kinetin L^{-1}, and 0.1 mg naphthalene acetic acid (NAA) L^{-1}. A higher proportion of embryos developed into plantlets when nurse-endosperm sacs or young embryos from the maternal parent, *A. platycarpa,* were placed adjacent to the hybrid embryos, and when the cultures were kept in the dark for one week after dissection. The plantlets did not grow to full plants. We hope to pursue these studies.

Cooperative Activities

Asian Grain Legumes Network

The Asian Grain Legumes Network (AGLN), known until 17 December 1986 as the Asian Grain Legume Program (AGLP), was initiated at the beginning of 1986 to strengthen the collaboration between ICRISAT's Legumes Program and scientists in Asia working on ICRISAT's three mandate legume crops; groundnut, chickpea, and pigeonpea. The concept for this Network came from two meetings held at ICRISAT Center, the Consultative Group Meeting for Asian Regional Research on Grain Legumes, 11-15 December 1983, (ICRISAT Annual Report 1983, p. 177) and the Review and Planning Meeting for Asian Regional Research on Grain Legumes, 16-18 December 1985, (ICRISAT Annual Report 1985, pp. 210-211).

The Coordinator of the Network was appointed on 1 January 1986 with an Office in the Legumes Program at ICRISAT Center. The Network has a special relationship with India because of the many cooperators associated with ICRISAT through ICAR. The Coordinator visited the People's Republic of China in late 1985 and will visit again early in 1987. During 1986 the Coodinator visited all the other countries that are presently in the Network (Bangladesh, Burma, Indonesia, Nepal, Pakistan, The Philippines, Sri Lanka, and Thailand). Contact has been made with other countries in Asia and visits made to the Republic of Korea, Japan, and Taiwan.

These visits have been used to carry through the recommendations put forward by the Review and Planning Meeting mentioned above. Contacts were made to integrate AGLN activities with those of regional and international organizations. Preliminary surveys were made to determine disease and pest incidence as a basis for recommending appropriate research activities. Enquiries were made on the need to collect germplasm of the three legume crops in each country. Plans were made with the Regional Co-ordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber crops in the Humid Tropics of Asia and the Pacific (CGPRT) in Bogor, Indonesia, to conduct a socioeconomic survey of groundnut in Indonesia and Thailand. The need for joint special projects with national programs for basic studies were ascertained. Training requirements and personnel requiring training were identified. An indication of the agroclimatological data available in each country was obtained. These data can be used to identify agroecological zones, within which specific legume genotypes can be recommended. A genotype x environment study, in conjunction with the Australian Centre for International Agricultural Research (ACIAR), was planned.

The Director General of ICRISAT signed a Memorandum of Understanding (MOU) in Dhaka, Bangladesh on 9 September 1986 with the Director General of the Bangladesh Agricultural Research Institute and another in Rangoon, Burma on 10 September 1986 with the

Managing Director of the Agriculture Corporation. These MOU's indicate the interest these countries have in collaborating with ICRISAT on research on grain legume crops, and will facilitate the movement of scientists and material between ICRISAT and these countries. ICRISAT already has MOU's with Pakistan, The Philippines, and Thailand.

National and International Trials

Arhar Regional Trial (ART). The Arhar Regional Trial was initiated in 1981/82 to identify medium-duration genotypes suitable for environments representative of the State of Andhra Pradesh in India. From 1984 the States of Karnataka and Maharashtra have cooperated and participated in this trial. These ARTs are conducted not only on Vertisols, but also on Alfisols because there are large Alfisol areas in these states where pigeonpea can be grown. On the basis of mean performance over 3 years ICPL 270, a wilt-resistant line, consistently outyielded the two control cultivars included in the trial on Vertisols, yielding 1.71 t grain ha^{-1} compared to 1.34 t grain ha^{-1} for BDN 1 and 1.51 t grain ha^{-1} for C 11. Consequently, this line will be tested in adaptive trials in farmers' fields in Andhra Pradesh and Karnataka.

On Alfisols, the shorter-duration lines Hy 4 and ICPL 95 performed better than the controls, BDN 1 and C 11. These lines gave average yields that were 22% higher than the mean of the controls (0.93 t ha^{-1}) over 3 years' trials. These data clearly indicate that on Alfisols, the shorter-duration genotypes have an advantage over the traditional, medium-duration types because the latter suffer from terminal drought stress. In addition to its high yield, ICPL 95 has wilt resistance and we plan to test it in adaptive trials in farmers' fields in the region.

Pigeonpea Observation Nurseries. 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 lines in response to specific requests. The performance of our short-duration pigeonpea lines in these trials has been very encouraging (Table 19).

Use of ICRISAT Pigeonpea Wilt-resistance Sources by National Programs

Fusarium wilt is a major disease of pigeonpea, not only in the Indian subcontinent, but also in eastern and southern Africa. To provide resistant lines for use by national breeding programs, seeds of lines that are found resistant at ICRISAT Center are shared with scientists in national programs through cooperative, disease-resistance nurseries. For fusarium wilt, two such nurseries have been operated for the past 6 years. The nursery in India is conducted jointly with ICAR and a separate nursery is provided to cooperators in eastern Africa.

ICAR/ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR). The results of this trial from 1981 to 1983 were reported last year (ICRISAT Annual Report 1985, p. 209). The results of the trial for the next three seasons (1983/84 to 1985/86) are summarized here. There was variability in the reactions of the lines across locations; this may indicate variability in the pathogen (*F. udum*). However, ICP 9174 offers particular potential as it showed resistance (<20% wilt) in 11 out of 12 locations tested. It is now being used in resistance-breeding programs. Six other lines also showed resistance at most of the locations where they were tested (Table 20), indicating that they have broadbased resistance.

International Pigeonpea Wilt Nursery (IPWN). This nursery has been grown in Kenya and Malawi since the 1980/81 season. During the past 5 seasons, 222 entries that showed <20% wilt at ICRISAT Center were evaluated in Kenya (Machakos) and Malawi (Limbe and Lilongwe). Five lines, ICP 8864, ICP 9145, ICP 9155, ICP 10957, and ICP 10960, showed <20% wilt for 2 consecutive years in Kenya. In Malawi, in tests at Limbe (4 years) and Lilongwe (1 year), lOlines ICPV 1 (ICP 8863), ICP 9142, ICP 9145,

Table 19. Performance in various countries of short-duration pigeonpea lines in trials supplied by ICRISAT, 1985/86.

Country/ Location	Trial[1]	Lines tested	Grain yield ($t\ ha^{-1}$) Range	Mean	Highest-yielding line
Argentina (Salto)	EPIT	14	1.26-3.52	2.15	ICPL 8311
	EPAY	17	0.83-2.38	1.82	ICPL 8311
Argentina (Green villages)	EPIT	14	1.69-4.42	2.88	ICPL 8324
	EPAY	18	1.64-3.85	2.63	ICPL 8321
Burma	EPIT	20	1.15-4.05	1.92	ICPL 87
China	PON	6	0.78-1.20	1.06	C 322
Ethiopia (Alemaya)	PON	6	0.40-1.67	0.91	ICPL 87
(Dire Dawa)	PON	6	0.67-4.87	2.17	ICPL 6
Indonesia	EPIT	16	0.41-1.55	1.07	ICPL 147
Zimbabwe	EPIT	20	1.61-3.76	2.84	ICPL 151
	EVPIT	10	1.54-3.35	2.50	ICPL 84039

1. EPIT = Early maturity Pigeonpea International Trial.
EPAY = Early maturity Pigeonpea Adaptation Yield Trial.
PON = Pigeonpea Observation Nursery.
EVPIT = Early maturity Vegetable Pigeonpea International Trial.

Table 20. Pigeonpea lines found to have broadbased resistance in the ICAR/ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR) at 12 Indian locations, 1983/84, and 1985/86.

Entry	Wilt reaction[1] Anni-geri	Badna-pur	Baroda	Berham-pur	Delhi	Dholi	Gul-barga	ICRISAT Center	Kanpur	Pudu-kottai	Ranchi	Sehore
ICP 8848[2]	S	R	R	NT	S	R	NT	R	R	NT	R	R
ICP 8858	NT	R	R	NT	S	NT	R	R	NT	R	R	R
ICPV 1[2] (ICP 8863)	S	R	S	NT	R	R	R	R	R	R	R	R
ICP 9174	S	R	R	R	R	R	R	R	R	R	R	R
ICP 12745	s	R	R	R	R	R	S	R	R	R	R	S
ICPL 84007	R	S	R	R	S	R	R	R	R	R	R	S
Bandapalera	S	S	R	R	R	R	S	R	R	R	R	S
Control												
ICP 2376	s	s	S	S	S	S	S	S	S	S	S	S

1. S = Susceptible (>20% plants wilted); R = Resistant (<20% plants wilted); NT = Not tested.
2. Also tested at Palem, and found to be resistant.

ICP 9156, ICP 10960, ICP 11295, ICP 11297, ICP 11299, ICP 12733, and ICP 12738, showed <20% wilt while the susceptible control, ICP 2376, showed >90% wilt in all years.

This nursery has helped to identify good sources of wilt resistance for eastern Africa. Entry ICP 9145, in addition to exhibiting wilt resistance in Malawi, has been found to have good yield potential and is now being considered for on-farm testing there.

Use of ICRISAT Pigeonpea Sterility Mosaic Resistance Sources by the Indian National Program

At ICRISAT Center, large-scale screening of pigeonpea germplasm and breeding materials for resistance to sterility mosaic (SM) is carried out in fields under artificial epiphytotic conditions. High and uniform incidence of SM is created by inoculating 10- to 15-day-old seedlings with the disease using either the leaf-stapling or the infector-hedge technique.

During the past three seasons (1983/84 to 1985/86), 107 entries found resistant to SM at ICRISAT Center were evaluated in ICAR/ ICRISAT Uniform Trials for Pigeonpea Sterility Mosaic Resistance (IIUTPSMR) at 11 different SM-endemic locations in India. Ten lines showed resistance (<20% SM) at 6 or more of the locations where they were tested (Table 21). ICP 10976 was tested at 11 locations and was resistant at 10 locations, being susceptible only at Bangalore. This line has been recommended by AICPIP for use in the national resistance-breeding program.

Table 21. The maximum percentages of plants that showed sterility mosaic symptoms in the ICAR/ ICRISAT Uniform Trial for Pigeonpea Sterility Mosaic Resistance (IIUTPSMR). Of 107 lines tested, the 10 lines shown below were resistant (<20%) at six or more locations, 1983/84, and 1985/86.

Entry	Badnapur	Bangalore	Dholi	Faizabad	ICRISAT Center	Kanpur	Pantnagar	Pudukottai	Varanasi	No. of locations where found resistant
ICP 7035	0	22	0	17	0	5	6	28	0	7
ICP 7234	0	NT[1]	NT	0	0	0	0	10	NT	6
ICP 8862	9	NT	NT	10	3	2	0	13	NT	6
ICP 10976[2]	2	62	13	4	0	18	11	3	6	10
ICP 10977[2]	0	28	37	15	0	5	17	28	0	1
ICP 10984	2	49	42	7	0	0	5	0	15	1
ICP 11049	3	15	0	0	0	20	9	61	0	8
BSMR 235	0	22	30	10	0	13	9	63	5	6
BSMR 258	0	35	64	18	2	88	8	69	5	6
ICPL 8324	0	NT	NT	13	0	8	0	0	NT	6
Susceptible control										
BDN 1	100	63	85	99	100	87	37	100	100	

1. NT = Not tested.
2. Also tested at Ludhiana and Vadodara, ICP 10976 resistant at both locations, ICP 10977 resistant only at Ludhiana.

Workshops, Conferences, and Seminars

Pigeonpea Scientists' Meet

We were pleased to welcome 30 scientists from outside ICRISAT, and several who were undergoing long-term training in our program, to a meeting that concentrated on the improvement of medium-duration pigeonpea. This meeting was held at ICRISAT Center, 24-26 Nov 1986. A field tour of our trials was followed by presentations that highlighted our recent research findings. The visiting scientists then presented brief reports of their activities in the improvement of medium-duration pigeonpea. In addition there were four special topics —vegetable pigeonpea, pigeonpea in rice fallows, multilocational testing, and a report on the findings of a questionnaire that had been completed by the participants and others. The discussion on all these topics was lively and productive. Two ICRISAT videotapes were screened; one on *Heliothis* control using ULV insecticide application, and the other on sterility mosaic disease research. The visiting scientists spent a morning in our fields selecting plants and lines from which they would like to receive seed to sow at their locations next season. In the final session the visitors gave their views on how ICRISAT could be of greater assistance to their work. They voiced concern that our increased emphasis on short-duration pigeonpea will lead to a reduction in research on medium-duration types. We assured them that we would continue to devote substantial resources to medium-duration types but that some reduction was inevitable.

Consultative Group Meeting for Eastern and Central African Regional Research on Grain Legumes

This meeting was organized by ICRISAT at the International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, 8-10 Dec 1986. It was intended to develop an understanding of the ongoing national and regional grain legume research programs, with particular reference to groundnut, pigeonpea, and chickpea, and to develop plans for ICRISAT to participate in strengthening and supporting these programs. Delegates from six countries in the region (Burundi, Ethiopia, Kenya, Rwanda, Sudan, and Uganda) and from several research and donor agencies participated in the meeting. The delegates presented reports on their research results and plans. There was strong interest in strengthening pigeonpea research and development in the region, but particularly in Kenya and Uganda where this crop is of major importance. The importance of ICRISAT's role in providing germplasm accessions and training was emphasized. In a final unanimous resolution, ICRISAT was urged to increase its research contributions by establishing a physical presence in the region.

Entomologists' Travelling Seminar in Thailand

An entomologists' travelling seminar (6-12 September, 1986) was organized by our AGLN Coordinator and national scientists in Thailand. This followed the workshop on Food Legume Improvement for Asian Farming Systems organized by ACIAR at Khon Kaen. Two entomologists from ICRISAT joined 14 entomologists and other scientists from Thailand, Australia, and the USA on a tour of pigeonpea and groundnut crops growing in research stations and farmer's fields in the north of the country. No pigeonpea was seen in farmers' fields. On research stations the pigeonpea was severely damaged by pests including *M. testulalis, M. obtusa,* and *C. gibbosa* even though insecticides had been intensively used. The entomologists exchanged information and ideas during their travel and all agreed that this seminar was very useful.

Looking Ahead

We intend to further intensify our efforts to develop short-duration pigeonpea with high and stable yields. We will also search for increased photoinsensitivity in these types. The adaptation of short-duration genotypes to new and nontraditional environments and cropping systems will be studied in collaboration with scientists in ICAR and eastern Africa. We also hope to cooperate with these and other scientists in genotype x environment studies. Our work on short-duration hybrids will be confined to the conversion of new lines to male sterility, and the development and testing of a limited number of experimental hybrids. Emphasis on short-duration vegetable types will be increased. We will investigate the potential of new plant types, such as dwarfs and single-culm plants. The incorporation of resistances to biotic and abiotic stresses in all duration types will continue to be of high priority. International testing and collaboration with national programs and regional networks will be focussed in eastern and southern Africa, Southeast Asia, and the Caribbean, with emphasis on adaptive trials. Our medium-duration, high-protein lines will be tested for stability and productivity in India and other countries in Southeast Asia. An intensive evaluation of medium- and long-duration germplasm accessions will be carried out to examine their potential across a range of environments. Population improvement in medium-duration types and disruptive selection in short-duration pigeonpea will be continued. The quality parameters, and the acceptability and marketability of vegetable-type pigeonpea will be investigated to further sharpen our breeding and development efforts.

Our agronomists will give major research emphasis to identifying both short- and medium-duration genotypes that perform better in environments where moisture is limited. The observed genotypic variation in response to differing moisture availabilities indicates good scope for genetic enhancement of drought resistance. Considerable effort will also be given to defining the improvements in specific plant characters necessary to improve yield. This will largely involve detailed examination of existing data but will also include experiments on such factors as environmental control of pod set. We will continue to develop optimum agronomic practices for new plant types, such as dwarf, short-duration pigeonpea for northern India.

Experiments will continue on the interactions between mineral nutrition and soil moisture availability in pigeonpea. We are also continuing studies on optimizing the benefits of symbioses of *Rhizobium* and mycorrhizae with pigeonpea. The search for genotypes more tolerant to salinity will continue.

In order to facilitate more studies on basic aspects of such major diseases as sterility mosaic, wilt, and phytophthora blight, our pathology projects have been reorganized into three projects covering basic aspects, and one project on applied aspects of host-plant resistance. In the case of sterility mosaic, the causal agent has not yet been unambiguously identified and we will continue our efforts on identification and on understanding the epidemiology of the disease. Studies on factors affecting pigeonpea wilt will be undertaken in addition to studies on the race situation and on the perfect stage of the wilt fungus. Efforts to identify sources of resistance to the P3 isolate of phytophthora blight, and to understand the epidemiology of blight disease will be continued. Work on identification of various leaf spot diseases affecting pigeonpea will be undertaken. Screening for multiple disease resistance and its utilization will continue to receive major attention.

A nematologist was recruited to our staff at the end of 1986. He will assess the crop losses caused by nematodes and screen our materials for resistance to these pests.

In entomology, we intend to further strengthen our research on screening for plant resistance to *Heliothis* and other lepidopteran borers at ICRISAT Center and at Hisar. We will also devote more resources to our studies of plant resistance to podfly at Gwalior. Our studies of the mechanisms of such resistances will be continued. We will evaluate and review our research on the populations and movements of *Heliothis* in collaboration with TDRI. We hope to complete the current phase of our economic threshold studies on this crop in the coming year.

Our biochemists will evaluate new food products incorporating pigeonpea and study their consumer acceptance in comparison with soybean and cowpea, in order to enhance the utilization of pigeonpea in Africa and Asia. The nutritional potential of such products will also be compared. The effect of cooking on protein digestibility in pigeonpea will also be studied.

The AGLN will collect the names of scientists and administrators in Asian countries interested in research on groundnut, chickpea, and pigeonpea, will produce a Directory of these AGLN cooperators, and will make available an information bank for the cooperators. The AGLN will also work toward involving ICRISAT scientists in grain legume research planning meetings in Asian countries that will further coordinate our research activities with those in national programs. This coordination will be aimed at developing appropriate national and regional trial networks for groundnut, chickpea, and pigeonpea. Where appropriate the AGLN will provide financial assistance to these trial networks. The AGLN will continue to promote the training of legume scientists from Network countries. Attempts will be made to complete the signing of MOU's with all countries associated with the AGLN.

We hope to further strengthen our inputs and collaboration in the several countries of Africa that are interested in improving their pigeonpea crops.

Publications

Institute Publications

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. International Pigeonpea Newsletter no. 5. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0255-786X.

Journal Article

Sharma, S.B., and Nene, Y.L. 1986. Extraction of *Heterodera cajani* cysts using modified sieving technique. Indian Journal of Nematology 16(1): 123-124 (JA 512)

Conference Papers

Chauhan, Y.S., Venkataratnam, N., and Johansen, C. 1986. The agronomy of multiple harvest pigeonpea. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 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. 1986. The promise of high protein pigeonpea. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 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. 1986. Promising pigeonpea varieties from ICRISAT. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 276)

Jain, K.C., and Faris, D.G. 1986. The potential of medium-duration pigeonpea. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 273)

Lateef, S.S., Sithananthan, S., and Reed, W. 1986. Insect resistant pigeonpea is feasible. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 277)

Pawar, C.S., Srivastava, C.P., and Reed, W. 1986. Some aspects of population dynamics of *Heliothis armigera* at ICRISAT Center. Pages 79-85 *in* Proceedings, Oriental Entomology Symposium, 21-24 Feb 1984, Trivandrum, Kerala. Trivandrum, Kerala: Association for Advancement of Entomology, University of Kerala. (CP 177)

Raju, T.N., and Nene, Y.L. 1986. The value of disease resistant pigeonpea. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 275)

Reddy, D.V.R., Nene, Y.L., and McDonald, D. 1986. Virus disease problems of groundnut, chickpea, and pigeonpea in Asia. Pages 67-75 *in* Virus diseases of rice and leguminous crops in the tropics: proceedings of an International Symposium, 1-5 Oct 1985, Tsukuba, Japan. Tropical Agricultural Research Series No. 19. Tsukuba, Ibaraki, Japan: Tropical Agriculture Research Center, Ministry of Agriculture, Forestry and Fisheries. (CP 237)

Rupela, O.P. 1986. *Rhizobium* inoculant production system for developing countries. Pages 219-222 *in* Current status of biological nitrogen fixation research: proceedings of the National Symposium, 6-8 Feb 1986, Hisar, Haryana, India. (Singh, R., Nainawatee, H.S., and Sawhney, S.K., eds.) Hisar, Haryana, India: Haryana Agricultural University. (CP 240)

Saxena, K.B., Faris, *D.G.,* and Gupta, *S.C.* 1986. The potential of early maturing pigeonpea hybrids. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 271)

Saxena, K.B., Faris, *D.G.,* Reddy, L.J., Sharma, D., Reddy, B.V.S., Gupta, S.C, and Green, J.M. 1986. Prospects of hybrid pigeonpea. Pages 379-388 *in* New frontiers in breeding researches. Proceedings of the 5th International Congress Society for the Advancement of Breeding Researches in Asia and Oceania (SABRAO), 25-29 Nov 1985, Bangkok, Thailand. Bangkok, Thailand: Faculty of Agriculture, Kasetsart University. (CP 241)

Singh, U., Jambunathan, R., Saxena, K.B.,and Faris, D.G. 1986. Nutritive value of green and mature pigeonpea seed. *In* Papers presented at ACIAR Workshop "Food Legume Improvement for Asian Farming Systems," 1-5 Sep 1986, Khon Kaen, Thailand. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 274)

LEGUMES

GROUNDNUTS

Contents

Cover photo: Threshing groundnuts harvested from experimental plots, ICRISAT Center, 1986.

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GROUNDNUT

Production of groundnut in the semi-arid tropics (SAT) exceeds that of any other legume and comprises 70% of the world production of this important food and cash crop. The seeds contain approximately 25% protein and 50% edible oil, the haulms are a valuable and nutritious animal feed, and shells can be used to manufacture particle board, as a filler in animal feeds, or as fuel. The average yield of groundnut in the SAT (around 0.8 t ha^{-1} of dried pods) is lower than the world average (estimated at 1.1 t ha^{-1} of dried pods in 1985), and much lower than the yields of over 3 t ha^{-1} obtained in developed countries. The low yields in the SAT are due to low and unreliable rainfall, and to damage by pests and diseases.

During the 1985/86 postrainy and 1986 rainy seasons, we continued research on drought and nutrient stresses, and on disease and pest problems. The major emphasis of our research has continued to be the use of genetic diversity in groundnut and its wild relatives to breed for stable resistance or tolerance to the major yield reducers.

Physical Stresses

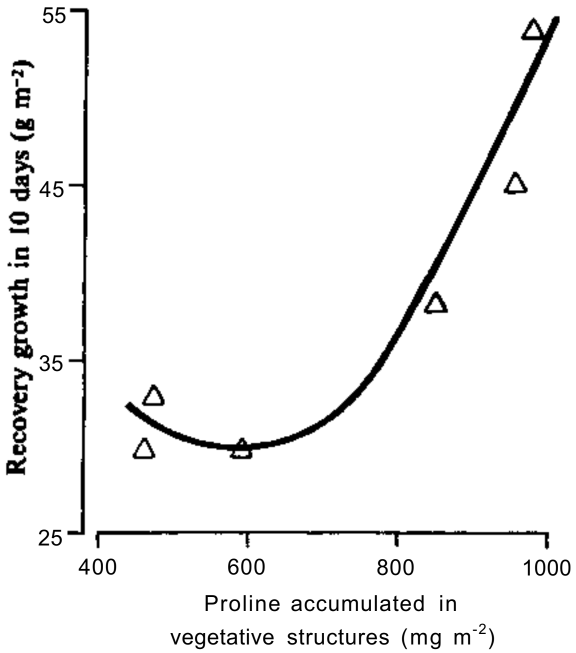
Drought

Drought Recovery Responses

In the 1984/85 postrainy season, in collaboration with scientists from the University of Agricultural Sciences, Bangalore, we investigated genotypic differences in recovery response from mid-season drought (ICRISAT Annual Report 1985, p. 217). In six genotypes, we measured the amount of proline in the leaf, stem, and roots of drought-stressed plants before rewatering, and the recovery growth rate (growth analysis at 10-day intervals) following the irrigation that relieved the stress. Proline accumulation in the vegetative parts immediately before drought alleviation was closely associated with an increase in shoot biomass in the 10 days following the irrigation (Fig. 1). More investigations are needed to understand this result.

Rooting Differences of Genotypes

We subjected 10 selected genotypes to end-of-season drought by withholding water from 92 days after sowing (DAS) to 123 DAS (final harvest). For five of these genotypes, available soil water was monitored at weekly intervals using neutron probes at 15-cm intervals through



$$y = 82.8\ (\pm 25.70) - 0.178\ (\pm 0.0776)x + 0.00015\ (\pm 0.000054)x^2$$

$$r^2 = 0.94$$

Figure 1. Relationship between proline accumulated (mg m^{-2}) and growth over 10 days after recovery irrigation in six groundnut genotypes, ICRISAT Center, postrainy season 1984/85.

the soil profile from 0-105 cm deep. The total water extracted throughout the season was similar for all five genotypes. But, genotypes did differ in their rate of water extraction from different soil profiles. NC Ac 17090 was superior to the others in the speed with which it extracted water from the surface layers (Fig. 2a), thus confirming earlier observations made in collaboration with scientists from Nottingham University, UK (ICRISAT Annual Report 1985, p.217). This factor accounts for the greater water-use efficiency of NC Ac 17090 in conditions of frequent surface wetting by light rains, as at Anantapur (ICRISAT Annual Report 1985, p.216). By 97 DAS ICGV 86707 extracted water sooner from deeper zones (Fig. 2b) and so survived with green foliage for longer than the other genotypes. However, it should be noted that this attribute of ICGV 86707 is associated with low yield potential under well-watered conditions. The drought-susceptible genotype EC 76446(292) was the least efficient in extracting water from deeper soil zones.

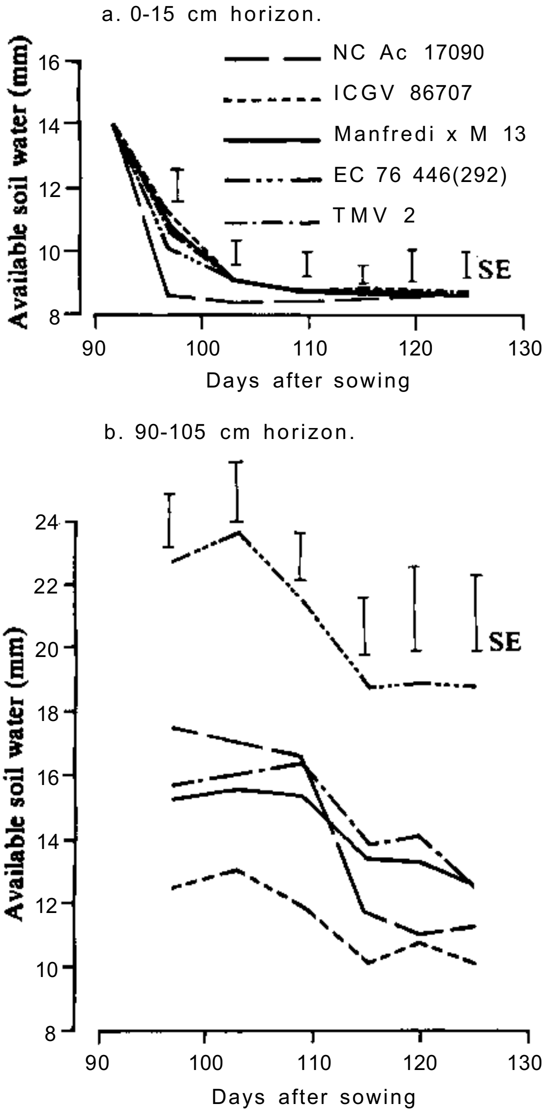


Figure 2. Genotypic differences in soil water extraction by five groundnut cultivars from two soil horizons (a. 0-15 cm, and b. 90-105 cm) during endseason drought, ICRISAT Center, postrainy season 1985/86.

Effects of Sowing Depth and Application of Anti-evaporant on Drought Responses

Earlier work showed that about 20% yield loss in groundnut crops occurs because the farmer sows deep to ensure stand establishment in the event of unfavorable moisture conditions in the top soil horizon (ICRISAT Annual Report 1984, p.221). We therefore investigated the use of a compound that retards evaporation to control drying in the upper layers of the soil. For a few days after spraying with this long-chain alcohol the upper horizon in plots sprayed with evaporation retard ant had more water than that in non-treated control plots. This maintenance of water content improved germination (Fig.3) from shallow (5 cm)-sown seed. We also investigated the interaction between depth of sowing and subsequent drought stress. Seeds of cultivar J 11 were sown at two depths (5 cm and 10 cm) and irrigated using the line-source sprinkler system. Deep sowing reduced pod yields by 30% across most water deficits (Fig. 4a), and growth analysis showed that this effect was due to lower crop growth rates after emergence. Acetylene reduction activity decreased with increasing water deficit (Fig. 4b), and the deeper-sown crop always had lower acetylene reduction activity than the shallow-sown crop at all water deficits.

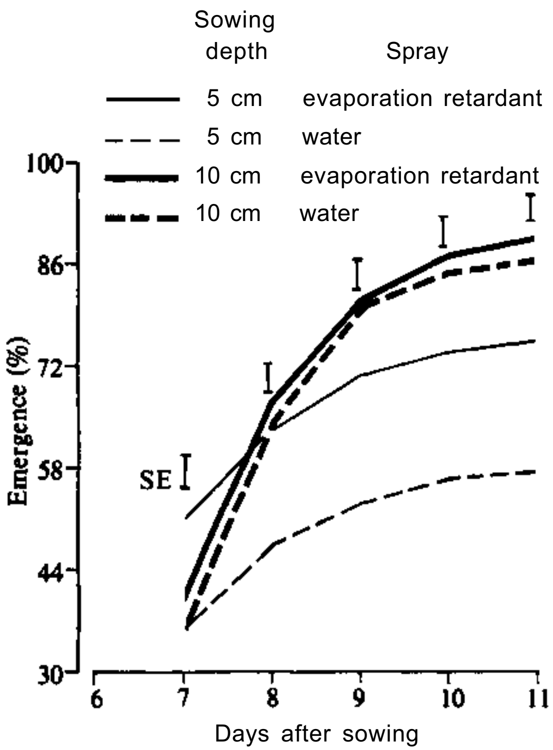


Figure 3. Effect of evaporation retardant and water sprays on emergence of groundnuts sown 5 and 10 cm deep, ICRISAT Center, postrainy season 1986.

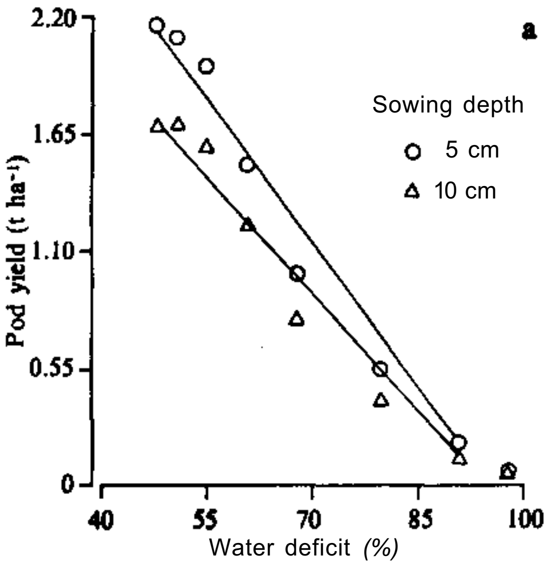
Biotic Stresses

Foliar Fungal Diseases

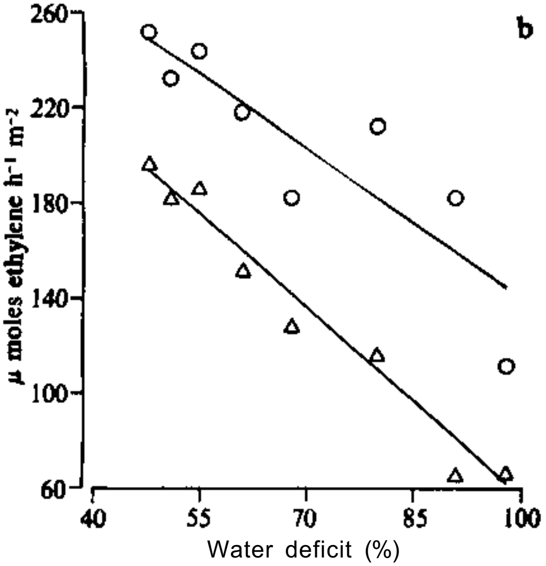
The low and irregular rainfall in the 1986 rainy season did not favor development of rust or leaf spot diseases but levels of rust (*Puccinia arachidis*) and late leaf spot (*Phaeoisariopsis personata*) were sufficiently high to permit effective resistance screening of germplasm accessions and breeding lines.

Resistance Screening

In 1986, from 2060 germplasm accessions we identified 60 with resistance to rust and/or late leaf spot and these will be screened again in the 1987 rainy season.



5 cm **$y = 4323\ (\pm 232) - 45.13\ (\pm 3.24)\ x$**
$r^2 = 0.97$
10 cm **$y = 3469\ (\pm 200) - 36.39\ (\pm 2.79)\ x$**
$r^2 = 0.96$



5 cm $y = 350\ (\pm 35.0) - 2.09\ (\pm 0.49)\ x$
$r^2 = 0.75$
10 cm $y = 325.6\ (\pm 14.4) - 2.72\ (\pm 0.20)\ x$
$r^2 = 0.97$

Figure 4. Effect of water deficit (%) on: a. pod yield (t ha^{-1}), and b. acetylene reduction activity (μ moles ethylene h^{-1} m^{-2}) in groundnut cultivar J 11 sown 5 and 10 cm deep, ICRISAT Center, 1986.

In advanced screening trials the resistance of 46 germplasm accessions to rust or late leaf spot diseases was confirmed for a 2nd year. This material now provides a wide range of pod types and seed colors for use in resistance breeding.

Resistance Breeding

Yield trials at Bhavanisagar. In the 1985/86 postrainy season at Bhavanisagar we evaluated 124 selections resistant to rust and/or late leaf spot for yield using the rust-resistant parent NC Ac 17090 and the foliar diseases susceptible cultivars Kadiri 3 (Robut 33-1), JL 24, and ICGS 11 as controls. Several of the selections significantly outyielded the national control JL 24 and ICGS 11, but only two of them significantly outyielded all four control cultivars.

Yield trials at ICRISAT Center. In the 1986 rainy season we made a preliminary yield evaluation of 151 rust- and/or late leaf spot-resistant selections. Eighty-two resistant selections outyielded the national control (JL 24), and 15 selections outyielded the rust-resistant control (NC Ac 17090).

We also evaluated the yield of 22 selections with rust and/or late leaf spot resistance and with tolerance to such stress factors as leaf-miner, jassids, bud necrosis disease (BND), and drought. Nineteen selections significantly outyielded the national control (JL 24), and two selections, ICGV 86708 and ICGV 86687, also significantly outyielded the rust-resistant parent NC Ac 17090.

Multilocational yield trials. We conducted multilocational yield trials with 116 rust- and / or late leaf spot-resistant advanced lines under high-and low-input conditions (high input = 60 kg P_2O_5 ha^{-1}, with supplemental irrigation, and control of insect pests; low input = 20 kg P_2O_5 ha^{-1}, rainfed, and with no insecticide applica-

Table 1. Performance of some rust-and/or late leaf spot-resistant groundnut selections, multilocational trials[1], rainy season 1986.

		Pod yields (t ha^{-1})				Disease scores[2]		
Entry	Original name	ICRISAT	Bhavanisagar	Hisar	Mean	Rust	Late leaf spot	Shelling %[3]
ICGV 86671	ICG (FDRS) 185	3.43	4.37	5.51	4.437	4	5	68
ICGV 86673	ICG (FDRS) 186	3.30	4.79	4.08	4.060	3	5	69
ICGV 86674	ICG (FDRS) 187	3.06	4.42	4.15	3.877	4	5	65
ICGV 86584	ICG (FDRS) 68	3.11	3.96	3.94	3.670	3	6	68
ICGV 86685	ICG (FDRS) 195	2.86	3.73	4.31	3.633	3	7	56
ICGV 86665	ICG (FDRS) 180	2.79	3.39	3.94	3.373	3	6	58
Controls								
NC Ac 17090[4]		2.61	2.68	4.02	3.103	3	6	65
JL 24[5]		1.65	3.57	3.52	2.913	9	9	74
ICGS 11[5]		1.74	3.16	3.57	2.820	9	9	70
SE		±0.17	±0.28	±0.36		±0.3	±0.3	
Trial mean (36 entries)		2.54	3.21	4.07		4.32	6.36	
CV (%)		11	15	15		11	8	
Efficiency over RBD		114	100	108				

1. 6 x 6 lattice design, plot size 4.8 m^2.
2. Field disease scored at ICRISAT Center on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage destroyed.
3. Based on 1 kg bulk samples from Bhavanisagar.
4. Rust-resistant. 5. Rust- and late leaf spot-susceptible.

tion) at ICRISAT Center and at four other ICRISAT cooperative subcenters, Dharwad, Anantapur, Hisar, and Bhavanisagar. At Hisar and Bhavanisagar the trials received supplementary irrigation. The rainfed trials at Anantapur and ICRISAT Center failed because of severe drought, and those at Dharwad were adversely affected. Pod yields of some of the lines under irrigated conditions at ICRISAT Center, Bhavanisagar, and Hisar are given in Table 1. ICGV 86671 gave the highest pod yield of 5.51 t ha^{-1} at Hisar. Its mean pod yield over the three locations was also the highest. In comparison, the national control JL 24 produced 3.52 t ha^{-1} at Hisar and 2.91 t ha^{-1} on an overall mean basis.

Evaluation of interspecific hybrid derivatives. We continued to select good plant types from interspecific hybrid derivatives with resistance to rust and late leaf spot. Those that significantly outyielded the control cultivars at ICRISAT Center last year (ICRISAT Annual Report 1985, p.220) were further evaluated in the 1986 rainy season in a multilocational trial at ICRISAT Center, Hisar, Bhavanisagar, Dharwad, and Anantapur. At ICRISAT Center, the trial was conducted both in irrigated and rainfed conditions, and the trial at Hisar and Bhavanisagar received supplemental irrigation, but it failed at Anantapur due to severe drought. Table 2 shows yields of some of the promising interspecific derivatives at different locations. Selection CS 29/1-B_2-B_1-B_1-B_1 yielded 6.28 t pods ha^{-1} at Hisar and had a mean yield of 2.98 t pods ha^{-1} over all locations, compared to 3.52 at Hisar and an overall mean of 2.64 t ha^{-1} for JL 24.

Table 2. Performance of some rust-and/or late leaf spot-resistant interspecific hybrid groundnut derivatives in multilocational trials[1], rainy season 1986.

		Pod yields (t ha^{-1})				Disease scores[4]		
						ICRISAT Center		Hisar
Entry	Pedigree	ICRISAT[2]	Hisar[2]	Bhavanisagar[2]	Dharwad[3]	Rust	Late leaf spot	Late leaf spot
ICGV 86699	CS 29/1-B_2-B_1-B_1-B_1	3.15	6.28	3.63	2.85	4	5	2
ICGV 86686	CS 13-B_1-B_1-B_1-B_1	2.87	5.19	3.85	2.68	5	6	3
ICGV 86695	2024/-B_3-B_1-B_1-B_1	2.53	5.49	3.69	2.66	4	6	2
ICGV 86694	904/I-B_2-B_2-B_1-B_1	2.86	5.10	4.12	2.19	4	6	6
ICGV 86701	978-B_2-B_2-B_1-B_1	2.47	6.02	2.86	2.91	4	5	3
ICGV 86700	CYS-P139-B_3-B_1-B_1-B_1	2.75	5.35	3.68	2.41	4	5	2
ICGV 86688	CS 9-B_1-B_1-B_1-B_1	2.99	5.05	3.39	2.66	4	4	2
ICGV 86687	CS 16-B_2-B_2-B_1-B_1	2.86	5.21	3.30	2.65	4	5	2
ICGV 86694	904-B_1-B_2-B_1-B_1	3.18	5.10	3.50	2.23	4	6	5
Controls								
NC Ac 17090[5]		2.58	4.57	3.15	2.75	4	7	5
JL 24[6]		1.58	3.52	2.97	2.50	9	9	8
Kadiri 3[6]		1.51	2.75	2.94	2.77	9	9	7
SE		±0.21	±0.50	±0.32	±0.21	±0.3	±0.4	±0.4
Trial mean (18 entries)		2.62	4.87	3.89	2.61	5	6	3
CV (%)		14	18	16	14	10	11	22

1. RBD, plot size 4.8 m^2.
2. Rainfed with supplementary irrigation.
3. Rainfed.
4. Field disease scored on a 1-9 scale, where 1 = no diseases and 9 = 50-100% foliage destroyed.
5. Rust-resistant. 6. Rust- and late spot-susceptible.

Photoperiod and Foliar Diseases

Research into interactions between daylength and foliar diseases is reported in the section on Adaptation.

Soilborne Fungal Diseases

The Aflatoxin Problem

Effects of drought. In a field trial at ICRISAT Center in the 1985/86 postrainy season, we again examined the effects of drought on preharvest seed invasion by *Aspergillus flavus.* We used eight groundnut genotypes, four with resistance to in vitro colonization of rehydrated, stored, mature seeds by *A. flavus* in laboratory inoculation tests (IVSCAF), and four susceptible ones. Late-season drought (from 95-125 DAS) significantly increased infection by *A. flavus* in seeds of all the genotypes we tested (Table 3), levels of infection being of the same order as those recorded in the 1984/85 postrainy-season trial (ICRISAT Annual Report 1985, p. 221). We found significant differences between genotypes in seed infection by *A. flavus;* the IVSCAF-resistant genotypes had lower levels of seed infection by this fungus at lifting than the IVSCAF-susceptible ones.

Table 3. Preharvest seed infection by *Aspergillus flavus* in eight groundnut genotypes grown under full irrigation and with drought stress, ICRISAT Center, postrainy season 1985/86.

	Seed infected by *A. flavus* (%)	
Genotype	Full irrigation	No irrigation from 95-125 DAS
IVSCAF-resistant[1]		
Ah 7223	0.0 (0.0)[2]	0.8 (5.2)
J 11	0.0 (0.0)	1.0 (5.7)
UF 71513	0.0 (0.0)	1.2 (6.2)
PI 337394F	0.5 (3.3)	1.7 (7.3)
SE	(±0.39)	
IVSCAF-susceptible		
TMV 2	1.0 (5.6)	3.7(11.0)
Gangapuri	3.0 (9.9)	9.5(17.9)
NC Ac 17090	4.5(12.2)	13.3(21.4)
EC 76446(292)	3.7(11.0)	16.7(24.1)
SE	(±0.47)	

1. IVSCAF = in vitro seed colonization by *A, flavus.*
2. Values in parentheses are arc sine transformations.

Effects of drought intensity on seed infection by *A. flavus.* In the 1983/84 and 1985/86 postrainy seasons, we examined the effects of different drought intensities on seed infection by *A. flavus* in various groundnut genotypes. Thirty-six genotypes were used in the 1983/84 season and 20 in the 1985/86 season. Adequate irrigation was applied to the entire experiment up to 95 DAS, then a line-source sprinkler irrigation system was used to create a gradient of water deficit from beds 1 to 10, bed 1 receiving full irrigation and bed 10 receiving a negligible quantity of water. Plants were harvested at 125 DAS and arranged in windrows with pods exposed to dry for 2 days. Mature pods were then picked from the plants and sun-dried to a seed moisture content of 7-8%. We tested 100 seeds from the dried pods from the 2nd, 4th, 6th, 8th, and 10th beds, in each replication, for infection by *A. flavus.*

In all genotypes, seed infection by *A. flavus* increased with increasing water deficit in both seasons (Tables 4 and 5). Regression analyses showed a significant ($P < 0.05$) linear relationship between the levels of water deficit and seed infection by *A. flavus* for all genotypes. Genotypes differed significantly for *A. flavus* seed infection across all water deficits. Genotypes TMV 2, Gangapuri, Kadiri 3 (Robut 33-1), and M 13, and all 11 interspecific hybrids derivatives were susceptible to *A. flavus.* The genotypes Ah 7223, J 11, Exotic 6, U 4-47-7, and C 55-437 showed low levels of seed infection across water deficits in both seasons. The use of this line-source irrigation method permits simultaneous screening for *A. flavus* seed infection and for drought tolerance, and this is particularly important since the two factors interact.

Table 4. Seed infection by *Aspergillus flavus* of groundnut genotypes grown under different drought intensities (expressed as percentage water deficit) at ICRISAT Center, postrainy season 1983/84.

	Seed infected by *A. flavus* (%)					
	Water deficit (%)					
	48	62	80	96	99	Variance[1]
Genotype	Bed 2	Bed 4	Bed 6	Bed 8	Bed 10	(%)
Ah 7223	0.0[2]	1.0	1.7	3.0	2.7	73.1
J 11	0.0	0.3	1.3	1.3	3.0	58.1
U4-47-7	0.7	1.0	2.0	2.7	3.3	58.9
Exotic 6	0.0	0.7	1.7	2.3	3.0	86.2
C55-437	0.0	1.3	2.3	2.3	3.3	76.5
U1-2-1	0.3	1.3	3.3	4.0	4.3	86.1
EC 102971	1.3	1.3	2.7	3.7	5.0	72.4
Faizpur	0.7	1.3	2.7	4.0	6.3	77.0
Monir 240-30	1.3	3.0	3.7	5.0	6.7	81.7
Var 27	1.3	3.0	3.7	6.3	7.3	84.0
NC Ac 841	2.3	4.0	5.0	6.7	7.7	77.0
26-5-2	2.0	3.0	4.7	5.7	7.7	76.2
GFA Spanish	2.0	3.0	5.7	6.7	7.7	86.5
U4-4-1	2.3	3.3	5.0	6.7	8.0	83.7
J 11 x Kadiri 3	2.0	2.7	4.7	6.3	8.7	73.1
NG 387	1.7	2.0	4.3	6.7	9.0	77.5
Virginia Bunch Uranale	3.0	4.7	7.7	6.7	9.0	66.0
Local 3	2.3	3.7	5.7	7.7	10.0	80.2
Sir of Bizapur	2.7	4.3	6.0	7.0	11.3	67.8
KG 61-240	3.3	6.0	10.7	16.7	22.0	84.7
CS 1	3.3	6.3	9.7	13.7	22.0	70.3
CS 2	4.3	6.0	10.7	15.3	22.3	77.6
CS 9	4.0	6.3	10.7	17.0	25.3	76.4
CS 11	4.3	6.3	9.7	14.0	18.3	75.3
CS 16	2.7	5.3	9.0	14.0	18.3	82.4
CS 30	3.7	7.0	11.3	15.0	17.3	86.7
CS 31	3.7	6.0	11.7	15.0	18.7	73.3
CS 32	3.7	5.7	7.3	8.0	14.3	53.6
CS 36	4.0	6.0	8.7	14.7	20.0	78.0
CS 37	5.0	7.3	11.0	19.0	26.0	79.4
CS 52	5.7	7.0	11.3	15.7	22.0	76.0
TMV 2	2.7	4.0	6.3	9.0	9.7	68.3
Gangapuri	3.3	5.3	7.7	12.0	16.7	64.4
Kadiri 3 (Robut 33-1)	2.7	4.7	7.3	8.3	11.0	73.8
M 13	3.3	5.3	8.3	11.0	15.0	77.0
EC 76446 (292)	6.0	10.0	17.7	23.7	29.0	88.3
SE	±0.5	±0.7	±1.1	±1.1	±1.3	
CV(%)	31	30	28	21	18	

1. Percentage variance of *A. flavus* infection levels accounted for by the linear regression of water deficits.
2. Zero values not used in calculation of SE.

Table 5. Preharvest seed infection by *Aspergillus flavus* at different drought intensities (expressed as percentage water deficit) in 20 groundnut genotypes, ICRISAT Center, postrainy season 1985/86.

	Seed infected by *A. flavus* (%)					
	Water deficit (%)					
	36	46	73	96	99	Variance[1]
Genotype	Bed 2	Bed 4	Bed 6	Bed 8	Bed 10	(%)
Ah 7223	0.0[2]	0.0	1.3	2.7	2.7	88.8
J 11	0.3	1.7	1.7	3.0	2.7	67.2
U4-47-7	0.0	0.0	1.0	2.0	2.7	90.2
Exotic 6	0.3	0.7	1.0	2.3	1.7	60.1
C55-437	0.0	1.0	2.3	3.0	3.0	92.3
UF 71513	0.0	0.3	1.7	2.3	3.0	73.0
PI 337394F	1.0	2.0	2.7	3.0	3.7	80.2
U1-2-1	0.0	2.0	2.3	2.7	3.7	62.2
Faizpur	2.7	6.0	7.3	10.0	9.3	78.1
Var 27	2.3	3.3	4.3	5.7	5.7	79.9
26-5-2	2.0	3.3	4.7	4.7	5.3	44.9
GFA Spanish	1.3	3.3	4.7	4.7	5.0	61.6
J 11 x Kadiri 3	3.0	4.3	5.3	6.7	9.0	73.0
NG 387	0.0	0.7	1.7	2.0	2.3	59.9
Local 3	3.0	4.0	4.3	5.0	6.7	48.8
Sir of Bizapur	1.3	3.3	4.7	5.3	5.7	81.3
TMV 2	1.7	2.3	5.0	5.7	5.3	66.2
Gangapuri	3.3	6.0	8.0	8.7	10.3	72.7
NC Ac 17090	5.3	10.7	17.0	22.0	24.3	91.1
EC 76446 (292)	6.7	13.7	20.0	28.0	29.3	91.1
SE	±0.5	±0.9	±0.8	10.6	±0.6	
CV (%)	33	29	28	16	16	

1. Percentage variance of *A. flavus* infection levels accounted for by the linear regression of water deficits.
2. Zero values not used in calculation of SE.

We continued screening germplasm accessions for resistance to aflatoxin production following colonization of seeds by aflatoxigenic strains of *A. flavus,* using techniques previously described (ICRISAT Annual Report 1981, pp. 171 and 173). Tests on seed of 108 genotypes grown in the 1985/86 postrainy season showed that genotypes supported aflatoxin B, production to levels ranging from 20 to 134 μg g^{-1} of seed.

Resistance screening in the field. In the 1985 and 1986 rainy seasons, we screened 401 groundnut germplasm accessions and breeding lines for resistance to preharvest seed infection by *A. flavus.* Severe to moderate drought occurred during pod maturation in both seasons. Levels of seed infection ranged from 2 to 38%. The most resistant genotypes will be further screened in the 1987 rainy season.

Of the several sources of resistance to infection by *A. flavus* identified in the 1984 season, some were further tested in the 1985 and 1986 seasons, and we confirmed resistance in a few genotypes, e.g., Exotic 6.

In the 1985/86 postrainy season 432 germplasm accessions were grown in an Alfisol field under late-season drought (95-125 DAS). Levels of seed infection by *A. flavus* ranged from 1 to 47%. We selected five genotypes that had less than *2%* seeds infected for further evaluation.

Breeding for resistance. During the 1985/86 postrainy and 1986 rainy seasons, we grew 764 bulk selections derived from *A.* flavus-resistant x adapted line crosses and made 529 selections based on pod yield, pod shape, and other agronomic characteristics. These selections will be evaluated for in-vitro resistance to invasion of rehydrated seeds by *A. flavus* and for yield potential. We made 1320 single-plant selections in 66 F_2 populations of crosses between *A. flavus*-resistant genotypes and high-yielding adapted lines.

We tested sound mature kernels of 200 breeding lines from the 1985 rainy season replicated field trials in 1986 for in-vitro resistance to invasion of rehydrated seeds by *A. flavus.* Data from one such trial are presented in Table 6. The yield levels were low due to drought, but the five selected breeding lines showed levels of seed colonization comparable to those of the *A. flavus*-resistant lines, J 11 and UF 71513.

In 1986 we made 18 new crosses using high-yielding lines and VRR 245 and U 4-7-5, the two lines reported to support only low aflatoxin production (ICRISAT Annual Report 1984, p. 210).

Table 6. *Aspergillus flavus* seed colonization (SC) and pod yield (t ha^{-1}).of selected groundnut breeding lines resistant *to A.flavus* grown in three environments at ICRISAT Center in the 1985 rainy season, and tested for seed colonization in 1986.

	Grown on Alfisol				Grown on Vertisol			
	HI[1]		LI[2]		LI[2]		Mean	
Genotype	SC (%)	Pod yield	SC (%)	Pod yield	SC (%)	Pod yield	SC (%)	Pod yield
ICGV 86717	8.9	1.31	14.9	0.97	28.6	0.70	17.5	0.99
ICGV 86718	16.0	1.00	15.6	0.80	7.2	0.95	12.9	0.91
ICGV 86719	12.8	0.82	14.3	0.92	14.5	0.98	13.9	0.90
ICGV 86720	13.3	0.77	13.7	0.78	25.6	0.84	17.5	0.79
ICGV 86721	15.7	0.82	22.6	0.63	15.1	0.98	17.8	0.81
Controls								
J 11[3]	8.7	0.55	10.0	0.41	10.5	0.54	9.7	0.50
UF 71513-1[3]	12.9	0.70	12.4	0.46	15.8	0.86	13.7	0.68
JL 24[4]	52.0	0.73	43.8	0.59	50.6	0.50	48.8	0.61
Kadiri 3[4]	30.7	0.91	32.2	0.76	52.3	0.67	38.4	0.78
SE	±3.6	±0.06	±2.7	±0.08	±3.2	±0.06		
Trial mean (64 entries)	28.8	0.72	29.6	0.62	34.9	0.70		
CV (%)	22	14	16	22	16	14		
Efficiency (%)	98	118	103	100	118	101		

1. HI = High input (60 kg P_2O_5 ha^{-1}), with irrigation and insecticide sprays.
2. LI = Low input (20 kg P_2O_5 ha^{-1}), rainfed without insecticide sprays.
3. Resistant to seed colonization by *A. flavus.*
4. Susceptible to seed colonization by *A. flavus.*

Stem and Pod Rots

We screened 308 germplasm accessions, interspecific hybrid derivatives, and breeding lines for resistance to stem and pod rots caused by *Sclerotium rolfsii* in a replicated trial in a Vertisol field during the 1985/86 postrainy season. Sorghum stubble was incorporated in the soil around plants to enhance the inoculum potential of *S. rolfsii*. Inoculum of the fungus raised on autoclaved groundnut shells was also applied to the soil to increase the number of infection foci.

We found significant differences among genotypes for incidence of stem rot and pod rot. The incidence of stem rot in different genotypes varied from 3.4 to 47.8%, and for pod rot from 7.2 to 81.4%. The cultivar Kadiri 3 (Robut 33-1), sown after every 10 test genotypes, showed consistently high incidences of stem rot (30-42%) and pod rot (50-85%). Two interspecific hybrid derivatives and a breeding line that had low levels of stem rot (<12%) and pod rot (<13.5%) were selected for further evaluation in the 1986/87 postrainy season.

Table 7. Sources of resistance to the groundnut pod disease caused by the nematode *Tylenchorhynchus brevilineatus,* farmer's field trials near Tirupati, Andhra Pradesh, India, 1985/86.

		Disease score[1]		
Genotype	Identity	1985 rainy	1985/86 postrainy	1986 rainy
ICG 1697	NC Ac 17090	2.0	1.4	1.5
ICG 4110	Ah 7864	1.7	1.5	1.5
ICG 6322	RMP 12	2.0	1.4	1.4
ICG 7889	PI 393517	2.0	2.1	1.7
ICG 7897	PI 405132	1.9	1.7	1,6
ICG 7898	PI 407454	2.2	1.6	1.6
ICG 10933	WO RTY ICHYIRICAD	1.8	1.3	1.5
ICG 10939	X 1-21-B	2.2	1.5	1.6
ICG 10943	X 1107-2-A	1.8	1.6	1.5
ICG 10963	X 1196-6-B-2	2.1	1.4	1.7
ICG 10964	X 14-4-3-8-B	1.7	1.8	1.6
ICG 11083	ZM 2034	2.0	1.3	1.6
	ICGS 62	2.0	1.4	1.5
	TCG 1518		1.9	1.6
SE		±0.24	±0.14	±0.06
CV (%)		17.2	15.9	7.8
Control				
ICG 7827	JL 24	4.7	4.7	4.4
SE		±0.03	±0.03	±0.08
CV (%)		3.6	3.4	6.3

1. Disease score on a 1-5 scale where:
 1 = very few small lesions on the pod; pod size normal,
 2 = few small lesions on the pod; pod size normal,
 3 = many small lesions on the pod; pod size normal,
 4 = 50% of pod surface discolored; pod size moderately reduced, and
 5 = 50-100% of pod surface discolored; pod size greatly reduced.

Table 8. Performance of some high-yielding groundnut selections with field resistance to bud necrosis disease (BND), ICRISAT Center, postrainy season 1985/86[1].

Entry	Original name	Botanical type[2]	Pod yield (t ha^{-1})	BND incidence (%)
ICGV 86029	GBPRS 138	SB	7.88	23
ICGV 86030	GBPRS 15	VB	7.83	19
ICGV 86031	GBPRS 312	SB	7.69	26
ICGV 86032	GBPRS 301	VB	7.27	25
ICGV 86033	GBPRS 45	VB	7.10	28
ICGV 86538	GBPRS 303	VB	6.99	30
Control				
Kadiri 3	Robut 33-1	VB	6.68	53
SE			±0.21	
Trial mean (25 entries)			6.33	
CV (%)			6	
Efficiency over RBD			94	

1. 5 x 5 lattice design, plot size 4.8 m^2.
2. SB = Spanish bunch, var *vulgaris* and VB = Virginia bunch, var *hypogaea.*

Nematode Diseases

In collaboration with scientists of the Andhra Pradesh Agricultural University (APAU), we screened 1616 groundnut germplasm accessions and breeding lines for resistance to the nematode disease caused by *Tylenchorhynchus brevilineatus* in replicated trials in a farmer's field near Tirupatiinthe 1985 and 1986 rainy and 1985/86 postrainy seasons. The disease incidence was high and uniform in the susceptible control cultivar JL 24 that was sown after every ten test genotypes. We identified 33 lines as resistant to the disease over three growing seasons. The performance of 14 lines found resistant in all three seasons is shown in Table 7. TCG 1518 is a high-yielding cultivar bred by APAU scientists at Tirupati from material supplied by ICRISAT.

Virus Diseases

Bud Necrosis Disease (BND)

During the 1986 rainy season we screened over 1000 selected breeding lines and interspecific hybrid derivatives for field resistance to BND. Disease incidence was less than 25% in JL 24 and TMV 2, the susceptible control cultivars. Breeding lines showing lower BND incidence and higher yield will be retested in 1987. We evaluated several breeding lines with desirable pod and seed characteristics, and with field resistance to BND (ICRISAT Annual Report 1985, p. 224) for their yield potential. Selected lines that outyielded the control cultivar Kadiri 3 (Robut 33-1) are listed in Table 8. Eight BND field-resistant selections, including those listed in Table 8, are currently being evaluated in an AICORPO-sponsored trial at eight locations, including ICRISAT Center, for field resistance to BND.

Applications of the insecticide dimethoate at concentrations sublethal to the thrips vector increased BND incidence and this effect can be used to facilitate screening when the natural incidence of BND is low. Twelve genotypes sown in a replicated trial, were sprayed with dimethoate at 200 g a.i. ha^{-1} at 1-week intervals until the crop was harvested. Ten genotypes showed increased

BND incidence following the insecticide treatment over the nonsprayed controls.

Peanut Clump Virus (PCV)

Causal agent. In disease surveys we detected PCV in farmers'fields in Cuddapah District. We produced antiserum with high titres for Bapatla (Andhra Pradesh) and Hyderabad (Andhra Pradesh) isolates of PCV. All the five geographically separated PCV isolates have been shown to differ in their serological cross reactions (ICRISAT Annual Report 1985, p. 224). Collaborating with the Scottish Crop Research Institute, Invergowrie, UK, we were able to utilize ^{32}P-labelled complementary DNA(C-DNA) probes to detect the viral RNA in dot blots prepared in nitrocellulose filters. The main advantage of this technique is that a C-DNA probe prepared for one isolate can detect the presence of all the five isolates.

Transmission. We found (ICRISAT Annual Report 1985, p. 225) that PCV is seed-transmitted in groundnut. Seeds from the cultivar M 13 naturally infected with the Bapatla and Hyderabad isolates have been tested for correlation between enzyme-linked immuno-sorbent assay (ELISA) and growing-out tests for the presence of PCV. Both the PCV isolates were present in nearly 11% of the seed, and the results of the ELISA could be correlated with growing-out tests on over 500 seeds. We have also tested seed transmission of the Hyderabad PCV isolate in *Sorghum bicolor* and *Setaria italica,* species known to be hosts for PCV (ICRISAT Annual Report 1985, p.225). In tests on over 600 *S. bicolor seeds* we were unable to detect any seed transmission. However, we found seed transmission to the extent of 10% in *S. italica* in tests on over 1500 seeds from PCV-infected plants. Research to date indicates that the fungus *Polymyxa graminis* can transmit PCV (ICRISAT Annual Reports 1982, p. 189; 1984, p. 212; 1985, p. 225). We studied the life cycle of *P. graminis* in wheat roots. Nine days after inoculation with root soakates containing cystosori of the fungus we observed zoosporangia in wheat roots and cystosori 7 days later. We are attempting to maintain a culture of *P. graminis* in wheat roots utilizing inoculum from root soakates.

Resistance screening. In the 1985/86 postrainy season we screened 250 germplasm accessions in a farmer's field near Pallipalem village in Prakasam District of Andhra Pradesh. Eleven entries showed tolerance of PCV and merit further testing.

Solarization. We used a soil solarization technique (ICRISAT Annual Report 1985,p.183) to treat several small areas of soil infested with PCV. This treatment considerably reduced incidence of the disease in groundnuts subsequently grown in the solarized soil compared with those grown in nontreated PCV-infested soil.

Peanut Mottle Virus (PMV)

Causal agent. Utilizing purified virus from peas, we produced an antiserum for PMV. The titre as determined by the precipiting ring test was 1:1280.

Resistance screening. In the 1985/86 postrainy and 1986 rainy seasons we screened 224 breeding lines for resistance to PMV. Eight lines showed less than 5% yield loss from PMV-infected plants and will be further tested in the 1987 rainy season. The four breeding lines and one germplasm accession that showed less than 5% yield loss in earlier tests (ICRISAT Annual Report 1985, p. 225) have failed to show significantly lower yield loss than susceptible controls in a replicated trial. Earlier, NC Ac 2240 was shown to be tolerant to PMV (ICRISAT Annual Reports 1982, p.189; 1983, p.199). We tested individual plants of advanced generation breeding lines from crosses involving NC Ac 2240 for tolerance to PMV, and made 40 selections with desirable pod and seed characters that will be tested in 1987 for tolerance to PMV.

We have conducted several tests on genotypes EC 76446(292) and NC Ac 17133 (RF) for seed transmission of PMV (ICRISAT Annual Reports 1982, p. 189; 1984, p.212; 1985, p.226), but these tests showed they did not transmit PMV through seed (Table 9). Several crosses involving these genotypes were tested for nonseed transmission. We also conducted additional tests on crosses involving FSB 7-2 and EC 76446(292), and Comet and NC Ac 17090, which were shown not to transmit PMV in initial tests (ICRISAT Annual Report 1985, p.226). Both the breeding lines transmitted PMV but at a very low frequency (Table 9). Over 15000 seeds of a breeding line from a cross involving 148-74-3-2-B and NC Ac 17090 were shown not to transmit PMV. Additional breeding lines currently being tested for PMV nonseed transmission are also listed in Table 9. We will retest them in 1987 at selected locations outside ICRISAT Center where the disease caused by PMV is economically important.

Table 9. Transmission of peanut mottle virus (PMV) through seed from field-inoculated groundnut genotypes; cumulative data from trials at ICRISAT Center over two *to* six seasons.

Entry	No. of seeds tested	Seed transmission of PMV (%)
EC 76446(292)	17682	0
NC Ac 17133 (RF)	18005	0
ICGV 86604	13284	0.03
ICGV 86702	16083	0.04
ICGV 86703	15145	0
ICGV 86704	4143	0
ICGV 86705	2914	0
ICGV 86706	1625	0
ICGV 86397	2692	0
ICGV 86015	1032	0

Peanut Yellow Spot Virus (PYSV)

Since PYSV is widely distributed (ICRISAT Annual Report 1985, p.226) and occurs in high incidence in India and Thailand, we modified the purification procedure in order to produce a better quality antiserum. The modified procedure involves clarification, treatment with polyethylene glycol, followed by two cycles of density gradient centrifugation in potassium tartarate solutions. This procedure gave higher virus yields and negligible host components as determined by electron microscopy (Fig.5)

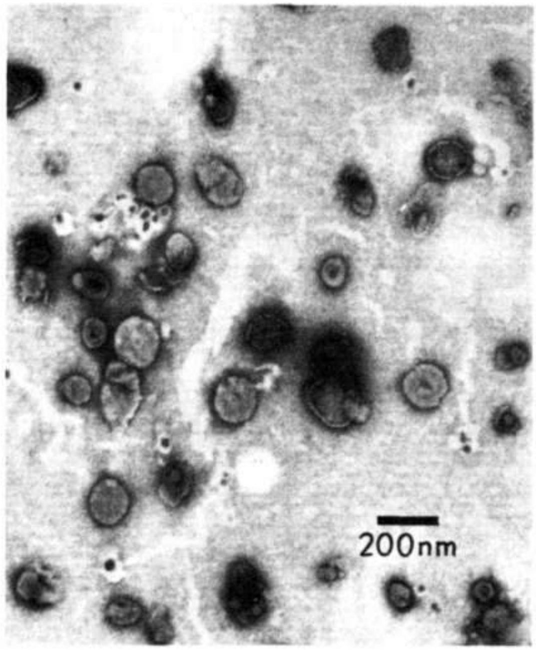


Figure 5. Purified preparation of groundnut yellow spot virus particles (bar represents 200 nm). ICRISAT Center, 1986.

Virus Disease Surveys

We conducted disease surveys utilizing a simple ELISA procedure (ICRISAT Annual Report 1985, p.226). Peanut stripe virus (PStV) was detected in several locations in Indonesia. Peanut mottle (PMV) and tomato spotted wilt (TSWV) viruses were detected in Thailand and Indonesia. In disease surveys in parts of Andhra Pradesh, India, we observed veinal chlorosis disease (ICRISAT Annual Report 1985, p.226) at incidences as high as 60%. The disease was observed at several locations in postrainy-season groundnut crops. We are currently investigating its etiology.

Insect Pests

Incidence at ICRISAT Center

Three species of soil insects not previously considered to be pests at ICRISAT Center reduced groundnut yields in 1986. An ant, *Dorylus orientalis,* destroyed many seeds of groundnut plants growing in small plots during the 1985/86 postrainy season. A detailed study of the soil fauna by scientists from the Termite Control Team of the Tropical Development and Research Institute (TDRI), London, showed that plants in a nonirrigated Alfisol field had been attacked and killed by the larvae of a jewel beetle (*Sphenoptera* sp: Buprestidae), the 'groundnut verpuchi'. There was up to 30% plant mortality in plots that were not protected by insecticide. Nine percent of the plants growing in an irrigated Alfisol field were also damaged by this pest, but with less drastic effect on the host. The same investigation added false wireworms (*Tenebhonidae* sp unk.) to the list of groundnut pod borers in India.

Our regular insect fauna did not create many problems this year. Thrips (*Frankliniella schultzei*) damage was severe early in the 1985/86 postrainy-season crop. Jassid (*Empoasca kerri*) populations were low to moderate in both seasons. The groundnut leaf miner (GLM) (*Aproaerema modicella*) threatened to became a problem in the 1986 rainy season, but had virtually disappeared before the third generation. GLM parasitism was not high (approximately 20%); laboratory rearing experiments indicated

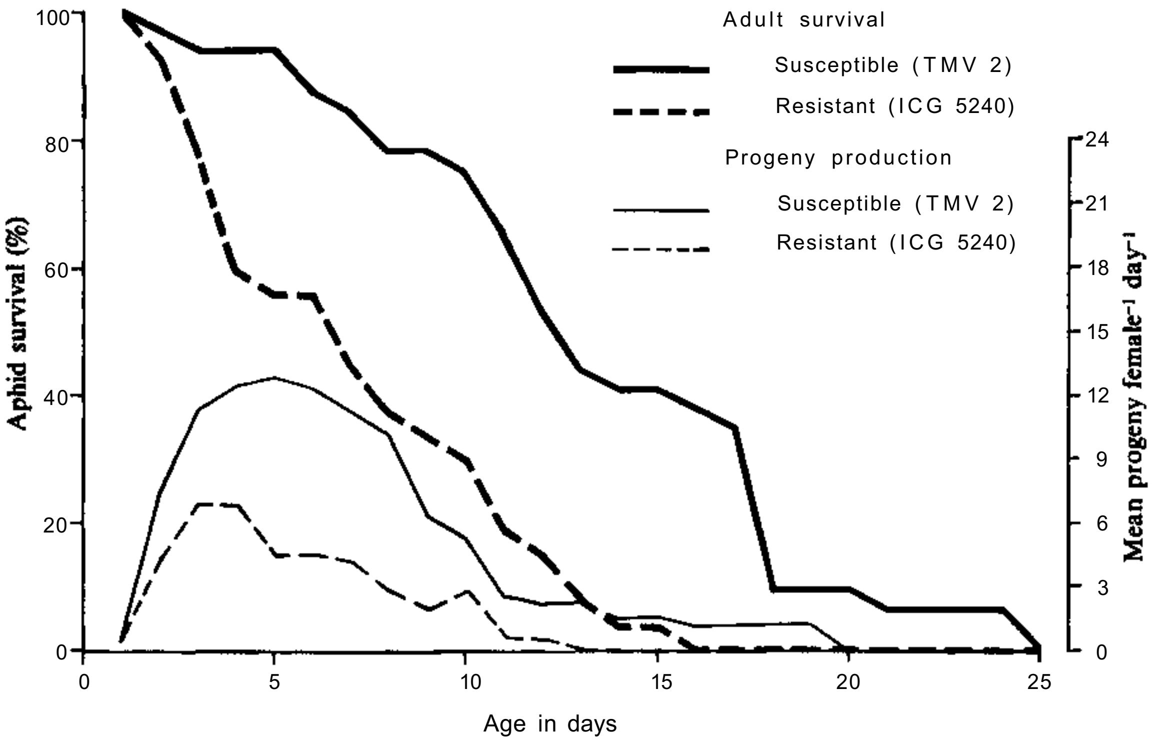


Figure 6. Adult survival and reproductive rate of *Aphis craccivora* on resistant and susceptible groundnut genotypes, greenhouse trial, ICRISAT Center, 1986.

Table 10. Groundnut genotypes with resistance to jassids (*Empoasca kerri*), ICRISAT Center, rainy season 1986.

Trial 1		Trial 2		Trial 3		Trial 4	
Genotype	Yellowed foliage (%)	Genotype	Yellowed foliage (%)	Genotype	Yellowed foliage (%)	Genotype	Yellowed foliage (%)
ICG 7965	1.7 (7.3)[1]	ICG 5043	1.0 (5.7)	ICG 8343	2.7 (9.4)	ICG 7026	7.3 (15.6)
ICG 5240	2.7 (9.4)	ICG 2307	1.3 (6.5)	ICG 8309	2.7 (9.4)	ICG 8036	8.0 (16.4)
ICGV 86031	3.3 (10.5)	ICG 5042	1.3 (6.5)	ICG 7437	3.7 (11.0)	ICG 9862	8.0 (16.4)
ICG 8277	4.3 (11.8)	ICG 5044	1.3 (6.5)	ICG 8896	5.7 (13.6)	ICG 8284	8.3 (16.6)
64-B3-20	5.0 (12.8)	ICG 5045	1.3 (6.5)	ICG 7652	7.3 (15.6)		
ICGV 86437	5.3 (12.9)	ICG 2306	2.7 (9.4)	ICG 1602	7.3 (15.6)		
ICG 1602	5.7 (13.9)	ICG 7644	4.3 (11.9)	ICG 7113	7.7 (15.6)		
ICG 2271	6.7 (14.6)	ICG 977	4.7 (12.3)	ICG 7448	7.7 (15.6)		
ICG 8010	7.3 (15.6)	ICG 7235	5.7 (13.7)	ICG 6749	8.0 (16.4)		
ICGV 86713	7.7 (15.2)	ICG 5679	7.3 (15.7)				
Susceptible controls							
ICG 221	21.7 (27.5)	ICG 221	25.0 (30.0)	ICG 221	23.3 (28.9)	ICG 221	26.7 (31.0)
ICG 799	21.7 (27.5)	ICG 799	19.0 (25.6)	ICG 799	21.7 (27.7)	ICG 799	20.0 (26.5)
SE	(±2.39)		(±1.31)		(±1.86)		(±1.87)
Mean	8.2 (15.55)		7.2(13.90)		9.7 (17.20)		11.9 (19.70)
cv %	(27)		(16)		(19.8)		(17)

1. Figures in parentheses are angular transformations.

that parasitism was not the only cause of death. White grubs (*Lachnosterna* spp) killed plants in two fields. Aphids (*Aphis craccivora*), and white flies (*Bemisia* spp) made their usual brief and inconsequential appearance during the rainy season.

Host-plant Resistance

Aphids (*Aphis craccivora*). After screening some 6000 genotypes for resistance to *A. craccivora,* we found that ICG 5240 has an antibiotic element that suppresses development of aphid populations. In screenhouse conditions, adult aphids survived nearly twice as long on the susceptible cultivar TMV 2 than on ICG 5240. The reproductive rate of the aphids on this resistant genotype was 25-35% of that on TMV 2 (Fig. 6).

Jassids (*Empoasca kerri*). Despite only moderate jassid densities in the 1986 rainy season it was possible to screen a further 400 genotypes for resistance to this pest. Thirty-three genotypes had 1-8% leaflets yellowed compared to 19-27% in the control cultivars (Table 10); one of them is the aphid-resistant genotype ICG 5240.

Thrips (*Frankliniella schultzei*). Trials were carried out in the 1985/86 postrainy season (12 genotypes) and in the 1986 rainy season (15 genotypes) to compare a range of thrips damage levels, assessed as percentage damaged leaflets, and as an injury rating. A thrips injury index (the product of these two parameters) was positively correlated with the incidence of bud necrosis disease (BND). This indicates the importance of vector resistance in reducing BND levels in the field.

Integrated Control

Relationship between insect density and drought. Throughout the 1985/86 postrainy season we measured the density of insect pests on groundnut plants grown along a drought stress gradient. Groundnut leaf miners were most dense on the most stressed plants. Jassid populations were influenced in the opposite direction. Initially, thrips were most abundant on the most stressed plants, but this pattern was reversed later in the growing season. *Microtermes* spp were most active where the soil was at 50-75% field capacity.

Setting research goals with a dynamic programming procedure. Information from field trials designed to give basic information for the development of an integrated control program for leaf miner was adapted to form the data base for a computer program developed to find the optimum solutions to farmers' pest control problems. It indicated that in the presence of less than 20% natural mortality, more than 70% host-plant resistance would be required (i.e., the pest's generation to generation rate of increase was reduced by 70% by the factors imbuing host-plant resistance).

The initial pest population was critical. If it rose much above the level we observed at ICRISAT Center, the farmer would need to apply an insecticide to optimize his yield. This particular simulation was constructed because of the practice of growing consecutive and overlapping groundnut crops in some areas of India. This means that newly sown fields are invaded by pests from neighboring fields of established crops.

The efficiency of an insecticide application is also important. The model indicated that if natural control and host-plant resistance did not reduce the population growth rate of the pest by about 60% of its potential, a spray operation would have to be more than 70% efficient. Lower spray efficiencies would result in crop failure. This indicated that we should know more about the efficiency of farmers' insecticide application activities. The 'trade off between host-plant resistance and the 'kill efficiency' of an insecticide was such that when a farmer's insecticide applications are not efficient he would obtain a better return by growing a cultivar with more

Table 11. Yield loss caused by *Spodoptera litura* larvae[1] to groundnut plants of cultivar TMV 2 when the infestation occurs at different crop stages, ICRISAT Center, postrainy season 1985/86.

Crop stage at larval release	Pod yield plant^{-1} (g)	Yield loss (%)	Haulm mass plant^{-1} (g)	Haulm loss (%)
10 DAE[2] (seedling stage)	7.2	37 (37)[3]	8.3	30 (31)[3]
30 DAE (flowering)	9.6	18 *(22)*	10.2	15 (22)
50 DAE (pegging)	9.7	17 (22)	9.8	19 (25)
70 DAE (pod formation)	10.4	13 (16)	9.4	23 (28)
10 + 30 + 50 + 70 DAE	5.7	53 (47)	7.1	41 (40)
30 + 50 + 70 DAE	7.7	33 (35)	8.3	31 (34)
50 + 70 DAE	9.7	17(21)	10.2	15 (20)
Control (No defoliation)	11.9	0 (0)	12.1	0 (0)
SE	±0.7	(±5.7)	±0.6	(±4.3)
CV (%)	18	(51)	15	(39)

1. 12 larvae plant^{-1}, 40 plants plot^{-1}, 5 replicates.
2. DAE = days after emergence.
3. Values in parentheses are arc sine transformations.

pest resistance than by improving his spray technique.

Integrated control of *Spodoptera litura.* *S. litura* is a serious pest of groundnut crops in Asia. A series of experiments is being carried out to determine the larval threshold densities that cause yield loss at various crop stages.

In a 1985/86 postrainy season experiment, we placed two fourth instar larvae on each plant at the crop stages indicated in Table 11. The larvae were confined to the experimental plots by an aluminium barrier. At the seedling stage 85% defoliation resulted in 37% pod loss. The crop recovered well from defoliation at this stage in terms of leaf area but at harvest the haulm biomass was still 30% lower than that of the control. The release of four batches of 2 larvae per plant with a 10-day gap between releases, resulted in 53% pod loss and 41% haulm loss. Defoliation at other stages resulted in lower levels of yield loss. Continuous defoliation, even at this relatively low larval density, caused up to 53% yield loss (Table 11).

In the 1986 rainy season, we released 1,2,5, or 10 fourth instar larvae per plant into 2.5 m^2 plots (about 80 plants) surrounded by aluminium barriers. At the seedling stage this resulted in 44,66, 87, and 100% defoliation and 14,22,48, and 51% pod loss (Table 12). Even though there was 50% defoliation during flowering and 30% at the pegging and pod-formation stage, we found no yield reduction. Thus, only the seedling stage is vulnerable to defoliation during the rainy season.

The implications of these data are:

- The damage thresholds in rainy-season and postrainy-season crops appear to be different.
- The rainy-season crop can tolerate a high level of defoliation without yield loss. This information, combined with our observation of higher levels of *Spodoptera* damage when insecticide is applied indicates that the application of insecticide for *Spodoptera* control should not be an automatic reaction by farmers to this pest.
- Farmers should not sow consecutive crops in close proximity to avoid infestation of newly emerged stands.

Table 12. Effect on pod and haulm yields (g $plant^{-1}$) by different densities of *Spodoptera litura* larvae at different stages of a groundnut crop (TMV 2)[1], ICRISAT Center, rainy season 1986.

Crop stage and number of larvae $plant^{-1}$	Pod yield $plant^{-1}$ (g)	Haulm yield $plant^{-1}$ (g)
Seedling (10 DAE)		
1	5.0	10.2
2	4.5	9.4
5	3.0	9.9
10	2.8	7.4
Flowering (30 DAE)		
1	5.5	11.6
2	6.1	12.9
5	5.3	11.8
10	6.0	12.0
Pegging (50 DAE)		
1	6.5	12.6
2	5.6	11.2
5	6.5	11.5
10	6.4	11.9
Pod formation (70 DAE)		
1	6.5	12.2
2	6.0	11.3
5	5.6	11.7
10	5.1	11.3
Control (No defoliation)	5.8	11.2
SE	±0.4	±0.7
CV (%)	18	14

1. 80 plants $plot^{-1}$, 5 replicates.

Storage Pests

Methods of evaluating the susceptibility of groundnut pods and kernels to key storage pests have been established. The techniques are sufficiently sensitive to demonstrate clear differences in the response of different genotypes to a range of pests.

Soil Insect Control

A number of soil insects damage groundnut roots and pods throughout the SAT. Of these, termites and white grubs are considered to be the major pests. When the farmers cash flow is sufficient, a standard method of protecting crops from these pests is to apply dieldrin or aldrin in a dry formulation to the soil at the time of sowing. Unfortunately, these insecticides can accumulate in the soil so that the product may not be suitable for sale, especially in overseas markets. ICRISAT is working with TDRI on other methods of protecting groundnut crops from soil insects.

An experiment carried out at ICRISAT Center in the 1986 rainy season indicated that chlorpyriphos, in a slow release formulation, is a potential alternative control agent to aldrin, in that it protected the crop from termites, white grubs, and various other pests. Seed dressing with insecticides was not effective. Isofenphos did not give satisfactory protection from soil insects but its systemic effect protected plants from groundnut leaf miner attack.

Breeding for Pest Resistance

From 879 segregating populations (F_2-F_7), grownunder natural pest infestation at ICRISAT Center in the 1986 rainy season, we made 220 selections that were highly to moderately resistant to jassid damage.

Yield Trials

We evaluated 170 advanced, pest-resistant breeding lines in four replicated yield trials under natural pest infestation at ICRISAT Center in the 1986 rainy season. We also tested a set of 78 other breeding lines in a multilocational trial at Anantapur, Bhavanisagar, Dharwad, Hisar, and ICRISAT Center. Yields of some of the breeding lines at ICRISAT Center where the trial was grown under high-input conditions with foliar diseases control are presented in Table 13. Several breeding lines belonging to the Virginia bunch (var *hypogaea*) and Spanish bunch (var *vulgaris*) groups, had significantly higher pod yields and higher levels of resistance to jassid damage than the control cultivars JL 24 and Kadiri 3 (Robut 33-1). Pod yield differences at other locations except for Hisar were not significant. At Hisar, two breeding lines, ICGV 86353 and ICGV 86405, produced pod yields of over 5 t ha^{-1}, when Kadiri 3 gave 3.6 t ha^{-1}. On an overall mean basis the breeding line ICGV 86400 ranked first.

Plant Nutrition

Nitrogen Fixation

Bradyrhizobium NC 92 Effects

Over the past three seasons, we have investigated by growth analysis the crop physiological basis for the previously reported yield increases in response to inoculation with *Bradyrhizobium* (*Rhizobium*) strain NC 92 (ICRISAT Annual Report 1984, p.218).

This research has shown that despite successful nodule formation by the introduced strain, there has not been increased nitrogen fixation in the field. This observation provides support for the results of greenhouse trials which have demonstrated that NC 92 has no special nitrogen-fixing attributes and suggests that other factors are responsible for the yield effects.

Iron Nutrition

Siderophore Production by *Bradyrhizobium* Strains

Siderophores, low-iron-inducible, iron-binding molecules with small molecular weight are believed to help in the iron nutrition of plants. Previously, there were no easy quantitive methods available for comparing the amounts of Fe-binding siderophores, so we developed an assay for ^{59}Fe-binding catechol-type siderophores.

Earlier, using a qualitative colorimetric test (addition of an equal volume of ferric chloride solution to the ethyl acetate extract) for siderophores, we could detect siderophores only from *Bradyrhizobium* strains NC 92 and 5a/ 70. How-

Table 13. Performance of some high-yielding, jassid-resistant/tolerant groundnut selections, ICRISAT Center, rainy season 1986[1].

Entry	Pedigree	Growth[2] habit	Pod yield (t ha-')	Jassid damage[3]
ICGV 86399	TMV 2 x NC Ac 2214	VB	3.66	4(10)[4]
ICGV 86377	Mani Pintar x (Robut 33-1 x NC Ac 2214)	VB	3.60	4(11)
ICGV 86402	Mani Pintar x NC Ac 2232	VB	3.57	11(18)
ICGV 86400	Mani Pintar x (Robut 33-1 x NC Ac 2232)	VB	3.36	3 (9)
ICGV 86351	Mani Pintar x (Robut 33-1 x NC Ac 2214)	VB	3.17	3 (9)
ICGV 86352	Manfredi 68 x NC Ac 343	SB	3.10	18 (26)
ICGV 86352	Mani Pintar x (Robut 33-1 x NC Ac 2214)	SB	2.92	4(10)
Controls				
NC Ac 343[5]		VR	3.58	9(16)
JL 24[6]		SB	1.99	21 (27)
Kadiri 3[6]		VB	1.92	20 (26)
SE			±0.19	(±1.8)
Trial mean (81 entries)			2.25	(22)
CV (%)			13	(15)
Efficiency over RBD			100	(14)

1. 9 x 9 lattice design, plot size 4.8 m^2, high input (60 kg P_2O_5 ha^{-1}, with irrigation, rust and late leaf spot control, and insecticide sprays).
2. VB = Virginia bunch, var *hypogaea;* SB = Spanish bunch, var *vulgaris;* and VR = Virginia runner, var *hypogaea.*
3. Jassid damage recorded as yellowed foliage (%).
4. Figures in parentheses are arc sine transformations.
5. Pest-resistant control.
6. Susceptible control.

ever, using our radiotracer method we were also able to detect siderophores in other strains, although the amounts produced were low compared to those of strains NC 92 and 5a/70 (Table 14).

Inoculation with strain NC 92 has increased groundnut yields in India, China, and Cameroon; strain 5a/70 has increased yield in a single trial at ICRISAT Center, whilst inoculation with other strains with lower siderophore production has never increased yield in our experiments. Hence it is possible that the yield responses to inoculation with strains NC 92 and 5a/ 70 may be due to effects on iron nutrition rather than on nitrogen nutrition.

Table 14. Siderophore production in culture by *Bradyrhizobium* strains.

Bradyrhizobium strains	Fe bound (μg g^{-1} dry cells)
NC 92	370
5a/70	312
NC 6	207
NC 43.3	128
NC 70.1	114
47 A1	93
IC 6001	93
SE	±20
CV (%)	14

Phosphorus Nutrition

Genotype-dependent Differences in VAM Colonization and Phosphorus Uptake

We reported earlier that groundnut root colonization by vesicular arbuscular mycorrhizae (VAM) and phosphorus uptake are genotype dependent (ICRISAT Annual Report 1985, p.236). In 1986, we further evaluated this by multilocational trials using 10 genotypes each of Spanish, Valencia, Virginia bunch, and Virginia runner types. There were genotype x site interactions for VAM infection, and significant variation ($P< 0.001$) within the four groups.

Genotype Response to VAM Colonization.

Twenty genotypes were selected from those included in the VAM-colonization and P-uptake studies of 1985, and further tested in 1986 in a replicated trial for response to inoculation with a mixture of VAM fungi (*Glomus constrtum, Acaulospora morroweae,* and *Glomus epigaeum* in equal proportions) at two locations. At ICRISAT Center, five genotypes gave significantly increased pod yield in response to VAM inoculation (Table 15). Similarly, at Anantapur VAM inoculation also resulted in increased pod yield over the control for two genotypes.

Table 15. Pod yield (t ha^{-1}) of groundnut genotypes showing response to VAM inoculation, in replicated field screening at two Indian locations, rainy season 1986.

	ICRISAT Center		Anantapur	
Genotype	Control	Inoculated	Control	Inoculated
ICG 7885			0.87	1.53
ICG 1521	0.58	0.83		
ICG 1506	0.47	0.84		
ICG 3047	0.41	0.65	0.76	1.44
Kadiri 3 (Robut 33-1)	0.59	1.21		
ICG 2490	0.39	0.73		
SE	±0.12		±0.18	
Trial mean (20 entries)	0.68	0.74	1.14	1.30

Adaptation

Photoperiod Studies

In a GTZ-funded project in collaboration with the University of Bonn, Federal Republic of Germany, we have studied the effects of photoperiod on the growth of a range of genotypes. Long days generally decreased yield by lowering the partitioning of assimilates to the pods, but did not change time of flowering.

Influences of Photoperiod on Roots

Earlier research showed that long days increased stem growth and decreased pod growth, but information was not available on the effects of photoperiod on root growth. We have now shown that growth of both shoot and roots are promoted by long days at the expense of pods (Table 16). This helps to explain the high proportion of drought-resistant genotypes observed amongst progeny derived from photoperiod-sensitive, foliar diseases-resistant parents, and also the lower yield potential of these drought-resistant types. Our research has found that many of the foliar diseases-resistant parents utilized in breeding programs are photoperiod-sensitive.

Photoperiod and Foliar Diseases

Collaborative research between pathologists and physiologists has investigated the interaction of foliar fungal diseases and photoperiod effects for five genotypes. These lines were studied for response to disease control by fungicides in both long-day (LD, 16 h) and short-day (SD, 13 h) conditions. Kadiri 3 (Robut 33-1) was insensitive to photoperiod, ICGV 86709 (ICG(FDRS)18) was only mildly photoperiod-sensitive and the other genotypes were strongly sensitive (Table 17).

Table 16. Effect of long (LD) and short days (SD) on mass of shoots, roots, and pods from two groundnut genotypes, greenhouse trial, ICRISAT Center, 1986.

Dry mass	NC Ac 17090		TMV 2		
(g $plant^{-1}$)	SD[1]	LD[2]	SD[1]	LD[2]	Mean
Shoots	17.3	41.3	16.1	38.2	28.2 (±3.03)
Roots	3.4	6.8	2.7	5.1	4.5 (±0.62)
Pods	15.7	6.0	9.6	5.1	9.0 (±0.70)

1. SD = 8 h daylength.
2. LD = 4 h night break.

Table 17. Effect of fungicide sprays and daylength on pod yields (t ha^{-1}) of five groundnut genotypes, field trial, ICRISAT Center, rainy season 1986.

		Daylength	
Treatment	Genotype	13 h	17 h
Water spray	Kadiri 3	1.57	1.56
	ICGV 86709	2.55	2.05
	NC Ac 17090	1.85	1.11
	NC Ac 17142	1.52	0.66
	EC 76446(292)	2.32	1.15
Chlorothalonil spray[1]	Kadiri 3	3.10	2.60
	ICGV 86709	2.86	2.29
	NC Ac 17090	2.78	1.02
	NC Ac 17142	2.04	0.82
	EC 76446(292)	2.56	1.12
SE		±0.18	
CV (%)		13	

1. Chlorothalonil as Daconil® applied six times (at the rate of 1.33 kg a.i. ha^{-1} in 500 L of water) at 10-day intervals beginning 50 DAS.

Yield responses to spraying with fungicides were also influenced by daylength. The LD-insensitive but disease-susceptible Kadiri 3 had a large response to fungicides in both long and short days. In the mildly photoperiod-sensitive ICGV 86709 there was a slight decrease in yield in LDs and only a marginal increase in yield in response to fungicides. However, in the photoperiod-sensitive lines yield was greatly decreased by LDs and only increased by fungicides in SDs, i.e., where the disease development was severe enough for defoliation to be a limiting factor to yield.

Plant Improvement

Breeding for Adaptation to Specific Environments and Requirements

From 305 bulk selections (F_2-F_9) grown in the 1986 rainy season, we made 470 new bulk selections for high yield.

Yield Trials

We evaluated 126 advanced breeding lines in two replicated yield trials grown under high- and low-input conditions at ICRISAT Center. Control cultivars included JL 24 and Kadiri 3 (Robut 33-1). Yields of some of the selections grown with high inputs are given in Table 18. The three high-yielding selections in one trial and the two that yielded most in the other trial significantly outyielded the control cultivars. In the first trial 32 other selections significantly outyielded the control Kadiri 3 (Robut 33-1).

We evaluated a further 102 advanced breeding lines in two multilocational trials (MLTs). The MLT 86-5 trial was conducted at ICRISAT Center, Anantapur, Bhavanisagar, Dharwad, and Hisar and the MLT 86-4 trial at the first four locations only. Performance of the top five selections on an overall mean basis in these two trials is presented in Table 19.

Table 18. Pod yields (t ha^{-1}) of some high-yielding, medium-maturing groundnut selections under high-input conditions[1], ICRISAT Center, rainy season 1986.

Entry	Original name	Growth habit[2]	Pod yield (t ha^{-1})
Trial 1 (9 x 9 triple lattice)			
ICGV 86294	ICGS 30 x JL 24	SB	4.60
ICGV 86312	ICGS 16 x VR 71-1	SB	4.27
ICGV 86300	ICGS 5 x C 166	VB	4.24
ICGV 86319	F334-A-B-14 x Ah 114	VB/SB	4.21
ICGV 86285	H 24 x H1L 13b/1 Hba x HaC (1) x H11	VB	4.20
Controls			
JL 24		SB	3.51
Kadiri 3	Robut 33-1	VB	2.80
SE			±0.24
Trial mean (81 entries)			3.44
CV (%)			12
Efficiency over RBD			110
Trial 2 (7 x 7 triple lattice)			
ICGV 86347	FSB7-2 x G 201	VB	4.36
ICGV 86350	Robut 33-1-21-11 x 877	VB/SB	3.99
ICGV 86331	ICGS 15 x ICGS 25	SB	3.48
ICGV 86346	ICGS 49 x VR 71-1	VB/SB	3.46
ICGV 86343	ICGS 20 x L.No.95-A	VB/SB	3.37
Controls			
Kadiri 3	Robut 33-1	VB	3.06
JL 24		SB	2.93
SE			±0.23
Trial mean (49 entries)			2.91
CV (%)			14
Efficiency over RBD			138

1. High input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays, plot size = 4.8 m^2.
2. SB = Spanish bunch cultivar, var *vulgaris;* VB = Virginia bunch cultivar, var *hypogaea.*

In the MLT 86-4 trial five selections at ICRISAT Center produced significantly greater pod yields than Kadiri 3 (Robut 33-1). Selection ICGV 86210 produced the highest pod yield (4.08 t ha^{-1}) at ICRISAT Center. At Anantapur, selection ICGV 86190 significantly outyielded both controls. At Bhavanisagar, selection ICGV 86231 gave the highest pod yield of 3.49 t ha^{-1}. Two selections, ICGV 86210 and ICGV 86215 had significantly greater pod yields than both control cultivars. None of the selections at Dharwad was significantly superior to the highest-yielding control Kadiri 3 (Robut 33-1).

In the MLT 86-5 trial at ICRISAT Center, selection ICGV 86236 significantly outyielded both control cultivars, and three others significantly outyielded JL 24. At Anantapur, Bhavanisagar, Dharwad, and Hisar none of the selections outyielded the best control cultivar at any location.

Table 19. Performance of the five highest-yielding, medium-maturing groundnut selections evaluated at five Indian locations[1], rainy season 1986.

			Pod yield (t ha^{-1})					
Entry	Original name	Growth habit[2]	ICRISAT Center[3]	Ananta-pur[5]	Bhavani-sagar[4]	Dhar-wad[5]	Hisar[4]	Mean
Trial 1; MLT 86-4 (8 x 8 triple lattice)								
ICGV 86197	Robut 33-1 x M 13	SB/VB	3.82	0.59	3.18	3.27	6	2.71
ICGV 86229	ICGS 15 x (TMV 10 x Chico)	VB	3.03	0.72	3.10	3.37		2.56
ICGV 86191	(53-68 x Robut 33-1) x (Robut 33-1 x NC Ac 316)	SB/VB	3.76	0.58	2.74	3.10		2.54
ICGV 86226	(Robut 33-1 x NC Ac 2821) x USA 20 x TMV 10)	VB	2.82	0.62	3.49	3.19		2.53
ICGV 86215	(Robut 33-1 x NC Ac 2821) x VR 71-1	SB	4.01	0.63	3.09	2.37		2.52
Controls								
Kadiri 3	Robut 33-1	VB	3.03	0.56	2.59	3.16		2.33
JL 24		SB	3.79	0.72	2.43	2.23		2.29
SE			±0.24	±0.90	±0.23	±0.32		
Trial mean (64 entries)			3.05	0.64	2.65	2.54		
CV (%)			14	26	15	22		
Efficiency over RBD			113	118	107	101		
Trial 2; MLT 86-5 (6 x 7 rectangular lattice)								
ICGV 86236	Ah 65 x Robut 33-1	SB	3.89	0.75	3.34	2.36	4.37	2.94
ICGV 86250	Robut 33-1 x Jacana	SB	3.12	0.65	3.07	2.65	4.46	2.79
ICGV 86260	Robut 33-1 x Ah 114	VB	3.01	0.54	3.16	2.70	4.48	2.78
ICGV 86249	Chalimbana x Robut 33-1	SB	3.36	0.48	3.14	3.00	3.72	2.74
ICGV 86257	(M 13 x Robut 33-1) x (53-68 x Robut 33-1)	VB	3.44	0.63	3.43	2.60	3.56	2.73
Controls								
Kadiri 3	Robut 33-1	VB	2.57	0.64	3.77	2.49	3.18	2.53
JL 24		SB	2.99	0.63	3.07	1.83	3.26	2.36
SE			±0.26	±0.08	±0.35	±0.23	±0.42	
Trial mean (42 entries)			2.81	0.61	3.06	2.24	3.37	
CV (%)			16	22	20	18	22	
Efficiency over RBD			95	110	101	101	22	100

1. Plot size =4.8 m^2.
2. SB = Spanish bunch, var *vulgaris* , VB = Virginia bunch, var *hypogaea.*
3. Under high-input conditions (60 kg P_2O_5 ha^{-1}, irrigation and protection against pests and diseases).
4. Rainfed plus supplementary irrigation and protection against pests.
5. Rainfed.
6. MLT 86-4 failed due to salinity problem.

Breeding for Earliness

During 1986, we modified the 'staggered harvesting' approach (ICRISAT Annual Report 1984, pp.227-229) by increasing the plot size for each harvest and reducing the number of harvests to two, i.e., at 75 and 90 DAS. Using this modified approach, we screened 396 breeding lines derived from early source line x adapted line crosses for pod and sound mature kernel (SMK) yields, and other maturity-related characteristics, in five field trials at ICRISAT Center. We retained 126 selections for further testing. We also evaluated 96 breeding lines selected during 1985 for earliness, yield, and adaptability in the 1986 rainy season at six locations in India.

Data on the pod yields from early harvests and the mean number of days to maturity of selected early maturing breeding lines from one of the trials are shown in Table 20. Table 21 shows the performance of the same lines in the 75- and 90-DAS harvests at ICRISAT Center under high-input conditions.

We analyzed the oil content of the SMK obtained from staggered harvests and found that selected early maturing lines had normal oil levels even at 75 DAS (Table 22).

We identified two new sources of earliness, ICG 147, a red-seeded var *fastigiata* type and ICG 3754, a white-seeded var *fastigiata* type, that matured in 90 days in the 1986 rainy season at ICRISAT Center under high-input condi-

Table 20. Performance of selected early-maturing groundnut breeding lines at six Indian locations[1], rainy season 1986.

		Pod yield (t ha^{-1})							
		ICRISAT Center							
Entry	Original name	(HI)[2] (90)[3]	(LI)[2] (95)	Anantapur (85)	Bhavanisagar (88)	Dharwad (95)	Hisar (84)	Mean	Mean number of days to maturity[4]
ICGV 86143	ICGS(E)217	3.34	0.74	0.79	2.42	2.47	3.60	2.23	103
ICGV 86127	ICGS(E)201	3.08	0.89	0.95	1.64	3.03	2.97	2.09	96
ICGV 86124	ICGS(E)198	3.35	1.02	0.67	1.83	2.90	2.72	2.08	99
ICGV 86133	ICGS(E)207	3.27	0.75	0.62	1.90	3.05	2.72	2.05	100
ICGV 86144	ICGS(E)218	2.83	0.66	0.74	2.01	2.98	2.58	1.97	97
ICGV 86146	ICGS(E)220	2.98	0.77	0.83	1.79	2.57	2.86	1.97	101
ICGV 86145	ICGS(E)219	3.25	0.78	0.79	1.59	2.75	2.49	1.94	96
Controls									
Kadiri 3	Robut 33-1	2.27	0.74	0.68	2.11	2.03	2.63	1.74	115
JL 24		2.64	0.68	0.71	1.47	2.82	2.03	1.73	99
Chico		1.07	0.38	0.34	0.93	1.56	3.27	1.26	84
SE		±0.20	±0.06	±0.08	±0.20	±0.02	±0.28		±1.7 - ±3.6
Trial mean (36 entries)		2.72	0.75	0.66	1.75	12.02	2.90		93-110
CV (%)		12	14	21	20	19	16		2.6-6.0
Efficiency over RBD		118	127	99	121	96	107		

1. Plot size = 4.8 m^2.
2. HI = High input (60 kg P_2O_5 ha^{-1} with irrigation and insecticide sprays).
   LI = Low input (20 kg P_2O_5 ha^{-1}, rainfed without insecticide sprays).
3. Figures in parentheses are the number of days from sowing to harvest.
4. Average of subjective estimates observed at five locations, three replications at each location.

Table 21. Performance of selected early-maturing groundnut lines harvested at 75 and 90 days after sowing (DAS) under high-input conditions[1], ICRISAT Center, rainy season 1986.

		Pod yield ($t\ ha^{-1}$)		SMK[2] yield ($t\ ha^{-1}$)		Shelling %		100-seed mass (g)		Oil (%)	
Entry	Original name	75 DAS	90 DAS	75 DAS	90 DAS	75 DAS	90 DAS	75 DAS	90 DAS	75 DAS	90 DAS
ICGV 86143	ICGS(E)217	2.61	3.34	1.36	2.36	57	71	33	36	46.0	44.0
ICGV 86127	ICGS(E) 201	2.34	3.08	1.44	2.32	64	76	35	42	46.8	45.5
ICGV 86124	ICGS(E) 198	2.57	3.35	1.61	2.52	65	76	36	46	45.6	45.9
ICGV 86133	ICGS(E) 207	2.62	3.27	1.53	2.38	62	73	36	44	45.7	44.0
ICGV 86144	1CGS(E) 218	2.55	2.83	1.58	2.13	67	76	33	43	45.2	43.6
ICGV 86146	ICGS(E) 220	2.33	2.98	1.57	2.18	68	74	32	44	45.6	44.6
ICGV 86145	ICGS(E) 219	2.55	3.25	1.68	2.47	68	77	36	42	46.0	44.3
Controls											
Kadiri 3	Robut 33-1	1.37	2.27	0.50	1.56	45	69	26	38	44.6	46.3
JL 24		2.19	2.64	1.37	1.95	66	74	37	46	46.8	45.6
Chico		1.08	1.07	0.61	0.78	63	75	21	24	53.0	50.9
SE		±0.16	±0.20	±0 12	±0.14	±2.5	±1.3	±1.3	±1.7	±0.6	±0.7
Trial mean (36 entries)		2.03	2.72	1.04	1.88	56	70	32	42	46.3	46.7
CV (%)		14	13	20	13	8	3	7	7	2	3
Efficiency over RBD		138	118	121	122	117	127	105	96	119	141

1. High input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays.
2. SMK = Sound, mature kernels.

tions. We made single-plant selections from these germplasm lines and purified them for pod and plant characteristics.

During 1986, we established a facility to screen breeding lines for dormancy of cured seeds from early maturing breeding lines trials. We screened the staggered harvests of 133 breeding lines and identified six lines with limited seed dormancy of up to 30 days. Their maturities ranged from 105 to 110 days.

Breeding Groundnut Genotypes for Confectionery Requirements

From segregating populations of confectionery groundnuts, we made 61 new large-seeded bulk selections with emphasis on uniformity of pod shape and seed size.

We crossed promising confectionery groundnut selections with high yielding pest- and disease-resistant breeding lines to combine these characters in new confectionery lines.

We evaluated 28 large-seeded selections against two control cultivars, M 13 and Chandra, under high-input conditions in the 1986 rainy season at ICRISAT Center. Yields of some promising selections are given in Table 23. Four selections produced significantly greater pod yields than Chandra, the higher-yielding of the two control cultivars. The fourth-ranking selection ICGV 86570 (ICG(CG)S 57) had ranked second in the 1985 rainy-season trial at ICRISAT Center (ICRISAT Annual Report 1985, p.242).

Nutritional and Food Quality Studies

We estimated oil and protein contents of 800 breeding lines grown in various trials in the 1985

Table 22. Oil percentage in selected early-maturing groundnut breeding lines in staggered harvests under high-input conditions[1] at ICRISAT Center, rainy season 1986.

Entry	Original name	Oil (%) in SMK[2] harvested at			
		75 DAS	90 DAS	105 DAS	120 DAS
ICGV 86053	ICGS(E) 19	51.4	52.1	51.6	49.4
ICGV 86065	ICGS(E) 34	50.7	50.7	49.7	50.4
ICGV 86066	ICGS(E) 36	51.9	52.0	49.9	50.8
ICGV 86074	ICGS(E) 61	51.1	50.6	49.9	51.2
ICGV 86077	ICGS(E) 85	50.9	51.6	50.1	50.3
ICGV 86079	ICGS(E) 90	50.2	50.1	49.3	49.5
ICGV 86091	ICGS(E) 125	50.7	51.0	50.7	50.3
ICGV 86103	ICGS(E) 147	51.0	50.7	50.0	50.6
ICGV 86112	ICGS(E) 174	52.0	51.7	49.9	49.5
ICGV 86117	ICGS(E) 188	53.2	51.3	50.5	50.9
Controls					
Chico		52.9	51.3	50.6	51.9
JL 24		44.2	45.3	45.0	47.2
Kadiri 3	Robut 33-1	44.4	45.8	46.7	45.1
SE		±0.64	±0.84	±0.72	±0.78
Trial mean (36 entries)		50	49	48	48
CV (%)		2.4	3.0	2.7	3.0
Efficiency over RBD		149	108	112	136

1. High input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays.
2. SMK = Sound, mature kernels.

Table 23. Performance of some high-yielding confectionery groundnut selections under high-input conditions[1], ICRISAT Center, rainy season 1986.

Entry	Original name	Growth habit[2]	Pod yield ($t\ ha^{-1}$)	100-seed mass (g)[3]
ICGV 86563	ICG(CG)S 47	VB	3.36	78
ICGV 86571	ICG(CG)S 60	SB	3.36	84
ICGV 86549	ICG(CG)S 11	VB	3.28	69
ICGV 86570	ICG(CG)S 57	SB	3.27	69
ICGV 86572	ICG(CG)S 61	SB	3.24	84
ICGV 86564	ICG(CG)S 49	VB	2.61	104
Controls				
Chandra		VR	2.67	81
M 13		VR	2.49	75
SE			±0.20	
Trial mean (30 entries)			2.68	
CV (%)			13	
Efficiency over RBD			100	

1. 5 x 6 = rectangular lattice design, plot size 4.8 m^2; high input = 60 kg P_2O_5 ha^{-1}, with irrigation and insecticide sprays.
2. SB = Spanish bunch, var *vulgaris,* VB = Virginia bunch, var *hypogaea,* VR = Virginia runner, var *hypogaea.*
3. Recorded from bulk sample.

rainy season. The oil content in these lines varied from 37 to 53%, and their protein contents from 18 to 30%. At Bhavanisagar, the oil content was high compared to other locations. We have selected lines with high oil content (50% or more) for further testing.

We started a new study to determine the relationship between such quality characters as seed size, oil content, and protein content. Our preliminary results indicate a negative association between oil content and protein content. The association of 100-seed mass with oil and protein contents was not significant. However, from tests on graded seed samples, we observed that within the same genotype oil content increased as seed size increased and the seed size variation could account for up to 6% variation in oil content.

We have carried out biological evaluation of some of our cultivars and the results obtained with male Wistar strain rats are reported in Table 24. We used a diet containing 10% protein to evaluate protein efficiency ratio (PER)—and a casein diet as a reference standard. PER is calculated as weight gained (g)/protein consumed (g). The net protein utilization value of ICGS 21 was significantly higher ($P = 0.05$) than that of other cultivars, indicating its superior quality. The PERs ranged from 70 to 75% of the casein value.

Using Wild *Arachis* Species

We have produced a wide range of interspecific derivatives, based on interspecific crosses between section *Arachis* species, and between those species and cultivated *Arachis hypogaea.* These have all been screened for rust and late leaf spot resistance, and selected lines have been screened for resistance to other constraints. Screening of derivatives and species showed that some had resistance to other pests and pathogens, so new crosses were made to produce populations which could be screened in early generations for resistance to these constraints.

Our emphasis in the past year has been to categorize the large number of derivatives, and to initiate new crossing programs.

Priorities for crosses are changing. We have already produced many derivatives with resistance to rust and late leaf spot, so species with resistance to other important pests and pathogens are being used. Table 25 summarizes the current knowledge of resistances of wild species in section *Arachis.* Resistances have been reported by other workers in Section *Rhizomatosae* Series *Eurhizomatosae* (see Barriers to Hybridization) and in Section *Arachis* Series *Perennes.*

In our crossing program we concentrated on species resistant to insects and viruses, and species resistant to early leaf spot to generate mate-

Table 24. Biological evaluation of selected groundnut genotypes, ICRISAT Center, 1986.

Entry	Original name	Biological value (%)	True protein digestibility (%)	Net protein utilization (%)	Protein efficiency ratio
ICGV 87119	ICGS 1	55.5	96.4	53.5	2.41
ICGV 87121	ICGS 5	55.4	95.7	53.0	2.42
ICGV 87123	ICGS 11	57.8	95.9	55.5	2.35
ICGV 87124	ICGS 21	65.1	99.4	64.7	1.97
ICGV 87128	ICGS 44	52.2	96.7	50.5	2.28
SE		±1.67	±0.61	±1.68	±0.07
Casein (Standard)		76.0	96.4	73.3	3.24
SE		±0.57	±1.05	±1.12	±0.07

Table 25. Immune, resistant, and tolerant reactions of wild *Arachis* species to pests and pathogens. (Results from ICRISAT screening and various authors).

Section Series	Pest or pathogen[1]											
Species	RUS	LLS	ELS	PSV	GRV	PMV	TSW	PCV	THR	APH	MIT	JAS
Arachis Annuae												
A. batizocoi	P									I		
A. duranensis	I			R					R			R
A. spegazzinii	I											R
Arachis Perennes												
A. helodes								T				
A. villosa	I								R	R		R
A. correntina	I					R	R		R	R	R	R
A. cardenasii	I	P				R	R		R			R
A. chacoense	I	R	R/1			R	R		R	R		
A. stenosperma	R	R	R									
Arachis spp				R(I)[4]		R(3)						
Ambinervosae												
Arachis spp												R(I)
Caulorhizae												
A. repens		R	I	R	R				I			R
Extranervosae												
A. villosulicarpa	I	I	P									
Arachis spp												R(1)
Triseminalae												
A, pusilla	I					R	R		R			R
Erectoides												
A. benthamii				R								
A. paraguariensis	I	R							I			
A. rigonii									R			R
A. appressipila	I	R										
Arachis spp		R(2)	R(2)	R(1)					I(3)			R(3)
Rhizomatosae												
A. glabrata	R		R	R	R[3]	R			R	R	R	R
A. hagenbeckii	I	R	I								R	R
Arachis spp		R(1)	R(3)				R/I(24)					R

1. RUS = Rust, *Puccinia arachidis*
   LLS = Late leaf spot, *Phaeoisariopsis personata*
   ELS = Early leaf spot, *Cercospora arachidicola*
   PSV = Peanut Stunt Virus
   GRV = Groundnut Rosette Virus
   PMV = Peanut Mottle Virus
   TSW = Tomato Spotted Wilt Virus
   PCV = Peanut Clump Virus
   THR = Thrips, *Scirtothrips dorsalis*
   APH = Aphids, *Aphis craccivora*
   MIT = Mites, *Tetranychus* sp
   JAS = Jassids, *Empoasca* sp
2. I = Immune, R = Resistant, and T = Tolerant.
3. Conflicting reports may be due to misidentification, or variation in the wild species, the pathogen, or the test conditions.
4. Numbers in parentheses are numbers of species.

rial for our Regional Groundnut Improvement Program for Southern Africa. These were combined as direct crosses, amphiploids, and autotetraploids, incorporating *A. batizocoi* where necessary as the only source of the B genome.

Crosses were also continued to introgress genes from the original and the new accessions (ICRISAT Annual Report 1985, pp. 241, 244). *A. batizocoi, A. cardenasii, A. duranensis, A. chacoense, A. stenosperma, Arachis* sp 30007 and *Arachis* sp 30081 were used to generate new populations for selection, as these species contain resistances to viruses and insect pests.

Characterization of Advanced Generations of Wild Species

Derivatives. Derivatives were sown in a split-plot design to ascertain whether there were any differences between lines with similar disease resistance, pod yield, and pod and kernel characteristics. In previous trials these lines had high pod and haulm productivity compared to the controls, whether foliar diseases were present or not, so yields were compared between plots sprayed with fungicides to control foliar diseases, and plots where the diseases were not controlled (Table 26 and Fig. 7). Local controls showed a large increase in yield when diseases were controlled. Most of the derivatives, even though they were resistant to foliar diseases, showed yield increases when sprayed. Two genotypes produced much higher yields of pods (over 60% increase) under sprayed conditions than when not sprayed (4.06 vs 2.39 t ha^{-1} for CS 39 and 4.06 vs 2.5 t ha^{-1} for CS 13). CS 13 was highly resistant to both pathogens, and CS 39 was highly resistant to late leaf spot but only slightly resistant to rust. Thus, although they had only low levels of disease, the presence of the pathogen had caused a reduction in yield in these

Table 26. Effect of controlling foliar diseases with chlorothalonil (Daconil®) on pod and haulm yields (t ha^{-1}) of advanced *Arachis hypogaea x Arachis cardenasii* derivatives, ICRISAT Center, rainy season 1986.

	Pod yield (t ha^{-1})		Haulm yield (t ha^{-1})	
Entry	Control (water)	Daconil®	Control (water)	Daconil®
CS 39	2.39	4.06	3.58	5.75
820	2.67	3.36	5.42	7.92
820/1	2.89	3.56	6.67	7.22
845	2.72	3.44	5.11	7.83
904	2.39	3.61	4.89	7.22
CS 3	2.67	3.72	4.86	7.22
CS 6	2.97	3.36	5.69	6.11
CS 13	2.50	4.06	4.72	7.36
CS 16	3.00	3.42	5.22	7.06
2133	3.14	4.06	6.64	8.28
2241	2.94	3.44	6.56	8.22
2477	2.78	3.50	5.72	8.06
Control				
Kadiri 3	1.28	3.33	2.25	4.11
JL 24	1.78	4.06	1.94	3.78
SE	±0.36		±0.58	
CV (%)	20.1		16.9	

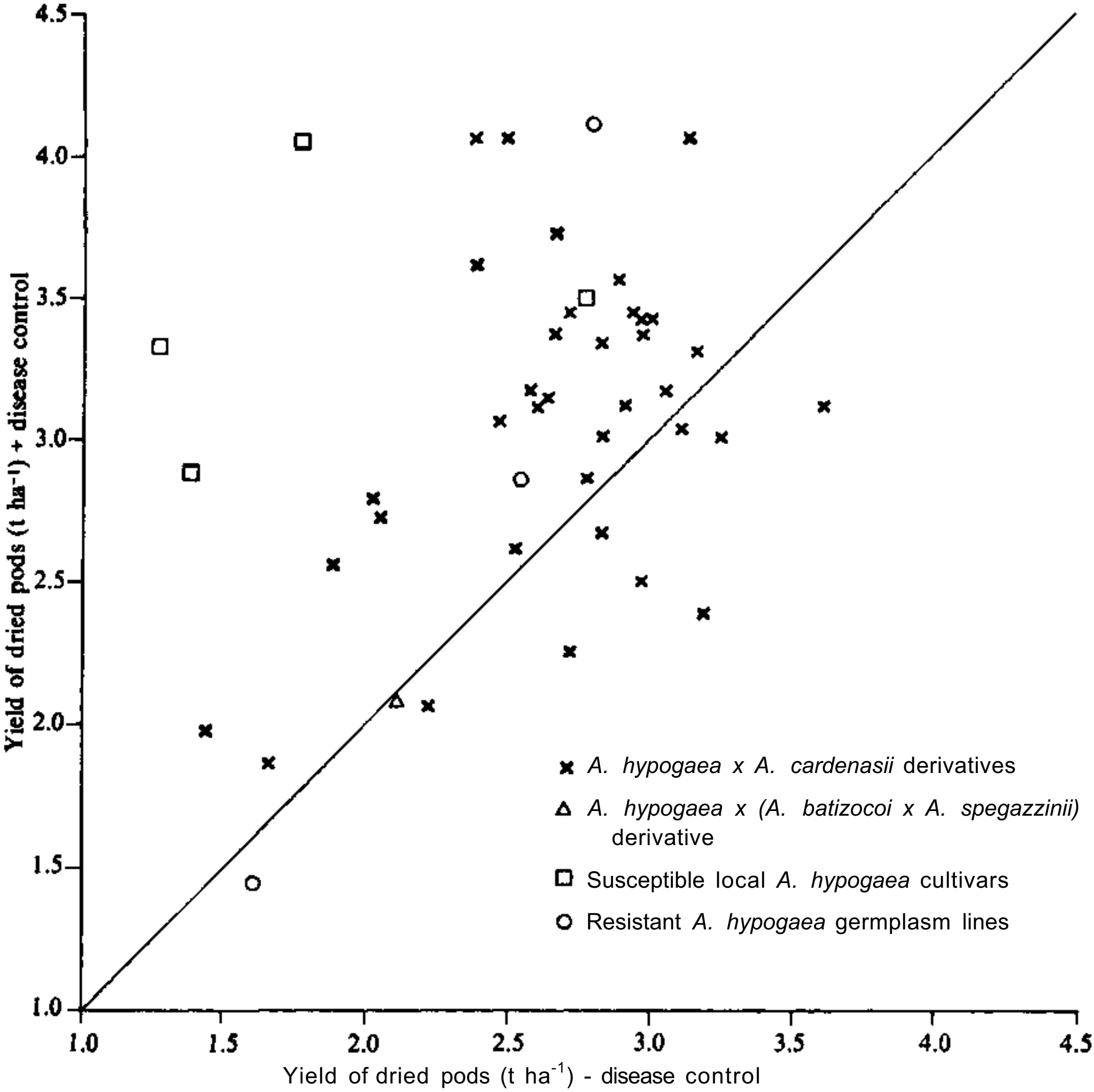


Figure 7. Yield of dried pods (t ha^{-1}) of Arachis wild species derivatives with (+) and without (-) disease control, ICRISAT Center, rainy season 1986.

two genotypes. One other resistant line, ICGV 87218, also gave a higher yield when foliar diseases were controlled.

A selection of resistant, high-yielding, and segregating lines (ICRISAT Annual Report 1985, p. 246) were grown in the 1986 rainy season. Overall yields, including those of controls, were lower than in 1985, but disease ratings were comparable, and the lines were stable.

Selection of New Derivatives

From material produced from crosses made over the period 1983-1985, using a wide range of wild species parents and various ploidy manipulations, more than 1800 progeny row selections were screened for rust and late leaf spot reaction, and for pod characters. Desirable single plants and uniform progeny rows were selected for cytological screening.

Several hundred early generation hybrids and backcrosses, from F_2 to BC_4F_3, involving a number of *A. hypogaea* parents and a wide range of section *Arachis* species, including new accessions, were grown for preliminary observations, and selections made for further selfing or backcrossing.

Sterile triploid hybrids produced when *A. hypogaea* is crossed with diploid species, are rendered hexaploid and fertile by colchicine treatment, and the hexaploids backcrossed to *A. hypogaea* to regain tetraploidy and full compatibility with cultivars of groundnut. However, triploids do produce some seed under certain conditions (ICRISAT Annual Report 1982, p.218), and in the 1986 rainy season all available triploids were increased vegetatively by cuttings, and planted in the field. Most have produced pegs, and many have produced pods.

Barriers to Hybridization

Embryos resulting from hormone-aided pollinations of *Arachis hypogaea* with *Arachis* sp 276233 (Section *Rhizomatosae*) had earlier given rise to callus, whose hybrid nature was verified by a study of esterase profiles by disc electrophoresis (ICRISAT Annual Report 1985, p. 247).

Shoots have been regularly and repeatedly produced on hybrid calli by culture on MS medium with 0.5 mg L^{-1} and 0.5 mg L^{-1} BAP, but promotion of an effective root system that will support the shoot when transferred to soil has not been achieved with sufficient regularity to satisfy the objective of the project. To achieve the transfer of in vitro-grown hybrid shoots to whole-plant systems, they where grafted onto 2-week-old groundnut seedlings. The stem of the stock seedling was cut above the first true leaves, a piece of plastic tube 1 cm long cut from a drinking straw was slipped over the stem, a central longitudinal cut made in the stem, the hybrid shoot inserted into the cut, and the plastic tube slid up the stem to hold the scion in place and to ensure good contact between stock and scion.

Using this technique, we were able to establish 97% of the scions from plants of *A. hypogaea* and 95% of the scions from plants of *Arachis* sp 276233 using *A. hypogaea* seedlings as stocks. Seventy-nine percent of hybrid shoots from in vitro culture used as scions established a union with the stock and survived (Fig. 8), the remainder died. Of those that became established, only 27% grew further and developed new shoots. Although some shoots grew well, growth was slow in most of them, and only 17% survived for more than 4 months (Fig. 9). There was also variation in leaf morphology, but detached leaf tests indicated that all the hybrid shoots were resistant to rust (Fig. 10). None of the grafted shoots produced flowers. These grafted hybrids are being multiplied by grafting the new growth onto fresh stocks. From nine plants, 55 shoots have been grafted and 13 are growing at the time of reporting.

ICRISAT Regional Groundnut Improvement Program for Southern Africa

The ICRISAT Regional Groundnut Improvement Program for Southern Africa is based at Chitedze Agricultural Research Station, near Lilongwe, Malawi. Our work is concerned primarily with the effective broadening of the genetic resources of the region and our priorities are vested in breeding and selecting for increased yields, quality, and earliness, and for resistance to early leaf spot, rust, and groundnut rosette virus diseases.

Weather and growing conditions at Chitedze. Rainfall during the season (November 1985 to April 1986) was 1003 mm, 11% above the long-term mean of 898 mm. Distribution was good

Figure 8. An established hybrid (G 229, *Arachis hypogaea x Arachis* sp 276233) 3 months after grafting onto a groundnut seedling, ICRISAT Center, September 1986.

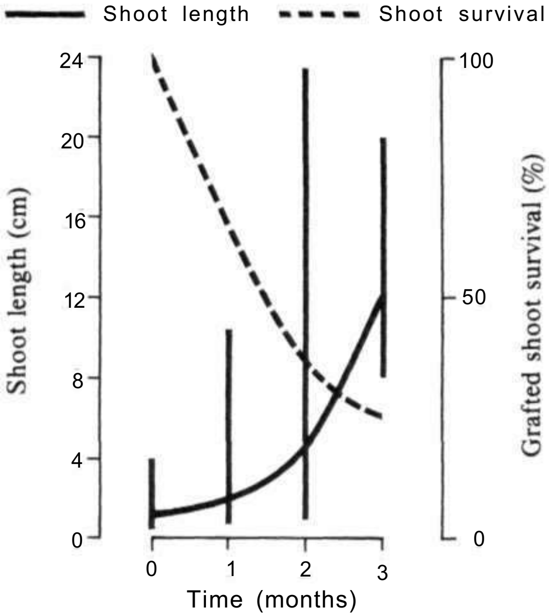


Figure 9. Growth of grafted hybrid groundnut shoots, and shoot survival (%). (Vertical bars indicate range of shoot lengths), greenhouse trial, ICRISAT Center, 1986.

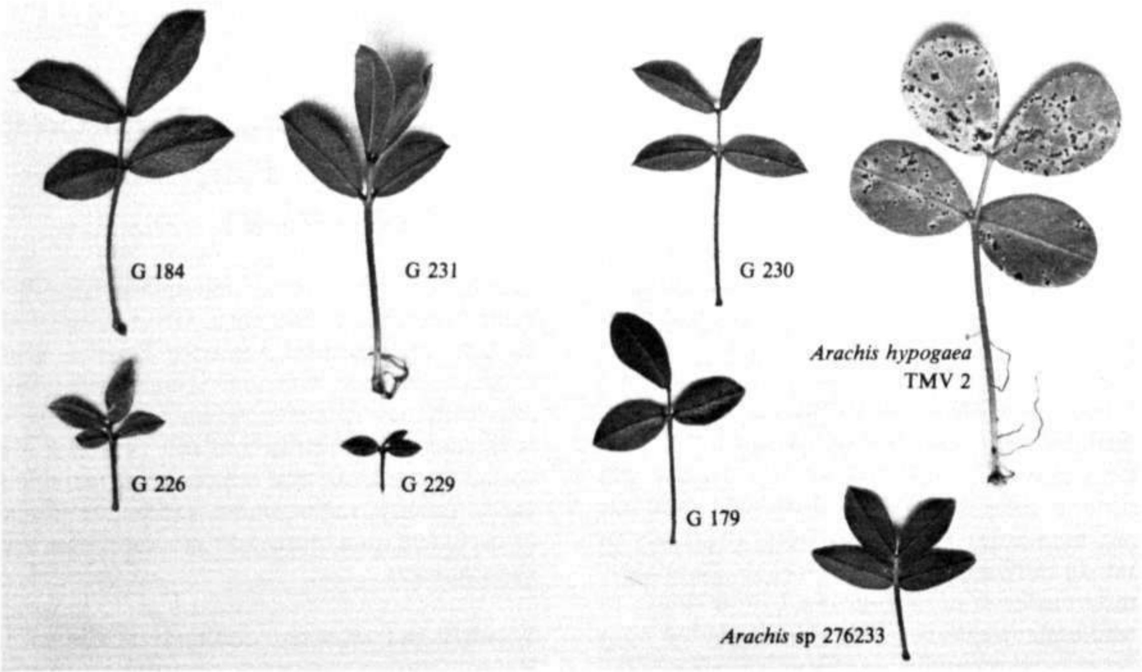


Figure 10. Rust reaction of leaves detatched from *Arachis hypogaea* TMV 2 (susceptible), *Arachis* sp 276233 (resistant), and six hybrid shoots (all resistant), laboratory test, ICRISAT Center, 1986.

and there were no dry spells; while this was conducive to high yields, it was also highly favorable for the development of early leaf spot.

The pH of soils in our fields ranges from 5.1 to 5.5 and available phosphate is generally low. We consequently applied 40 kg P_2O_5 ha^{-1}. Our hybridization block and F_1 generation plots received standard plant protection measures to control early leaf spot and aphids. All trials were sown on 60 cm ridges with either 10- or 15-cm spacing between plants according to the genotype's branching habit.

Fungal Diseases

Early Leaf Spot (*Cercospora arachidicola*)

Early leaf spot assumes epidemic proportions every season at Chitedze. Last year (ICRISAT Annual Report 1985, pp.249-250) we showed that the rate of leaf fall induced by early leaf spot was significantly slower than average in certain selections, particularly so in Valencia types, and that this seemed often, but not invariably, to be associated with high yield, indicating disease tolerance. To test this hypothesis and to estimate potential yields of our ICRISAT selections when early leaf spot was not a limiting factor, we controlled the disease in a number of selections by application of chlorothalonil at 10-day intervals, and compared yields from sprayed plots with yields from nontreated plots (Table 27).

Seed yields in excess of 5 t ha^{-1} were obtained from selections ICGMS 42 and ICGMS 30, an indication of the high yield potential of our germplasm accessions. When early leaf spot was not controlled, Virginia and Valencia selections gave the highest yields, and, with the exception of selections ICGMS 42 and 30, they responded least to control measures, suggesting that they have tolerance to early leaf spot. Rate of leaf fall was most rapid in Spanish types, where we recorded 50% defoliation by 93 days after emergence (DAE), slower in Virginia selections, where 50% defoliation occurred at 108 DAE,

Table 27. Response of selected Virginia, Valencia, and Spanish groundnut types to early leaf spot control, Chitedze, Malawi, 1985/86.

		Seed yield (t ha^{-1})		
Type	Identity	Nonsprayed	Sprayed	Response (%)
Virginia	ICGM 36	2.35	2.54	7.9
	Mani Pintar	3.62	4.22	16.4
	ICGM 623	3.40	4.28	25.8
	ICGMS 42	3.80	5.43	42.6
Valencia	ICGM 525	3.42	4.70	37.4
	ICGM 285	3.35	4.63	38.4
	ICGM 286	3.18	4.48	41.1
	ICGM 550	2.84	3.90	37.5
	ICGMS 30	3.34	5.87	76.1
Spanish	ICGMS 29	2.70	4.59	69.7
	ICGM 473	2.63	5.07	92.7
	Malimba	2.75	5.45	98.6
SE		±0.16		
Trial mean (24 entries)		3.86		
CV (%)		4.22		

and slowest in Valencia selections, where 50% defoliation occurred at 112 DAE.

We have initiated screening of wild *Arachis* species for resistance to early leaf spot under the exacting conditions at Chitedze. Out of 15 species tested, only three, *Arachis sp* 30003, *Arachis* sp 30085, and an accession of *A. chacoense,* showed very high levels of resistance which might warrant their use as parents in the generation of interspecific hybrids.

All 528 new germplasm and breeding material accessions received from ICRISAT Center and elsewhere were found to be susceptible to early leaf spot.

Virus Diseases

Groundnut Rosette Virus (GRV) Disease

Field incidence of GRV was again very low (<1%). But we managed a successful rosette screening nursery and achieved an overall GRV incidence of 98%.

Inheritance studies. We conducted a detailed study on the inheritance of resistance to GRV, using parents, F_1 and F_2 reciprocals, and their backcross generations. Preliminary φ^2 analyses of the ratio of susceptible to symptomless plants in the field confirmed earlier observations as to the double recessive nature of resistance, and of the absence of reciprocal differences in crosses involving parents of different botanical cultivars.

Vector ecology. We continued our studies on the dry-season ecology of the vector and virus by establishing 11 bait plots in western districts of the Central Region of Malawi in August 1986. All sites were infested with *Aphis craccivora,* but no plant developed rosette disease. We deduce that, while *A. craccivora* is continuously present throughout the dry season, host-plant reservoirs of rosette viruses, assuming these to be present, are not accessible until the onset of the rains.

The rosette viruses. GRV, the symptom-inducing agent of rosette, requires the presence of a second virus, groundnut rosette assistor virus (GRAV) for transmission by the aphid vector. In collaboration with the Scottish Crop Research Institute we studied the virus status of resistant and susceptible groundnut cultivars which had been heavily and repeatedly inoculated with both viruses by means of aphids. GRAV, but not GRV, was detected in all resistant cultivars, indicating that genes governing resistance to GRV do not confer resistance to GRAV.

Plant Improvement

Germplasm Evaluation

We evaluated 345 germplasm accessions obtained from the Zambia National Program and 60 newly collected germplasm accessions from Tanzania. Fifty lines are being further evaluated while the remainder are being maintained in our germplasm collection.

We carried out a final evaluation of 77 ICGM lines in three replicated yield trials, using cultivars important in the region as controls. Fifteen lines, 12 of which belong to the Valencia group, yielded significantly more than the highest-yielding control (Table 28).

We selected 8 alternately branching lines, 5 sequentially branching Spanish lines, and 12 sequentially branching Valencia lines for inclusion in regional trials. We have initiated a new regional trial for Valencia types in view of the importance and usefulness of this hitherto neglected group in southern Africa.

We have now successfully concluded the evaluation of 765 germplasm lines, and have identified 25 that have performed consistently well at Chitedze.

Hybridization

We completed a total of 151 crosses in the field. These included 63 crosses among breeding and germplasm lines (ICGMS 29, ICGMS 30, ICGM 285, ICGM 550, ICGMS 42, ICGM 336,

Table 28. Performance of some of the ICGM lines in the elite germplasm trial (Valencia), Chitedze, Malawi, 1985/86.

Identity	Origin	Time to maturity (days)	Pod yield (t ha^{-1})	Shelling %	100-seed mass (g)	Seed color	Mean early leaf spot score[1]
ICGM 284	Brazil	116	3.64	74	32	Red	9
ICGM 550	Sudan	115	3.57	67	53	Purple	8
ICGM 525	Argentina	116	3.52	67	47	Purple	8
ICGM 285	Brazil	108	3.42	73	38	Red	9
ICGM 286	Brazil	115	3.34	74	35	Red	9
ICGM 281	Bolivia	118	3.30	71	31	Red	9
ICGM 189	Brazil	115	3.28	75	35	Red	9
ICGM 197	Bolivia	115	3.20	75	30	Red	9
Control							
ICGMS 30	ICRISAT Malawi	124	2.83	70	38	Tan	9
SE		±1.1	±0.07				
Trial mean (36 entries)		110	2.7				
CV (%)		2.0	5.1				

1. Scored at 90 days after emergence on a 1-9 scale, where 1 = no disease and 9 = 50-100% of foliage destroyed.

ICGM 623, Egret, ICGM 473, H3/5, and OG 69-6-6-1 x NC Ac 17090) which had given high yields and had retained their leaves well under conditions of severe early leaf spot pressure at Chitedze. A total of 13900 pollinations were made which resulted in 2820 hybrid pods, a 20% success rate.

Twenty-four crosses among bold-seeded types (VAL 72, ICGM 376, TG 1, ICGM 419, ICGM 620, ICGM 367, Ah 114, RRI/24, RRI/6, and Chitembana) were made in the greenhouse; 2300 pollinations resulted in 400 hybrid pods, a success rate of 17%.

Breeding for Disease Resistance

Breeding material. We received 123 new rust- and late leaf spot-resistant interspecific derivatives and 85 *A. hypogaea* populations from ICRISAT Center. Thirty-four *A. hypogaea* populations were evaluated in a replicated yield trial and the remainder were sown in observation plots. All new populations were severely defoliated well before harvest. We selected 3 interspecific derivatives and 12 *A. hypogaea* populations and made 16 selections from them.

From 231 old F_3-F_{11} populations that included foliar diseases-, pest-, and *Aspergillus flavus*-resistant lines, we retained 110, and made 113 bulk and 11 single plant selections. Eight bulk selections and one single plant selection were rated visually as good for pod yield. These selections were 85/FDRS/18 (Colorado Manfredi x DHT 200) F_7-B_1, 85/FDRS/18 (Colorado Manfredi x DHT 200) F_7-B_2, 85/Rust F_4/19 (ICGS 1 x (SM 1 x EC 76446(292)))F_5-B_1 85/Rust F_4/19 (ICGS 1 x SM 1) x EC 76446(292)F_5-B_2, 85/Rust F_5/16 (Manfredi x M 13)x PI215696)F_6-B_1, 85/Rust F_5/ 16(Manfredi x M 13) x PI215696) F_6-B_2; 85/Rust F_7/23(J 11 x TG 3) x NC Ac 17090)F_7-B_1, 85/Rust F_7/24(J 11 x TG 3) x NC Ac 17090)F_7-B_1, and 85/SPS/98((Chico x PI 259747) x Robut 33-1 10-3)F_5-P_2-B_1.

A total of 71 selections were identified for advance into replicated yield trials.

Yield trials. In the replicated yield trial of the new foliar disease-resistant material, four selections significantly outyielded the control cultivar ICGMS 2. Based on pod shape, seed color, and pod yield, 10 selections were promoted to the elite yield trial and one to the regional yield trial. Most of these selections scored 8 or 9 for early leaf spot at harvest time on a 9-point scale where 1 = no disease and 9 = 50-100% foliage destroyed.

Rosette resistance screening. We screened 26 F_2 populations in the field, and retained 108 out of 1263 symptomless plants. Of these, 20 belonged to the sequentially branching group.

We also screened 161 plant progenies arising from rosette-resistant F_2 plants, and 35 bulk progenies arising from bulked symptomless F_2 plants which were subsequently found to be susceptible in greenhouse tests. We made 24 plant and 20 bulk selections from this material. These will be screened again in the 1986/87 season.

Breeding for High Yield and Quality

Breeding material. We sowed 79 F_1 crosses to confirm their hybridity and to advance them to the next generation; four were rejected because of doubtful hybridity. Most crosses which involved indigenous cultivars and promising ICRISAT breeding and germplasm lines performed poorly.

We grew 607 F_2-F_{13} populations for visual selection for pod yield and discarded 455. From the remainder we made 159 bulk and 33 single plant selections. We identified 81 bulk selections for replicated yield trials, and kept the remainder for further selection and generation advance. The performance of most of the selections was visually rated either as average or average-to-good. We made two good Virginia bunch selections from an F_2 population, Egret x ICGMS 5.

Yield trials. We evaluated 40 confectionery groundnut lines in two replicated yield trials. Only two cultivars, M 13 and SP 1, significantly outyielded the local cultivars, Chalimbana and Chitembana. In general, there was a marked reduction in seed size of introduced confectionery lines. Among the introduced material the highest 100-seed mass (67 g) was recorded for ICGV 86547 and 1CGV 86564 but this was lower than the average for the local confectionery cultivars Chitembana (79 g) and Chalimbana (92 g).

We evaluated 153 breeding populations in four replicated trials. Of the 42 tested in preliminary trials, seven outyielded the highest-yielding control. Of the 101 tested in elite trials, 33 gave significantly higher pod yields than the highest-yielding control. The performance of some of these lines is shown in Table 29. Twenty-four lines were promoted to our regional trials.

Regional Trials

The Virginia cultivar trial was grown at three locations in two countries and the Spanish cultivar trial at seven locations in four countries.

At all three Virginia trial sites, ICGMS 42 maintained its significant pod yield superiority over local varieties.

Spanish cultivar trials in Mozambique (Maputo), Botswana (Sebele), Malawi (Ngabu and Lupembe), and Zambia (Magoye), were adversely affected by highly variable emergence, poor plant stands, or very low shelling percentages, with consequently high coefficients of variation; yield differences were not significant. However, at Chitedze (Malawi) ICGMS 5, 11, 29, and 30, and at Masumba (Zambia) ICGMS 11, 12, 15, and 31, significantly outyielded the best local control entries.

We supplied sets of regional trials seed for the 1986/87 season to Angola, Botswana, Lesotho, Malawi, Mozambique, Zambia, and Zimbabwe.

Regional Program for West Africa

The groundnut improvement program was established at the ICRISAT Sahelian Center

Table 29. Performance of some of the breeding populations in elite yield trials, Chitedze, Malawi, 1985/86.

Entry	Pedigree	Time to maturity (days)	Pod yield (t ha^{-1})	Shelling %	100-seed mass (g)	Seed color	Mean early leaf spot score[1]
Alternate branching							
ICGMS 49	84/Phoma/7-B_1(P84/6/20)-B_2	154	5.16	69	60	Red	8
ICGMS 50	84/Phoma/6-B_1(P84/6/20)-B_1	155	5.00	71	48	Red	8
ICGMS 51	84/Phoma/5-B_1(P84/6/12)-B_1	162	4.74	66	53	Tan	8
ICGMS 52	84/ PP/ 140-B_1(CG st.20/ 1)-P1	141	4.34	75	62	Tan	9
ICGMS 53	84/ISMT/31(CS 43)-B_1	155	4.13	76	46	Tan	9
Local control							
Mawanga		153	4.01	68	54	Variegated	8
SE		±2.3	±0.06				
Trial mean (64 entries)		138	3.29				
CV (%)		3.3	3.8				
Sequential branching							
ICGMS 55	84/Phoma/ 10-B_1 (ICGM 291-B_1)	123	3.82	65	48	Tan	9
ICGMS 56	84/HYQF 9-B_1 (Goldin 1 x Faizpur 1-5 x Manfredi x M 13)	124	3.02	69	30	Red	9
ICGMS 57	84/RYT/8(JH 60 x PI 259747)-B_1	123	2.86	68	37	Purple	8
ICGMS 58	84/HYQBST/11(ICGS 51)	124	2.80	67	44	Red	8
ICGMS 59	84/RYT/5(Colorado Manfredi x DHT 200)-B_1	101	2.78	75	35	Red	9
Local control							
Malimba		109	2.13	75	28	Tan	9
SE		±1.5	±0.06				
Trial mean (36 entries)		*111*	2.37				
CV (%)		2.6	4.9				

1. Scored at 90 days after emergence on a 1-9 scale, where 1 = no disease and 9 = 50-100% of foliage destroyed.

(ISC), Niamey, Niger, in 1986. Cooperating with the national and international research programs on groundnut in West Africa, the ISC Groundnut Program aims to develop high-yielding breeding lines adapted to various agro-ecological zones in West Africa with resistance to the biotic and physical stress factors that limit groundnut production, to develop agronomic practices suitable for small farmers in the region. An agronomist has already been appointed and a breeder and a pathologist will join the team in early 1987. As an interim arrangement, ICRISAT Center seconded a pathologist to ISC during the 1986 rainy season to survey the diseases of groundnut in Niger, to identify suitable locations for the 1987 rainy-season trials, and to help prepare the work plan for the Groundnut Program at ISC.

Useful contacts for cooperative research were established with various scientists working on groundnuts in national programs and with l'Institut de recherches pour les huiles et oleagineux

(IRHO) and the Peanut Collaborative Research Program (Peanut-CRSP) in Burkina Faso, Guinea, Niger, and Nigeria.

Multiplication of Germplasm and Breeding Lines

One hundred and sixty-two high-yielding breeding lines and 67 germplasm lines selected for resistance to rust, late leaf spot, *Aspergillus flavus,* jassids, thrips, drought, and for confectionery purposes, obtained from ICRISAT Center were multiplied in field plots at Bengou, Niger, during the 1986 rainy season. These lines will form a genetic base for future research at the ISC. They have been harvested and are being evaluated.

Cooperative Activities

Asian Grain Legumes Network

The Asian Grain Legumes Network (AGLN), known until 17 December 1986 as the Asian Grain Legume Program (AGLP), was initiated at the beginning of 1986 to strengthen the collaboration between ICRISAT's Legumes Program and scientists in Asia working on ICRISAT's three mandate legume crops; groundnut, chickpea, and pigeonpea. The concept for this Network came from two meetings held at ICRISAT Center, the Consultative Group Meeting for Asian Regional Research on Grain Legumes, 11-15 December 1983, (ICRISAT Annual Report 1983, p. 225) and the Review and Planning Meeting for Asian Regional Research on Grain Legumes, 16-18 December 1985, (ICRISAT Annual Report 1985, p. 258).

The Coordinator of the Network was appointed on 1 January 1986 with an Office in the Legumes Program at ICRISAT Center. The Network has a special relationship with India because of the many cooperators associated with ICRISAT through ICAR. The Coordinator visited the People's Republic of China in late 1985 and will visit again early in 1987. During 1986 the Coordinator visited all the other countries that are presently in the Network (Bangladesh, Burma, Indonesia, Nepal, Pakistan, The Philippines, Sri Lanka, and Thailand). Contact has been made with other countries in Asia and visits made to the Republic of Korea, Japan, and Taiwan.

These visits have been used to carry through the recommendations put forward by the Review and Planning Meeting mentioned above. Contacts were made to integrate AGLN activities with those of regional and international organizations. Preliminary surveys were made to determine disease and pest incidence as a basis for recommending appropriate research activities. Enquiries were made on the need to collect germplasm of the three legume crops in each country. Plans were made with the Regional Co-ordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber crops in the Humid Tropics of Asia and the Pacific (CGPRT) in Bogor, Indonesia, to conduct a socioeconomic survey of groundnut in Indonesia and Thailand. The need for joint special projects with national programs for basic studies were ascertained. Training requirements and personnel requiring training were identified. An indication of the agroclimatological data available in each country was obtained. These data can be used to identify agroecological zones, within which specific legume genotypes can be recommended. A genotype × environment study, in conjunction with the Australian Centre for International Agricultural Research (ACIAR), was planned.

The Director General of ICRISAT signed a Memorandum of Understanding (MOU) in Dhaka, Bangladesh on 9 September 1986 with the Director General of the Bangladesh Agricultural Research Institute and another in Rangoon, Burma on 10 September 1986 with the Managing Director of the Agriculture Corporation. These MOU's indicate the interest these countries have in collaborating with ICRISAT on research on grain legume crops, and will facilitate the movement of scientists and material between ICRISAT and these countries. ICRI-

SAT already has MOU's with Pakistan, The Philippines, and Thailand.

Cooperation with AICORPO

During the 1986 rainy season we grew ten rainfed and three irrigated AICORPO-sponsored trials on Alfisols at ICRISAT Center.

All rainfed trials failed due to severe drought in October. The irrigated trials included two Hand Picked Selection Varietal Trials (HPS VT) and one Bud Necrosis Disease Resistant Varietal Trial (BNDRVT). In the HPSVT (New), ICGV 86028 and in the HPSVT (Old), ICG(CG)S 15 gave marginally higher yields than the control cultivar M 13. In the BNDRVT, four ICRISAT selections, ICGV 86029, ICGV 86030, ICGV 86031, and ICGV 86032 significantly outyielded both controls, JL 24 and TMV 2. The best line, ICGV 86030 gave 3.4 t pods ha^{-1} compared to the 2.3 t ha^{-1} of JL24.

The current status of ICRISAT lines undergoing rainy and postrainy multilocational testing in the AICORPO system is shown in Tables 30 and 31. ICGS 44, that could not be evaluated in the 1985/86 postrainy season adaptive trials in the Western Zone (Gujarat), is now being tested in the 1986/87 postrainy season.

International Trials

Early-maturing Varietal Trial

An international trial consisting of 24 early maturing lines was constituted and sent to 17 locations in Asia (10), Africa (5), and North America (2). Results of the trials received during 1986 were quite encouraging. In Haiti, ICGV 86061 yielded 51% more seed and matured seven days earlier than the local control. In the Philippines, ICGV 86077 produced 1.8 t pods ha^{-1} as against 0.9 t ha^{-1} from the local control cultivar. ICGV 86063 gave 3.4 t pods ha^{-1} compared to 2.6 t ha^{-1} from the local control, Tainan 9, in Thailand. At the Institute of Plant Breeding at Laguna in The Philippines, five of the ICRISAT lines were identified as new sources of earliness. These lines matured 10 days earlier than the commercial cultivar UPL-PN 4.

Confectionery Groundnut Varietal Trial

An International Confectionery Groundnut Varietal Trial was sent to 27 locations in: Asia (13), Africa (10), North America (2), South America (1) and Europe (1). In the 1985 trial, the larger-seeded ICGV 86573 (100-seed mass >70 g) outyielded the local controls in Burkina Faso, Cyprus, Gabon, Senegal, Sudan, and USA. In Cyprus, ICGV 86564 was found superior both in seed size (100-seed mass 99 g) and pod yield (7.2 t ha^{-1}), to the local control (100-seed mass 84 g and pod yield 6.8 t ha^{-1}). This line is being considered for release in Cyprus. Similary, ICGV 86564 gave 60% higher pod yield (3.1 t ha^{-1}) than the local control, Banki, in Pakistan.

Foliar Diseases Resistance Trial

An International Foliar Diseases Resistance Trial with 46 rust- and/ or late leaf spot-resistant selections was sent to 8 countries in 1986. Results from the 1985 trial indicated superior performance of resistant ICRISAT lines in Thailand and Bangladesh. In Thailand ICG(FDRS) 64 gave 3.9 t ha^{-1} compared to 2.2 t ha^{-1} by the rust-susceptible local control, Tainan. In Bangladesh, ICG(FDRS) 42 gave 3.6 t pods ha^{-1} compared to 1.6 t ha^{-1} by the local control, Dacca 1.

Pest Resistance Trial

In 1986 we sent an International Pest Resistance Groundnut Varietal Trial with 9 entries to 12 countries. In Bangladesh, several ICRISAT-bred pest-resistant selections outyielded the local control. The best line, ICGPRS 92, gave 3.8t dried pods ha^{-1} as against 21 ha^{-1} from the local control, Dacca 1.

Table 30. Current status of ICRISAT entries in AICORPO rainy-season trials 1986.

Trial	Entry	Zone[1]
Adaptive Trials	ICGS 11, 1,5	1
	ICG (FDRS) 4	5
National Elite Trial (Virginia runner)	ICG 2271	6
National Elite Trial (Virginia bunch)	ICGS 4, 6	4,5
	ICGS 47	1
National Elite Trial (Spanish bunch)	ICG (FDRS) 4	3,4
	ICG (FDRS) 10, ICGS 44-1	1.5
	ICGS 51	3,4
	ICGS 26	4
	ICG (FDRS) 1	5
	ICG (FDRS) 23	1
Coordinated Varietal Trial (Virginia bunch)	ICGS 76	4,5
	ICGS 65, 76, 49, 18	4
	ICG (C) 8, 12	5,6
	ICGS 79	5
	ICG (PRS) 92	6
Coordinated Varietal Trial (Spanish bunch)	ICG (FDRS) 43	1,3,4,5,6
	ICGS 82	1,3
	ICGS 81	1,6
	ICGS 57, 44-1, 75, ICG (FDRS) 1	4
Initial Evaluation Trial (Virginia runner)	ICG 2271	3,4,5
Initial Evaluation Trial (Virginia bunch)	ICG (PRS) 92	2,5
	ICGS 65	2
	ICGV 86001 to 86007	1, 2, 3, 4, 5, 6
Initial Evaluation Trial (spanish bunch)		
Old	ICGS 75	3
New	ICGV 86008 to 86013	1, 2, 3, 4, 5, 6
Extra Early Varietal Trial	ICGV 86014 to 86017	1,2,3,4,5,6
Hand Picked Selections Varietal Trial		
Old	ICG(CG)8 10 to 13, 17 to 21, 49	1,2,3,5,6
New	ICGV 86024 to 86028	1, 2, 3, 5, 6
Foliar Disease Resistant Varieties Trial	ICG (FDRS) 34	10 selected locations
	ICGV 86018 to 86023	
Bud Necrosis Disease Resistant Varietal Trial	ICGS 11, ICG(FDRS)4, ICGV 86029 to 86034	In selected locations

1. Zone 1 - Northern zone (Uttar Pradesh, Parts of Haryana, Punjab, Rajasthan, and Bihar).
Zone 2 - Western zone (Gujarat).
Zone 3 - Central zone (Parts of Maharashtra and Madhya Pradesh).
Zone 4 - Southeastern zone (Orissa and West Bengal).
Zone 5 - Peninsular zone (Andhra Pradesh, Karnataka, and parts of Maharashtra).
Zone 6 - Southern zone (Tamil Nadu).

Table 31. Current status of ICRISAT entries in AICORPO postrainy (rabi/summer) season trials, 1986/87.

Trial[1]	Entry	Zone[2]
National Elite Trial	ICGS 37	Northern
Coordinated Varietal Trial	ICGS 21,44, ICG(FDRS)33	Southern
Initial Evaluation Trial		
Old	ICGS 103, 105, 84, 103, 105	Northern and Southern
New	ICGS 87, 109, ICG (FDRS) 61, 68	Northern and Southern
Initial Evaluation Trial (early lines)	ICGS (E) 21, 18,20	Northern and Southern

1. All postrainy-season entries are Spanish bunch types.
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.

ICRISAT Breeding Lines in National Trials

We have supplied seed of high-yielding breeding lines to various countries, and our cooperators are using several of them in their groundnut improvement programs. ICGS 11, 12, 25, 33, and 36 are in intercropping trials in Burma; ICGS 36, 39, and 43 are producing pod yields of 3.5-4.6 t ha^{-1} in trials in Surinam; ICGS 6,11,35, 44, 76, and 812 are yielding 3 t ha^{-1} in trials in Bangladesh; and ICGS 4, 33, 34, 37, and 44 are yielding over 3.5 t pods ha^{-1} in Pakistan.

Workshops, Conferences, and Seminars

Second Regional Workshop on Groundnut Research and Improvement in Southern Africa

The meeting took place in Harare, Zimbabwe, 10-14 February. There were 28 participants representing national research programs in Botswana, Ethiopia, Mozambique, Swaziland, and Zambia. ICRISAT Center scientists presented special papers on the utilization of wild *Arachis* species in groundnut improvement, and on groundnut entomology. The ICRISAT regional team reviewed progress and activities subsequent to the first workshop held in 1984 in Lilongwe (ICRISAT Annual Report 1984, p.243). National program scientists reported on their research progress in groundnut breeding, agronomy, pathology, and entomology. The proceedings of the workshop are in press and will be available from Information Services, ICRISAT.

Groundnut Scientists' Meet

The meeting was held at ICRISAT Center, India, 29-30 September. There were 22 participants, most of whom were cooperating scientists from AICORPO, but also included representatives of national groundnut programs from Nepal, Pakistan, and Sri Lanka. Visiting scientists, in-service fellows, and trainees attended the field visits and discussion groups. ICRISAT groundnut scientists demonstrated their research work in both fields and laboratories. Participants from Nepal, Pakistan, and Sri Lanka outlined groundnut production constraints and described ongoing research in their countries, and representatives of the major groundnut-growing states of India reported problems and research progress in their areas. There was a special session on strategies for enhancing groundnut production in South Asia, where participants discussed the failure to increase groundnut production in the region, and considered how best to close the gap between the present low average and high potential yields.

Looking Ahead

Drought. We will continue to study mechanisms determining genotypic variation in drought recovery and tolerance. Screening of germplasm and breeding lines for drought tolerance will continue at ICRISAT Center and research will be initiated in West Africa. There will be continued interest in interactions of drought with fungal invasion of pods and with calcium nutrition.

Diseases. Research on foliar fungal diseases will continue to receive high priority. In India, the emphasis will be on breeding for resistance to late leaf spot and rust. Screening for resistance to early leaf spot will be expanded with greenhouse trials at ICRISAT Center and field trials in northern India. Field screening for resistance to early leaf spot disease will be expanded in southern Africa and will start in the West African program. There will be increased emphasis on development of interspecific hybrid material for early leaf spot resistance. We will continue to evaluate cultivars with resistance to rust and late leaf spot in cooperation with national and regional programs, and to study the economics of foliar diseases management in cooperation with ICRISAT economists.

We will continue to give high priority to research on the aflatoxin problem. Studies will continue on the interactions between drought, soil temperature, and invasion of pods and seeds by the aflatoxigenic fungi *Aspergillus flavus* and *A. parasiticus.* Cultivars with resistance to pod and seed invasion by these fungi will be evaluated in different environments in cooperation with regional and national programs.

Research on pod and stem rots caused by *Sclerotium rolfsii* will be increased with particular reference to groundnuts grown on Vertisols.

The research on groundnut rosette virus disease will continue to be coordinated from ICRISAT Center, with studies on epidemiology and resistance breeding being based in the southern Africa Program. This work will be supplemented by research in West Africa by the groundnut research team now based at ISC. We shall also coordinate research into peanut stripe virus in East Asia in cooperation with national and regional programs. Further disease surveys are planned for Asia and Africa.

Insect pests. We shall continue to give priority to incorporating resistance to the thrips vector of bud necrosis disease into high-yielding, commercially acceptable cultivars. A similar approach will be made to breeding for jassid resistance.

Wild *Arachis* species and interspecific hybrid derivatives will be screened for resistance to the tobacco caterpillar and aphids, particularly *Aphis craccivora* the vector of rosette virus in Africa and of other important groundnut viruses worldwide.

Research to develop integrated pest management systems will continue using computer programs to determine optimal use of insecticides.

In cooperation with TDRI we will further investigate the damage caused to groundnut by termites, and work on their management.

We will carry out surveys in Asia and Africa to determine the status of groundnut pests.

Plant nutrition. We shall place less emphasis on symbiotic nitrogen fixation but give higher priority to investigating the role of mycorrhizae in groundnut nutrition. Utilization of rock phosphate by various groundnut genotypes and VAM-fungal combinations will be studied.

There will be further investigation of the calcium requirement of groundnut pods. Higher priority will be given to research on iron chlorosis.

Photoperiod effects. In collaboration with the University of Bonn we will continue research into the response of groundnut genotypes to different photoperiods. We shall continue our research into the interaction of photoperiod with resistance in some groundnut genotypes to foliar fungal diseases.

Plant improvement. Breeding for resistance to stress factors and adaptive breeding for particular traits will continue. We will extend evaluation of short-duration, foliar diseases-resistant, and confectionery cultivars, to different countries. Cooperative research with ICRISAT biochemists into seed quality factors for confectionery groundnuts, and into oil quality will be expanded.

We will continue to screen new accessions of wild *Arachis* species for useful traits and incorporate them into desirable agronomic backgrounds.

Publications

Institute Publications

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502324, India: ICRISAT. ISBN 92-9066-112-7. (CPE 038)

Journal Articles

Bunting, A.H., Gibbons, R.W., and Wynne, J.C. 1985. Groundnut *(Arachis hypogaea* L.). Pages 747-800 *in* Grain legume crops (Summerfield, R.J., and Roberts, E.H., eds.). London, UK: Collins.

Dwivedi, S.L., Amin, P.W., Rasheedunisa, Nigam, S.N., Nagabhushanam, G.V.S., Rao, V.R., and Gibbons, R.W.1986. Genetic analysis of trichome characters associated with resistance to jassid *(Empoasca kerri* Pruthi) in peanut. Peanut Science 13(1): 15-18. (JA518)

Mehan, V.K., McDonald, D., and Ramakrishna, N. 1986. Varietal resistance in peanut toaflatoxin. Peanut Science 13(1): 7-10. (JA 548)

Mehan, V.K., McDonald, D., Ramakrishna, N.,and Williams, J.H. 1986. Effects of genotype and date of harvest on infection of peanut seed by *Aspergillus flavus* and subsequent contamination with aflatoxin. Peanut Science 13(2):l-5. (JA 563)

Singh, A.K. 1986. Utilization of wild relatives in the genetic improvement of *Arachis hypogaea* L. 7. Autotetrapolid production and prospects in interspecific breeding. Theoretical and Applied Genetics 72(2): 164-169. (JA 516)

Singh, A.K. 1986. Utilization of wild relatives in the genetic improvement of *Arachis hypogaea* L. 8. Synthetic amphidiploids and their importance in interspecific breeding. Theoretical and Applied Genetics 72(4):433-439. (JA 530)

Singh, A.K., Venkateshwar, A., Rau, T.P.S., and Moss, J.P. 1986. Modified C and QF chromosome banding for *Arachis* L. chromosomes. Current Science 55(18):942-944. (JA 590)

Conference Papers

Gibbons, R.W. 1986. Biological constraints to increased groundnut production in the semi-arid tropics. Pages 47-61 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP252)

Mehan, V.K., McDonald, D., and Subrahmanyam, P. 1986. Bacterial wilt of groundnut: control with emphasis on host plant resistance. Pages 112-119 *in* Bacterial wilt disease in Asia and the South Pacific: proceedings of an International Workshop, 8-10 Oct 1985, Los Banos, Laguna, Philippines. Canberra, Australia: Australian Centre for International Agricultural Research. (CP 230)

Moss, J.P., and-Sastri, D.C. 1986. Wide hybridization in *Arachis:* problems and prospects. Pages 41-50 *in* New genetical approaches to crop improvement (Siddiqui, K.A., and Faruqui, A.M., eds.). Karachi, Pakistan: PIDC Printing Press. (CP 67)

Reddy, D.V.R., Nene, Y.L., and McDonald, D. 1986. Virus disease problems of groundnut, chickpea, and pigeonpea in Asia. Pages 67-75 *in* Virus diseases of rice and leguminous crops in the tropics: proceedings of an International Symposium, 1-5 Oct 1985, Tsukuba, Japan. Tropical Agricultural Research Series No. 19. Tsukuba, Ibaraki, Japan: Tropical Agriculture Research Center, Ministry of Agriculture, Forestry and Fisheries. (CP 237)

Singh, A.K. 1986. Alien gene transfer in groundnut by ploidy and genome manipulations. Pages 207-209 *in* Genetic manipulation in plant breeding. Proceedings of an international Symposium, 8-13 Sept 1985, West Berlin, Federal Republic of Germany (Horn, W., Jensen, C.J., Odenbach, W., and Schieder, O., eds.). West Berlin, Federal Republic of Germany: Walter de Gruyter and Co. (CP 227)

Sivakumar, M.V.K., and Sarma, P.S. 1986. Studies on water relations of groundnut. Pages 83-98 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, JCRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 244)

Williams, J.H., Nageswara Rao, R.C., Matthews, R., and Harris, D. 1986. Responses of groundnut genotypes to drought. Pages 99-106 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 254)

Williams, J.H., Nageswara Rao, R.C., and Vasudeva Rao, M.J. 1986. Breeding for drought tolerance on groundnut *(Arachis hypogaea* L.). Pages 207-222 *in* proceedings of the Workshop on Varietal Improvement for Rice-based Farming Systems, 11-15 Mar 1985, Phitsanulok, Thailand. Los Banos, Laguna, Philippines: International Rice Research Institute. (CP 226)

Thesis

Soumano, D. 1986. Heterosis and heritability estimates in crosses of Virginia and valencia-type groundnuts *(Arachis hypogaea* L.). M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 65 pp.

RESOURCE MANAGEMENT

Contents

Cover photo: Distributing sensors used to measure light interception, atmospheric humidity, and windspeed in alley-cropped leucaena on an Alfisol. These sensors are linked to the mobile laboratory in the background that houses the datalogger and other instruments used to measure aspects of crop physiology. ICRISAT Center, postrainy season 1986.

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RESOURCE MANAGEMENT

The Resource Management Program (RMP), now one year old, seeks to integrate research over a wide range of disciplines from the physical sciences through engineering and agronomy to economics and sociology. Terms of reference are also broad, but the primary objective of the Program can be stated in simple terms: to develop systems of production which match material from ICRISAT's crop improvement programs to the physical and social environments prevailing in the semi-arid tropics (SAT). In this context, "matching" means attempting to maximize production without sacrificing stability of yield from year to year and without squandering irreplaceable resources such as topsoil and groundwater reserves.

In terms of methodology, the program has three broad divisions which cut across its component disciplines. First, the resources of the SAT are measured at experimental sites (mainly in India and West Africa at present), at collaborating centers, on farmer's fields, and in villages. This information is analyzed, assessed, and stored in comprehensive data bases, comparable in function to the germplasm stored in the Genetic Resources Unit (GRU) and accessible to specialists both nationally and internationally. For example, records from the long series of Village Level Studies (VLS) have been provided to more than 30 groups throughout the world. The collection and analysis of rainfall records is also central to the work of the Program because the undependable distribution of rain within growing seasons limits the manipulation of all other resources within the SAT.

The second main thrust of research is implicit in the name of the Program: the management of resources by procedures such as land shaping, water conservation, cultivation and fertilizer application, pest and weed control, and attempts to increase productivity by growing species in mixtures. The report that follows describes how such management practices attempt to overcome constraints on production which rarely operate independently.

Finally, the Program monitors the rate at which new technology generated by ICRISAT and by other research centers spreads through the work of extension services. The impact of new hybrids or new management techniques on individual villages is then analyzed in terms of increased food supplies and their consequences for general well-being. This exercise provides the feedback that is essential for further improvements in technology.

As this report demonstrates, the RMP has active links with scientists in the two Crop Improvement Programs, and with staff in a number of national universities as well as in organizations such as the Indian Council for Agricultural Research (ICAR). International collaboration includes projects sponsored by universities and institutions in Europe, Japan, and North America.

Even in very simple agricultural systems, the use of resources by farmers involves the intuitive exploitation of many interacting resources. There is therefore no uniquely logical way of presenting the work of RMP which spans two continents, several major soil types, a range of rainfall regimes, and many different cropping systems. In the 1985 Annual Report, the main division was by soils but a methodological basis has been chosen for 1986. This arrangement emphasizes the point that, throughout the SAT, the same fundamental processes need to be explored and understood before resources can be managed with maximum efficiency.

Measurement and Analysis of Resources

Physical

Agroclimatic Zonation for West African Semi-Arid Tropics

Rainfall in West Africa shows a significant north-south gradient because of the interseasonal movement of the Intertropical Convergence Zone north and south of the equator. A range of natural vegetation patterns lies along this gradient. Almost all the climatic zonation schemes developed for West Africa have used these two criteria, i.e., mean annual rainfall and vegetation. However, the existing schemes may be considered inadequate in terms of research on crop improvement. Mean annual rainfall alone cannot be considered as a sufficiently useful index of probable season length since the potential evapotranspiration (PE), which changes from one region to another, influences the proportion of rainfall available for crop growth. Moreover, for annual cereal crops which are sown and harvested according to rainfall patterns in a given year, the most important constraint is the available length of the growing season. In addition, soil characteristics such as texture, slope, and water-holding capacity play a very important role in cultivar performance.

As criteria for soil-climatic zonation we have therefore used the length of the growing season, computed from monthly rainfall and PE for 157 stations in West Africa, and the soil type. We used growing season lengths of 60-100 days for the Southern Sahelian Zone, 100-150 days for the Sudanian Zone, and 150-210 days for the Northern Guinean Zone. The choice of these groups is also based on the present knowledge of predominant maturity durations of pearl millets and sorghums grown in West Africa. Growing season isolines for West Africa were superimposed on the Food and Agriculture Organization of the United Nations (FAO)/United Nations Education, Scientific and Cultural Organization (UNESCO) map. In order to identify a manageable number of soil/climatic zones, we used only the dominant soil, instead of the associated soils or the soil inclusions defined in the FAO/UNESCO map. From the extent of coverage of soils in each climatic zone, the priority soil/climatic zones in West Africa could be reduced to 17 and are shown in Table 1 in order of their approximate extent.

Probabilities of Dry Spells for Sorghum and Pearl Millet Cultivation in West Africa

Precipitation probabilities are available for several locations in West Africa. These provide useful information, but are still insufficient to answer the specific question of probabilities of dry spell occurrences, since there are occasions when dry-spell frequency is higher and seems unrelated to rainfall totals. Common procedures for computation of dry spells are often based on a monthly calendar. These analyses have only limited value for specific applications to sorghum and pearl millet in West Africa since the sowing dates of these crops and their phenology change with rainfall distribution each year. To overcome this problem, we used the specific definition of 'onset of rains', in each year as the sowing date and computed the length of dry spells (or days until next day with rainfall greater than a threshold value) at different probability levels.

Dry-spell lengths at 90% probability level for Niamey, Niger (mean annual rainfall 560 mm), Kaolack, Senegal (800 mm), Ouagadougou, Burkina Faso (830 mm) and Sikasso, Mali (1300 mm) are shown in Figure 1. These records show that dry spells in the phase from emergence to panicle initiation up to 20 days after sowing (DAS), are more probable than those during the panicle initiation to flowering phase (20-60 DAS). At Niamey, the length of dry spells increases with time after 90 DAS. Kaolack and Ouagadougou, with nearly similar mean annual rainfall, show some differences in the lengths of dry spells. The length of dry spells becomes progressively longer after 90 DAS at Kaolack and after 120 DAS at Ouagadougou. Since the dry-

Table 1. Soil/climatic zones, their approximate extent and priority ranking in the West African semi-arid tropics.

Soil type	Climatic zone	Length of growing season (days)	Approximate extent (10^6 ha)	Percentage of total area	Priority ranking
Luvisols	Sudanian	100-150	32.0	16.7	1
Arenosols	Southern Sahelian	60-100	30.0	15.6	2
Luvisols	Northern Guinean	150-210	20.7	10.8	3
Luvisols	Southern Sahelian	60-100	10.3	5.4	4
Acrisols	Northern Guinean	150-210	10.6	5.5	5
Nitosols	Northern Guinean	150-210	5.0	2.6	6
Vertisols	Sudanian	100-150	5.5	2.8	7
Vertisols	Southern Sahelian	60-100	4.0	2.1	8
Regosols	Sudanian	100-150	12.2	6.4	9
Regosols	Southern Sahelian	60-100	7.5	3.9	10
Nitosols	Sudanian	100-150	2.9	1.5	11
Fluvisols	Northern Guinean	150-210	2.2	1.1	12
Fluvisols	Sudanian	100-150	3.9	2.0	13
Fluvisols	Southern Sahelian	60-100	2.5	1.3	14
Arenosols	Sudanian	100-150	2.2	1.2	15
Vertisols	Northern Guinean	150-210	1.8	0.9	16
Planosols	Southern Sahelian	60-100	2.4	1.3	17

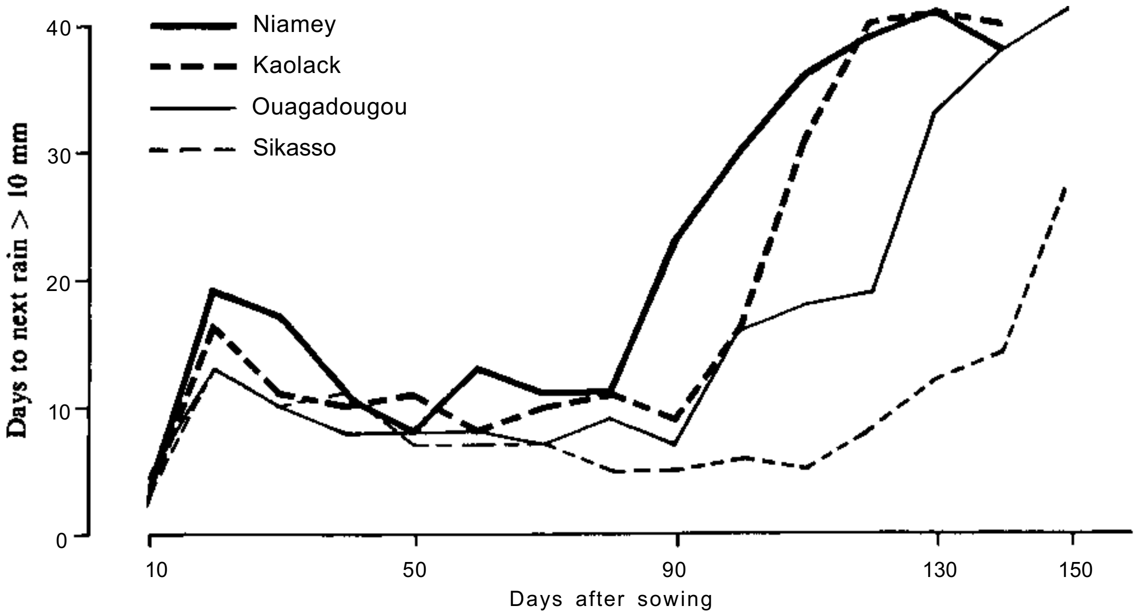

Figure 1. Number of days until the next rainfall greater than 10 mm (at 90% probability level for at least 50 years data) at selected locations in West Africa.

spell analysis shown in Figure 1 is based on the computed date of sowing for each year of rainfall records available, these data could be used as a guide for the various maturity durations of varieties when breeding at different locations. Breeding strategies should be oriented towards maturity in 80 days at Niamey, in 90 days for Kaolack, 110 days for Ouagadougou, and 140 days for Sikasso.

Predicting and Exploiting Rainy-season Potential from the Onset of Rains in the Sudano-Sahelian Zone

The unpredictable and variable nature of rainfall in West Africa has been extensively studied and is often given as the reason for frequent crop failures. Although the existence of long-term trends is uncertain, it is clear that rainfall series for regions immediately south of the Sahara contain extended periods of both high and low rainfall. Unfortunately no strategies have yet been evolved in the Sahelian region to cope with such climatic variations by considering actual or intraseasonal weather. We have developed a methodology termed "Weather-responsive crop management tactics" that combines knowledge from the analysis of historical rainfall data with current weather to make changes in management depending on the onset of rains. The first field test of this methodology was carried out during the 1986 rainy season at the ICRISAT Sahelian Center (ISC).

From an agronomic standpoint, the dates of onset and ending of the rains and the duration between the two, i.e., the length of the growing season, determine agricultural productivity in the Sahelian region. We have studied the association between these three growing-season characteristics using the long-term daily rainfall record for 58 locations in Niger and Burkina Faso. The date of onset of rains (X) is defined as: that date after 1 May when rainfall, accumulated over 3 consecutive days, is at least 20 mm, and when no dry spell within the next 30 days exceeds 7 days. The date of ending of rains (Y) is taken as: that date after 1 September following which no rain occurs over a period of 20 days. The length of growing season (Z) is taken as the difference (Y-X+1). For all the 58 locations, the variables X and Y were found to be normally distributed. We obtained the probabilities for growing-season lengths of varying durations for given dates of onset of rains.

Computed probabilities of growing-season lengths for early, normal, and delayed onset of rains for selected locations in the Sahelian Zone are in Table 2. These data show that an early onset of rains offers a longer growing season while delayed onset results in a considerably shorter growing season. For example, if the onset of rains at Niamey occurs 20 days earlier relative to the average date of onset of rains (12 June), there is a 43% probability that the growing season will exceed 115 days. On the other hand, if the rains are delayed till the end of June, there is only a 2% probability that the growing season will exceed the mean length of 95 days. The implications of the above analysis are that crop management tactics in the Sahelian Zone may have to be altered depending upon the onset of rains. If the rains start early at a given location, it may be safe to plant those crop cultivars recommended for median-season length calculated for that location. If precipitation is delayed 10 days after the calculated average date of onset of rains, short-duration cultivars that will mature in the remaining growing season may be more productive. The objective here is to minimize the effects of drought by making the most efficient use of the scarce rainfall in a drought year, but to maximize production in the good years by exploiting the longer growing season.

Field test. We tested this concept for the first time at ISC in the 1986 rainy season. The first rains of 26 mm fell on 18 May and enabled land to be prepared. Subsequent rains exceeding 20 mm totalled over 2 days came on 22 and 23 May (20 days earlier than 12 June, the computed average date of onset of rains). This offered a 43% probability for the growing season to exceed 115 days (Table 2). Pearl millet CIVT was sown on 23 May in a trial designed to study the response of pearl millet to actual and "assured"

Table 2. Probability of growing season length exceeding specified duration for variable onset of rains at selected locations in the Sahelian Zone.

Location	Mean annual rainfall (mm)	Average growing season (days)	Onset of rains (days)[1]	Probability that growing season will *exceed* length specified (%)			
				75 days	95 days	115 days	135 days
Dosso	610	99	-20	100	98	52	2
			-10	100	83	14	0
			0	98	48	2	0
			+10	83	14	0	0
			+20	67	6	0	0
Niamey	560	94	-20	100	98	43	1
			-10	99	81	7	0
			0	98	39	0	0
			+10	81	7	0	0
			+20	61	2	0	0
Zinder	482	80	-20	100	97	27	0
			-10	100	69	3	0
			0	96	23	0	0
			+10	69	3	0	0
			+20	45	0	0	0
Tahoua	385	76	-20	100	95	21	0
			-10	100	62	1	0
			0	94	17	0	0
			+ 10	62	1	0	0
			+20	38	0	0	0

1. Days before (-) or after (+) average date for onset of rains (0).

rainfall. The latter treatment was designed to supplement, if necessary, the actual rainfall each week with irrigation if the difference between the actual and the average rainfall (computed from the daily rainfall data from 1905-1984 for Niamey) indicated a deficit. During the 1986 rainy season, actual rainfall fell below the average in only 2 weeks (31 May to 6 June and 7 to 13 June). We gave two supplemental irrigations, one of 10 mm on 6 June and another of 21 mm on 14 June.

We harvested the pearl millet on 3 September when measured soil water contents were 190 mm in the rainfed soil profile and 210 mm in the irrigated treatment. The volumetric water content at different soil depths (Fig. 2) was adequate throughout both profiles. On 4 September, we applied 100 kg diammonium phosphate ha^{-1} and reridged the field. On 8 September we sowed an early maturing, erect cowpea cultivar (IT84E1-108), recommended by the International Institute of Tropical Agriculture (IITA)/ICRISAT cowpea program. We spread the pearl millet stalks between the ridges as a mulch to conserve soil moisture during the early stages of cowpea growth.

Our objective in sowing cowpea after pearl millet was threefold. First, to exploit the long growing season as indicated by the analysis of onset of rains above; second, to discover whether a sequential crop of cowpea significantly reduces the amount of water in the soil profile relative to a bare soil; and third, to evaluate the response of the sequential cowpea to "life-saving" irrigations. The sequential cowpea consisted of two treatments: rainfed and irrigated. We gave a supplemental irrigation of 40 mm to the irrigated

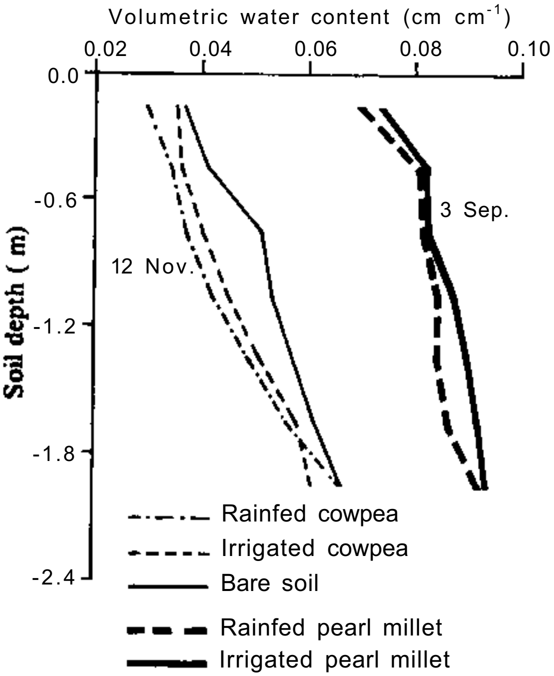

Figure 2. Soil water profiles at pearl millet harvest and at sequential cowpea harvest, ISC, Sadore, Niger, rainy season 1986.

cowpea on 12 October. A further supplemental irrigation was planned for 30 October, but was not given since we received 14 mm of rain on 29 October. The cowpea was harvested on 12 November, yields for the pearl millet-cowpea sequential crops are shown in Table 3. The sequential cowpea did not yield much grain, but hay yields were substantial, especially from the irrigated treatment. We measured soil water on 12 November, following the cowpea harvest and found a total in the 210-cm soil profile (Fig. 2) of 103 mm in the irrigated, 99 mm in the rainfed, and 114 mm in the bare soil treatments. These differences in residual water content are not significant.

Evaporation from sparse vegetation. This was the second season during which we made detailed measurements of evaporation from a sparse dryland pearl millet crop at ISC. Preliminary results from the 1985 season (ICRISAT Annual Report 1985, pp. 332-334) indicated that in this type of vegetation much of the rainfall is lost as direct evaporation from the soil, and conventional methods of calculating crop water use were often inaccurate. The principal aim of this season's work was to make further measurements of plant, soil, and total evaporation and to use these to develop models that will give more accurate predictions of sparse-crop evaporation.

One of the main instruments used was the Institute of Hydrology's (UK) new evaporation measuring device called the "Hydra". The battery-operated instrument is composed of a sonic anemometer, that measures vertical wind-speeds very rapidly, an infrared hygrometer, that measures humidity in the air with a beam of infra-red light, and a thermocouple that gauges fluctuations in air temperature. These sensors

Table 3. Crop yields (t ha^{-1}), water use (WU), and water-use efficiency (WUE) of a pearl millet-cowpea sequential cropping system, ISC, Niger, rainy season 1986.

	Pearl millet					Cowpea				
				WUE (kg ha^{-1} mm^{-1})					WUE	
Treatment	Grain yield	Straw yield	WU (mm)	Grain	Straw	Grain yield	Hay yield	Water use	Grain	Hay
Irrigated	1.73	4.10	398	4.4	10.3	0.05	0.68	237	0.2	2.9
Rainfed	1.21	3.65	374	3.2	9.8		0.42	223		1.9
SE	±0.10	±0.41	±7	±0.31	±1.2	±0.01	±0.01	±4	±0.05	
CV (%)	10	15	3	12	17	50	3	3	3	

are linked to a microprocessor that analyzes the measurements as they are made, to give a direct measure of evaporation and heat loss from the crop. Evaporation from the pearl millet crop was quite variable during the comparatively wet 1986 season. Actual evaporation ranged from around 90% PE on days following substantial rain storms to about 50% PE in drier soil. Measurements of soil moisture, made using a neutron probe, indicate that there were periods with substantial amounts of drainage from the soil.

Human and Social

Trends in Farm Size in the Indian SAT

In 10 ICRISAT study villages in five representative regions of the Indian SAT, historical profiles of land ownership and use for 400 sample households show a steadily declining trend in farm size (Fig. 3). That trend is especially pronounced for the mean owned area which fell from about 9.0 ha (among land owners) in 1940 to about 4.0 ha by 1984. During those 45 years, some of the largest farms in the villages shed a considerable amount of land. That behavior partially accounts for the steeper decline in the mean relative to the median farm size in terms of owned and operational holdings (Fig. 3).

Because the distribution of land ownership is skewed, the median size of holding gives a more realistic picture of what is happening to farm size over time. The median operational holding declined from about 4.9 ha in 1950 to about 3.0 ha in 1984.

An increasing proportion of relatively small and more marginal farm households, and a sustained increase in the number of holdings are other manifestations of the regularly declining farm size that we observed in 9 of the 10 study villages. Shrinking farm size is not unique to the Indian SAT, but has been clearly documented for many states and for the nation in the 5-year agricultural censuses of operational holdings.

Declining farm size has implications for technology design and assessment. First, declining farm size diminishes the prospects for

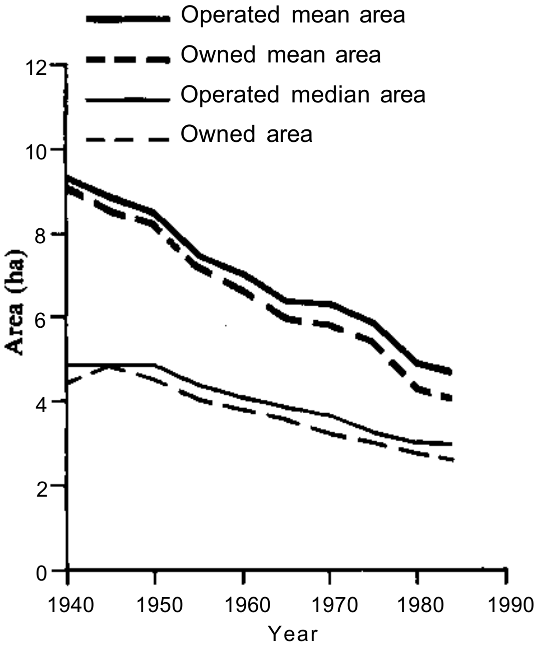

Figure 3. Trends in mean and median farm size from 1940 to 1984 among land owners in 10 study villages in four representative regions of the Indian SAT.

watershed-based development in dryland agriculture. More farms in a watershed means that more boundaries have to be covered in soil conservation bunding programs. The scope for group action is also reduced if consensus has to be reached by a larger number of individuals. Additionally, shrinking farm size means an increase in the ranks of part-time farmers who may be less committed to agriculture and hence, more reluctant to invest time and money in improved land and water management practices. Secondly, a gradual but sustained drop in the numbers of large farmers, and a decline in their average size reduces the economic attractiveness of tractorization in the Indian SAT where the development of tractor-hire markets is constrained by the covariate demand for agricultural power. However, declining farm size should increase the demand for divisible, high-yielding improved varietal technologies.

Crop Rotation in Traditional Farming Systems

Crop rotation, like intercropping, is one of the important features of traditional farming systems. Rotations satisfy multiple agronomic and economic objectives. They are temporal phenomena; their understanding requires longitudinal data on cropping histories of fields. Plot-specific cropping information collected for 10 years in the ICRISAT Village Level Studies offered a unique opportunity to examine the extent to which farmers practiced rotations.

The records show that farmers use rotations both for crops and for cropping systems. However, even when farmers understand the importance of crop or cropping systems rotation, they often fail to follow a predetermined order of crop successions. Rainfall during the sowing season, carry-over effects of preceding crops, prices, and other variables often obstruct the planned sequencing of crop successions. Information on the degree to which farmers followed crop rotations in the study villages is presented in Table 4. In 30 to 40% of the 3-year cropping sequences, the planned rotation was followed by the farmers in different areas. In 41 to 52% of the cases, the sequence was disrupted because other crops or cropping systems were substituted for crops or cropping systems appropriate to the rotation sequence.

To a large extent, farmers attempt to capture the benefits of rotating crops through different spatial arrangements rather than through temporal ordering. Two examples of this are: continuous intercropping with altered crop combinations or changed row arrangements of the same crops; and changed directions of crop sowing during different years. These arrangements can allow the rotation of cereals with legumes, or legumes with oilseed crops within a single plot, when rotating them between plots is not feasible. However, they offer no alternative for the crop-fallow rotation that has been an important practice in SAT areas. Periodical resting of land helped the recovery of soil productivity in several ways. But because of increased population pressure, the extent of the fallowing is now less feasible.

A special enquiry into crop-fallow rotations, which involved some retrospective data collection, indicated that the extent of fallowing has declined in all the study areas (Table 5). The proportion of plots fallowed for 4 years or more declined from 51 to 69% during the early 1950s, to 7 to 11% during the early 1970s. The proportion of plots fallowed for a shorter period of 1-2 years increased in the latter period.

Table 4. Important crop-rotation sequences in selected villages in three districts in the Indian SAT (1975-1984).

		Percentage of		
District	Number of rotation sequences identified[1]	Completed sequences	Incompleted sequences[2]	Distorted sequences[3]
Mahbubnagar	196	40	16	44
Sholapur	180	30	18	52
Akola	212	36	24	41

1. Events of crop/cropping system that change with specific order of succession. If the sequence was repeated at least twice on the same plot during the reference period it was considered a rotation. Sequences lasted 2 to 4 years.
2. Incomplete due to lack of required information for one year preceding or succeeding the period of field work.
3. Failure of potential sequence to materialize due to a single irregular crop/system change or event related to rainfall and/or other exigencies.

Table 5. Comparison of duration of fallowing of plots as part of crop-fallow rotation at two points of time in selected villages in three districts in the Indian SAT[1].

Region (District)	No. of plots covered	Reference periods: I Early 1950s II Early 1970s	Percentage of the plots fallowed between two cropping sequences by period of fallow (years):			
			1 year	2 years	3 years	4 years and above
Mahbubnagar	45	I			31.1	68.9
		II	22.2	55.6	15.6	6.6
Sholapur	58	I		15.5	32.8	51.7
		II	29.3	38.0	22.4	10.3
Akola	37	I		16.2	32.4	51.4
		II	29.7	37.8	21.6	10.8

1. Based on plot-specific investigations conducted for crop rotation study during 1977/78. Information for early 1950s (the period of land reforms) was collected by retrospective enquiry. Respondents include both VLS panel farmers as well as others.

An important implication of these findings is that the crops which can fit into more intensive cropping systems, and can ensure potential benefits of crop successions by means of their spatial arrangement within a plot, should get higher priority. The practice of crop rotation between plots, even if they are profitable, may not be adopted by the farmer because of climatic constraints and other factors indicated earlier.

Land Fragmentation, Subdivision, and Consolidation in the Indian SAT

In such developing regions as the Indian SAT where population densities are relatively high, land fragmentation, or a spatial scattering of land holdings, is often cited as a deterrent to technical change. Land consolidation, in contrast, enhances the attractiveness of farm investment opportunities, particularly those relating to land and water management, improves factor-market access, diminishes the cost of labor supervision, and in general sets the stage for the expression of improved managerial performance. In the Indian SAT, despite these apparent benefits and the existence of operational programs in most states, consolidation schemes have been successful only on a widespread scale in the irrigated regions of Punjab, Haryana, and western Uttar Pradesh.

To assess the need and prospects for land consolidation in the Indian SAT, we conducted a detailed study on several aspects of land fragmentation in 10 ICRISAT study villages located in five representative climatic and edaphic regions. We examined:

- the level of land fragmentation in the Indian SAT vis-a-vis other rural Indian regions;
- how fragmentation is changing within and over generations;
- the degree to which land subdivision at inheritance is responsible for land fragmentation;
- the determinants of land subdivision at inheritance;
- how farmers perceive the costs and benefits of owning spatially scattered holdings;
- how closely those perceptions are reflected in empirical estimates of costs and benefits, and
- the extent to which program structure and administrative expertise explains the success of consolidation programs in northwestern India compared to the much more modest performance of such schemes in the SAT regions.

Incidence of Fragmentation

We found that the incidence of land fragmentation, measured independently of farm size, was not high in SAT regions. In 1982-83, about one third of the farm households individually or jointly owned one field, another third possessed two spatially separated fields, and the remainder had more than two noncontiguous fields. The most fragmented holding in the sample of 293 cultivator households in 1982-83 contained 9 parcels. Parcel size in the sample ranged from 0.1 ha to more than 20 ha. Only about 20% of the parcels were smaller than 0.8 ha. In the villages we studied, we did not encounter extreme fragmentation, characterized by minute or very irregularly shaped fields.

This estimated level of land fragmentation in SAT regions is much lower than in some other Indian regions, most notably eastern India, where consolidation could foster the harnessing of underutilized groundwater resources. In most of India's dry SAT, untapped resources are not abundant; thus, the dynamic cost of reduced productivity potential usually attributed to fragmentation is considerably less than in more favorably endowed environments. Furthermore, from the private perspective of individual farmers, the level of land fragmentation is not appreciably increasing over time. Holdings today are about as fragmented as they were 20 years ago.

In spite of the rather low level of fragmentation in the study villages, inter-regional variation in the spatial dispersion of parcels is marked (Fig. 4). Fragmentation is greatest in the Mahbubnagar villages and least in the Akola villages where more than half of the cultivator households own only one parcel.

Although these inter-regional differences in land fragmentation are conditioned by a complex set of forces accumulating over time, resource endowments, and, to a lesser extent, institutional regulations in the land market account for a sizeable share of the inter-regional variation in land fragmentation. The land.man ratios are higher in the Maharashtra villages than in the Andhra Pradesh villages. Lower

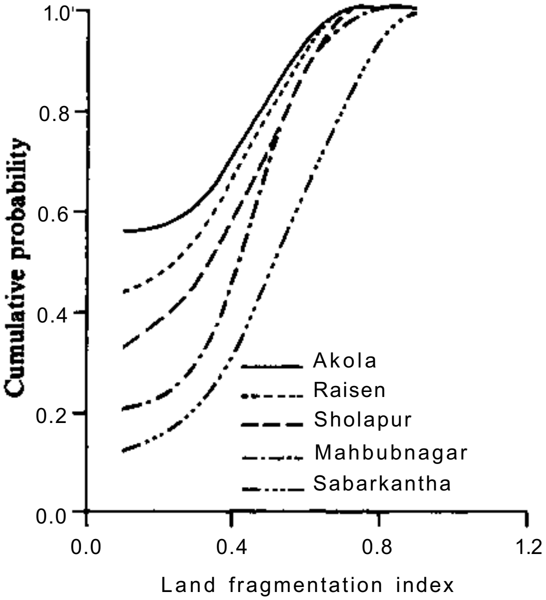

Figure 4. Distribution of land fragmentation in villages in five districts in the Indian SAT, 1982/83.

population pressure on land is also signalled by lower irrigation intensity in the Akola and Raisen villages.

Variation in land quality also matters. Within each village, soils are more homogeneous in the Akola villages than in the other villages. Less soil heterogeneity limits the scope for spatial diversification which in turn should reduce the pressure for land subdivision leading to fragmentation. Greater soil heterogeneity in the Mahbubnagar villages also makes it more difficult for brothers to strike a bargain without having to resort to the equal partition of all plots at inheritance or at family division.

While differences in tenurial systems do not seem to explain much of the inter-village variation in land fragmentation, some rules and regulations have apparently had an impact on its incidence. Foremost among these is *Agrah Kriya,* literally meaning "on request", which was enforced until the early 1960s in some regions, including Akola, of the British-ruled Central

Provinces. *Agrah Kriya* stipulated a right of first refusal for each brother for inherited land.

Agrah Kriya dampened land fragmentation in two ways. First, it increased the cost of transacting land thereby enhancing incentives for heirs to demand fewer, larger plots in preference to more, but smaller plots at inheritance. Secondly, it stimulated consolidation through land-market transactions by giving brothers, who often owned subdivided contiguous plots, first refusal on adjacent plots for sale. Although *Agrah Kriya* has not been enforced in many years, older farmers in the Akola villages remember it as inhibiting land subdivision and as promoting the exchange of plots among brothers.

Subdivision

Table 6 presents a detailed picture of the incidence of family division and land subdivision for the sample. About 27% of the sample households did not inherit land, i.e., they were landless at inheritance. About 45% of the remaining households that had land to bequeath did not subdivide plots. They were comprised of single-heir households, joint households that did not divide intergenerationally, and multiple-heir households that transferred land intact from one generation to the next. But 55% of households did subdivide some land intergenerationally; 95% of multiple-heir households, which split,

Table 6. Division of land at inheritance in ICRISAT study villages in the Indian SAT by number of households by region in 1984.

	Number of households by region						Number of plots	
Division/Category	Mahbub-nagar	Sholapur	Akola	Sabar-kantha	Raisen	Total	Divided	Undi-vided
Undivided plots	21	27	23	26	30	127	0	490
One heir	15	13	9	10	20	67	0	245
Multiple heirs, multiple plots, joint household	3	3	7	14	9	36	0	162
Multiple heirs, one plot, joint household	3	5	5	2	1	16	0	16
Multiple heirs, household divided, no plots divided	0	6	2	0	0	8	0	67
Divided plots	41	38	22	39	16	156	409	237
One plot divided equally among heirs	6	9	10	3	4	32	32	0
Multiple plots divided equally among heirs	18	10	1	10	3	42	135	0
Multiple plots, each heir receiving a share of each plot but unequally	5	5	0	2	2	14	66	0
Multiple plots, all divided but each heir does not share each plot	3	2	0	0	0	5	24	0
Multiple plots, at least one plot undivided and one divided	9	12	11	24	7	63	152	237
Total households and plots	62	65	45	65	46	283	409	727

subdivided some land at inheritance. About one-half of those households subdivided each plot equally among heirs.

Removing the 67 single-heir households gives a sample population of 216 farm households that could have subdivided land at inheritance. Of those, about one household in three engaged in equal land subdivision among heirs.

At the plot level, the empirical probability of plot division was 0.36 based on the 1136 plots in the sample and 0.45 based on the 891 plots owned by multiple-heir households. Actual subdivision resulted in 1530 plots passed on to the succeeding generation, an increase of 34%. If all plots of multiple-heir households had been equally subdivided among heirs, the original 1136 plots would have been partitioned into 2650 plots, about a 130% increase. Hence, about 35% of the potential for subdivision was realized. Actual land subdivision resulted in considerably less fragmentation than if equal plot subdivision had been rigidly followed.

For the multiple-heir, land-owning households in the sample, we analyzed the forces responsible for the interhousehold variation in the incidence of land subdivision. Several plot, household, and regional characteristics significantly ($P < 0.05$) influenced subdivision, but the impact of demographic determinants, such as number and age of heirs, had the strongest effect on subdivision. An additional heir above the mean level of 3.0 changed the predicted probability of subdivision from 0.45 to 0.57. A proportional 10% increase in the mean age of heirs resulted in a 12.7% increase in the incidence of subdivision. Clearly, population growth has strongly conditioned the trajectory of plot subdivision leading to land fragmentation in the study villages.

The area of the plot had a less marked effect on subdivision than the total land endowment in number of plots and farm size. Nonetheless, small plots, i.e., those falling below the 25% cumulative distribution quartiles, were much less likely to be subdivided. For such plots, the estimated probability fell from 0.45 to about 0.15. This result suggests that there are strong economic and other forces restraining the subdivision of relatively small plots. Those forces to some extent make redundant legislation for consolidation which specifies the size below which land cannot be subdivided.

Variation in soil quality also had a marked influence on the decision to subdivide land. Villagers appear to be extremely reluctant to subdivide plots on shallow black soil. The estimated probability of subdividing a plot on deep black soil is 0.55. Switching to shallow black soil results in a steep decline to 0.20. These results highlight the potential difficulties in exchanging land in a public sector consolidation program in villages with heterogeneous soils. As expected from our earlier discussion on the incidence of fragmentation, regional differences were also sharp. The estimated probability of subdividing land in Akola was only 0.21. In Mahbubnagar, that estimate increased to 0.66.

Costs and Benefits

In general, farmers owning more than one parcel, felt that the costs of land fragmentation outweighed the benefits. All multiple-parcel holders perceived that land fragmentation entailed some costs. Increased travel time and greater problems in supervising cropping operations figured prominently in the list of costs. Only one farmer mentioned that fragmentation acted as a deterrent to investing in irrigation. The lack of response on investment disincentives, potentially associated with fragmentation, amply reflects the scarcity of groundwater resources in the study villages.

On the benefit side, the majority of the farmers thought that some benefits did accrue from spatially scattered plots. Risk reduction was frequently alluded to as a beneficial consequence of fragmentation. Holding several spatially dispersed parcels was often associated with greater opportunities to exploit soil variation within the village. Farmers perceived that some crops can be profitably grown only on some soils in the village; hence, access to soil variation through fragmentation encourages crop diversification which, in turn, facilitates resource adjustment as seasonal input demands vary by crop. Nevertheless, more than 40% of the households felt no benefits were derived from spatially dispersed holdings.

Based on farmers' perceptions, the costs of land fragmentation should be much more numerically visible than the benefits. We estimated costs at the household and plot levels.

At the household level, land productivity was hypothesized to depend on household resource endowments and characteristics, and village and cropping-year effects. Regressors in the vector of resource endowments included irrigated area, land value, bullocks, farm size, family labor, and the degree of land fragmentation. Age, education, and caste of the household head comprised the set of personal characteristics.

Across the five regions, we found no compelling evidence that land fragmentation per se led to diminished land productivity. With the exception of the Akola villages, farm households that had more fragmented holdings, and/or owned more parcels of land were characterized by significantly higher net returns per hectare. To explain that result, one could hypothesize that less able farmers, in a sense, deselected themselves from the set of fragmented landholders by selling off or by leasing out parcels to more committed and capable farmers. While that hypothesis merits closer scrutiny, one can at least infer that land fragmentation in, and of itself, is not an economic liability at existing levels of technology in the study villages. Apparently, the cost of land fragmentation as perceived by farmers is not large enough to be readily quantified.

Prospects for Consolidation

Based on our results, one would be hard pressed to recommend that investing in consolidation programs should be accorded a high priority in the study regions. The significance of differences in soil quality in influencing plot subdivision within the household highlights the degree to which soil heterogeneity can inhibit plot exchange in a consolidation program within a village. Soils are much more homogeneous in the areas of northwestern India where consolidation has been successful.

To the extent that land fragmentation is a problem it should be tackled at its source by making it less attractive for heirs to resort to the equal division of all plots. Land subdivision is not preordained but is conditioned by forces that operate at the plot, household, and regional level. We discussed one legislative rule, *Agrah Kriya,* that apparently has had a considerable impact in reducing the incidence of land subdivision in the Akola villages. Comparative research on ways to increase the cost of plot subdivision at inheritance should be assigned a high priority on the consolidation research agenda.

Labor Absorption in the Indian SAT

Earlier (ICRISAT Annual Reports 1982, pp. 309-313, and 1985, p. 328), we reported the scope for increasing farm employment with the adoption of improved land and water management technology packages in the assured-rainfall Verti sol regions. Recently, we analyzed the determinants of, and prospects for, absorbing more labor in agriculture in 10 study villages in 5 different agroclimatic and edaphic production environments in the Indian SAT (ICRISAT Annual Report 1982, pp. 315-316).

We regressed labor use (in hours per hectare of gross cropped area) on household resources; including land, access to irrigation, the family work force, and draft power availability. We also allowed for the effects of soil quality and year-to-year variation.

Table 7 reports elasticities that express the proportional change in labor used within a household in response to a proportional change in a specific resource. In the Mahbubnagar, Sholapur, and Sabarkantha districts where rainfall is erratic, labor absorption is strongly linked to irrigation. A 10% increase in irrigated area leads to a 3 to 6% rise in labor use per unit of gross cropped area. In the other two regions, rainfall is heavier and assured, so the contribution of irrigation is much smaller. Thus, irrigation appears

Table 7. Estimated labor use intensity elasticities of household resource endowments in ten villages in five districts in the Indian SAT, 1975-1985.

State (District)	Village	Household resource endowment: Farm size (operated area, ha)	Irrigated area (ha)	Family workers (%)	Bullocks (number)	R^2	Observations (number)
Andhra Pradesh (Mahbubnagar)	Aurepalle[2]	-0.03	0.39***	-0.11*	0.14***	0.78	289
Andhra Pradesh (Mahbubnagar)	Dokur[3]	-0.12**	0.57***	0.09	0.002	0.48	141
Maharashtra (Sholapur)	Shirapur[2]	-0.21**	0.32***	0.16	0.01	0.54	274
Maharashtra (Sholapur)	Kalman[3]	-0.31**	0.30***	-0.03	0.18**	0.66	145
Maharashtra (Akola)	Kanzara[2]	-0.16***	0.05***	-0.06	0.12***	0.35	291
Maharashtra (Akola)	Kinkheda[3]	-0.04	0.06***	0.03	0.001	0.24	138
Gujarat (Sabarkantha)	Boriya[4]	-0.16***	0.31***	0.02	0.07	0.45	130
Gujarat (Sabarkantha)	Rampura[4]	0.01	0.46***	0.12*	0.10*	0.56	123
Madhya Pradesh (Raisen)	Papda[5]	-0.01	0.00[1]	-0.01	-0.10	0.02	99
Madhya Pradesh (Raisen)	Rampur Kalan[5]	-0.22***	0.01	0.04	0.08	0.27	96

1. Expresses the proportional change in labor use intensity per unit of gross cropped area in response to a change in the household's resource endowment. The elasticities are estimated at the arithmetic means of the dependent and independent variables.
2. 1975/76- 1984/85.
3. 1975/76- 1979/80.
4. 1980/81 - 1984/85.
5. 1981/82- 1984/85.

to be a sine qua non for augmenting labor absorption in the lower and less-assured rainfall regions, while in the higher and more assured rainfall regions, considerable scope exists to utilize labor more intensively in dryland agriculture. For example, in Kanzara from 1975 to 1985, the intensity of labor use per unit of gross cropped area grew at an annual rate of about 3% for men and 5% for women reflecting intensification within dryland cropping systems, and substitution of more labor-intensive cotton/mungbean systems for more labor-extensive cotton/sorghum intercrops.

As expected, the coefficients for farm size were, with one exception, negative and statistically significant in 6 of the 10 villages. An inverse relation between farm size and labor use intensity prevails throughout developing-country agriculture, particularly in irrigated tracts. At present levels of technology, that relation appears to hold also in the predominantly dryland agricultural cropping systems in India's SAT.

With the regular decline in farm size over time, the intensity of labor use will also increase. But the size of that effect will be small: a 10% reduction in operated area lead to a 1 to 3% increase in labor-use intensity in those villages where the nexus with farm size was statistically significant. Likewise, agrarian reform, effectively reducing farm size, would appreciably increase the intensity of labor use only in the Sholapur villages.

The mixed signs and insignificant coefficients for family work force support our findings that the labor markets in these villages work fairly well and are reasonably competitive. Most cultivator households are both buyers and sellers of labor.

The positive coefficients for draft power availability in nine of the ten villages are also consistent with our earlier observations that the bullock-hire markets are not well developed in several of the villages. Apparently, cropping systems that are more intensive in their demand for draft power are also more intensive in their demand for labor. Imperfections in the hire market are attributed to the highly covariate nature of demand—all farmers want to use bullocks at the same time for timely plowing and cultivation. However, bullock availability is not so important as access to irrigation and farm size in conditioning the intensity of crop labor use in most of the villages.

Privatization of Common Property Lands

Rural common property resources (CPRs) like village pastures, community forests, watershed drainages, village wastelands, etc. contribute significantly to rural people's income and income equity (ICRISAT Annual Report 1985, pp. 322-324). However, records from 80 villages in 20 districts of seven states, all in the dry tropics, showed that the area of commons has rapidly declined during the last 30-40 years. This is largely due to public policies for privatizing CPRs to provide land to the landless or rural poor. In practice, however, most of the land did not go to the landless (ICRISAT Annual Report 1983, p. 335).

The rural poor have already been dispossessed of 17-45% of the CPR land they received in different areas. Reasons, as revealed by Table 8,

Table 8. The dispossession of privatized CPR-lands by rural poor[1] in study villages of seven states in dry regions of India since 1951/52.

State (Number of villages)	Total land dispossessed by recipients of CPR-lands (ha)	CPR-land dispossessed as % of total land received	Dispossessed land unsuited for cropping (%)	Number of households dispossessed of CPR-land	Percentage of households who were dispossessed of land because: Farmers inability to develop/use it	Pressing cash need	Land was too poor/small	Farmers did not have bullocks
Andhra Pradesh (6)	247	44	24.7	296	14.3	15.5	14.9	81.0
Gujarat (8)	66	45	15.1	75	22.6	6.7	17.0	53.4
Karnataka (9)	152	45	15.1	131	30.6	12.4	34.4	72.4
Madhya Pradesh (10)	149	23	8.7	127	16.6	2.2	11.5	46.6
Maharashtra (8)	119	40	15.5	119	26.7	9.4	21.0	52.0
Rajasthan (7)	150	33	36.4	155	24.7	2.4	17.1	52.0
Tamil Nadu (7)	223	17	24.1	179	17.9		9.3	76.8

1. Rural poor are defined to include landless householders and those who own less than 2 ha of land.

range from submarginal quality of land to lack of complementary resources to develop such lands and to use them productively. Several households preferred selling these lands to meet current cash requirements rather than retain the lands as nonproductive assets. Privatization of CPRs does not seem to have achieved its goal of helping the rural poor.

Income and Nutrition

We reported earlier (ICRISAT Annual Report 1983, p. 323) that differences in household per person income did not explain much of the variation in nutritional adequacy among individuals in the six ICRISAT study villages where we monitored nutrition and health in 1976/77 and 1977/78. That finding contradicted the prevailing view that malnutrition is essentially an income problem.

To explore further the link between income and nutrition, we compared the responsiveness of household food and nutrient intake to changes in expenditure. Finding both food and nutrient consumption responsive to changes in expenditure would support the prevailing view; finding food consumption responsive and nutrient consumption insensitive to changes in expenditure would reinforce our earlier result; and finding neither responsive would cast suspicion on the reliability of the household data on nutritional status and expenditure.

For our comparison, we used records of food and total expenditure over the same 2 years and from the same households for which nutrition and expenditure data were complete. We concentrated on six food groups: grains, meat, milk, pulses, sugar, and vegetables. Across the sample households in the six study villages, the share of these six food groups in total household expenditure was 60%, reflecting the dominance of food in the consumer budgets of these poor households.

We focused on energy and eight nutrients—proteins, ascorbic acid, calcium, carotene, iron, niacin, riboflavin, and thiamine. Our sample is generally malnourished by Indian standards. The sample means met less than half of the Indian standards for carotene and ascorbic acid, less than three quarters of the Indian standards for calcium and riboflavin, and they were below these standards for energy. The sample averages are above Indian standards only for proteins, iron, and thiamine.

A double logarithmic function was chosen to generate, in a readily interpretable form, constant elasticity relation between household expenditure, and food and nutrient intakes. Binary variables for villages and crop years were included to allow for village endowments. Additionally, we exploited the time series provided by the panel data by taking differences between crop years so that fixed household effects could be held constant.

All the estimated food expenditure elasticities in Figure 5 were statistically significant and did not differ significantly from unity. This implies that a proportional change in household expenditure is accompanied by a similar proportional increase in the quantity of food consumed. In contrast, none of the estimated nutrient elasticities in Figure 5 were positive and statistically significant ($P < 0.05$).

The estimates in Figure 5 corroborate our earlier finding that, in these poor villages in the Indian SAT, increases in income do not lead to substantial improvements in nutrition. Food expenditures increase substantially—more or less in proportion to income—but the marginal increments in food purchases are not devoted primarily to obtaining more nutrients. Instead, people choose to pay proportionally more for nutrients as their incomes rise, apparently to purchase other desirable food attributes. Perhaps with more education about the relation between nutrients and other food characteristics; or with the development of plant varieties in which the nutritional benefits are strongly associated with the food attributes that consumers value highly, more positive associations could be developed between nutrient intakes and income. But our study suggests that optimism about better nutrition when income rises in such communities is unwarranted.

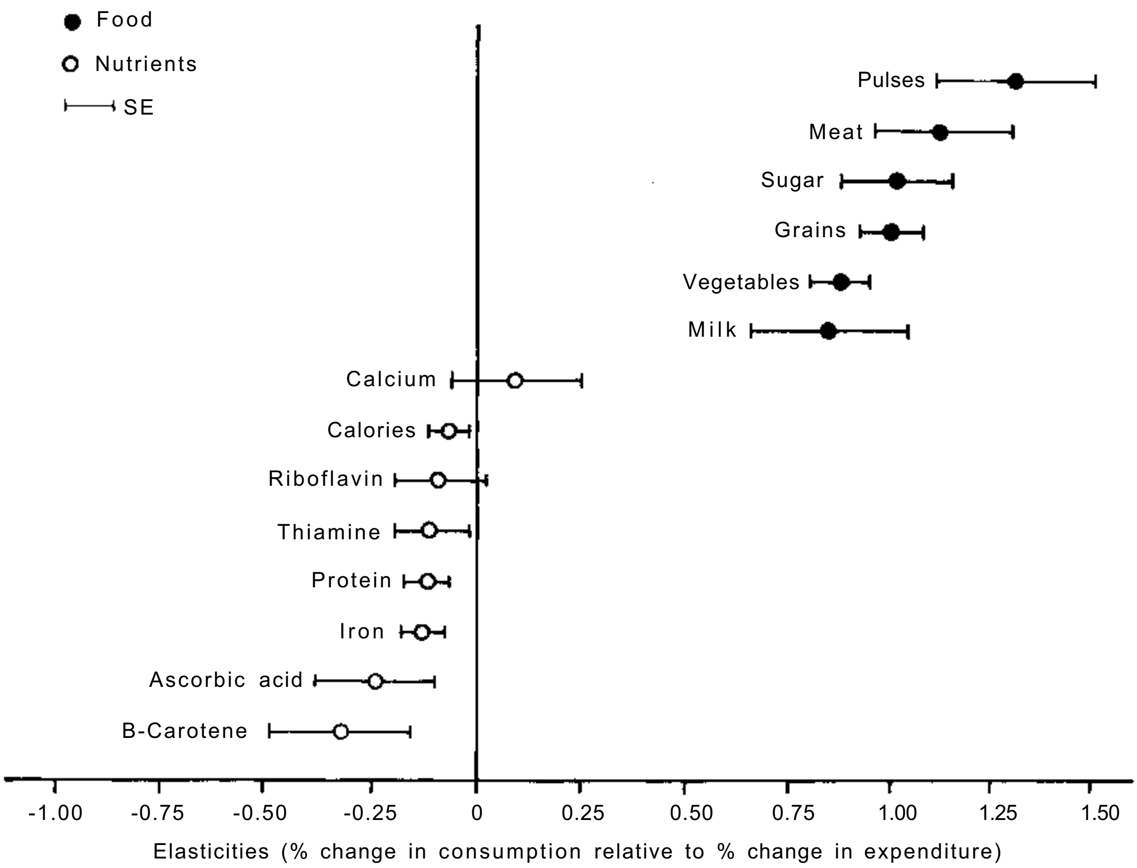

Figure 5. Estimated elasticity for food and nutrient household expenditure in three ICRISAT study villages in India, 1976/77 and 1977/78.

Management of Resources

Water

Water Balance Studies in Phanda

Quantitative estimates of runoff in different soil and rainfall zones are required to design and evaluate management alternatives such as installing water-harvesting structures. Our earlier work on rainfall-runoff relations was based on measurements on a Vertisol (suborder Pellustert) at ICRISAT Center that receives a mean annual rainfall of 780 mm. In the present study we measured runoff from cropped, 1-ha watersheds on a Vertisol (suborder Chromustert) at the State Agriculture Farm, Phanda (near Bhopal) that receives a mean annual rainfall of 1250 mm. Runoff was measured with flumes and stage-level recorders from one watershed in 1984, and three in 1985 and 1986. We compared measured runoff on annual, weekly, and daily bases with runoff predicted for corresponding periods by a runoff model using the modified curve number technique (ICRISAT Annual Report 1982, pp. 289-291).

About 90% of the runoff was produced between 15 July and 31 August. The runoff model predicted annual runoff fairly accurately (Table 9) and seems acceptable for predictions that involve long periods. However, the weekly and daily predictions of the model were not reliable.

Table 9. Measured and predicted annual runoff for 1-ha Vertisol watersheds at Phanda, Madhya Pradesh, India, 1984-86.

	1984	1985	1986
Seasonal rainfall (Jun-Oct) (mm)	943	1124	1308
Number of runoff-producing storms	9	15	22
Measured runoff (mm)	366	443	707
SE		±7.2	±4.7
Measured runoff (percentage of seasonal rainfall)	39	39	54
Predicted runoff (mm)	384	433	746
Error in prediction (%)	+4.9	-2.3	±5.5

Economics of Water Harvesting and Supplementary Irrigation

In the ICRISAT Annual Report 1985, pp. 280-281, we reported that double cropping on Vertisols in the rainfall-assured region of Madhya Pradesh was not possible in 1984 because of the lack of moisture in the seedbed. Most fields sole-cropped with soybean in the rainy season could not be sown to wheat or chickpea in the postrainy season. In contrast, sufficient rain fell in October 1983 to moisten the upper soil layers and to ensure successful double-cropping.

Because irrigation was needed only in some years to establish the postrainy-season crop, water harvesting and supplementary irrigation appeared to be economically desirable. The economics of that intervention were evaluated by a Ph.D scholar.

The simulation model used for the evaluation consisted of several component modules for rainfall, runoff, soil-water-balance, yield response to irrigation, and tank-water-balance. The economic objective was to maximize net present value. With water harvesting and supplementary irrigation, it was assumed that a soybean-wheat double-cropping sequence would be followed every year. No water was applied to soybean, but a presowing irrigation of 5 cm was given to wheat. The benchmark for comparison was soybean sown in the rainy season followed by wheat in such years as 1983, when presowing irrigation was not required. Without water harvesting and supplementary irrigation, in years such as 1984 when rains were inadequate to establish the wheat crop, the land was assumed to be fallowed.

The economic assessment was carried out for our Begumganj test site (ICRISAT Annual Report 1984, pp. 288-289) where the long-term average rainfall is 1300 mm. The average annual potential for generation of runoff was estimated to be 450 mm. Moreover, a 30-year run of the soil-water-balance model showed that in 2 out of 3 years wheat cannot be grown after soybeans because the top soil layers are too dry for adequate germination. Hence, the gross returns with water harvesting and supplementary irrigation could be higher than farmers' present practice in 2 out of 3 years.

As the exact optimal values of the design parameters for storage structures or tanks are unknown for this location, simulation experiments were conducted at a uniformly spaced grid of points on command area and tank size. The size of the watershed was specified as 5 ha. Simulations were run for three different seepage rates—0, 10, and 20 mm day^{-1}. Response surfaces were approximated by quadratic polynomials and the optimal values of tank size and command area were obtained by differentiation. The nature of the response surface, a contour map of discounted economic returns for a seepage rate of 10 mm day^{-1} is presented in Figure 6, where the experimental points are indicated by dots. For tank sizes of less than 200 ha mm, the

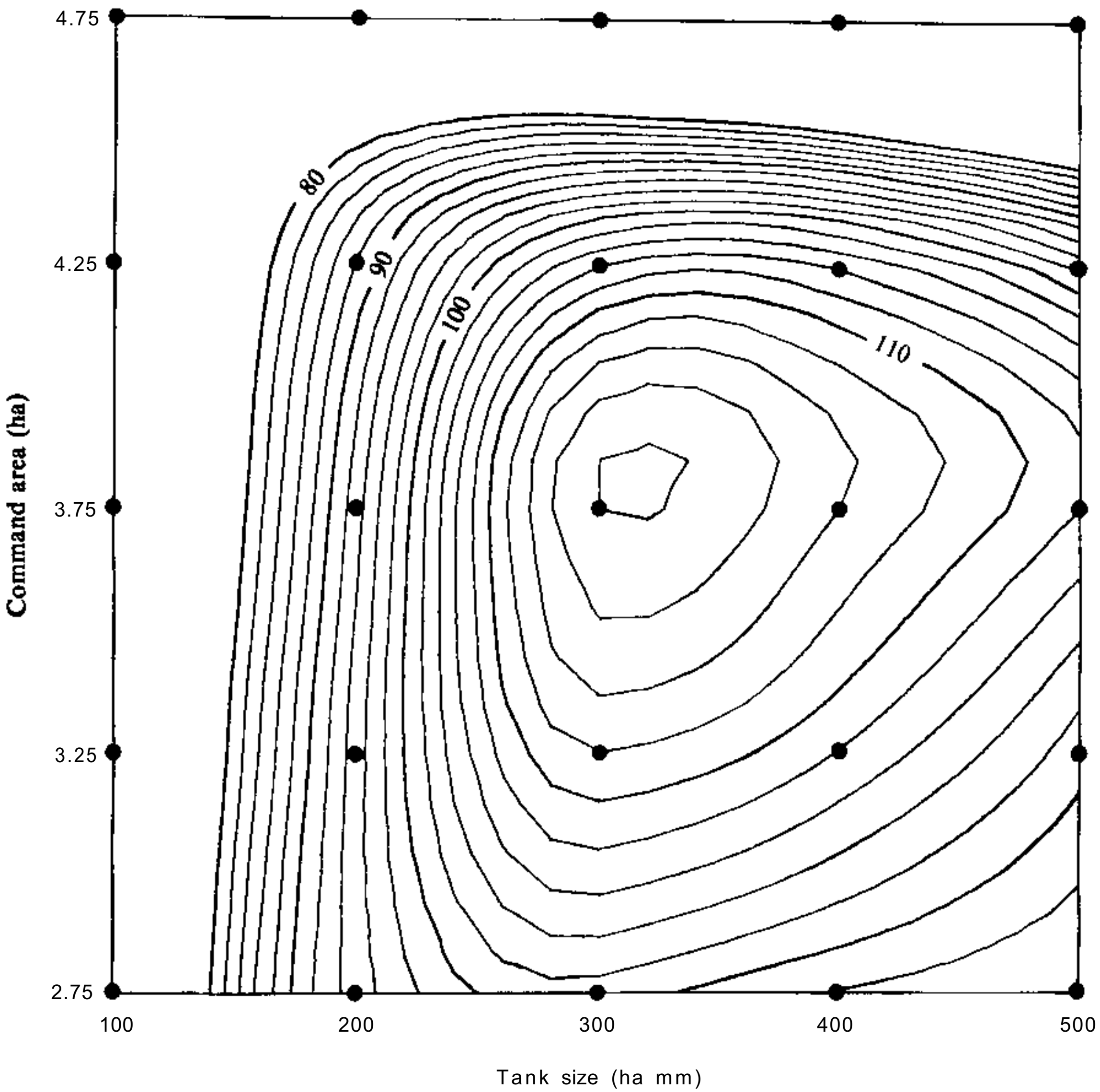

Figure 6. Economic return contours evaluated at the seepage rate of 10 mm day^{-1}. (Source: Pandey, S. 1986. Ph.D. thesis, University of New England, Armidale, NSW, Australia.)

response of economic returns to increasing tank size is steep for command areas of up to 4.5 ha. A small tank is likely to constrain the area of irrigated wheat. As the size of the tank increases, other factors such as the availability of runoff to fill the tank, and the availability of sufficient irrigated area to use all the water stored in the tank become more constraining, and the response tapers off.

The results for three seepage rates are presented in Table 10. Optimal tank size is insensitive to changes in seepage rate, but optimal size of the command area decreases with increases in the seepage rate. The ratios of catchment to

Table 10. Optimal design parameters at different seepage rates for a simulated tank at Begumganj, Madhya Pradesh, India.

Seepage rate (mm day^{-1})	Command area (ha)	Tank size (ha mm)	Net present value ('000 Rs)
0	4.05	346	136
10	3.66	337	118
20	3.30	360	98

command area are 22, 33, and 47% for seepage rates of 0, 10, and 20 mm day^{-1}.

The most important parameter governing the profitability of water harvesting and supplementary irrigation was the seepage rate. Water harvesting and supplementary irrigation are economically attractive only if the seepage rate is less than 10 mm day^{-1}.

Would it pay to apply sealants to reduce seepage? The benefit from seepage control at the planning stage (when the tank's optimal location and size are yet to be determined) is approximately Rs 20 000 for each 10 mm reduction in seepage day^{-1}. With the approximately optimal tank size of 350 ha mm, the maximal amount that can be spent on reducing seepage by 10 mm day^{-1} is approximately Rs 12 m^{-2} of dam floor surface. Expressing this figure as an annual cost at a 10% discount rate, seepage control is profitable only if the annual cost of sealing is not more than Rs 1.27 m^{-2}. The annual cost estimates for a silt-sodium carbonate mixture, often used as a sealant, that can reduce seepage by 50% is approximately Rs 2 m^{-2}. Hence, control of seepage with that sealant is unlikely to be profitable if the uncontrolled seepage rate is less than 20 mm day^{-1}. Other types of sealing, such as polythene sheets and cement brick lining (approximate cost Rs 25 m^{-2}) are also likely to be prohibitively expensive if the uncontrolled seepage is less than 20 mm day^{-1}. Although the benefits from the tank critically depend on the rate of seepage, cost-efficient techniques for its reduction are seemingly not available.

This appraisal has highlighted the importance of measuring and understanding factors that determine seepage losses in rainfall-assured Vertisol regions. In 1986, we started diagnostic tests on the incidence and control of seepage near the Begumganj test site. Our initial estimates gave seepage losses considerably higher than 20 mm day^{-1}. The model can also be extended to other sites within the rainfall-assured Vertisol region of Madhya Pradesh to derive more information on the parameters conditioning the economics of water harvesting and supplementary irrigation in this potentially productive environment.

Composite Watershed Management

The objective of composite water management is to improve the combined use of surface and groundwater resources in a watershed in order to stabilize and increase agricultural production.

Erratic and undependable rainfall is one of the major constraints limiting agricultural production in the SAT, especially in regions with red soils (Alfisols) that have poor water retentivity. Alfisols are derived from granitic rocks. The main aquifer in granites is the layer of weathered material extending down to a few tens of meters, below which the hard basement rock is rather impermeable. The depth of dugwells and borewells in such a situation is also generally shallow. Better management of water resources, including surface and subsurface storage, can help farmers to increase and stabilize production.

In collaboration with other organizations ICRISAT staff selected two Alfisol watersheds in Andhra Pradesh, South India, for composite water management studies. One watershed (Aurepalle, Fig. 7) has an area of about 70 km^{-2} while the other (Kandakuru-Manilla, Fig. 8) has an area of about 40 km^{-2}.

In both watersheds, a traditional tank irrigation system has steadily been abandoned over last two decades. Farmers now prefer to irrigate from wells and extensive exploitation of the aquifers has led to a fall in the water table.

To assess the potential of an improved water management system for such watersheds, we

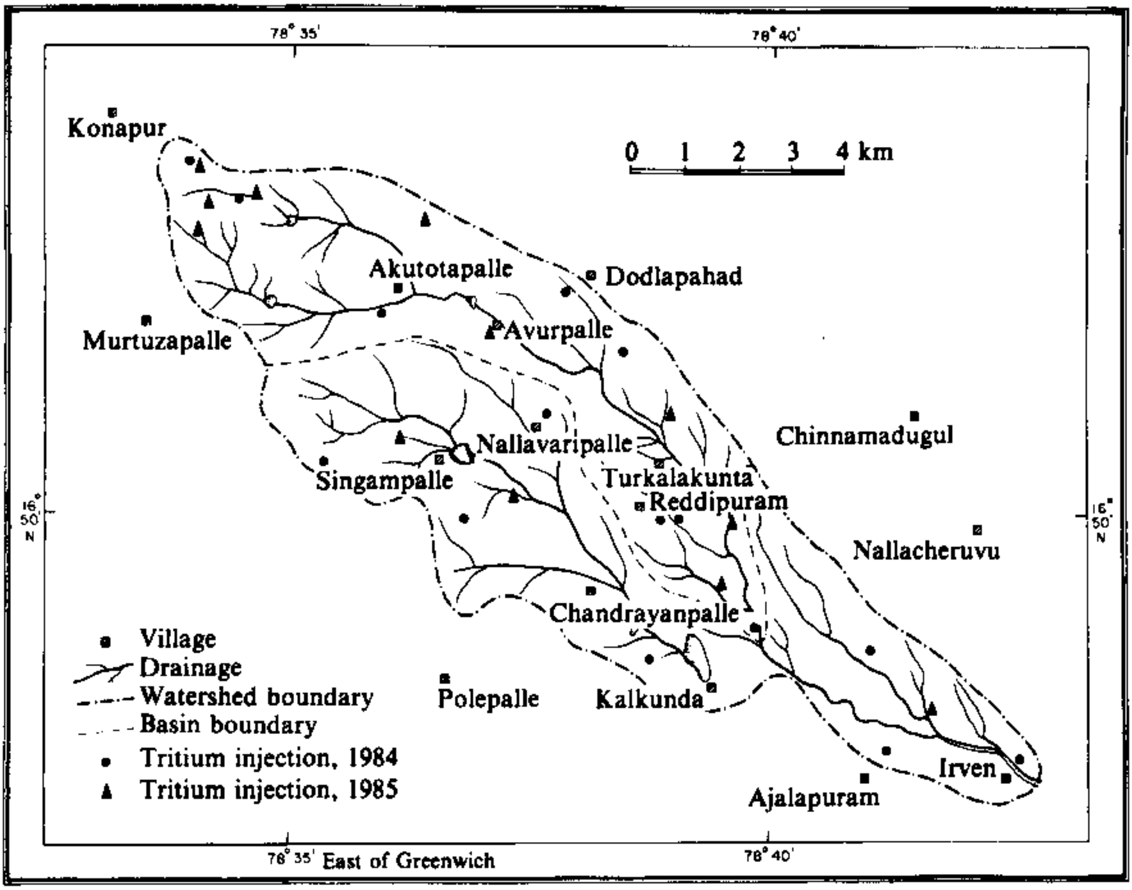

Figure 7. Drainage map of Aurepalle watershed with recharge measurement sites.

focused on the following aspects:

- Collection of socio-economic data on farm holdings, family sizes, cropping preferences, irrigation practices, income, and preparation of a linear programming model.
- Collection of basic surface hydrological data on rainfall distribution, meteorological parameters, water balance of tanks, etc., and subsurface information on water-table fluctuation, recharge, aquifer properties, and groundwater potential through various hydrogeological and geophysical surveys, and drilling wells.

Rice is traditionally grown even in watersheds with scanty rainfall. Irrigation is provided from tanks, wells, or other water-harvesting structures. A special study of the water balance of terraced rice fields, has been initiated to assess deep percolation.

Aerial photographs and ground verification of lineaments, slopes, and overburden thickness, have been used to select sites for construction of check-dams and mini-percolation tanks with storage capacities of the order of 0.1 to 0.4 x 10^6 m^3. These tanks are designed to have minimal evaporation loss and consequently an increased ponding period resulting in more groundwater recharge. The traditional irrigation tanks in the area lose about 40 to 50% of their stored water through evaporation each year because their average depth is shallow compared to their spread. Further, siltation and lack of maintenance have greatly reduced their percolation efficiency.

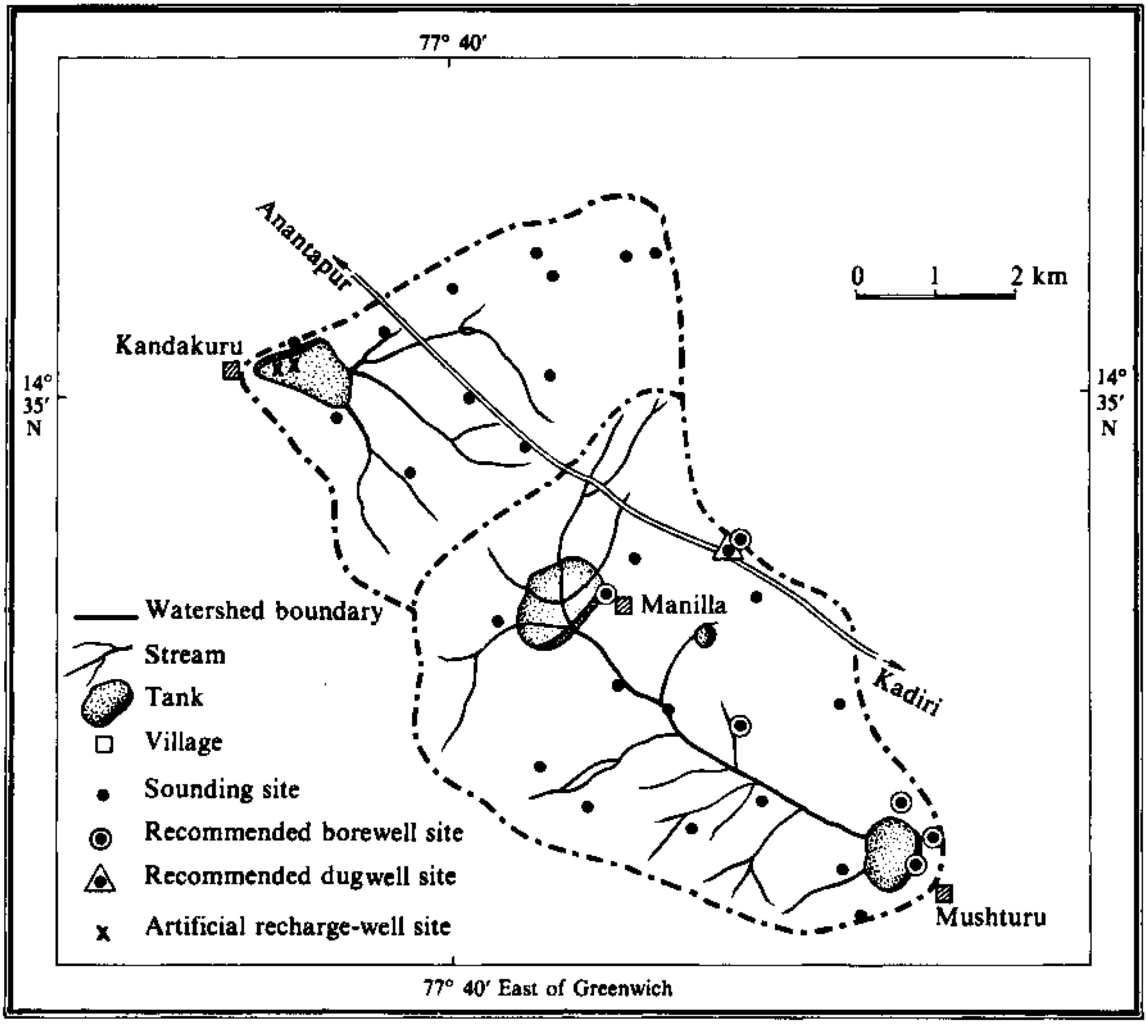

Figure 8. Kandakuru-Manilla watershed with sounding locations.

In a pilot experiment conducted recently, the tank water was transferred to a nearby open well through a siphon system. Results of this 6-month experiment, demonstrated the feasibility of the large-scale transfer of water from tanks to wells in areas suffering from excessive extraction of groundwater.

The annual rainfall over the Aurepalle watershed was 563 mm in 1984, and 586 mm in 1985. At Anantapur, the rainfall in 1985 was only 392 mm. The inflow to the Aurepalle tank was equivalent to 18.3 mm in 1984 and 13.3 mm in 1985. Deep percolation through dryland infiltration and seepage from tank beds and rice fields was estimated as about 15% of the rainfall in both years of the experiment. The average evaporation from the tanks was found to be 4 to 7 mm day^{-1}, and the average percolation between 5 and 15 mm day^{-1}.

The water level fluctuation in wells of the Aurepalle watershed was of the order of 2.2 m during the experimental period. The thickness of the weathered layer (phreatic aquifer) in the Aurepalle watershed ranges from 4 to 22 m with an average of about 10 m. The transmissivity of the phreatic aquifer has a range from 36 to 146 m.

Based on the interpretation of resistivity soundings in the Aurepalle watershed, sites for 10 exploratory boreholes were selected. The four drilled so far yield from 3000 to 36000 L per day.

A preliminary water balance model has been prepared for the Aurepalle village sub-watershed. Land use development models, based on surface and subsurface hydrological data collected for three seasons from both watersheds, will be prepared to devise a management plan for optimal use of water resources to increase agricultural production.

A small-scale solar-powered pump was designed to lift water from shallow aquifers and a prototype has demonstrated the feasibility of exploiting the Rankine cycle for small-scale solar pumps. The prototype lifts about 500 L water h^{-1}, over a head of 1 m.

During this multidisciplinary study ICRISAT scientists have been helped by staff of the following institutions:

National Geophysical Research Institute, Hyderabad, Andhra Pradesh.
Andhra Pradesh State Ground Water Department, Hyderabad.
Minor Irrigation Department, Andhra Pradesh State, Hyderabad.
Andhra Pradesh State Irrigation Development Corporation, Hyderabad.
Institute of Economic Growth, New Delhi.
University of Darmstadt, Federal Republic of Germany.
University of Hohenheim, Federal Republic of Germany.
University of Hyderabad, Andhra Pradesh.
Karnataka University, Dharwad, Karnataka.
Action for Food Program, New Delhi (Hyderabad Unit).

Response of Postrainy-season Sorghum to Water Use

We conducted a field study on an Alfisol during two postrainy seasons (1983/84 and 1984/85) to examine the yield response of sorghum (cv CSH 8R) to water use, and to determine the sensitivity of yield to water deficits at different growth stages and at three nitrogen application rates. The three growth stages were:

GS1 = emergence to panicle initiation;
GS2 = panicle initiation to 50% flowering; and
GS3 = 50% flowering to physiological maturity.

A line-source sprinkler irrigation technique was used to apply different amounts of water along both sides of the line-source sprinkler line which formed the main plot. The four main treatments, consisting of timing and amount of irrigation, were:

M_1 = gradient irrigation at all growth stages of sorghum (control);
M_2 = gradient irrigation at GS1 and GS2, but no irrigation at GS3;
M_3 = gradient irrigation at GS1 and GS3, but no irrigation at GS2;
M_4 = gradient irrigation at GS2 and GS3, but no irrigation at GS1.

The three nitrogen subtreatments were:

N_1 = 40 kg N ha^{-1};
N_2 = 80 kg N ha^{-1}; and
N_3 = 120 kg N ha^{-1}.

Nitrogen rates > 80 kg N ha^{-1} had identical highly significant linear yield-water use relationships (with the exception of M_1 in 1983/84). This suggests crop performance was not restricted by nitrogen availability. The 40 kg N ha^{-1} rate appeared inadequate in 1983/84 but may have been adequate in 1984/85. In both years, peak yields were obtained in the M_4 teatment suggesting that drought in GS1 is not harmful.

To account for variation in grain yield (Y), or relative grain yield (ratio of actual to maximum grain yield, Y/Ym) in terms of seasonal water use (ET) at different crop growth stages, or relative water use (ratio of actual to maximum water use, ET/ETm); Y and Y/Ym were regressed against ET and ET/ETm at different growth stages. Total seasonal water use accounted for 70% to 80% of the variation in sorghum grain yield with different nitrogen application rates (Table 11). Accountability improved to 84 or 86% when ET or ET/ETm was considered separately for GS1, GS2, and GS3. Relative

Table 11. Functions explaining variation in sorghum grain yield (Y, kg ha^{-1}) or relative grain yield (Y/Ym) to seasonal water use (ET, mm) or relative water use (ET/ETm). Analysis of 2-year pooled data, ICRISAT Center, postrainy seasons 1983/84 and 1984/85.

Function number	Nitrogen level	Function	r^2/R^2	rse
1	N,	Y = 457 + 11.0 ET	0.80	540
2	N_2	Y = 290 + 13.06 ET	0.70	785
3	N_3	Y = -112 + 15.7 ET	0.75	816
4	N_1	$Y = 1571 - 13.9\ (ET)_1 + 7.5\ (ET)_2 + 15.3\ (ET)_3$	0.84	478
5	N_2	$Y = 2407 - 52.8\ (ET)_1 + 22.2\ (ET)_2 + 14.3\ (ET)_3$	0.86	538
6	N_3	$Y = 2866 - 58.5\ (ET)_1 + 17.1\ (ET)_2 + 20.7\ (ET)_3$	0.88	559
7	N_1	$Y = 1339 - 431\ (ET/ETm)_1 + 1152\ (ET/ETm)_2 + 3014\ (ET/ETm)_3$	0.81	522
8	N_2	$Y = 2158 - 2591\ (ET/ETm)_1 + 2943\ (ET/ETm)_2 + 3310\ (ET/ETm)_3$	0.86	540
9	N_3	$Y = 3168 - 3699\ (ET/ETm)_1 + 2503\ (ET/ETm)_2 + 4773\ (ET/ETm)_3$	0.83	658
10	N_1	$\log Y/Ym = 1.012 \log(ET/ETm) + 0.40 \log(ET/ETm)_2 + 0.19 \log(ET/ETm)_3$	0.66	0.21
11	N_2	$\log Y/Ym = 0.193 \log(ET/ETm)_1 + 0.55 \log(ET/ETm)_2 + 0.33 \log(ET/ETm)_3$	0.83	0.16
12	N_3	$\log Y/Ym = -0.274 \log(ET/ETm)_1 + 0.51 \log(ET/ETm)_2 + 0.47 \log(ET/ETm)_3$	0.84	0.16

yield (Y/ Ym) was also regressed against ET/ ETm with the assumption that when ET/ETm = 0 at any growth stage then Y/Ym = 0. About 84% variation in Y/Ym could be accounted for when ET/ ETm was considered at three growth stages.

Since different crop growth stages have different evaporation requirements because of differences in their duration, leaf area index, and potential evaporation, yield reductions caused by withholding certain amount of irrigation at a particular growth stage are not unique functions of sensitivity to drought. A decline in relative yield (Y/Ym) with decrease in relative water use (ET/ETm) at a particular growth stage is an accurate measure of crop sensitivity to water deficit. The coefficients of equations 10, 11, and 12 are therefore a measure of the sensitivity of crop growth stages to drought (Table 11). It is clear that crop sensitivity to drought depends upon both the amount of nitrogen fertilizer applied, and crop growth stage. At a low nitrogen application rate (N_1 level) the crop is most sensitive to water deficit at GS1. This is possibly due to poor root development in dry soil. At higher nitrogen application rates (N_2 and N_3 levels), the relative crop sensitivity at GS2 and GS3 increased, and that of GS1 decreased. At higher fertility, the greater yield sensitivity of GS2 to drought compared with GS3 is due to the reduction in seed number per panicle rather than seed mass.

We found that about 84% of the variation in grain yield or relative grain yield of postrainy-season sorghum could be accounted for by water use or relative water use of the crop when considered separately for growth stages GS1, GS2, and GS3. At a low nitrogen application rate, GS1 was more sensitive to drought than GS2 or GS3, indicating the importance of this stage for crop establishment when fertility is poor. Stress in GS 1 especially at higher nitrogen rates appeared to increase grain yields, perhaps because more nutrients and water were available when roots penetrated the subsoil.

Pearl Millet Response to Water Deficit

We conducted an experiment on an Alfisol during the dry season of 1984 to study the effect on pearl millet of drought imposed at different phenological stages. The experiment was arranged in a split-plot design with three replications. Five drought treatments formed the main plots and the two cultivars (BJ 104 and ICH 412) the subplots. The main treatments were:

M_0 = adequate moisture throughout the season;
M_1 = drought during growth stage 1 (GS1), i.e., from emergence to panicle initiation;
M_2 = drought during GS2, i.e., from panicle initiation to anthesis;
M_3 = drought during GS3, i.e., from anthesis to physiological maturity; and
M_4 = drought during the later part of both GS2 and GS3.

Seed was sown on 30 January and the total amount of irrigation applied ranged from 22 to 72 mm. The durations of GS1 and GS2 were 6 days longer in ICH 412 than in BJ 104, but the grain-filling period (GS3) was similar in both cultivars. Drought in GS2 delayed flowering in ICH 412 by 4 days. The grain-filling period was reduced by 4-5 days in both cultivars due to water deficits in GS3.

Table 12 shows the contribution to TDM by main culms and tillers of the two cultivars. Main culms contributed more than tillers to the TDM of ICH 412 in most treatments, and tillers contributed more in BJ 104 in all treatments. ICH 412 produced more TDM (main culms + tillers) than BJ 104 in all treatments ($P < 0.05$).

The contribution of main culms was more in M, than in the control (M_0) in both cultivars. TDM of ICH 412 in M_3 was 56% lower than that for the Mj treatment and the corresponding reduction in TDM was 49% for BJ 104.

The total grain yields of both cultivars were similar except for M_0 in which ICH 412 produced 21% more grain than BJ 104 (Table 13). Drought in GS3 caused maximum reduction in grain yield in both cultivars. Tillers provided most of the grain in BJ 104. Tiller contribution to total grain yield ranged between 64 and 75% in BJ 104 and between 13 and 36% in ICH 412.

ICH 412 used more water than BJ 104 (Table 14). This was primarily due to the longer duration of ICH 412. Both cultivars used least water in the M_3 treatment. ICH 412 was more efficient in its use of water for TDM than BJ 104, except for the M_3 treatment. ICH 412 had the highest WUE for TDM in M_2 while in BJ 104 there was no difference in WUE among treatments, except in M_4.

Table 12. Effect of five drought treatments on TDM (t ha^{-1}) of two pearl millet cultivars grown on an Alfisol, ICRISAT Center, dry season 1984.

Drought treatment	TDM (t ha^{-1})					
	Main culms		Tillers		Main culms + tillers	
	BJ 104	ICH 412	BJ 104	ICH 412	BJ 104	ICH 412
M_0	1.75	6.71	4.88	3.88	6.63	10.59
M_1	2.12	7.76	4.64	3.39	6.76	11.16
M_2	1.49	5.04	4.57	4.92	6.06	9.96
M_3	0.94	3.42	2.52	1.47	3.46	4.89
M_4	1.49	4.78	3.73	2.72	5.22	7.50
SE[1]	±0.28		±0.27		±0.42	
SE[2]	±0.27		±0.22		±0.35	

1. SE for comparing drought treatment at same or different levels of cultivars.
2. SE for comparing cultivars at same level of drought treatment.

Table 13. Effect of five drought treatments on grain yield (t ha^{-1}) of two pearl millet cultivars, grown on an Alfisol, ICRISAT Center, dry season 1984.

Drought treatment	Grain yield (t ha^{-1})					
	Main culms		Tillers		Main culms + tillers	
	BJ 104	ICH 412	BJ 104	ICH 412	BJ 104	ICH 412
M_0	0.91	2.64	2.01	0.92	2.93	3.56
M_1	1.04	2.69	2.56	0.79	3.60	3.48
M_2	0.70	1.95	2.06	1.10	2.76	3.04
M_3	0.32	0.85	0.58	0.13	0.90	0.97
M_4	0.74	1.73	1.70	0.61	2.44	2.34
SE[1]	±0.09		±0.10		±0.14	
SE[2]	±0.10		±0.10		±0.13	

1. SE for comparing drought treatment at same or different levels of cultivars.
2. SE for comparing cultivars at same level of drought treatment.

Table 14. Effect of five drought treatments on water use (WU) and water-use efficiency (WUE) for grain yield and total dry matter (TDM) production by two pearl millet cultivars, grown on an Alfisol, ICRISAT Center, dry season 1984.

Drought treatment	WU (mm)		WUE (kg ha^{-1} mm^{-1})			
			Grain yield		TDM	
	BJ 104	ICH 412	BJ 104	ICH 412	BJ 104	ICH 412
M_0	484	653	6.1	5.4	13.7	16.2
M_1	517	651	7.0	5.3	13.1	17.3
M_2	466	526	5.9	5.8	13.0	19.0
M_3	254	361	3.5	3.1	13.6	13.5
M_4	418	433	5.9	6.8	9.3	17.3
SE[1]	±8.7		±0.41		±0.89	
SE[2]	±8.5		±0.35		±0.77	

1. SE for comparing drought treatment at same or different levels of cultivars.
2. SE for comparing cultivars at same level of drought treatment.

Crop Modelling

We tested the revised SORGF model (ICRISAT Annual Report 1984, p.254) by comparing the simulated and observed response of two sorghum cultivars (CSH 8 and M 35-1) to drought in two postrainy seasons (1979/80 and 1980/81). The experiment was conducted on an Alfisol that holds about 8.5 cm of plant-extractable water above 90 cm at ICRISAT Center, with two moisture treatments (irrigated and drought-stressed) and two cultivars.

In both years, water was applied five times in irrigated treatments and thrice in the drought treatments, but the timing of irrigations was different. In the 1st year, sorghum was sown on 19 November 1979 and the field was irrigated to field capacity just after sowing. In the irrigated treatment, water was applied at 19,39,57, and 76 days after emergence (DAE). The drought treatment received two irrigations at 19 and 57 DAE. In the 2nd year, sorghum was sown on 10 October 1980 followed by an irrigation on 11 October to charge the soil profile. In the irrigated treatment, four irrigations were given at 10, 28, 39, and 70 DAE. The drought treatment received two irrigations at 10 and 39 DAE. At each irrigation in both experiments, the soil profile was fully charged.

Grain yields from the irrigated treatment were 3.83 t ha^{-1} for CSH 8 and 2.10 t ha^{-1} for M 35-1 in the 1st year, while these were 6.12 t ha^{-1} for CSH 8 and 3.95 t ha^{-1} for M 35-1 in the 2nd year. A comparison between the observed and simulated percentage reduction in grain yield showed that the model was capable of simulating the impact of drought.

Figure 9 shows observed and simulated grain yields of two sorghum cultivars, CSH 6 and ICSV 1 (CSV 11), as a function of plant density. This experiment was conducted at ICRISAT Center, on a medium-deep Vertisol that holds about 15 cm of plant-extractable water in the rooting zone. Sorghum was sown on 21 June 1983, at five levels of plant density ranging from 4 to 20 plants m^{-2} and was grown rainfed (rainfall June to October = 102 cm).

Both the cultivars produced similar grain yields up to a density of 12 plants m^{-2}, but above this CSH 6 gave higher grain yield than ICSV 1 (CSV 11). Simulated grain yields for CSH 6 were higher than ICSV 1 (CSV 11) at each plant density. Maximum grain yields were observed at 16 plants m^{-2} for both cultivars, 5.3 t ha^{-1} from CSH 6, and 4.5 t ha^{-1} from ICSV 1 (CSV 11). Further increase in plant density did not increase grain yield in CSH 6 but decreased grain yield in ICSV 1 (CSV 11). Simulated grain yields in both cultivars increased with increasing plant density. However, these were between 3 and 15% of the observed grain yield. The correlation coefficient between observed and simulated grain yield was good (r=0.90).

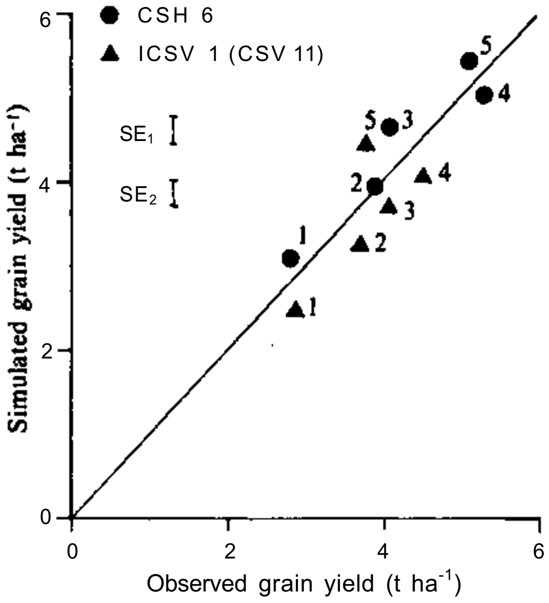

Figure 9. Relationship between observed and simulated grain yield of two sorghum cultivars for five plant densities (1 *to* 5 denotes lowest to highest density) on Vertisols, ICRISAT Center, rainy season 1983. SE, is standard error of the observed means to compare cultivars, at same plant density. SE_2 is standard error of the observed means to compare plant densities for the same cultivar.

Soil

Subsoiling

Research initiated in 1984 on the long-term effects of subsoiling an Alfisol was continued in 1985 and 1986 (ICRISAT Annual Report 1984 pp. 267-268). We grew maize (Deccan Hybrid 103) in 1984 but in 1985 and 1986, changed to sorghum (CSH 6) which is more tolerant to drought. We tested three tillage treatments:

T_1 = normal tillage (control);

T_2 = normal tillage with subsoiling every year; and

T_3 = normal tillage with subsoiling after 3 years.

A heavy tractor was used to draw conventional rippers that shatter the soil to a depth of 50-60 cm without inverting it. During the cropping periods the total rain received was 384 mm in 1984, 294 mm in 1985, and 420 mm in 1986.

In 1985, root samples were collected at 40 DAE from all treatments, while in 1986 the root observations were only made for T_2 at 59 DAE. We estimated root density by sampling the soil beneath plants and between crop rows using a bucket auger and measured root lengths by washing out and counting intersections on a grid. In 1985 the root density at 20-30 cm depth in T_2 was significantly different from that in T_3. In both years we recorded significantly larger root density (to a depth of 60 cm) in T_2 than in T_1.

At 69 DAE in 1986, we collected soil core samples down to 40 cm to measure soil bulk density. Results are in Table 15. In T_1 bulk density was highest at 0-20 cm and tended to decrease with depth. Annual subsoiling (T_2) reduced bulk density at 0-30 cm by comparison with T_1 but peak values still occurred at 10-20 cm. Triennial subsoiling reduced bulk density at 0-10 cm by comparison with T_1 but there was no benefit in deeper soil.

In 1985 T_2 and T_3 significantly increased the total dry matter (TDM) at 53, 70, and 83 DAE, compared to T, (Fig. 10). In the 2nd year of the trial T_2 gave significantly more TDM at these samplings, than T_3. In 1986, differences in TDM between treatments were significant only at 81 DAE.

Table 15. Effect of subsoiling on soil bulk density (g cm^{-3}) of an Alflsol 69 days after emergence of a sorghum crop grown at ICRISAT Center, rainy season 1986.

Soil/ depth (cm)	Soil bulk density — Tillage treatments T_1	T_2	T_3	SE
0-10	1.98	1.79	1.84	±0.031
10-20	1.96	1.90	2.01	±0.037
20-30	1.84	1.73	1.86	±0.029
30-40	1.77	1.76	1.81	±0.019

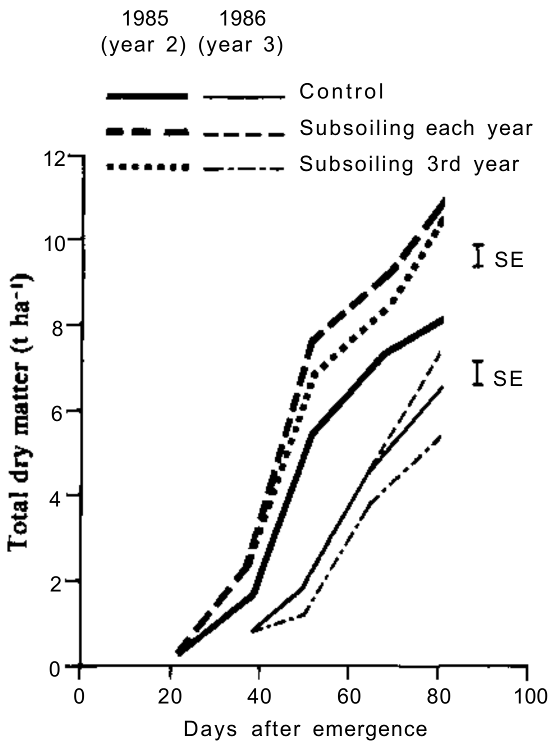

Figure 10. Effect of subsoiling an Alflsol on total dry matter of sorghum, ICRISAT Center, rainy seasons 1985 and 1986.

Annual subsoiling increased grain yield and TDM at harvest in all years though drought severely limited the growth and yield of maize in 1984 (Table 16). In 1985 TDM yields in T_2 and T_3 were not significantly different. In T_3 the effect of subsoiling in 1984 had diminished by 1986 and there was no significant difference in grain yields and TDM between T_1 and T_3 (Table 16). On average, sorghum grain yield increased 36% and TDM 32% in the year subsoiling was done but fell to only 25.4% more than T_1 grain yield and 20% more than T_1 TDM in the following year.

The average yields of 2 t ha^{-1} grain and 3 t ha^{-1} fodder for normal tillage, were exceeded by 0.7 and 0.9 t ha^{-1} in the 1st year of subsoiling and 0.5 and 0.6 t ha^{-1} in the following year. The value of the increase in grain and fodder yield is more than the cost to the farmer of subsoiling; approximately Rs 1200 ha^{-1} for the hire of a heavy tractor exceeding 100 hp.

Table 16. Effect of subsoiling on grain yield and total dry matter (TDM) production (t ha^{-1}) in maize and sorghum cultivars grown on an Alfisol, ICRISAT Center, rainy seasons 1984-86.

	1984		1985		1986	
	Maize (DH 103)		Sorghum (CSH 6)		Sorghum (CSH 6)	
Tillage treatment[1]	Grain	TDM	Grain	TDM	Grain	TDM
T_1	0.28	2.90	3.09	6.16	2.03	5.66
T_2	0.51	4.08	4.07	8.00	2.90	7.68
T_3			3.87	7.56	2.16	5.83
SE T_1	±0.11	±0.14	±0.33	±0.68	±0.33	±0.96
SE T_2	±0.07	±0.1				

1. T_1 = Normal tillage.
T_2 = Subsoiled every year (started 1984).
T_3 = Subsoiled every 3rd year (started 1984).

We measured cumulative infiltration one month after harvesting the crop. Figure 11 shows the mean infiltration characteristics for each tillage treatment in 1986. There was little difference between the control (T_1) and T_3 which had been subsoiled in 1984. Cumulative infiltration after recent subsoiling (T_2) was approximately twice the control. These results suggest that deep tillage is needed more often than every third year to benefit infiltration and root penetration.

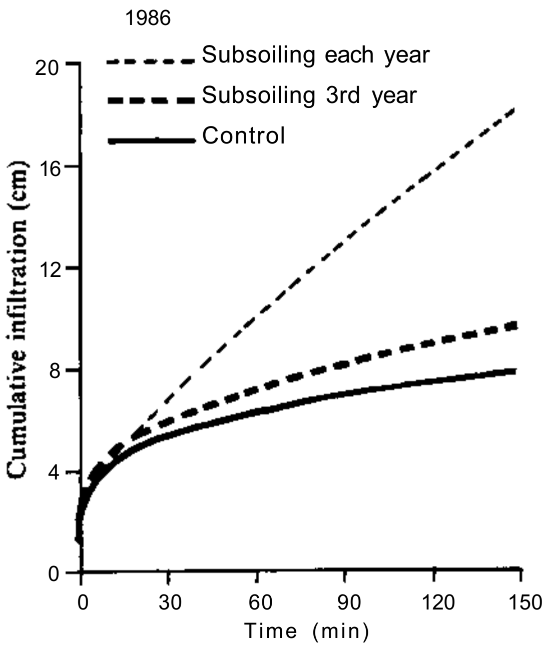

Figure 11. Effect of subsoiling an Alfisol on cumulative infiltration, ICRISAT Center, rainy season 1986.

Animal-drawn Crust-breaking Equipment

The establishment of a uniform plant stand of a desired density is often frustrated by poor seedling emergence through a soil crust. On sandy and loamy soils in arid and semi-arid regions, failure of seedling emergence is common in crops such as pearl millet, sorghum, soybean, cotton, mung bean, cowpea, and many other small-grained crops. Once a crust is formed over the seeded rows, it should be either wetted frequently, or broken mechanically, but the frequent application of water is rarely practical in arid and semi-arid regions.

We developed an implement at ICRISAT Center (ICRISAT Annual Report 1982, pp. 268-269) to break the soil crust over rows of germinated seeds and thus facilitate seedling emergence. The implement consists of two spiked rollers placed one behind the other in a frame, such that their axles remain perpendicular to the direction of travel during operation.

This tandem-roller crust-breaker is as easy to use as a manually operated single-row implement. However, to use it as a multiple-row implement, it is necessary to attach the required number of crust-breaker units to either a wheeled-tool carrier or a tractor. Moreover, the working width of a tandem-roller crust breaker is only 15 cm. In order to overcome these limitations and to get wider coverage in a single pass, we designed, developed, and tested an animal-drawn implement called the "inclined-roller crust breaker".

This implement consists of two wooden rollers, each 500 mm long and 150 mm in diameter. Nails are fixed on the rollers in rows running along the roller axis, at a spacing of 25 mm, and projecting 25 mm above the surface. The rollers are arranged side by side in a U-frame made of mild-steel flats such that their axles make a 170° included angle at the center of the frame. The axle of each roller is inclined at an angle of 5° from the perpendicular to the direction of travel. This arrangement permits a width of coverage almost equal to the sum of the length of the two rollers. It also counter-balances the side forces, arising from the inclination of the rollers. The axle housings are 20 mm shorter at the center of the frame than at the outer ends, so that the entire length of the rollers comes in contact with the soil surface when the implement is brought to the operating position by raising its beam to an

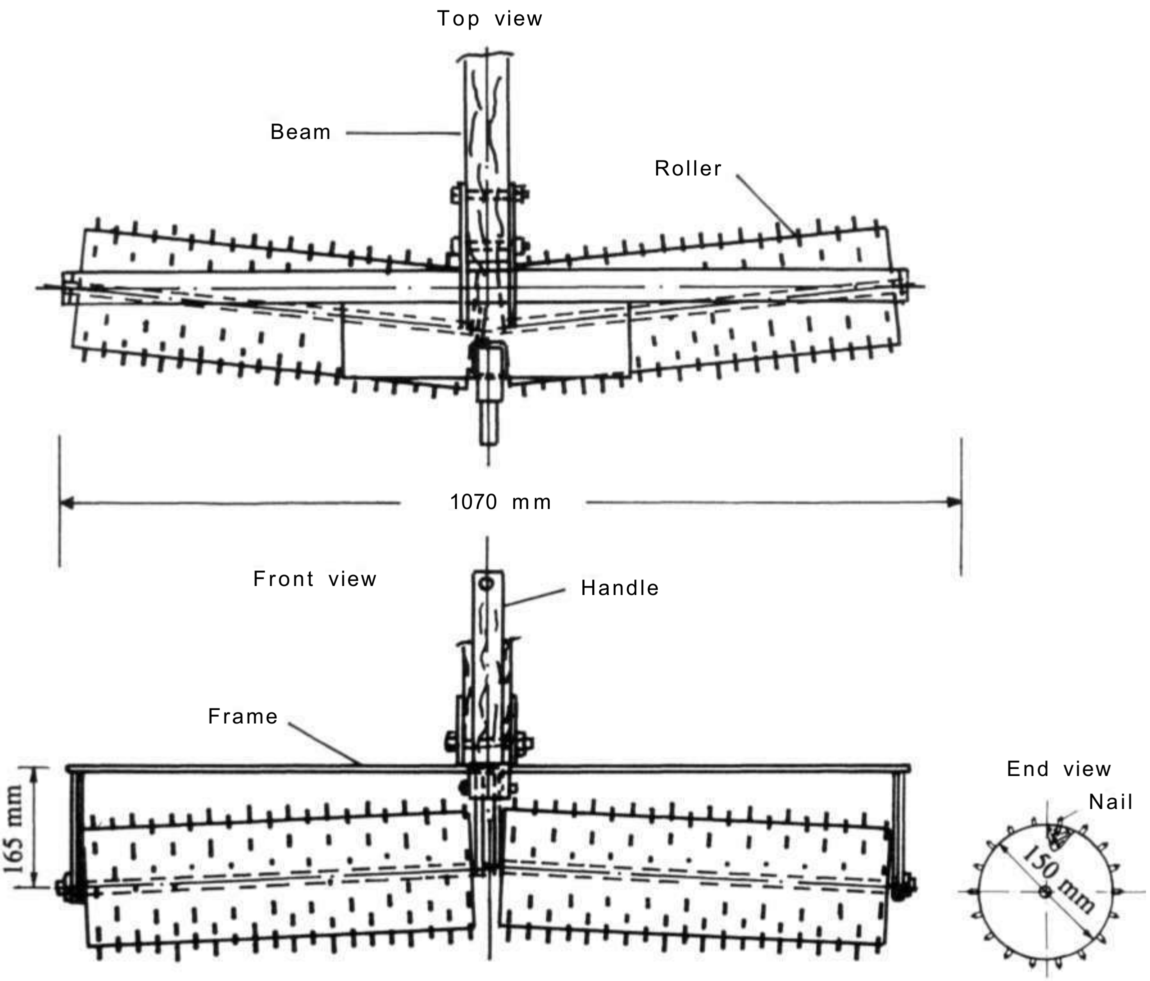

Figure 12. Engineering details of inclined-roller crust breaker, developed at ICRISAT Center.

Figure 13. Inclined-roller crust breaker independent unit on an Alfisol, ICRISAT Center, 1986.

angle of about 30° with the horizontal. The constructional details of the implement are shown in Figure 12. The implement can be pulled by a pair of bullocks, either as an independent unit (Fig. 13), or as an attachment to an indigenous blade harrow (bakhar), or a wooden plank (Fig. 14).

We evaluated the performance of the inclined-roller crust breaker by assessing the emergence of pearl millet and sorghum in two trials conducted on an Alfisol in the dry and rainy seasons of 1986. Both trials were laid out in a randomized block design with four replications. The treatments were: 1. unbroken crust, and 2. crust broken either with an inclined-roller crust breaker, a tandem-roller crust breaker, or manually with a sickle. For each plot, 100 seeds were sown in two 5-m rows at a depth of 30 mm for pearl millet and 50 mm for sorghum. On the same day 40 mm water was applied by sprinkler, resulting in the formation of a crust of reasonably uniform strength (measured with a pocket penetrometer) in the range of 200-250 kPa (2-2.5 kg cm^{-2}) on the 4th day after irrigation. Crust breakers were used on 4 DAS, and seedling emergence was recorded 5 days after breaking the crust.

The inclined-roller crust breaker effectively broke the crust, but injured less than 1% of the

Figure 14. Inclined-roller crust breaker attached to a plank on an Alfisol, ICRISAT Center, 1986.

seedlings. In both trials, emergence was significantly ($P<0.01$) higher in plots with broken crust than in plots with unbroken crust (Table 17). However, the differences in the methods of breaking the crust had no significant influence on seedling emergence. The action of the inclined-roller crust breaker was as effective as that of the tandem-roller crust breaker or a hand tool. The inclined-roller crust breaker required 2.8 ±0.1 h to cover 1 ha whereas < 200 h were required to break the crust manually. The work rate was equivalent to 3 or 4 tandem-roller units attached to an animal-drawn tool bar. The average field capacity of this implement is < 0.35 h^{-1} and its estimated cost is about Rs 250 ($20).

Crop Residues

In the long term, "farming systems" which ensure the generation and maintenance of a favorable soil structure are critical to the successful use of Alfisols in the SAT. The incorporation of organic matter is one possible way to improve soil structure. However, in an experiment at ICRISAT Center when 5 t ha^{-1} of non-decomposed dry crop residue (rice straw) were incorporated into the soil, we encountered nitrogen deficiency and sowing problems that reduced crop yields. We recorded similar observations when sorghum straw was used. This suggests that, in a semi-arid environment, the incor-

Table 17. Mean seedling emergence (%) through unbroken and broken soil crust, ICRISAT Center, dry and rainy seasons 1986.

	Sorghum		Pearl millet	
Treatment	Mean (%)	SE	Mean (%)	SE
Soil crust unbroken[1]	16.4	±2.75	1.4	±0.26
Soil crust broken with inclined-roller crust breaker[1]	73.1	±0.84	55.1	±2.53
Soil crust broken with tandem-roller crust breaker[2]	73.7	±1.52	52.7	±7.43
Soil crust broken manually with a sickle[3]	71.0	±0.96	52.8	±1.83

1. Based on two seasons' data.
2. Based on dry-season data.
3. Based on rainy-season data.

poration of large amounts of nondecomposed dry crop residues without the addition of nitrogen fertilizers may not be beneficial.

At ICRISAT Center we investigated the use of crop residues as a surface mulch incorporated into the soil in subsequent years. In 1981, we initiated an experiment to discover whether the application of groundnut shells applied to the soil surface affected runoff, soil loss, and crop yield. We applied shell at rates of 2.5, 5.0, and 10.01 ha^{-1}. Each plot was provided with a multislot divisor system to measure runoff up to about 120 mm per storm. Two neutron access tubes were placed in each plot to monitor soil moisture. For the first 2 years, soil temperature was measured twice daily at three soil depths 5, 15, and 30 cm.

Table 18 clearly indicates the effectiveness of this system of crop residue management in reducing runoff and soil loss, and in increasing crop yields at ICRISAT Center. In terms of average values over 4 years, organic matter at 10 t ha^{-1} reduced seasonal runoff by 90%, and soil loss by 91%, and increased yields of sorghum by 27%, and pigeonpea by 59% compared with the nonmulched treatment.

The soil temperature records showed that as the quantity of mulch increased, the soil temperature at all depths generally decreased. The organic mulch was found to be most effective in reducing the soil temperature during the early part of the rainy season. During the first week of July 1981, an organic mulch of 10 t ha^{-1} reduced the soil temperature (weekly average of daily

Table 18. Effects of groundnut-shell mulch on crop yield, runoff, and soil loss of Alfisol, ICRISAT Center, 1981-85.

	Crop yield (t ha^{-1})			
	Intercropping			
Organic matter rate (t ha^{-1})	Sorghum	Pigeonpea	Runoff (mm)	Soil loss (t ha^{-1})
No mulch	2.07	0.84	282	3.92
2.5	2.27	0.97	147	1,95
5.0	2.42	1.11	88	1.21
10.0	2.63	1.34	26	0.35
SE	±0.17	±0.09	±13	±0.23

values) by 6°C (from 33 to 27°C) compared to the nonmulched treatment. Similar differences in soil temperature (ranging from 3 to 5°C) were observed during relatively dry weeks. This has implications because, in some SAT areas, high soil temperature during the early part of the rainy season is one of the causes of poor seedling emergence and poor crop stand (ICRISAT Annual Report 1984, p. 19 and 1985, pp. 83-85). In the later part of the rainy season, however, the differences in soil temperatures were generally not significant. One of the reasons for this was the high rainfall during 1981 (1170 mm) when unusually low soil temperatures were generally recorded. The soil temperatures at 15- and 30-cm depths showed a similar trend. However, the differences of temperature between the various mulch treatments at these depths were smaller than at 5-cm depth.

Residual Effects of Short- and Medium-duration Pigeonpeas on Sorghum

We conducted an experiment on a Vertisol to study the effects of short- and medium-duration pigeonpeas on succeeding sorghum crops to supplement the information emanating from our long-term experiment on Vertisols (ICRISAT Annual Report 1985, pp. 286-288). In the first year (1985 rainy season), there were four treatments consisting of fallow, maize (Deccan 103), short-duration pigeonpea (ICPL 87) and medium-duration pigeonpea (ICP 1-6) with three replications. All the treatments received a uniform application of 20 kg P ha^{-1} as single superphosphate (SSP) and maize received an extra 30 kg N ha^{-1} as urea.

In the second year (1986 rainy season) we grew a uniform crop of sorghum (CSH 6) on all treatments. Further, each of the four main treatments were subdivided into 4 subplots each receiving nil, 30, 60, and 90 kg N ha^{-1} as urea.

It is clear from Table 19 that both short- and medium-duration pigeonpeas have little residual effect in terms of N on the succeeding sorghum crop yields.

Table 19. Effect of preceding crops on sorghum grain yield (t ha^{-1}) in response to N fertilizer on a Vertisol, ICRISAT Center 1986.

	Applied fertilizer (kg N ha^{-1})				
Preceding crop	0	30	60	90	Mean
Fallow	4.21	5.08	4.75	4.96	4.75
Maize	3.26	4.28	4.29	4.84	4.17
Short-duration pigeonpea	3.15	3.81	4.33	4.91	4.05
Medium-duration pigeonpea	2.87	3.96	5.04	4.99	4.21
SE	±0.34	±0.43	±0.46	±0.49	

Short-duration pigeonpea produced 836±32 kg fallen leaves ha^{-1} and medium-duration pigeonpea produced 796±57 kg fallen leaves ha^{-1}. These leaves were incorporated into the plots before sowing sorghum. The short-duration pigeonpea thus added 11 kg total N ha^{-1} and the medium-duration 10 kg total N ha^{-1} to the system from fallen leaves. Even if one assumes 50% mineralization of this organic N, the contribution from leaves seems very small.

Nutrients

We continued research initiated in 1982 in collaboration with the International Fertilizer Development Center (IFDC) on sources of phosphorus, nitrogen, farmyard manure, and crop residues and their management for increased agricultural production. In farm trials at Gobery, Niger we compared three sources of rock phosphate; Parc-W rock phosphate (PRP), Tahoua rock phosphate (TRP), and Parc-W partially acidulated rock phosphate (PARP 50) with single superphosphate (SSP). Partial acidulation is a process that uses only a fraction of the sulfuric acid required to convert the insoluble tricalcium phosphate fully to the water-soluble form. In the case of PARP 50, rock phosphate was acidulated at the 50% level.

When applied at a rate of 66 kg P_2O_5 ha^{-1}, the relative agronomic effectiveness compared with SSP (100%) was 63% for TRP, and 42% for PRP indicating that TRP is more suitable for direct application than PRP (Fig. 15). PARP 50 was 91% as effective as SSP, confirming that this less-expensive product can adequately meet the phosphorus needs of pearl millet and also potentially save Niger substantial sums in foreign exchange on imported fertilizers.

In order to compare the management of calcium ammonium nitrate (CAN) and urea (U), we point-placed CAN (CANG) and urea (UG) and compared these treatments with urea broadcast, and incorporated (UBI). CANG performed better than UG and UBI (Fig. 16). Records of ^{15}N from previous years showed that significantly

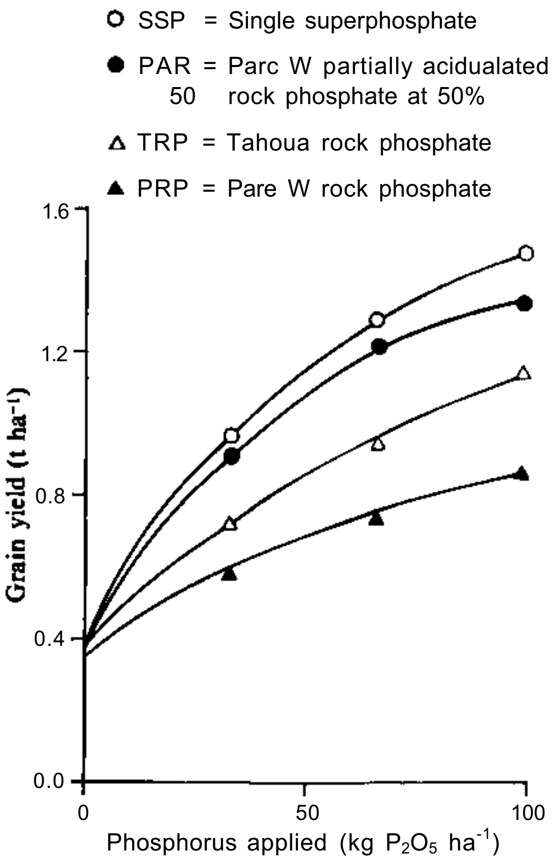

Figure 15. Effect of phosphorus sources and rates of application on pearl millet grain yield (t ha^{-1}), Gobery, Niger, rainy season 1986.

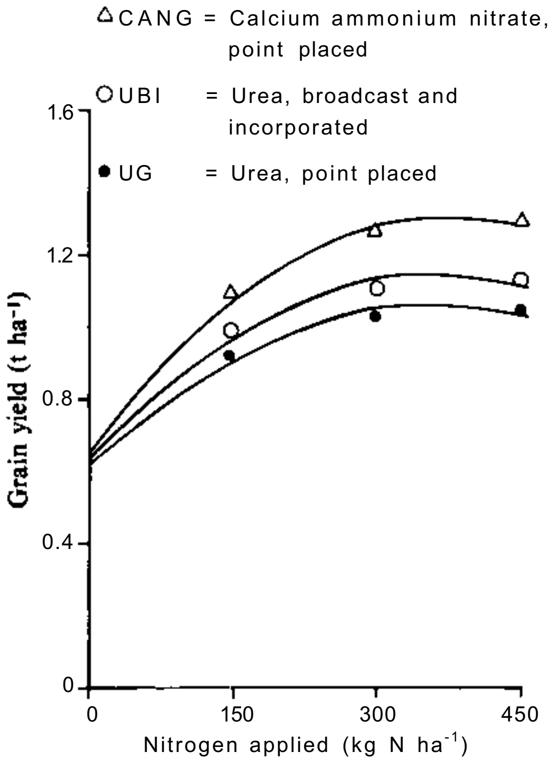

Figure 16. Effect of different sources, methods of application, and rates of N application on pearl millet grain yield (t ha^{-1}), Gobery, Niger, rainy season 1986.

faster losses of urea occurred from point placement, possibly due to the adverse effect of concentrated urea on the local soil microbial population resulting in delayed nitrification. The high concentration of NH_4 in the soil promoted volatilization losses. CANG performed better than UG because half of its N is in the form of nitrate and hence is less volatile than urea.

Sulfur

We observed a dramatic response to sulfur under continuous cropping on the same piece of land as shown by the difference in the response of pearl millet to TSP (containing little or no sulfur) and

SSP (containing 12% sulfur) after 5 years of cropping (Fig. 17). The relative agronomic effectiveness of TSP was only 60% at the rate of 30 kg P_2O_5 ha^{-1}.

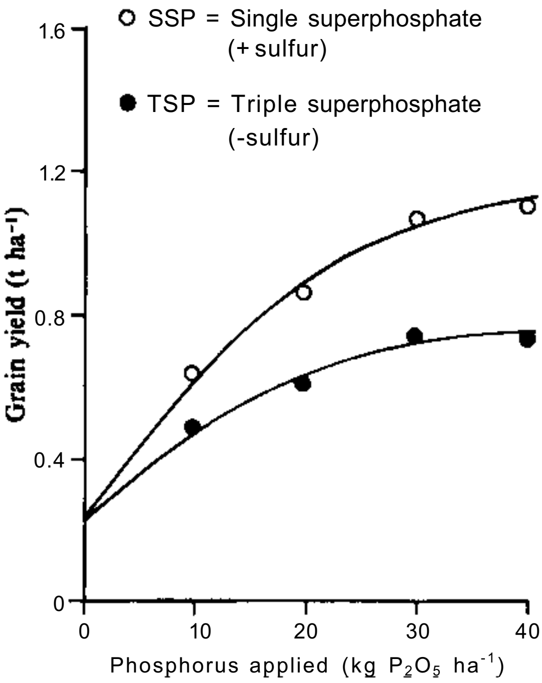

Figure 17. Effect of phosphate fertilizers with and without sulfur on pearl millet grain yield (t ha^{-1}) after 5 years continuous cropping, ISC, Sadore, Niger, rainy season 1986.

Soil Management at ISC

In an experiment started in 1983, we added 4 t ha^{-1} of pearl millet stover in the first year to the plot receiving crop residue. In 1984, 1985, and 1986, the stover produced in this treatment was left on the soil surface. Additions of crop residues have continued to improve yields from 1984, but as Table 20 shows, the highest yields were obtained when crop residues were supplemented with mineral fertilizers. Chemical properties measured after the 1986 crop season showed that crop residues together with fertilizers significantly increased the organic matter content and reduced the aluminum and hydrogen saturation of the exchange complex.

We continued to study the effects of presowing cultivation, fertilizer addition, and residual fertility on the establishment, growth, and yield of three pearl millet cultivars. We evaluated the residual effect from 1984 onwards by imposing a cultivar treatment that included two improved cultivars 3/4HK and CIVT, and Sadore Local in 75-cm rows at 13.3 hills m^{-2}. The direction of the rows was perpendicular to the prevailing direction of erosive winds. Pearl millet was sown after 40 mm of rain. This was followed by a drought spell of 17 days during which only 3.7 mm of rain fell. Establishment and subsequent hill survival were significantly superior for plowing and to a lesser extent for

Table 20. Effect of application of pearl millet crop residues over a 4-year period (1983-86) on grain yield (kg ha^{-1}) of pearl millet, and soil chemical properties measured at the end of the 1986 rainy season, ISC, Sadore, Niger.

Treatment	Grain yield (kg ha^{-1})	Bray P[1] (mg P kg^{-1} soil)	pH (KCl suspension)	Organic matter (%)	Total N (mg kg^{-1} soil)	Ca + Mg (cmol(+) kg^{-1})	A1 + H saturation (%)
Control	56	2.6	4.1	0.24	126	0.43	48
Crop residue	743	3.0	4.4	0.29	155	0.68	20
Fertilizers	816	7.1	4.1	0.25	151	0.44	43
Crop residue and fertilizers	1532	8.1	4.4	0.33	171	0.72	16
SE	±66[1]	±0.46	±0.04	±0.01	±8	±0.34	±3
CV (%)	12[1]	18	2	10	10	11	19

1. Does not apply to control where SE = ±13 and CV = 35%.

ridging compared with sandfighting and the zero-tilled control (Fig. 18).

Pearl millet responded well to fertilizer addition and cultivation. There was also a highly significant ($P < 0.01$) interaction of tillage and fertilizer. The intensive tillage methods of plowing and ridging did better on fertilized plots. On nonfertilized plots, mean plant height was 50 cm for plowing, 34 cm for ridging, 21 cm for sandfighting, and 33 cm for control. On plots that received fertilizer, corresponding values were 82, 60, 42, and 40 cm respectively (SE ±3 cm).

These trends were similar for grain yield. Ridging and plowing increased grain yield significantly ($P < 0.01$) as did fertilizer. Local pearl millet gave a significant response to fertilizer. There were no residual effects of fertilizer applied in 1984.

In another stand sown in a previously fallow field on the same date with the same plant density, we observed similar early advantages due to tillage. Plant stands in the two experiments measured 2-3 weeks after sowing were regressed with millet (CIVT) yield on fertilized plots. The effects of cultivation (plowing or ridging) versus no tillage control on stands and yields were significant for both experiments. Results show the importance of vigorous early crop establishment: each additional 133 hills ha^{-1} produced approximately 6.5 kg ha^{-1} more grain, in spite of the general differences in yield levels between the fields.

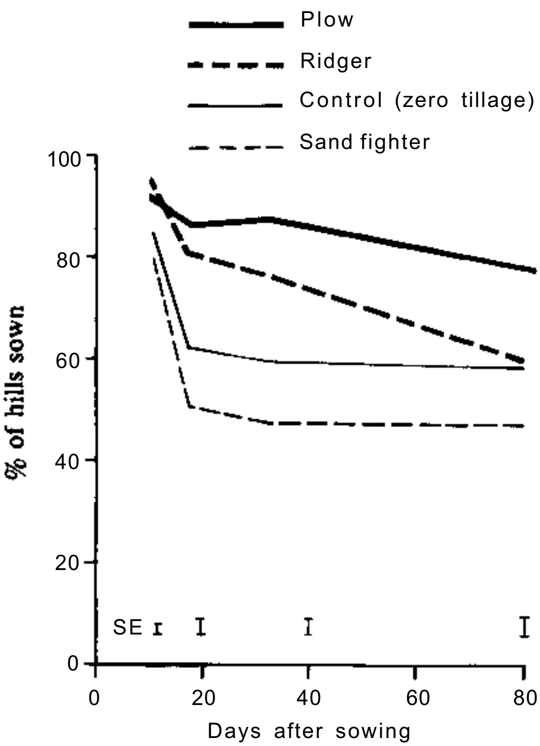

Figure 18. Effect of presowing cultivation method on pearl millet stands measured as a percentage survival of hills sown 13.3 m^{-2}, ISC, Sadore, Niger, rainy season 1986.

Crop Systems

Intercropping at ISC

Pearl millet and cowpea are grown extensively as intercrops in the dry regions of West Africa. Yields of both species are often very low, being limited by inadequate and erratic rainfall, poor soils and lack of improved varieties. The flowering of indigenous millets and cowpea coincides with the end of the rainy season when there is a high probability of drought. In the traditional systems, the two crops compete for light, water, and nutrients throughout most of the season, limiting yields particularly when rains end early in the season, as in recent years. Improved varieties have been introduced whose plant types and maturity cycles differ from the local materials that were initially selected for monoculture systems. Emphasis has been on adapting these new varieties for intercropping systems. In the last 3 years, agronomic trials have explored important factors such as appropriate dates for sowing cowpea in relation to pearl millet, densities, fertility and genotypes. All these influence productivity in intercropping systems.

Genotypes for Intercropping

At ISC, contrasting cowpea types have been screened since 1984 to identify useful traits for intercropping. The initial screening consisted of 300 lines sown in sole and intercropped stands with a single pearl millet cultivar, CIVT. In 1985 and 1986 we used 75 lines selected from the 1984 screening. Results over the 3 consecutive years have shown significant positive correlations between sole and intercrop yields. In 1984, the driest year on record (260 mm), yields of both cowpea and pearl millet were severely reduced and the correlation coefficient (r) was 0.45 ($P < 0.05$). During 1985 (rainfall 545 mm) and 1986 (rainfall 657 mm) moisture was not limiting. The correlation coefficients were 0.75 ($P < 0.01$) in 1985 and 0.91 ($P < 0.01$) in 1986. Genotype performance varied in both cropping seasons. As previously reported (ICRISAT Annual Report 1986 p. 272), greater yield advantages were obtained with intercrop combinations involving cowpea cultivars that mature in 55 to 65 days. These cultivars gave acceptable yields without seriously affecting the performance of pearl millet.

Traditionally, when pearl millet is intercropped with a later-maturing cowpea, the millet is often sown after the first substantial rainfall and cowpea is sown later in the season. Because grain and hay yields of cowpea are small, we explored the effect of changing agronomic components such as date of sowing, density, and choice of cultivars on the performance of pearl millet and cowpea in the intercrop. We compared the performance of three morphologically different types of cowpea; two early maturing (IT82D 716 and TVX 3236) and one late-maturing cultivar (Local Sadore). Each cultivar was grown in an intercrop with pearl millet in two successive seasons at ISC. Yields of early cowpeas were improved by sowing the cowpea with or shortly after the pearl millet (Table 21). The late-maturing cultivar significantly reduced the pearl millet yield when sown simultaneously. Grain yield of cowpea was negligible when sown 3 weeks after pearl millet. In another experiment where early cowpea and pearl millet were sown

Table 21. Intercropped cowpea and pearl millet yields (kg ha^{-1}) in relation to sowing time, ISC, Sadore, Niger, rainy seasons 1985 and 1986.

Sowing time of cowpea in relation to pearl millet	Season	Cowpea cultivar[1]								
		IT82D 716			TVX 3236			Local Sadore		
		G[2]	H	M	G	H	M	G	H	M
Simultaneous	1985	350	730	1055	485	930	1040		2270	340
	1986	150	273	980	185	380	570	40	1280	560
1 week later	1985	200	215	1255	240	750	1310		1970	630
	1986	180	186	610	120	400	740	30	1310	660
3 weeks later	1985	70	185	1515	80	270	1120		590	1310
	1986	120	170	880	100	160	810	13	450	840
Sole cowpea	1985	600	1260		930	1160			2430	
	1986	405	460		590	650		204	2026	
Sole millet	1985			1375			1375			1375
	1986			1096			1096			1096

	1985	1986
SE Cowpea grain	±90[3]	±19
SE Cowpea hay	±79	±78
SE Millet grain	±54	±72

1. IT82D 716 = early erect, TVX 3236 = early spreading, Local Sadore = late spreading.
2. G = Cowpea grain, H = Cowpea hay, and M = Pearl millet grain.
3. SE for cowpea grain yield for 1985 is based on IT82D 716 and TVX 3236 only.

Table 22. Effect of plant population and fertilizer N on four sorghum cultivars, Sotuba, Mali, rainy season 1986.

Treatments	Time to 50% flowering (days)	Plant height (m)	Number of panicles m^{-2}	Grain yield (t ha^{-1})
Cultivar				
Malisor 84-3	61	1.88	68.2	2.07
Malisor 84-1	62	2.31	57.3	2.48
Malisor 84-7	64	1.41	61.7	2.37
CSM 388	88	5.45	54.5	1.35
SE	±1.5	±0.04	±4.0	±0.12
Population (plants m^{-2})				
5	68	2.72	51.1	2.16
10	69	2.80	69.8	1.98
SE	±2.2	±0.28	±2.4	±0.11
N applied (kg ha^{-1})				
0	71	2.77	58.7	2.02
50	66	2.74	62.2	2.11
SE	±2.2	±0.28	±2.4	±0.11
CV (%)	18	25	28	32

in paired rows, we recorded intercropping advantages of up to 58% with little reduction in pearl millet yields. These results show that pearl millet/cowpea intercropping performance can be improved by the use of appropriate genotypes and agronomic manipulation.

Crops in Mali

We continued our studies on developing alternative and more productive sorghum- and pearl millet-based cropping systems in Mali. As a part of this objective we also evaluated the performance of different sorghum and pearl millet lines being developed by our breeders.

Sorghum

We evaluated three improved sorghum cultivars developed by our breeding program under two levels each of plant population and fertilizer N. The performance of these cultivars and CSM 388, a local cultivar at Sotuba (1986 rainfall 918 mm) is shown in Table 22. The new cultivars flowered earlier, were less tall than, and out-yielded CSM 388. Late-flowering CSM 388 encountered drought during the grain-filling stage, but the improved cultivars escaped stress because of their earliness. The cultivars were not affected by plant population or rate of applied fertilizer. These results were consistent with our previous studies. As Malisor 84-1 and Malisor 84-7 were found to be consistently higher-yielding than Malisor 84-3, we recommend these two cultivars for future farm testing.

Pearl Millet

We evaluated five pearl millet cultivars for their agronomic responses under two levels each of density and fertilizer N at Cinzana (1986 rainfall 632 mm). Souna x Sanio, an improved Malian cultivar out-yielded other cultivars in spite of its poor tillering ability (Table 23). As in previous years, Pool 4 gave the lowest yield of the five cultivars. Increasing plant density had a negative effect on grain yield, while applying 50 kg N ha^{-1} resulted in significant yield increase. All pearl millet cultivars were able to escape the late-season drought. However severe bird damage and pollen wash were two serious problems noticed on these early cultivars.

Intercropping

Our studies on cropping systems aim to develop more productive systems by incorporating commercial crops and improved cultivars. During 1986 we examined the three intercropping systems, maize/pearl millet, sorghum/groundnut, and sorghum/cowpea.

In our previous studies we examined maize/pearl millet intercropping for its productivity by considering such agronomic factors as density, fertility, and time of sowing. This year we used two maize and three pearl millet cultivars. There were no significant differences in grain yields within species.

We evaluated seven sorghum cultivars from our breeding programs for their performance, alone and intercropped with cowpea. Table 24 shows the performance of sorghum cultivars under the two systems. S 34, S 35, and Malisor 1 yielded particularly well. Intercropping greatly reduced cowpea grain and fodder yields. Malisor 7, a short-statured early sorghum, was the least competitive cultivar. The low-yielding CSM 388 did not suffer from cowpea competition and produced its normal yield under intercropping. Total Land Equivalent Ratio (LER) values did not reflect the grain-yield potential of the cultivars. S 34 and S 35, though higher yielding, had poor competitive ability thus producing lower LER values.

We examined the influence of sowing dates of sorghum cultivars on the productivity of the

Table 23. Effect of plant population and fertilizer N on five pearl millet cultivars, Cinzana, Mali, rainy season 1986.

Treatments	Time to 50% flowering (days)	Plant height (m)	Number of panicles m^{-2}	Grain yield (t ha^{-1})
Cultivar				
Composite Precoce	51	2.48	67.6	1.83
ICMV 2 (IBV 8001)	52	2.45	79.0	1.68
Souna x Sanio	53	2.59	58.2	1.95
Pool 4	58	2.67	79.1	1.37
ICMV 7 (ITMV 8304)	52	2.62	66.1	1.69
SE	±0.3	±0.03	±0.3	±0.1
Population (plants m^{-2})				
3.3	54	2.54	63.9	1.79
6.6	52	2.58	76.2	1.61
SE	±0.4	±0.02	±1.9	±0.07
N applied (kg ha^{-1})				
0	54	2.52	62.7	1.57
50	53	2.61	77.0	1.84
SE	±0.4	±0.02	±1.8	±0.07
CV (%)	5	6	19	27

Table 24. Performance of improved sorghum genotypes sole-cropped, and intercropped with cowpea (yields in t ha^{-1}), Sotuba, Mali, rainy season 1986.

Genotype	Sorghum grain yield		Intercropped cowpea grain yield[1]	Sorghum LER[2]	Cowpea LER	Combined LER
	Sole	Intercrop				
Malisor 84-1	2.85	2.43	0.43	0.85	0.37	1.22
Malisor 84-7	2.15	1.46	0.57	0.68	0.49	1.17
Malisor 84-3	1.72	1.41	0.42	0.82	0.37	1.19
S 34	2.67	2.15	0.43	0.80	0.38	1.18
S 35	3.02	2.37	0.43	0.78	0.37	1.15
82 S 50	2.34	2.30	0.38	0.98	0.33	1.31
CSM 388	1.40	1.37	0.42	0.98	0.36	1.36
SE	±0.09		±0.02			
CV (%)		33	19			

1. Sole cowpea grain yield = 1.16 t ha^{-1}.
2. LER = Land Equivalent Ratio.

sorghum/groundnut system. Malisor 34 suffered most while CSM 388 performed well with groundnut (Table 25). However, in terms of absolute yields, Malisor 7 was the lowest yielder and S 34 the highest. Groundnut produced higher yields with Malisor 7 but when the total productivity of the system is considered, CSM 388 performed better because of its higher yields. The sorghum sowing date significantly affected both sorghum and groundnut yields. Delaying sorghum sowing date increased groundnut yield considerably, but at the expense of sorghum

Table 25. Effect of sorghum cultivar and sowing date on performance of sorghum/groundnut intercrops, Sotuba, Mali, rainy season 1986.

Treatment	Intercrop sorghum[1]		Intercrop groundnut[1]		Combined LER
	Grain yield (t ha^{-1})	LER[2]	Pod yield (t ha^{-1})	LER	
Sorghum cultivar					
Malisor 84-7	0.78	0.37	2.33	0.81	1.18
S 34	1.26	0.31	2.24	0.78	1.09
CSM 388	1.10	0.59	2.14	0.75	1.34
SE	±0.10		±0.10		
Sorghum sowing date at:					
Groundnut sowing date	1.31	0.50	1.98	0.69	1.19
4 weeks later than groundnut sowing date	0.79	0.30	2.50	0.88	1.18
SE	±0.08		±0.07		
CV (%)	44		18		

1. Sole crop yields: Malisor 84-7 = 2.08 t ha^{-1}, S 34 = 3.950 t ha^{-1}, CSM 388 = 1.87 t ha^{-1}, groundnut = 2.85 t ha^{-1}.
2. LER = Land Equivalent Ratio calculated using trial means for respective sole crops.

growth and yields. Groundnut, being susceptible to early competition benefited by the delayed sowing of sorghum which resulted in poor sorghum stand and lower sorghum grain yields.

Microclimatology of Intercrops

In the 1985 and 1986 rainy seasons, we conducted multi-disciplinary experiments with pathologists in ICRISAT's crop improvement programs to relate crop microclimate to the incidence of foliar diseases (rust, *Puccinia arachidis,* and late leaf spot *Phaedisoriopsis personata*) of groundnut. Previous unpublished studies at ICRISAT Center indicated that intercropping consistently reduced rust incidence on groundnut but there was no effect on late leaf spot, contrary to reports elsewhere that groundnut foliar diseases are more severe in an intercrop because of increased humidity. The main aim of the experiments was to compare the temperature, windspeed, humidity, and leaf wetness in sole and intercropped groundnut, Kadiri 3 (Robut 33-1) in a 1:3 row arrangement with pearl millet, BK 560 in large plots, 30 x 20 m. Both experiments were sown in early July on medium-deep Alfisols and the crops were rainfed.

Another objective was to compare the microclimate in the intercrops with that in an automatic weather station, sited nearby (400 m). For most of the season, the average daylight air temperature (0600-1800 h) at 1 m height at the weather station was only marginally different from the air temperature above the groundnut canopy within the intercrop; but during the period from 50 to 60 DAS, the temperature within the intercrop was about 2°C higher than at the weather station. In marked contrast, the windspeed within the intercrop (30 cm above ground) was considerably less than the values recorded at the weather station (Fig. 19). The reduction in windspeed in the intercrop would have been even greater had the orientation of the rows (East-West) been at right angles to the prevailing winds which were predominantly westerly.

Comparison of the microclimate of the sole and intercropped groundnut during the 1985 season shows that the average daylight canopy temperatures were within 1°C throughout the season except for a 10-day period between 45-55 DAS when there was a severe drought (Fig. 20). Average windspeed above the sole groundnut crop was 2.60 ± 0.49 m s^{-1} compared to 1.45 ± 0.58 m s^{-1} in the intercropped groundnut. The reduction in windspeed in the intercrop reached a maximum at 30 DAS when the pearl millet attained a height of 0.8-1.0 m after which the windspeed was consistently 1.25 to 1.50 m s^{-1} less than in the sole groundnut. In contrast, the difference in saturation vapour pressure deficit between the two stands was small although the intercrop microclimate was marginally more humid (-0.24 ± 0.21 kPa). This is not surprising since the August and September rainfall was one of the lowest since 1972 (ICRISAT Annual Report 1985, p. 3). However there were still consistent differences in the relative leaf wetness of the two canopies during daylight but there was no apparent trend during the night.

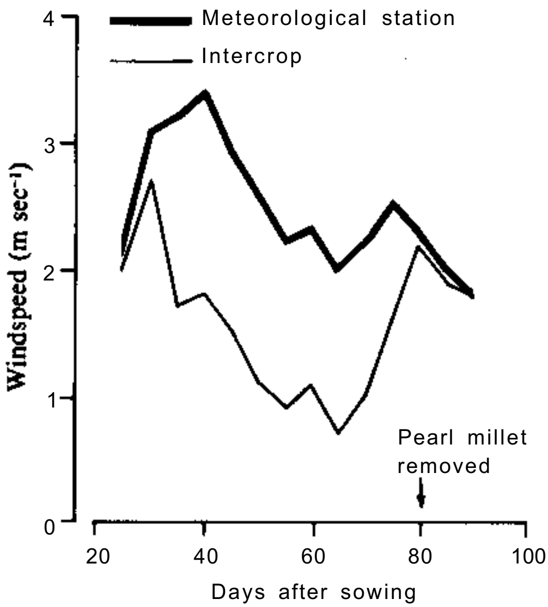

Figure 19. Comparison of windspeed measured above a groundnut crop in a groundnut/ pearl millet intercrop and at the meteorological station, ICRISAT Center, rainy season 1985.

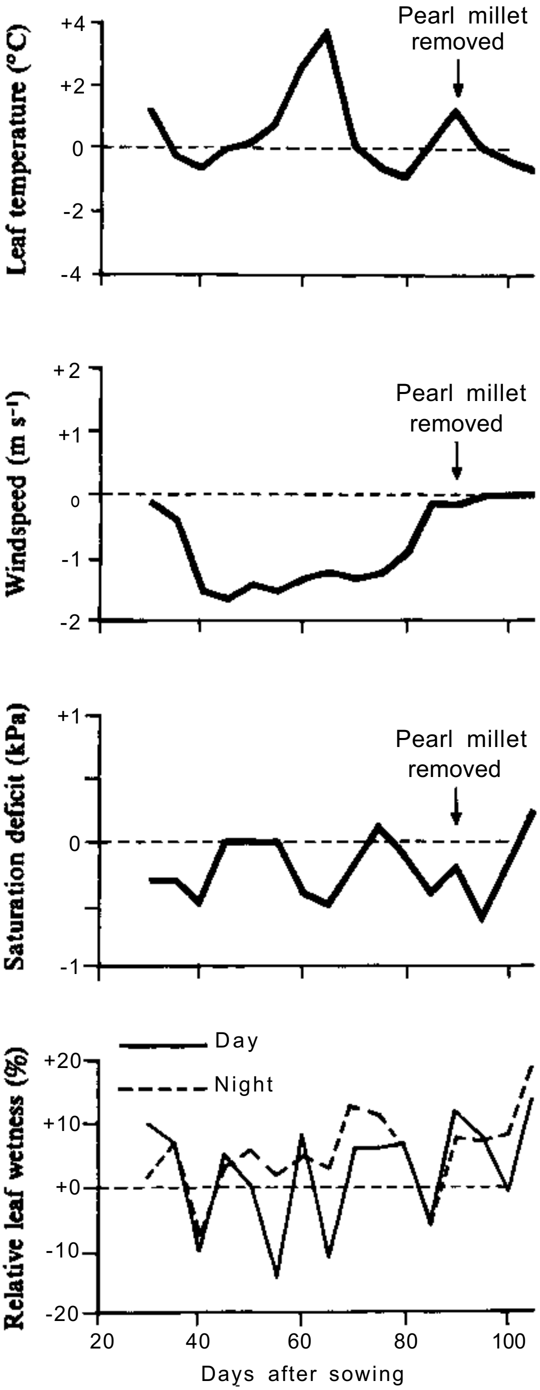

Figure 20. Differences between microclimatic elements in an intercrop and in sole groundnut grown on an Alfisol, ICRISAT Center, rainy season 1985.

Because of the long periods of drought in both 1985 and 1986 there was no significant build-up of foliar diseases during the experimental period and there were no significant differences between treatments in the spore counts of rust and leaf spot fungi. During the last 2 weeks of the 1985 season there was an outbreak of leaf spot that reduced pod yield of nonsprayed groundnut by 30%; but comparing intercropped and sole stands, there was no difference between the relative yields of groundnut sprayed with chlorothalonil (Daconil®) to control foliar diseases, and nonsprayed groundnut. We still need to compare microclimates in a more typical season when the high incidence of foliar disease is responsible for yield losses of the order of 70% (ICRISAT Annual Report 1984, p. 203).

The drought of the last 2 years provided an excellent opportunity to compare the performance of the pearl millet, groundnut and intercrop canopies in terms of their formation and functioning. For example, the rate of canopy development expressed in terms of leaf area index (ICRISAT Annual Report 1985, p. 276) or as fractional radiation interception (Fig. 21) was faster in both years than in 1978, an average rainfall year. The 1986 stands had a much smaller canopy, maintained throughout the growing season but the 1985 stands began to senesce from 45 to 50 DAS. The pearl millet stands intercepted about the same radiation in the 3 years but the efficiency of radiation conversion (e) was reduced by approximately 20 to 30% in 1985 and 1986 (Table 26). The 1985 groundnut crop was less productive than the 1978 crop because it intercepted 40% less radiation but e was about the same, whereas with more severe drought in 1986, the total intercepted radiation was reduced by 20% and e by 47%.

The results from the last two seasons are contrary to our earlier conclusion about the 1:3 pearl millet/groundnut system which suggested that the intercrop advantage of 8 to 31 % is due to an increased efficiency of utilization of intercepted radiation by the groundnut and a substantial increase in pearl millet tiller production (ICRISAT Annual Report 1981, p. 264). In 1985, the exceptionally high yield advantage was

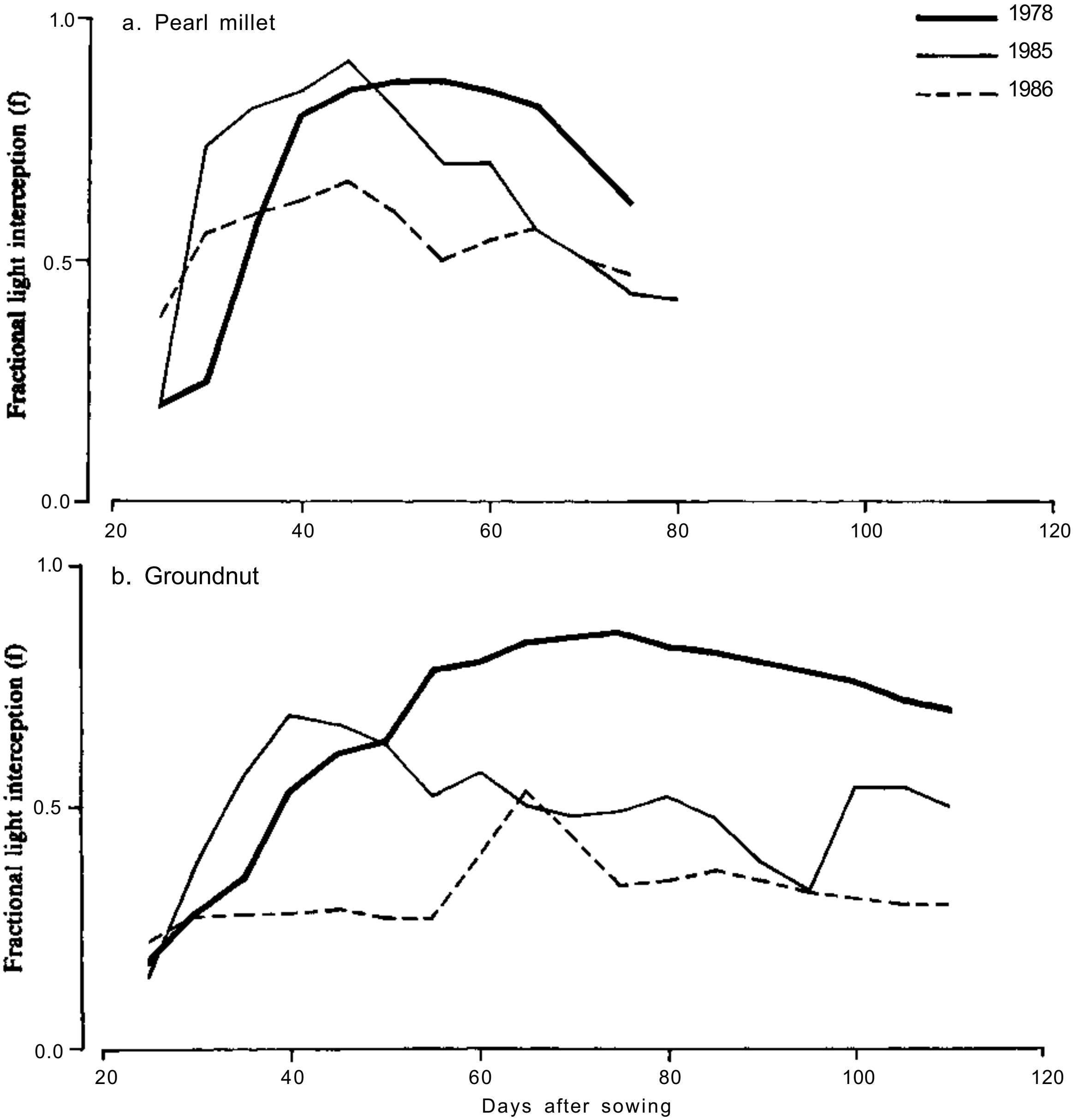

Figure 21. Fractional light interception of: a. pearl millet, and b. groundnut grown on Alfisols, ICRISAT Center, rainy seasons 1978, 1985, and 1986.

mainly due to the increased harvest index of the pearl millet and to a small increase in groundnut yield. In 1986, the intercrop gave a 12% reduction in combined yield because the prolonged drought led to severe moisture competition between pearl millet and groundnut; the intercropped groundnut yield was only 0.05 t ha^{-1} compared to 0.16 t ha^{-1} in the sole crop (Table 25).

This is the first time that we have observed an actual reduction in crop yield as a result of intercropping pearl millet and groundnut. Earlier

Table 26. Comparison of canopy performance and grain yield of pearl millet, groundnut, and pearl millet/groundnut intercrops grown on an Alfisol, ICRISAT Center, rainy seasons 1978, 1985, and 1986.

Year	Crop	Total radiation Intercepted (MJ m^{-2})	Efficiency of radiation conversion (g MJ^{-1})	Grain yield (t ha^{-1})	SE
1978	Pearl millet	640	1.13	2.23	±0.05
	Groundnut	940	0.48	1.19	±0.02
	Pearl millet/ground nut	40	0.87	1.23/0.84	±0.05/±0.02
1985	Pearl millet	617	0.92	1.23	±0.06
	Groundnut	550	0.46	0.93	±0.06
	Pearl millet/groundnut	580	0.29	0.85/0.82	±0.05/±0.06
1986	Pearl millet	568	0.89	1.81	±0.07
	Groundnut	752	0.25	0.16	±0.02
	Pearl millet/groundnut	780	0.18	1.04/0.05	±0.02/±0.01

studies have consistently showed that the intercropping advantage increased from 20 to 80% as irrigation decreased from 584 to 300 mm. However, in these line-source sprinkler studies, water was applied at regular intervals, whereas in 1986 the crops experienced a long period of drought that included both midseason and terminal stresses. All our previous studies have emphasized the advantage of intercropping in drought conditions: now we need to identify the rainfall regimes that are not suitable for intercropping systems.

Agroforestry

Analysis

A study funded by the Ford Foundation was started in 1985 to assist ICRISAT in evaluating the role of agroforestry in the SAT and to formulate future research needs. Evaluation has involved the examination of demands for different forestry products that agroforestry systems can provide, identification of the types of agroforestry systems likely to be appropriate, and consideration of how far these systems are likely to fulfill the requirements. We have also begun to diagnose the adoptability of agroforestry systems, particularly in the Indian SAT.

Although the extension of agroforestry technology in the SAT could provide a great range of usable and marketable tree-derived products, we place priority on those agroforestry systems that involve our mandate crops. It is not within our capability to address all shortages of forestry and agroforestry products in the SAT countryside.

Of the multitude of products from agroforestry, fodder production from trees appears most attractive as an area of research. Fodder is a valuable commodity in both India and sub-Sahelian Africa. In India, farm-gate prices of fodder have more than doubled in real terms over the last 10 years in many locations. Fodder has a high value for use on farms, and the flexibility of agroforestry systems allows production either on a cut-and-carry basis, or by in situ grazing during fallow periods and in the dry season. Tree-based fodder supplements may improve the feed efficiency of cereal stovers.

This emphasis on fodder does not mean that other tree products should be neglected: where possible, products like poles and fuelwood can also be exploited. Benefits such as improved field microclimate, fertility and soil conservation must be considered as well. Systems designed to exploit them are likely to be more adoptable in the SAT if they complement the primary use of leafy prunings as fodder or browse.

Many agroforestry systems have been proposed and tested in the SAT, and future research at ISC and ICRISAT Center will focus on those most likely to be extensible by national programs. One of these is the multiple-storied or "parkland" systems that exist in the dry SAT. Notable are the *Prosopis cineraria*/pearl millet association in Rajasthan, India and the *Acacia albida* associations with various crops in many parts of Africa. These systems have evolved by tradition; few farmers actually plant and tend the trees, but they implicity sow by not uprooting volunteers.

These systems usually succeed through some physiological or phenological trait that lessens competition between a tree and crops grown beneath its crown, for instance, deep rooting (as in the case of *P. cineraria*) or leaf-shedding during the cropping season (as with *A. albida*). Management can also play a part. Lopping trees for fodder in the *P. cineraria/*pearl millet areas and in *Acacia nilotica/* cereal stands throughout India are two examples of traditional management systems that lessen competition with crops.

The potential for improving these systems is great. One way is by tree selection and breeding programs, e.g., selecting for fast early growth and thornless types in *P. cineraria.* Another would be to adapt these systems to a modified reforestation scheme in which, throughout the year, trees are lopped for fodder until established, or planted in cropped fields to provide a continuous source of fodder and wood. In both examples, the canopy management of the trees is important, as it provides a steady source of agroforestry products and lessens negative impacts on crops grown in association.

Another technology with potential in wetter regions of the SAT is alley cropping, a system wherein pruned tree hedgerows are established at regular intervals in the field, allowing crops to be grown between. Loppings from the hedgerows are either applied to the soil as green manure or removed as fodder.

Our alley cropping trials and those of the Indian agroforestry program show that in the Indian SAT, trees compete strongly with crops, especially for water. Methods that decrease hedgerow competition and enhance beneficial effects need to be worked out before this system can be extended to farmers of the SAT. Such options include wide spacing between rows (10-20 m), and using crops such as sorghum and pearl millet that are more tolerant of tree competition than pigeonpea.

Our studies at ISC have shown that short (1 m) mechanical windbreaks increase crop yields in dry areas where wind can damage crops by desiccation, sand blasting, and burying. Arboreal windbreaks have been shown by others to increase crop yields in river valleys of the Sahel, but more research is needed on their long-term competition with crops. Also, alternative tree species suitable for windbreaks in the Sahel need to be identified.

Bund and boundary plantings are two Indian examples of systems where trees have little or no direct effect on crop performance, yet have a vital role in the farming system as a whole. Block plantings of trees can have a direct effect on crop growth when planted sequentially on the same piece of land in a rotational scheme. The use of forest litter to mulch fields is often overlooked, although it is an accepted practice in semi-arid parts of Mexico. In areas of West Africa where grazing is an important part of the farming system, a silvipastoral component would be practical.

Experiments

The emphasis of our agroforestry research is on the evaluation of methodologies such as experimental design, and the sustainability of agroforestry systems; and on the beneficial effect of trees in reducing soil degradation on shallow soils. Our research complements the wider effort of the All India Coordinated Research Program on Agroforestry (AICRPA) which concentrates on the development and management of suitable agroforestry systems. A geometric design experiment was started in 1984 on medium-deep Alfisols to examine whether row orientation would affect the crop-tree interaction. During the first year of establishment of the trees (*Leucaena leucocophala* (Lam)), the annual crop sown in the 1984 rainy season was sorghum, in 1985 it was sunflower, and in 1986 it was again sorghum. There were four row orientations radiating from a central plot of sole leucaena (Annual Report cover).

Row orientation appeared to have an effect on the height of the crop plants during the first month of the rainy season (July) when windspeed ranged from 3 to 4 m s^{-1}. The westerly winds also resulted in a distinct rain-shadow on the eastern side of the North-South leucaena hedgerows but at final harvest there were no significant differences in crop yield between the orientations (Table 27). In 1985, the reduction in sunflower yield extended to 2.7 m from the leucaena (Fig. 22), a distance that corresponds to the lateral spread of the leucaena roots (ICRISAT Annual Report 1985, p. 304). The reduction in grain yield was equivalent to a 50% loss in a 5.4 m hedgerow spacing. The growth of sorghum was unaffected by the leucaena in the first year, but in 1986 a small reduction was observed to a distance of 1.2 m, equivalent to a 20% reduction in a 5.4 m hedgerow spacing. Thus, sorghum could be grown at a closer spacing than sunflower and row orientation is unlikely to have a major influence on crop productivity in our environment where windspeed is relatively low and hedgerows are cut to 0.8 m at regular intervals.

Systematic designs have been used very successfully in the past to examine the interactions between crops over a wide range of populations,

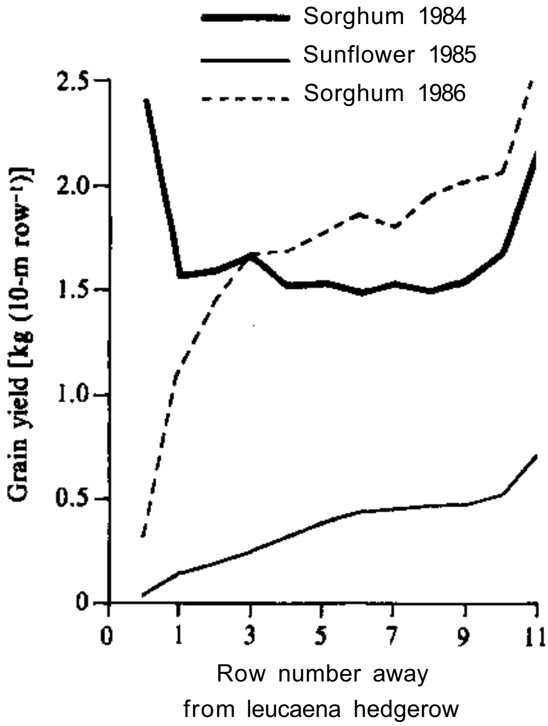

Figure 22. Yields of sorghum and sunflower as function of distance from leucaena hedgerow on an Alfisol, ICRISAT Center, rainy seasons 1984, 1985, and 1986.

and they are particularly useful for agroforestry research where basic information such as optimum population is lacking. These designs are suitable only for short-term and preliminary studies because they cannot have randomization within complete blocks. However, inferences from such experiments will help us to develop more appropriate agroforestry systems for long-term operational scale research. In 1984, we used

Table 27. Row orientation and grain yield (g $plant^{-1}$) of sorghum at two distances from a leucaena hedgerow on an Alfisol, ICRISAT Center, rainy season 1986.

	Row orientation						
Distance (m)	N-S	E-W	NW-SE	SW-NE	SE	Mean	SE
0-1.4	129	168	148	130	±32	144	±16
1.8-2.7	250	259	266	253	±14	257	± 7

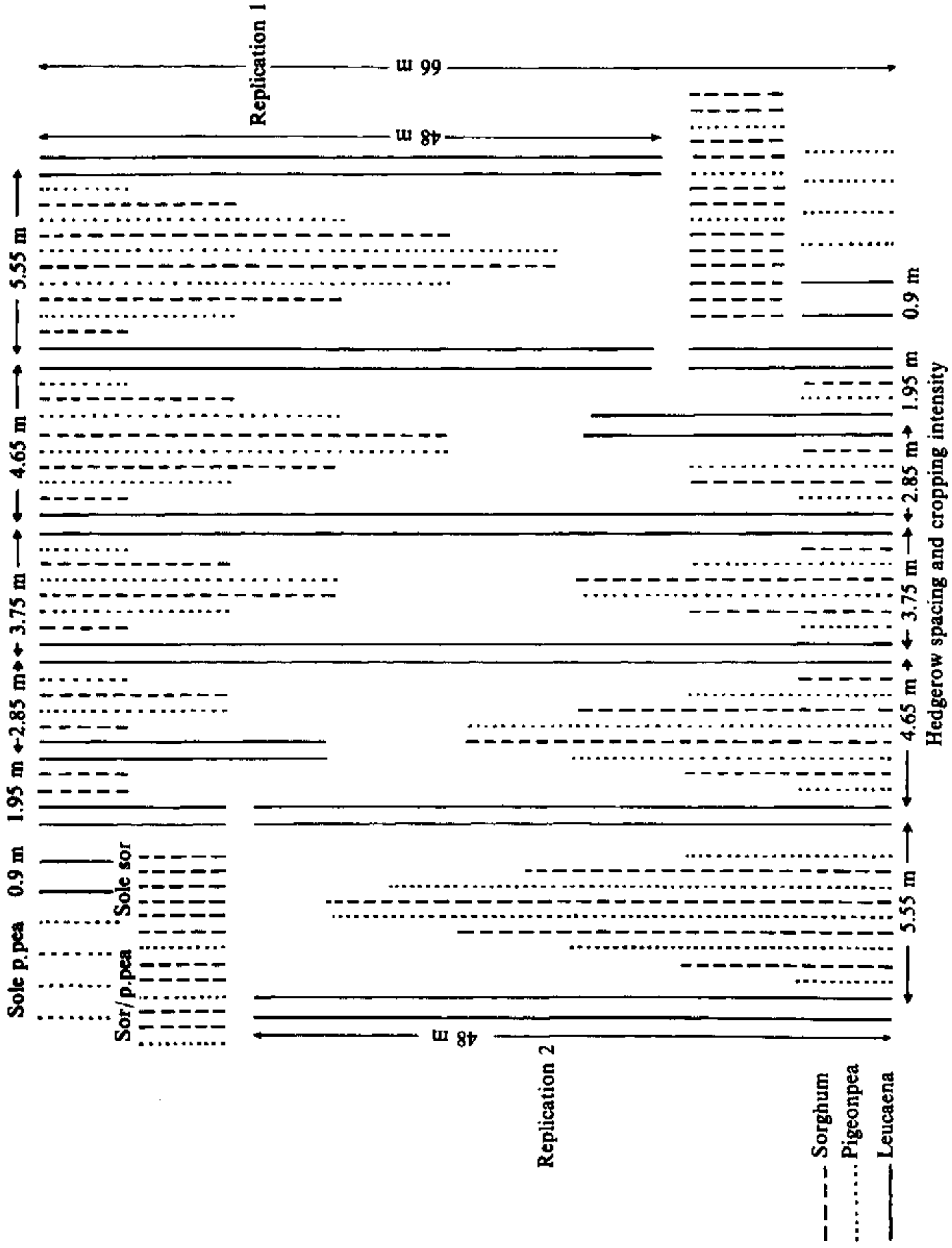

Figure 23. Layout of 2-way systematic design for agroforestry research on the influence of hedgerow spacing and cropping intensity, ICRISAT Center, 1986.

a 2-way systematic design to examine the effect of tree spacing (paired hedgerows) and the effect of cropping intensity on the productivity of agroforestry systems on shallow Vertic Inceptisols (Fig. 23). In one direction, we have five hedgerow spacings of leucaena which increase by 0.9 m from 1.95 m to 5.55 m. Within each spacing, a 1:1 row arrangement of sorghum/pigeonpea is sown during the start of the rainy season. Row width of the stands is constant (0.45 m) so that there are two rows of the annual crop in the 1.95-m alleys and ten rows in the 5.55-m alleys. Cropping intensity was altered by reducing the two crop rows nearest the trees at 8-m intervals until a single leucaena row remains. In 1985, the growth of the stands of sole pigeonpea and sorghum was reduced by the adjacent trees because of moisture competition so, in July 1986 a polythene root barrier was installed at a depth of 0.5 m, 0.2 m away from the trees.

During the first year of the leucaena (1984), the grain yield of sorghum was relatively unaffected by hedgerow spacing but sorghum yield was only 45 to 62% of the sole sorghum stand (Fig. 24). In the next 2 years, the grain yield of sorghum at the two lowest spacings declined dramatically, and in 1986 yield at the wider spacings was less than 30% of the sole crop. In all 3 years the rainfall was about 30% below the long-term average. The sole sorghum yield was about 2.7 t ha^{-1} in both 1984 and 1985 but was exceptionally high at 5.1 t ha^{-1} in 1986, because of the favorable rainfall distribution for sorghum growth.

The addition of leucaena hedgerows greatly increased the competition in the agroforestry treatments because the grain yield of sorghum was reduced by 40 to 60% in all 3 years compared to the sole sorghum crop. In 1984, the growth and yield of pigeonpea in the agroforestry treatments were unaffected by the presence of leucaena but, in 1985, pod yield declined dramatically (from 50 to 4% of sole-Crop yield) as hedgerow spacing decreased. The prolonged drought in 1985 reduced the yield of sole pigeonpea to 0.17 t ha^{-1} from 1.5 t ha^{-1} in 1984.

A major objective of our agroforestry research is to manage the leucaena hedgerows to maxim-

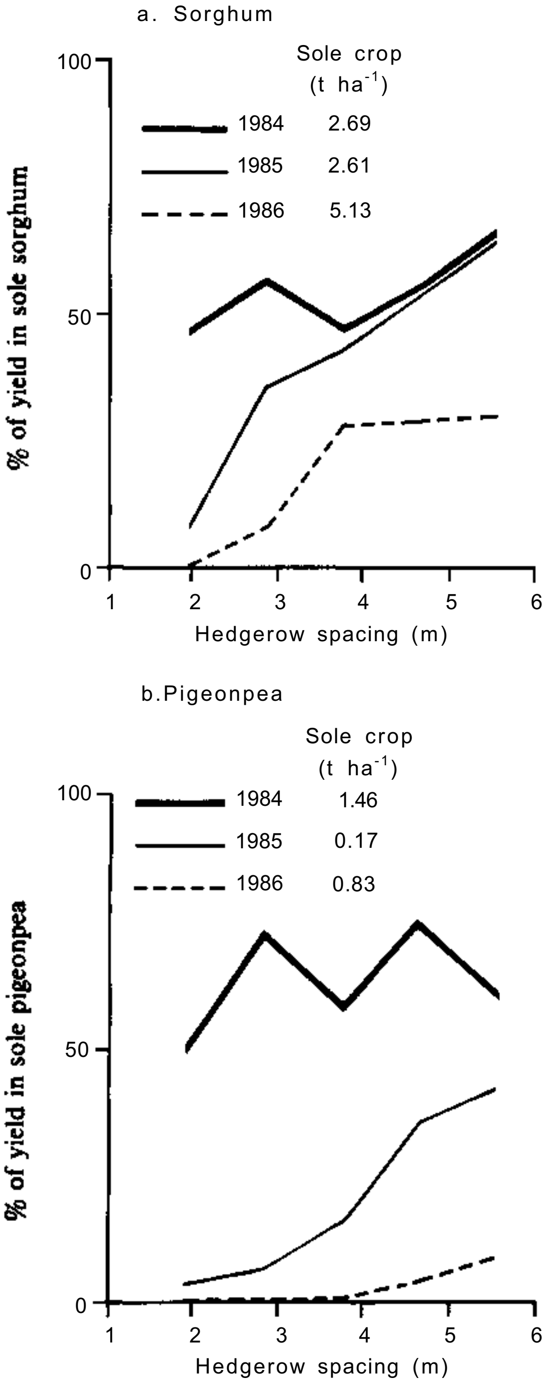

Figure 24. Grain yields of: a. sorghum, and b. pigeonpea (as a percentage of sole crop yield) at five hedgerow spacings on a Vertic Inceptisol, ICRISAT Center, rainy seasons 1984-86.

ize fodder production during the dry season when fodder shortage is acute, and to minimize the reduction in crop yield during the rainy season. Narrow hedgerows (< 4 m) are not satisfactory for crop growth during the rainy season but fodder production during the dry season is dependent on both spacing and cropping intensity. At the highest cropping intensities, fodder production ranged from 3.5 to 4.5 t ha^{-1} but production remained relatively constant at 6.5-7.5 t ha^{-1}, below a cropping intensity of 60%. Despite three cuts, fodder production during the rainy season greatly exceeded production in the dry season. The greater production in the rainy season is probably due to the more humid environment because the hedgerows intercepted similar amounts of radiation in both periods. These initial analyses suggest: 1. that competition for resources between crops and leucaena during the rainy season could be reduced further by wider hedgerow spacings or by more frequent defoliations, and 2. that long-duration crops like pigeonpea are unsuitable for growing in close proximity to leucaena (Fig. 25).

Operational Scale Research

An operations trial at ISC combined several promising components of research which have emerged over the past 4 years. They can be summarized as follows:

- Application of limited quantities of P (30 kg P_2O_5 ha^{-1}) was economical (ICRISAT

Figure 25. A two-way systematic design to examine the effect of leucaena tree spacings, and the effect of cropping intensity on the productivity of an agroforestry system. Note that the growth of pigeonpea is severely affected by competition from leucaena, ICRISAT Center, rainy season 1986.

Annual Report, 1985, p. 305) and increased yields by 2-3 fold.

- An improved variety of pearl millet, ICMV 5 (ITMV 8001), recommended for release to farmers in Niger, gave increased and stable yields in multilocational testing.
- TVX 3236, an early maturing semi-erect type of cowpea, consistently outyielded other cultivars in the IITA/ICRISAT cowpea program.
- Ridging and sowing on ridges, gave better plant establishment in pearl millet and survival later in the season (ICRISAT Annual Report 1985, p 268).
- Use of animal traction for ridging and weeding results in a significant reduction in labor requirement (ICRISAT Annual Report 1985, p. 273).

These components have been systematically combined over the period 1986 to 1988 in order to evaluate relative advantages of one or more combinations. To evaluate the residual effect of a legume on pearl millet sown the following year, the rotation of sole crops or intercrops was also included. There were 13 different treatment combinations (Table 28). In the traditional treatment, local cultivars of pearl millet (Sadore Local) and cowpea (Local Sadore) were grown with only hand cultivation and no fertilizer was applied. Pearl millet was sown with the first rains of the season and cowpea was sown 3 weeks later. The experimental design is a completely randomized block design with 8 replications, the area of the individual plots being 500 nr^2. In the traditional treatment, the spacing for pearl millet was 1.5 x 1.0 m, while in other treatments, a spacing of 1.5 x 0.7 m has been adopted. In the intercrop, traditional forage cowpea (Local Sadore) was spaced 1.0 x 2.0 m while sole cowpea (TVX 3236) was spaced 0.75 x 0.2 m. All the inputs including labor times were monitored throughout the season.

The 1986 rainy season was the first year of this trial, and our results to date indicate that there was a significant effect of ridging (with animal traction) on grain and straw yields of sole and intercropped pearl millet. Ridging had no significant effect on intercropped cowpea grain and hay yields but resulted in a significant increase of sole-cropped cowpea grain yield.

Table 28. Tillage and rotation combinations under evaluation in operational scale research, ISC, Sadore, Niger, 1986-1988.

Treatment combination		Sole/intercrop		
Tillage	Continuous crop/rotation	1986	1987	1988
By hand[1]	Continuous	M/C[2]	M/C	M/C
By hand	Continuous	M	M	M
By hand	Rotation 1	M	C	M
By hand	Rotation 2	C	M	C
By hand	Continuous	M/C	M/C	M/C
By hand	Rotation 1	M/C	C	M/C
By hand	Rotation 2	C	M/C	C
Animal[3]	Continuous	M	M	M
Animal	Rotation 1	M	C	M
Animal	Rotation 2	C	M	C
Animal	Continuous	M/C	M/C	M/C
Animal	Rotation 1	M/C	C	C
Animal	Rotation 2	C	M/C	C

1. Traditional treatment with local cultivars of pearl millet and cowpea and no fertilizer use. All other treatment combinations receive fertilizer at 30 kg P_2O_5 ha^{-1}.
2. M = Pearl millet, C = Cowpea, and M/C = Pearl millet/cowpea intercrop.
3. Animal traction for ridging and weeding.

Evaluation of Management

Chemical Pest Control

Adoption by Pigeonpea Growers in India

Our surveys of large pigeonpea tracts in the Indian SAT indicated that insecticides are used by less than 10% of growers (ICRISAT Annual Report 1982, p. 141). Chemical pest control, in particular control of the pod borer *Heliothis armigera,* will however, remain a crucial element in any pest management strategy for pigeonpea until cultivars with substantial levels of resistance are forthcoming. Until then, research aimed at reducing pest losses in farmers' fields has to be concerned with reducing the costs of chemical control. As a result of such research, we identified low-volume (LV) sprayers and action thresholds, based on egg or larvae counts, as components potentially suitable for small farmers. We introduced these components in Farhatabad, one of our on-farm research locations in India (ICRISAT Annual Report 1985, p. 299). The village is characteristic of one area where pigeonpea is mainly grown as a sole crop on nonirrigated medium to deep black soils. We returned to Farhatabad in 1985 and, with the assistance of the Karnataka State Department of Agriculture, surveyed pigeonpea growers' perceptions and adoption of pesticides, spraying implements, and action thresholds.

The questionnaire survey covered a sample of 77 farmers randomly drawn from three strata of landowners in the village. The sample was biased towards farmers who owned most land so that a larger proportion of respondents could be expected to have experience in the use of relatively expensive spraying implements. Although growing pigeonpea and pesticide use by farmers were not preconditions for inclusion in the sample, all respondents had experience with pestichde use in pigeonpea.

Perceived losses. Farmers estimate that seed losses due to *H. armigera* are about 20% of the potential pigeonpea yield in years of average infestation, even when the crop is treated with pesticides. Without treatment, the loss is believed to be about 50%. At a potential yield in farmers' fields of 1 t ha^{-1} the value of seed loss in years of average infestation and when *H. armigera* is not controlled amounts to nearly Rs 2000 ha^{-1}. This loss is, on average, reduced to Rs 760 ha^{-1} with chemical control, providing a private gross benefit of about Rs 1200 ha^{-1}.

Adoption of Pesticide Application Techniques

The technological options available to farmers at Farhatabad were:

- dusting by hand or with a duster;
- high-volume (HV) spraying with a backpack sprayer or with a sprayer mounted on a bullock cart; and
- low-volume (LV) spraying with a hand-held sprayer or with a battery of three sprayers mounted on a Tropicultor.

Adoption of dusting began in 1967 and HV spraying in 1968. Diffusion of these techniques was slow for the first 6 years but at the time the survey was conducted adoption was nearly complete for dusting and HV spraying (Fig. 26). Contrary to our expectations, many farmers did not follow a sequence of adoption steps from dusting to backpack sprayers and then to sprayers mounted on a bullock cart. All respondents immediately used sprayers mounted on a bullock cart when they adopted spraying, and about one in eight respondents used sprayers when they adopted insecticides. Furthermore, spraying and dusting are often combined on the farms. Two-thirds of the farmers who sprayed their crops with HV sprayers also used dusts.

Adoption of hand-held LV sprayers is rapid. In 1982 only two farmers had used them. In the

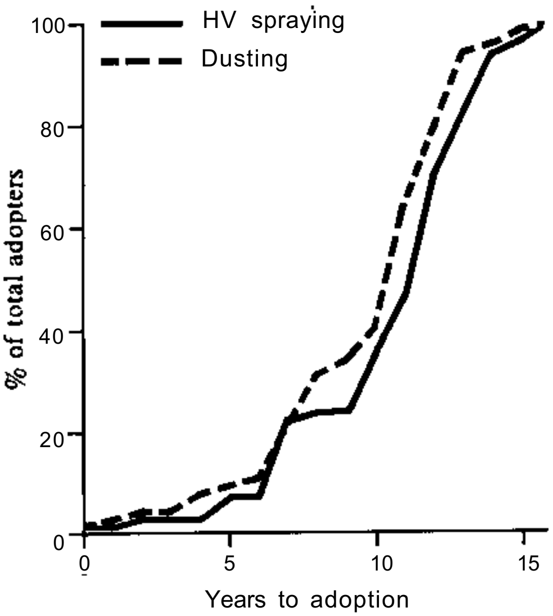

Figure 26. Diffusion paths for dusting and HV spraying, Farhatabad, India, 1967-86.

following year 36 farmers adopted LV spraying and adoption has further advanced since the survey was carried out. Farmers from the village reckoned that more than 100 LV sprayers had been in use during the 1985/86 growing season.

Farmers' acquaintance with LV spraying from a Tropicultor was limited. Only one unit was available in the village, two respondents had used this technique, and only eight respondents had seen, but not used it.

Perceptions and Elements of Costs

Respondents perceived HV spraying from a bullock cart to be easy work and to provide good crop protection. However, many respondents were concerned about damage to crops caused by the bullock cart and about the health hazards of spray to laborers and bullocks.

All 38 respondents who had used LV sprayers agreed that LV spraying is lighter work than HV spraying, that it is more effective, and that it requires less time. However, nearly 90% of these farmers also regarded LV spraying as more hazardous and impossible in windy weather. LV sprayers were perceived as more prone to fail than HV sprayers but they were also believed to be easier to repair. Most LV spray users reported no difficulties in preparing the concentrated spray solution.

The investment of Rs 800-1000 for a HV sprayer and Rs 500-600 for a LV sprayer is not too high to prevent widespread ownership on farms of more than 4 ha of owned land. Farms of more than 4 but less than 10 ha, on average, owned three sprayer units per four farms, and large farms with more than 10 ha owned on average 1.6 units per farm. However, only one out of four farms with less than 4 ha land owned either a HV or a LV sprayer. Farmers who do not own spraying equipment can rent it in the village at Rs 10 day^{-1} for a HV sprayer, or Rs 26 day^{-1} for a hand-held LV sprayer, and the owner of the Tropicultor would be willing to let his Tropicultor, fitted with three LV units, for about Rs 70 day^{-1}. There was no indication that daily wages for pesticide application are higher than wages for less hazardous agricultural operations, or that wages are differentiated according to the technique of pestcide application.

Saving of total labor time and larger area sprayed per unit of time are major advantages of LV over HV sprayers. On average, farmers require about 6 h ha^{-1} to treat sole-cropped pigeonpea with a HV sprayer but only 4.4 h ha^{-1} when a LV sprayer is used. Since HV spraying requires at least three people, its total labor requirements exceed 2 man-days ha^{-1}, whereas only half a man-day is required for spraying with a hand-held LV sprayer. LV spraying with a Tropicultor requires slightly more than 1 h ha^{-1} (Table 29).

Table 29. Time requirement (h ha^{-1}) for pesticide application by different techniques, Farhatabad, India, 1984/85.

Application technique	Number of respondents	Mean	SE(±)
Spraying with HV sprayer mounted on bullock cart			
Sole-cropped pigeonpea	70	6.1	0.13
Intercropped pigeonpea	66	5.7	0.16
Hand-spraying with LV sprayer			
Sole-cropped pigeonpea	38	4.4	0.23
Intercropped pigeonpea	33	4.1	0.22
LV sprayer mounted on Tropicultor	10	1.2	0.00

Safety

Respondents took only rudimentary precautions to protect their health. Most washed their hands or bathed after spraying, but very few tied a piece of cloth around nose and mouth when spraying. Spraying in the wind direction, as particularly recommended when LV sprayers are used, was rarely practised. Gloves, goggles, and face-masks had not been available to the majority of farmers. However, recent reports indicate that face-masks have become available in local shops. A local doctor, who is a farmer himself, believed that there were about 70 cases of monocrotophos poisoning in the village during the 1984/85 growing season. Most of the victims were believed to be inexperienced farmers who used LV sprayers for the first time.

Adoption of Thresholds

Economic thresholds, introduced with LV sprayers, have not been adopted as rapidly as LV sprayers. More than 60% of the respondents exclusively followed a fixed treatment routine after their pigeonpea crops flowered. Farmers who used thresholds combined this decision-rule with conventional treatment routines. Furthermore, most adopters used threshold levels that were considerably higher than the recommended ones. We do not yet know the reasons for this. We suspect that pest-loss relations and spray efficacy in farmers' fields and on research stations deviate considerably and can contribute much to explain the discrepancy between the thresholds recommended and applied.

Material inputs, like pesticides and sprayers, can usually be used by unskilled and untrained personnel. Intellectual inputs, like thresholds, in contrast, require investment in information and knowledge. Compared to routine spraying schedules, thresholds based on insect counts require regular field visits and monitoring of the pest populations. The need to visit fields cannot, however, explain the low aggregate rate of adoption of thresholds by the sample farmers because all farmers claimed to visit their pigeonpea fields at least every second day.

To quantify the effect of knowledge and training on thresholds, we performed a probit analysis with threshold adoption as the dependent variable and years of schooling as a proxy for knowledge and training as regressor. Schooling was expressed with two dummy variables, one for school attendance of up to 4 years, and another attendance for more than 4 years. We expected attendance for more than 4 years to

Table 30. Probit analysis of adoption of thresholds for controlling *Heliothis armigera* in pigeonpea by 76 respondents from Farhatabad, Karnataka, India, 1985.

Variable	Mean	Estimates: Coefficient	Estimates: Asymptotic t-ratio
Constant		-2.23*	-2.50
Sole-cropped pigeonpea area as % of total owned area	40.9	-0.006	-1.05
Average perceived loss in treated pigeonpea	22.1	0.072*	2.11
Use of LV sprayers (= 0 if not used)	0.49	0.440	1.34
Male family labor ha^{-1} cultivated area	0.47	-0.500*	-2.50
School attendance up to 4 years	0.20	0.570	1.23
School attendance 5 or more years	0.50	0.910*	2.19
Likelihood ratio test, with 6 degrees of freedom (DF)		13.4	
Probability of threshold adoption by all sampled farmers		0.37	
Probability of threshold adoption for farmers with more than 4 years of schooling		0.50	

have a significant effect on threshold adoption. In the regression analysis, we controlled the effects on threshold adoption of the proportion of pigeonpea area in total operated area, the perceived average pest loss when the crop is treated, use or non-use of LV sprayers, man-land ratio (measured as male family labor ha^{-1}), and farmers' experience with pesticide use (measured in number of years since pesticide adoption). The regression analysis (Table 30) showed that only the effects of family labor availability and the dummy variable for more than 4 years of schooling are statistically significant. The analysis indicates a threshold adoption probability of $P = 0.37$ for the whole sample but an adoption probability of $P = 0.50$ for farmers who had attended school for more than 4 years. Thus, early adoption of thresholds can be expected to be substantial only where farmers have had considerable formal training.

In summary, pesticide use in pigeonpea has spread quickly in an area where this crop is grown as a remunerative sole crop. The use of modern labor-saving spraying implements is also quickly adopted, even by farmers who do not own such implements. During the early phase of adoption, when farmers are inexperienced in the use of potentially hazardous sprayers, safety considerations require close attention by agencies promoting the use of such implements. Thresholds, a knowledge-and-information intensive component of pest management, may be too difficult to be quickly adopted by poorly trained and often illiterate small farmers.

Insect Control

On dryland crops, particularly pigeonpea, the use of dust to control insects is still a common practice, largely because dusting does not require water or a complicated appliance. Commonly dust in a thin cloth bag is dabbed on plants along the crop rows, or a duster—readily available in the market is used. We have developed a wheeled tool carrier (WTC)-mounted duster, like the bullock-drawn WTC-mounted LV and ULV sprayers (ICRISAT Annual Report 1984, pp. 273 and 292).

In 1985/86, using these developments we compared dusting with spraying for the control of insects in intercropped pigeonpea at ICRISAT Center. Endosulfan (35% EC) was used at 2 L ha^{-1} for spraying, and 4% dust at 25 kg ha^{-1} for dusting when 10 eggs and/or 3 small larvae of *Heliothis armigera* were recorded $plant^{-1}$. Two applications were required for optimal pest control. There were no significant differences between spraying and dusting. One of the major hazards of dusting is that it poses a higher risk of inhaling toxic chemicals to the operator.

This year we compared the WTC/ULV system in farmers' fields at Chevella with a farmer's traditional HV sprayer mounted on a bullock cart. One ULV application reduced the pod damage to 23.5% as against 31.5% for two HV applications. A saving of Rs 250 ha^{-1} was recorded with ULV over HV application.

In the 3 years of pest/ parasitoid monitoring in sole and intercropped stands of groundnut and pigeonpea on Alfisols under nonsprayed conditions, no significant differences were recorded in the incidence of insects between sole and intercrops of either compoent (Table 31).

Use of Nitrogenous Fertilizer

In a joint research project with the IFDC, we are examining farm-level constraints on the use of nitrogenous fertilizer on nonirrigated sorghum. One important sorghum cropping system in India in which fertilizer use is negligible is postrainy-season production (September through February) in undependable rainfall areas. (ICRISAT agroclimatologists have designated as "undependable" those areas generally unsuitable for rainy-season cropping due to the erratic distribution of rainfall.) In 1984/85, fertilizer trials were conducted on farms in Shirapur village, Sholapur District, a major area for growing sorghum in the postrainy season. In each of six fields, we laid out replicated dosage trials. Basal urea was applied in doses ranging from 5 to 50 kg N ha^{-1}. The trials were managed

Table 31. Average pest incidence/damage and yields in sole and intercropped groundnut and pigeonpea grown on Alfisols, ICRISAT Center, 1983-86.

	Plants (%) with:			Pod damage (%)			Yield (kg ha^{-1})	
Cropping system	Thrips	Jassids	Leaf miner	Borer	Podfly	Total insects	Groundnut	Pigeonpea
	Groundnut			Pigeonpea				
Sole	37	27	23	19.0	18.6	39.0	501	937
Intercrop	34	28	25	22.1	21.9	49.3	342	558
SE	±0.7	±0.1	±1.2	±1.7	±4.0	±4.2	±50	±73

by farmers and none of their practices other than fertilizer application were altered.

No significant response to nitrogen was evident. Follow-up farmer interviews and a review of on-station experiments led to the identification of sowing date as the key variable in fertilizer response. In the traditional cropping system, sowing begins as soon as the monsoon rains have ended, and the crop relies primarily on moisture stored in the deep black soils. Under this receding soil moisture regime, response to fertilizer is negligible in most years, discouraging use in all years. On-station experiments have shown that when the sowing date is advanced to take advantage of the last month of the monsoon rains, response to nitrogenous fertilizer is greater and more reliable over the years. Nevertheless, waterlogging is a serious obstacle to advancing the sowing date. Moreover, the incidence and severity of pest attacks increase. The costs and risks which accompany the advanced sowing date outweigh the possible benefits.

Collaborative Projects with National Programs

West Africa

In the area of resource characterization, the agroclimatology program at ISC has established links with the National Meteorological Services of Niger, Mali, Burkina Faso, and Senegal to climatologically analyze historical rainfall data. An information bulletin on "Agrometeorology of Burkina Faso" has been prepared in cooperation with the Burkina Faso Meteorological Services and will soon be available in English and French. The soil fertility program conducts cooperative studies in villages with the Laboratory of Soils, Institut national de recherche agronomique du Niger (INRAN) and with Institut burkinabe de la recherche agronomique et zootechnique (IBRAZ) in Burkina Faso. The IITA cowpea program at ISC has conducted two joint trials with INRAN. One trial tested cowpea entries from ISC and the national program as sole crops at five locations in Niger whose annual rainfall ranged from 300 to 800 mm. The second trial was an evaluation of three contrasting cowpea and pearl millet cultivars at three locations. We also have cooperative linkages with the Semi-Arid Food Grain Research and Development (SAFGRAD) in Burkina Faso, and with the national programs of Mali and Senegal.

In cooperation with Centre de cooperation internationale en recherche agronomique pour la developpement (CIRAD)/Institut de recherches agronomiques tropicals et des cultures vivrieres (IRAT) we have established a project, along with the Centre regional de formation et d'application en agrometeorologie et hydrologie operationnelle (AGRHYMET) in Niamey, on water balance and cultivar adaptation of groundnut and other crops in West Africa. In the preliminary phase of this project, which started in

November 1986, an already tested and validated water-balance model BIP 4, was implemented on the AGRHYMET computer system and on the Rainbow microcomputer. This model will be used to simulate water balance for several locations in West Africa to understand groundnut cultivar adaptation.

Dryland Watershed Projects

In 1986, joint Indian Council of Agricultural Research (ICAR)/ICRISAT projects began on two experimental watersheds with contrasting soil types. Mittemari in the Kolar district of Karnataka has Alfisols and a mean annual rainfall of 690 mm. Chevella in the Medak district of Andhra Pradesh has primarily Vertic soils and 870 mm annual rainfall.

On the Mittimarri watershed, where we collaborate with staff based at the University of Agricultural Sciences, Bangalore, groundnut/pigeonpea intercrops were grown to study responses to land management and primary tillage practices. Ten local farmers cooperated in these trials, that showed that improved management significantly increased yields compared with local practice but that differences between the treatments were hard to distinguish, possibly because the season was extremely dry. A census provided a record of household resources and farming practices as a basis for a rapid appraisal of the responses to new technology.

On the Chevella catchment area where we collaborate with Central Research Institute for Dryland Agriculture (CRIDA) staff based in Hyderabad, a land management trial was complemented by a pest-control survey and by a comparison of different types of machines for seed and fertilizer distribution. The time needed to sow 1 ha was similar for ICRISAT and CRIDA planters and was about half the time for a traditional planter. The ICRISAT planter required more draft than the CRIDA machine but needed less labor. In terms of yield, there were no clear-cut differences between mechanical and hand-metered machines, again, possibly because water was the limiting factor in this season. The economic survey at Chevella drew attention to the decline in the area under pearl millet attributable to the prevalence of ergot disease, and to a number of areas appropriate for further adoptive research including fertilizer recommendations for intercrops, the introduction of drought-resistant cultivars, and improving the cost-effectiveness of seed fertilizer drills.

Multilocational Groundnut Modelling Experiments

This year we have started multilocational field experiments on groundnut in collaboration with the national programs in India and Thailand. The objectives of these experiments are; to collect data to validate the groundnut growth model, PNUTGRO, developed at the University of Florida, Gainesville, and to identify areas where further field research is needed to impove this model. In addition to ICRISAT Center, the experiments are being conducted at the following institutes in India: Haryana Agicultural Univesity (Hisar), Gujarat Agricultural University (Anand), Tamil Nadu Agricultural University (Coimbatore and Bhavanisagar), Punjab Agricultural University (Ludhiana), Marathwada Agricultural University (Parbhani), Andhra Pradesh Agricultural University (Rajendranagar and Anantapur), and at Khon Kaen in Thailand by Khon Kaen University scientists. Minimum data sets on crop, soil, weather and management are being collected at each location.

Workshops, Conferences, and Seminars

International Symposium on Agrometeorology and Plant Protection in the Semi-Arid Zones

In cooperation with World Meteorological Organization (WMO), we organized an International Symposium on Agrometeorology and

Plant Protection in the Semi-Arid Zones from 8-12 December at Niamey. This meeting was cosponsored by the Food and Agriculture Organization of the United Nations (FAO), United Nations Development Programme (UNDP), United Nations Environmental Programme (UNEP), Organization for African Unity (OAU) and the Technical Centre for Agricultural and Rural Co-operation (CTA). Sixty-six scientists from 22 countries in Africa, Asia, and Europe participated. At the symposium, the participants reviewed the major insect pests and diseases of crops in the semi-arid zones, the influence of climatic factors on their dynamics, and modeling their development. Methods of forecasting the critical periods of insect and disease incidence were discussed. A procedure was proposed for zonation of climates in terms of their potential for disease development. The utilization of real-time agrometeorological information and modeling procedures for plant protection was described. At a round-table discussion on the final day, the participants reviewed the practical applications of the presentations made during the course of the symposium and developed a set of recommendations for the application of agro-meterological information for plant protection by the national programs in the semi-arid zones. Proceedings of the symposium will be published jointly by WMO, ICRISAT, and OAU.

Looking Ahead

In terms of structure and direction, the Resource Management Program has several major objectives for 1987. The natural termination of many individual projects will provide an opportunity to consolidate research into a number of major themes. These themes will link disciplines within the Program even more closely than at present and will also strengthen collaboration with scientists in the Crop Programs. Particular emphasis will be placed on designing experiments which seek to explain responses to imposed treatments in terms of mechanisms instead of simply describing them in statistical terms. Without such understanding, generalizations remain vague and little credence can be given to predictions from models.

The Program will become increasingly committed to research on the management of Vertisols in Ethiopia in collaboration with national scientists there and with several international organizations. The emphasis of agroclimatic analysis will also shift to Africa. The agroecological potential of the ICRISAT mandate areas in Malawi, Botswana, Zimbabwe, and Ethiopia will be studied to refine our research focus in crop improvement and resource management. At ISC, agroclimatic analysis in the Sudano-Sahelian Zone will concentrate on relations between the onset of rains and the length of the growing season which are central to cropping strategies and response farming. Analysis of climatic records for Indian stations will emphasize the identification of isoclimes for the transfer of technology from one region to another.

The aim of new work on soil physical properties will be to develop a better quantitative understanding of the key processes of water entry, soil erosion, seedling emergence, and the performance of root systems. An associated aim will be the evaluation of the potential of different management practices to modify significant physical properties. For the study of rain-related processes, increasing use will be made of simulated rain to provide a range of conditions over a short time-span. New techniques will have to be developed to characterize seedbeds and subsoils.

Field tests at ISC will examine the scope for sequential or relay cropping and for supplementary irrigation. The advantages of ridging will be investigated in greater detail in collaboration with the University of Wageningen and work on the relation between rainfall pattern, land preparation, and sowing will assess the relative merits of early tillage and delayed sowing.

Collaborative research on rice-based cropping systems with ICAR and the International Rice Research Institute(IRRI) will explore the feasibility of introducing our early genotypes of groundnut, pigeonpea, chickpea, and sorghum into rice fallows that do not have sufficient moisture for another wetland rice crop. A major objective is to identify genotypes and management strategies which would maximize the use of residual moisture following a rainy-season rice crop.

An assessment by the Agronomy and Economics Groups on prospects for agroforestry in the SAT will be completed in 1987 and will provide a basis for decisions about the future direction of agroforestry research at ICRISAT Center and at ISC where priority will be given to screening germplasm accessions of trees and shrubs and studying competition between trees and crop stands.

The integration of animals in traditional farming systems, important throughout the SAT, will receive new attention from the International Livestock Center for Africa(ILCA)/ICRISAT program in the Sahel. The ISC contribution will include the selection of forage legumes suitable for intercropping.

The Economics Group will complete several studies including a benchmark appraisal of soil fertility in the study villages. At the end of early acceptance studies of the Vertisol technology and a late-adoption study of cereal hybrids, the focus of technology transfer studies will be shifted towards the transfer of promising short-duration pigeonpea cropping systems. The joint investigation will continue with economists of Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) University to assess the rapid expansion of the soybean area in Madhya Pradesh, India. The whole-farm models for technology assessment will be fully documented and smaller models, less versatile but easier to use, will be built to run on microcomputers.

The economists will continue to collaborate with entomologists and pathologists on pest management strategies suitable for SAT countries and farmers. The focus of economic research on resource management will be shifted towards institutional constraints on groundwater use by resource-poor farmers.

A book putting together the results of the ICRISAT village studies initiated in 1975, placing them in thematic perspective, and drawing implications for economic development in India's SAT will be completed.

Publications

Institute Publications

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Farming systems principles for improved food production and the control of soil degradation in the arid, semi-arid, and humid tropics: summary proceedings of an Experts' Meeting, 20-23 Jun 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-115-1.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agroforestry research in the semi-arid tropics: a report on the Working Group Meeting, 5-6 Aug 1985, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-116-X.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-112-7.

Journal Articles

Bhende, M.J. 1986. Credit markets in rural South India. Economic and Political Weekly 21(38-39):A119-A124. (JA 509)

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)

Jodha, N.S. 1986. A case study of the degradation of common property resources in India. Pages 196-207 *in* Land degradation and society (Blaikie, P., and Brookfield, H., eds.). London, UK: Methuenand Co., Ltd. (JA 581)

Jodha, N.S. 1986. Common property resources and rural poor in dry regions of India. Economic and Political Weekly 21(27): 1169-1181. (JA 597)

Jodha, N.S. 1986. Research and technology for dryland farming in India: some issues for future strategy. Indian Journal of Agricultural Economics 41(3):234-247. (CP 322)

Natarajan, M., and Willey, R.W. 1986. The effects of water stress on yield advantages of intercropping systems. Field Crops Research 13:117-131. (JA 439)

Mayande, V.M., Bansal, R.K., and Sangle, R.D. 1985. Performance of various animal drawn wheeled tool carrier systems. Journal of Agricultural Engineering 22(2):27-34. (JA 478)

Mayande, V.M., Sarin, R., and Thierstein, G.E. 1985. An evaluation of animal-drawn wheeled tool carriers under on-farm conditions in semi-arid tropical India. Agricultural Mechanization in Asia, Africa and Latin America 16(4):17-24. (JA 474)

Narasimham, N.V., von Oppen, M., and Parthasarathy Rao, P. 1985. Consumer preferences for groundnut quality. Indian Journal of Agricultural Economics 40(4):524-535. (JA 521)

Pawar, C.S. 1986. Ultra low volume application for pest control in pigeonpea. Indian Journal of Plant Protection 14(2):37-4l. (CP 285)

Pawar, C.S., Bhatnagar, V.S., and Jadhav, D.R. 1986. *Heliothis* species and their natural enemies, with their potential for biological control. Proceedings of the Indian Academy of Sciences (Animal Sciences) 95(6):695-703. (CP 268)

Sivakumar, M.V.K. 1986. Canopy-air temperature differentials, water use and yield of chickpea in a semi-arid environment. Irrigation Science 7(3): 149-158. (JA 580)

Stoop, W.A. 1986. Agronomic management of cereal/cowpea cropping systems for major toposequence land types in the West African savanna. Field Crops Research 14(4):301-319. (JA 536)

Thakur, R.P., Subba Rao, K.V., Williams, R.J., Gupta, S.C., Thakur, D.P., Nafade, S.D., Sundaram, N.V., Frowd, J.A.,and Guthrie, J.E. 1986. Identification of stable resistance to smut in pearl millet. Plant Disease 70(1):38-41. (JA 471)

Walker, T.S., Singh, R.P., and Asokan, M. 1986. Risk benefits, crop insurance, and dryland agriculture. Economic and Political Weekly 21(25 and 26):A81-A88. (JA 574)

Conference Papers

Bationo, A., Mokwunye, A., and Baanante, C.A. 1985. Agronomic and economic evaluation of alternative phosphate fertilizer sources in Niger. Pages 110-122 *in* Appropriate technologies for farmers in semi-arid West Africa. Proceedings of a symposium, 2-5 Apr 1985, Ouagadougou, Burkina Faso (Ohm, H.W., and Nagy, J.G., eds.). West Lafayette, Indiana, USA: Purdue University.

Bationo, A., Mughogho, S.K., and Mokwunye, A. 1986. Agronomic evaluation of phosphate fertilizers in tropical Africa. Pages 283-318 *in* Management of nitrogen and phosphorus fertilizers in sub-Saharan Africa. Proceedings of a Symposium, 25-28 Mar 1985, Lome, Togo (Mokwunye, A., and Vlek, P.L.G., eds.). Dordrecht, Netherlands: Martinus Nijhoff.

Fussell, L.K., and Serafini, P.G. 1985. Crop associations in the semi-arid tropics of West Africa: research strategies past and future. Pages 218-235 *in* Appropriate technologies for farmers in semi-arid West Africa. Proceedings of a Symposium, 2-5 Apr 1985, Ouagadougou, Burkina Faso. West Lafayette, Indiana, USA: Purdue University. (ISC 8503)

Ghodake, R.D. and Kshirsagar, K.G. 1985. An evaluation of the impacts of improved dryland technology on factor shares. Pages 17-18 *in* Contributed Papers Abstracts of 19th International Conference of Agricultural Economics, 26 Aug-4 Sep 1985, Malaga, Spain. Malaga, Spain: International Association of Agricultural Economics. (Abstr.) (JA 331)

Mughogho, S.K., Bationo, A., Christianson, B., and Vlek, P.L.G. 1986. Management of nitrogen fertilizers for tropical African soils. Pages 117-172 *in* Management of nitrogen and phosphorus fertilizers in sub-Saharan Africa. Proceedings of a Symposium, 25-28 Mar 1985, Lome, Togo (Mokwunye, A., and Vlek, P.L.G., eds.). Dordrecht, Netherlands: Martinus Nijhoff.

Ong, C.K. 1986. Agroclimatological factors affecting phenology of groundnut. Pages 115-125 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 251)

Pawar, C.S., Srivastava, C.P., and Reed, W. 1986. Some aspects of population dynamics of *Heliothis armigera* at ICRISAT Center. Pages 79-85 *in* Proceedings, Oriental Entomology Symposium, 21-24 Feb 1984, Trivandrum, Kerala. Trivandrum, Kerala: Association for Advancement of Entomology, University of Kerala. (CP 177)

Sahrawat, K.L. 1986. Recent developments in urease and nitrification inhibitors. Pages 85-97 *in* Soil biology: proceedings of the National Symposium on Current Trends in Soil Biology, 25-27 Feb 1985, Hisar, Haryana, India. Hisar, Haryana, India: Haryana Agricultural University. (CP 219)

Sivakumar, M.V.K., and Sarma, P.S. 1986. Studies on water relations of groundnut. Pages 83-98 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 244)

Spencer, D.S.C. 1985. A research strategy to develop appropriate agricultural technologies for small farmer development in sub-Saharan Africa. Pages 308-325 *in* Appropriate technologies for farmers in semi-arid West Africa. Proceedings of a Symposium, 2-5 Apr 1985, Ouagadougou, Burkina Faso (Ohm, H.W., and Nagy, J.G., eds.). West Lafayette, Indiana, USA: Purdue University.

Virmani, S.M., and Piara Singh. 1986. Agroclimatological characteristics of the groundnut-growing regions in the semi-arid tropics. Pages 35-45 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 260)

Walker, T.S., and Jodha, N.S. 1986. How small farm households adapt to risk. Pages 17-34 *in* Crop insurance for agricultural development: issues and experience (Hazell, P., Pomareda, C, and Valdes, A., eds.). Baltimore, Maryland, USA, and London, UK: The Johns Hopkins University Press. (CP 114)

Walker, T.S., and Witcombe, J.R. 1986. ICRISAT presentation: yield variability in sorghum and millet. Pages 167-175 *in* Summary Proceedings of a Workshop on Cereal Yield Variability, 26-29 Nov 1986, Feldafing, Federal Republic of Germany. Washington, D.C., USA: International Food Policy Research Institute. (CP 284)

Willey, R.W., Natarajan, M., Reddy, M.S., and Rao, M.R. 1986. Cropping systems with groundnut: resource use and productivity. Pages 193-205 *in* Agrometeorology of groundnut: proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. (CP 329)

Theses

Abikar, M.A. 1986. Evaluation of different cropping systems on shallow black soils in semi-arid India. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 93 pp.

Nabila, P.M. 1986. The effect of rainy season legumes on the yield and nitrogen response of postrainy season sorghum. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 97 pp.

Pandey, S. 1986. Economics of water harvesting and supplementary irrigations in the semi-arid topics of India: a systems approach. Ph.D. thesis, University of New England, Armidale, New South Wales, Australia. 312 pp.

TRAINING

Contents

Cover photo: In-service trainee from Malawi emasculating pigeonpea, ICRISAT Center, 1986.

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TRAINING

The individualized training programs at ICRISAT Center were coordinated by the Training Officers who report to the Deputy Director General. The Training Advisory Committee that includes the Deputy Director General, Program Directors, and Leaders selected Postdoctoral Fellows (formerly International Interns and Research Fellows), In-service Fellows, Research Scholars (MSc and PhD), In-service Trainees, and Apprentices from candidates nominated by national Ministries of Agriculture, Universities, or SAT research and development programs. One hundred and eighty one participants representing 44 countries received 4490 weeks of training at ICRISAT Center (Tables 1 and 2). In addition, more than 23 individuals from 9 countries were guided in university-related individual study programs by ICRISAT staff located in Niger and Mali.

At ISC, a technician from the Projet formation de la protection des vegetaux of the Comite interetats de lutte contre la secheresse dans le Sahel (CILSS), Institut du Sahel (INSAH), and The Netherlands, was trained for 4 months in the evaluation of varietal resistance of pearl millet to *Striga hermonthica.* A student from l'Institut pratique de developpement rurale (IPDR), Niger, studied seedling establishment under drought stress in pearl millet. Two students from the University of Niamey did their project work on root development and growth analysis of a set of pearl millet genotypes during the cropping season. In the Resource Management Program, five students worked on water use, growth, and yield of pearl millet under normal and assured rainfall; phenology, growth and yield of early groundnut cultivars; water use, transpiration, growth and yield of four cowpea cultivars; and fertilizer use. One student from IPDR, Niger, studied the uniformity of sprinkler irrigation and soil characteristics with the aid of a rainfall simulator. Another student studied forage legumes associated with pearl millet in collaboration with the University of Louvain, Belgium.

At the USAID/ICRISAT Mali program during 1986, a technician was trained in recombining groups of sorghum lines to develop varieties. ICRISAT scientists supervised the field projects of eight undergraduate students from the agricultural college of Katibougou. They worked on various aspects of productivity in intercropping systems using sorghum/groundnut, maize/pearl millet, and pearl millet/cowpea; the effect of density and N-fertility on the productivity of varieties of sorghum and pearl millet; improving sorghum populations; the significance of tillering in cereal breeding programs; and the vitreosity of sorghum grain. Two Malian students pursuing their M.S. degrees in USA on USAID fellowships returned to Mali for their thesis

Table 1. Participants in longterm training programs, ICRISAT Center, 1986.

Category	Number	Weeks	Countries
Postdoctoral Fellows	9+ 6[1]	526	5
In-service Fellows	26+ 4	211	15
Research Scholars	14+ 17	1076	12
In-service Trainees	92+ 8	2559	35
Apprentices	4+ 1	118	3
Total present	145+36	4490	44[2]

1. Number continuing into 1987.
2. Different countries.

Table 2. Participants by region, country, and category in training, ICRISAT Center, 1986.

Region/Country	IS[1]	ISF	RSc	PDF	App	Total
Western Africa						
Benin	2					2
Burkina Faso	2					2
Cameroon	1					1
Chad				0+1[2]		0+1
Ghana	1		1			2
Guinea	2					2
Mali	7	1	1			9
Mauritania	1					1
Niger	4					4
Nigeria	6	1				7
Senegal	8					8
Sierra Leone	1					1
The Gambia	4					4
Eastern Africa						
Ethiopia	5	1	0+2			6+2
Kenya	1		0+2			1+2
Somalia	4		3+1			7+1
Sudan	5	1 + 1				6+1
Uganda	2					2
Southern Africa						
Botswana	1	1				2
Malawi	4	1				5
Mozambique	1		0+1			1+1
Swaziland		1				1
Tanzania	3					3
Zambia	1	1				2
Asia						
Fiji	1					1
India	1	13	4+5	4+2		23+7
Indonesia	1					1
Nepal	3+1					3+1
Pakistan	0+5					0+5
People's Democratic Republic of Yemen	1					1
People's Republic of China	5	0+1				5+1
South Korea		0+1				0+1
Sri Lanka	2	1				3
Thailand	5	2				7
The Philippines	1+2	1+1				2+3
Mesoamerica						
Antigua	1					1
Barbados	1					1
Mexico	3					3
Others						
Federal Republic of Germany		3+2			3+2	
Italy	1					1
The Netherlands		0+2			2	2+2
UK			1 + 1	1 + 1	1 + 1	3+3
Australia		0+1	1+1	1	2+2	
USA		1	3+1			4+1
Total	92+8	26+4	14+17	9+6	4+1	145+36

1. IS = In-service trainees, ISF = In-service fellows, RSc = Research Scholars, PDF = Postdoctoral fellows, App = Apprentices.
2. Number continuing into 1987.

research at Cinzana station where they worked on soil aluminium toxicity; and the adoption and impact of improved cowpea varieties. Three Malian students returned to Mali after obtaining their degrees on USAID fellowships and joined the Malian National Program. Two more students are presently studying sorghum grain quality and adoption of improved cultivars at universities in USA on USAID fellowships.

In-service Training Activities

Before beginning their 6-month individualized programs in May, 32 of the 83 rainy-season in-service trainees from Francophone countries participated in an intensive 8-week English course at Osmania University, Hyderabad.

The rainy-season group was subdivided on the basis of pretraining evaluations and application information to facilitate the guidance of the participants in their specialized areas of interest. Twenty participants worked on cereals, 14 on legumes, 24 on crop production, and 25 on aspects of resource management. Each participant identified, designed, sowed, supervized, harvested, analyzed results, and wrote reports for their 188 experiments, yield trials, or demonstrations (Table 3). In addition, participants

Figure 1. An in-service trainee weighing sorghum fodder in an experimental plot, ICRISAT Center, 1986.

Table 3. Experiments, trials, and demonstrations planned and conducted by rainy-season in-service trainees, ICRISAT Center, 1986.

Experiment or trial involving	Crops				Others	Total
	Sorghum	Pearl millet	Groundnut	Pigeonpea		
Varieties	23	12	16	7		58
Fertilizers	9	5	5	1	1	21
Weed control	5	3				8
Plant density	6	3	6	1		16
Sowing dates			3	1		4
Sowing methods	1					1
Competition	2					2
Inoculation			2			2
Pathology	5	2	5	1		13
Entomology	7			1		8
Intercropping					25	25
Steps in technology	1					1
Demonstrations	2	2	3		1	8
International trials	13	6	1	1		21
Total	74	33	41	13	27	188

Figure 2. An in-service trainee from China threshing sorghum panicles, ICRISAT Center rainy season, 1986.

were guided by research scientists in five experiments that were a part of ongoing ICRISAT research activities.

The postrainy season in-service programs started in September with eight representatives from three countries (Pakistan, Nepal, and The Philippines). Seven participants studied chickpea and pigeonpea improvement and one concentrated on groundnut breeding (Table 4).

Selected practical field and laboratory experiments were designed for trainees who are to continue working on specialized areas of research and development in their countries when they complete their studies at ICRISAT. Ninety-two research scientists were involved in this work; they presented lectures related to their area of

Table 4. Experiments[1] and trials initiated by postrainy season in-service trainees, ICRISAT Center, 1986

	Crops			
Type of trial	Ground-nut	Pigeon-pea	Chick-pea	Total
Variety	2	3	7	12
International variety		3	3	6
International screening			1	1
Breeding			3	3
Total	2	6	14	22

1. Eight experiments were part of ongoing research programs.

specialization or guided participants in scheduled, individual field or laboratory skill-development experiences. All the participants were trained in the presentation of seminars, oral and written communication, experimental planning and management, data collection procedures and analysis, and scientific report writing. Technical guidance was given to selected participants in soil and climatic evaluations, weather data collection and utilization, experimental plot layout, soil-testing procedures and evaluation, basic agronomy, seed and fertilizer calculations, sowing and fertilizer application methods, tillage operations for experimental plots, weed and pest control, disease scoring and screening techniques, crop botany and plant physiology, plant-soil-environment relationships, experimental techniques, nursery management, utilization of microcomputers in data handling and processing, germplasm utilization and conservation, basic plant breeding, crop production agronomy, cropping systems and their management, agricultural economics, and in transfer of technology techniques (Table 5).

In order to study agricultural research station activities, university operations, and extension services related to the objectives of the in-service training programs, the participants made tours and field trips in India during their time at ICRISAT Center.

The agroclimatologists provided special instruction on the collection and utilization of meteorological data in planning cropping systems for research and development programs in Mali and Zambia for participants from those countries. Trainees from India and Nepal studied techniques to identify, select, and produce inoculants to improve groundnut nodulation. A

Figure 3. Postrainy-season trainees with ICRISAT training officer observing a sorghum breeding experiment, ICRISAT Center, 1986.

Table 5. Specific in-service training activities guided by program scientists, ICRISAT Center, July-October, 1986.

Discipline	Participants and length of study period			
	1 week	2 weeks	3 weeks	8 weeks
Genetic Resources				
Sorghum	4			
Pearl Millet	2			
Groundnut	9			
Cereals				
Sorghum				
Physiology	13			
Pathology	11			
Striga resistance screening	2			1
Entomology	4	10		
Breeding		13		
Grain quality		3	1	
Pearl Millet				
Pathology		4		
Entomology	5	4		
Breeding		5		
Grain quality		2		
Legumes				
Chickpea				
Breeding		1		
Pigeonpea				
Pathology	3			
Entomology	1	10		
Breeding			15	
Groundnut				
Physiology	9			
Pathology	1			
Virology	11			
Entomology	1	1		
Breeding			10	
Cytogenetics	4			
Resource Management				
Agroclimatology	4		1	
Cropping systems	14			
Soil fertility	16			
Soil physics and conservation	7			
Land and water management	19			
Farm power and machinery	9			
Agricultural economics	1			
General				
Microbiology	5			
Plant protection	25			
Plant quarantine	1			
Experimental statistics	15	10		
Microcomputer special uses	9			
Research station management	11	4		
Technology transfer	1			

Figure 4. In-service trainee group at a tea plantation in Ootacamund, Tamil Nadu, India, during their study tour, 1986.

scientist from India conducted research for 6 months on genotype × environment interactions in pigeonpea improvement. The results from his guided study will contribute to an international study of such interactions. A scientist from Barbados studied biological control of *Heliothis armigera* on pigeonpea, and a scientist from Antigua participated in a study of methods to improve pigeonpea breeding and agronomy. A technologist from the Cooperative Oilseed Growers Federation, Madhya Pradesh, India received training in *Rhizobium* production and quality control techniques.

Eight scientists from El Salvador (2), Guatemala (1), Mexico (3), and Nicaragua (2) were trained in sorghum production and improvement by ICRISAT staff based at CIMMYT in Mexico.

The first 4-week training program developed and guided by staff from ICRISAT Center and the SADCC/ICRISAT Regional Sorghum and Millet Improvement Program was conducted in April at Matopos, Zimbabwe. Participants from Lesotho (1), Malawi (2), Swaziland (2), Tanzania (2), and Zambia (2) studied sorghum and millet breeding nursery management, insect and disease identification and screening techniques, and experiment station development.

In-service Fellowships

In a week-long intensive program guided by the pearl millet pathologists eight pathologists from national research programs in India studied the biology and epidemiology of the major pearl

Table 6. In-service fellow study program areas with research program scientists.

Program/ Discipline	Participant countries	No. of weeks
Cereals		
Sorghum		
Physiology	Sudan	5
Pathology	The Philippines[1]	25
Pearl Millet		
Microbiology	India	4
Legumes		
Chickpea		
Pathology	India	8
Pigeonpea		
Pathology	India	2
Breeding	India	23
Groundnut		
Pathology	People's Republic of China	2[2]
Virology	Thailand[1]	5
Entomology	Sri Lanka	4
Microbiology	India	7
	Sudan	8
Breeding	Malawi	8
Cytogenetics	South Korea	9
Resource Management		
Agronomy		
Cropping systems	Nigeria	15
	Kenya	6
Engineering		
Soil fertility	Ethiopia	12
	Mali	4
Research Support		
Farm Development and Operations		
Farm machines and operations	Botswana	4

1. Two participants.
2. Continuing into 1987.

Table 7. Total weeks of specialized longterm training programs guided by program scientists, ICRISAT Center, 1986.

Research programs	Research scholars MSc	Research scholars PhD	Postdoctoral Fellows	Apprentices
Cereals	49	97	236	22
Legumes	30	342	188	68
Resource Management	149	366	101	27

millet diseases and related screening techniques for identification of resistances.

Senior and mid-level scientists from 15 countries (Table 6) worked with ICRISAT research program scientists on topics related to their national research activities.

Research Scholarships

MSc and PhD students (Table 7) conducted thesis research on the following topics:

Cereals Program

An MSc student from Somalia satisfactorily completed his thesis on the effect of recurrent selection on general and specific combining abilities of two random-mating sorghum populations at the Andhra Pradesh Agricultural University (APAU), India. This work indicated that five cycles of recurrent selection were effective in increasing grain yields of two populations. The recurrent selections for grain yields were primarily effective for general combining ability which indicated this trait involved largely additive effects.

A PhD student from Iowa State University, USA completed his field studies on the effectiveness of selection on spaced plants of pearl millet. He used direct and indirect selection yield indices based on phenological and morphological traits. Preliminary analysis indicated population with selection method interactions for the ICRISAT pearl millet composites NELC, EC, and D_2C.

A PhD student from Haryana Agricultural University (HAU), India completed his thesis

Figure 5. A research scholar from the USA (left) showing his pearl millet experiment to his Supervisor from Iowa State University, ICRISAT Center, 1986.

research on pathogenic variability in the smut pathogen (*Tolyposporiun penicillariae*) and the inheritance of resistance to smut in pearl millet. He was unable to demonstrate pathogenic differences among smut isolates on 6 to 8 pearl millet cultivars and his data indicated that the resistance was dominant.

Legumes Program

An Indian PhD student from APAU completed studies on the identification of physiologic races of chickpea wilt (*Fusarium oxysporum* f.sp *ciceri*). Four races of the fungus were serologically related, but showed differences in linear growth, growth temperature range, and total sugar content.

A PhD student from HAU completed laboratory studies on the variability in the chickpea blight pathogen (*Ascochyta rabiei*). A set of differential cultivars was used to identify six distinct races of the blight pathogen present in India. Three of the races appear to be the same as those described earlier in Syria.

PhD students from the University of Bonn, Federal Republic of Germany continued their studies on the photoperiodic effects on growth and yield of groundnut, and root respiration of groundnut genotypes as related to nitrogen fixation and drought resistance.

Studies on the epidemiology of rust (*Puccinia arachidis*) and late leaf spot (*Phaeoisariopsis personata*) diseases of groundnut are being completed by a PhD student from APAU.

A student in the Australian National University, Canberra began her PhD thesis research on the characterisation of biological differences between groundnut lines resistant and susceptible to *Aspergillus flavus.*

A PhD student from the Indian Institute of Technology, Kharagpur commenced his thesis research on genotypic differences in salinity tolerance of pigeonpea. He will screen genotypes for tolerance to salinity, investigate genotypic mechanisms related to differences in salinity tolerance, and study symbioses with rhizobia at different salinities.

An Ethiopian PhD student studied at APAU. His thesis research on chickpea involves the relationships among five generations, and the effects of spacing and selection in the F_4 generation on performance in F_5.

An MSc student from Mali completed his thesis on heterosis and heritability estimates in crosses of Virginia and Valencia type groundnuts. In the study, the heterosis for pod yield ranged from 80 to 120% in crosses involving Kadiri 3 (Robut 33-1) and two stable interspecific derivatives (CS 16 and CS 49). In gereral, Virginia x Virginia crosses showed higher heterosis estimates than Valencia x Valencia crosses.

An MSc student from the University of Nairobi, Kenya started his thesis research on the inheritance of dwarfism in pigeonpea. Another MSc student from Kenya initiated studies on the effects of photoperiod and temperature on the partitioning of dry matter in the vegetative and reproductive phases in pigeonpea.

Resource Management Program

The effects of shading on dry matter partitioning in groundnut were studied by a PhD student from the University of Nottingham, UK. The data indicated that in the rainy season shading did not reduce biomass production or groundnut pod yields.

An APAU PhD student continued studies on the effects of methods of urea application on its transformation and utilization in soils.

A PhD student from Iowa State University, USA initiated studies on women's participation in agricultural production; she is making a cross-cultural, comparative evaluation between SAT regions of India and Niger.

A PhD student from The Netherlands worked on the feasibility for rainfall insurance in the Indian SAT. He conducted studies to determine the willingness of farmers to participate in an insurance or lottery plan, and to identify the farmers' constraints.

A Cornell University, USA PhD student continued research on late adoption of high-yielding varieties and early acceptance of improved technologies. Preliminary analysis indicated that soil type and rainfall patterns explain many of the interregional variations in adoption in India.

An Indian PhD student from the University of New England, Australia, completed field work on studies of household economics. Initial results suggest that the farm profit effect on output price is not so strong for farm households that practice diversified cultivation in the Indian SAT as for more specialized farm households in the humid tropics.

A PhD student from the University of Hohenheim, Federal Republic of Germany, utilized a discrete stockastic programming model of farm production to explore the likely production response to increased groundwater availability.

A PhD student from the Technical University of Darmstadt, Federal Republic of Germany completed field research on hydrological studies in a red soil semi-arid watershed. During this work a methodology for monitoring recharge of tank storage water, and a method for reducing evaporation losses—thus augmenting groundwater resources have been evolved.

A British student from the University of Nottingham, UK initiated her PhD thesis research on the comparison of microclimates in a pearl millet/ leucaena intercropping system, and on partitioning of light and water use by both species. One season's data indicated that physical prevention of moisture competition between the two crops increased the LER from 1.5 to 1.8.

A Somalian MSc student at APAU completed his thesis research on the evaluation of different cropping systems on shallow black soils in the Indian SAT. Despite low pearl millet yields, a pearl millet/ pigeonpea intercrop showed a higher LER advantage (36%) over the sole crop compared to intercropping systems of groundnut/ pigeonpea (23%) and sorghum/ pigeonpea (14%).

An APAU MSc student from Ghana completed his thesis research with a study on the effect of rainy-season legumes on the yields and nitrogen response of postrainy-season sorghum. Dry matter and N-uptake data suggested that residual N from the legumes was available to the sorghum later in the postrainy season, and that applied N influenced the crop performance throughout the season. The legume-sorghum sequencial cropping system gave more gross income than the traditional fallow-sorghum sequential cropping system.

A comparison of the growth and yield of hybrid and local sorghum cultivars on four sowing dates under both rainfed and irrigated conditions was studied by a Somalian MSc student at APAU. The data confirmed earlier findings that yields of both cultivars were reduced by delayed sowing and that irrigation stimulated plant growth which reduced the incidence of shoot fly (*Contarinia sorghicola*) damage.

An MSc student from Mozambique conducted research for an APAU thesis on the interactions in responses when intercropping groundnut with maize. The data indicated that sowing date had a predominant effect on groundnut yields irrespective of the sowing arrangement or population. Light utilization studies indicated that both the growth of the groundnut canopy and plant population determine the amount of energy intercepted by the crops.

Postdoctoral Fellowships

International interns and research fellows conducted research within the approved research projects of the Institute (Table 7) as follows:

Cereals Program

A 2-year study on the feeding behavior of the earhead bug (*Calocoris angustatus*) and its effects on sorghum grain quality were completed by an Indian research fellow. Results indicated that the major damage to the grain was due to a salivary enzyme secreted and not the mechanical damage by the earhead bug.

An Australian international intern began work on an examination of the physiological basis for resistance to midseason heat and drought stress in sorghum.

Studies on the genetics of resistance to downy mildew (*Peronosclerospora sorghi*) in sorghum were intiated by an international intern from the USA. There was inconclusive evidence of a one- or two-gene inheritance pattern in 8 of the 14 resistant lines he investigated.

An international intern from UK completed a 2-year study in pearl millet physiology on the relationship between the length of the vegetative phase and crop growth and grain yield in pearl millet.

An intern from the USA studied pearl millet cytoplasmic male sterility (cms) systems to obtain a better understanding of the inheritance of fertility restoration in the A1 cms system; and to explore the potential for diversification of the cytoplasmic base of pearl millet F_1 hybrids. Preliminary crossing has been completed and initial evaluations of 30 potentially different male-sterile cytoplasms have begun.

Legumes Program

Inheritance studies on fusarium wilt (*Fusarium oxysporum*) and root rots (*Rhizoctonia* sp) and the effects of grafting on the spread of wilt in chickpea were completed by an Indian research fellow. It was found that a dominant gene was involved in the inheritance of root rot and that late-wilting genotypes used as stocks can support resistant scions. This suggests that a diffusable gene product from the resistant scion imparts resistance to the susceptible stock.

An international intern from Australia completed a 2-year study of embryo culture and intergeneric pigeonpea hybridization.

Studies on the effects of environmental stresses on geocarposphere and seed mycoflora, and on aflatoxin contamination of groundnut seed were

Figure 6. An Australian international intern working on pigeonpea intergeneric pigeonpea hybridization observing a pigeonpea embryo under a microscope, ICRISAT Center, 1986.

completed by an Indian research fellow. The results indicated that pod exudates may increase or inhibit growth and germination *of Aspergillus flavus,* and that levels of seed infection were significantly higher in drought-stressed plots than in fully irrigated plots. Populations of the fungus in pods, and in the soil from around pods increased as the crop matured. Aflatoxin contamination of seeds was higher in later-sown plots. Differences in genotype responses to fungal invasion of seeds to development of food and soil mycoflora were evident.

An international intern from the USA completed studies indicating that the antiserum produced to the groundnut witches' broom mycoplasma-like organisms (MLO) can detect MLO in crude extracts of infected leaves, stems, and pegs by using a protein A indirect ELISA procedure. It was shown that two isolates of peanut clump virus (PCV) were seed transmitted in groundnut M 13 and in at least one graminaceous host. A simple ELISA procedure was developed to detect viruses in seed lots and in disease surveys.

An international intern from the UK completed a 2-year study of factors and pests causing groundnut storage losses. Screening techiniques to identify genetic differences in resistance to storage pests were developed. He also completed work on a manuscript on pest management in stored groundnuts that will be published as an ICRISAT Information Bulletin in early 1987.

An Indian postdoctoral fellow started work in pigeonpea pathology on a study of the epidemiology of phytophthora blight. The work will include the taxonomy, host-range, and mode of survival of the phytophthora blight pathogen (*Phytophthora drechsleri* f. sp *cajani*) through the dry season.

Resource Management Program

Sorghum production as affected by various topographic features such as slope and soil depth, was studed by a postdoctoral fellow from Chad. Initial findings indicated that manipulation of sorghum plant populations at anthesis had no effect on the final amount of water used, but that the allocation of dry matter was significantly affected. Studies on root growth were also initiated.

A 2-year field study assessing fertility in farmers' fields and evaluating component fertilizer practices in the Indian SAT was completed by an international intern from the USA who was funded by the Rockefeller Foundation. Data indicated that under farmers' conditions late-sown sorghum crops did not respond to nitrogenous fertilizers.

An Indian research fellow completed a 2-year study of the consequences of land fragmentation and prospects for consolidation in the Indian SAT. His data indicated that land fragmentation was not an economic liability at present levels of technology.

An Indian research fellow completed a 2-year study on groundnut marketing. He developed a preference index for market samples that correlated well with market prices, thus giving confidence to the use of the preference index as a tool when screening groundnut cultivars for consumer preferences.

Apprentice Activities

Laboratory and field tests on groundnut genotypes with field resistance to bud necrosis disease (BND) were conducted for 6 months by an apprentice from The Netherlands. The tests showed that among eight field-resistant, BND-resistant lines, three breeding lines were tolerant to the tomato spotted wilt virus (TSMV). In pearl millet breeding a 6-month study on the expression of dwarfing genes was completed by an apprentice from The Netherlands. A 7-month study was conducted by an apprentice from the UK on the effect of drought on the density of insect pests, particularly the groundnut leaf miner (*Aproaerema modicella*), during the post-rainy season. It was found that groundnut selections NCAc 343, M 13, and NCAc 17090 indicated resistance to the insect. Leaf miner attack was more severe on stressed plants, and the highest numbers of insect parasites were found on nonstressed plants. Another apprentice from the UK is continuing to evaluate termite responses to soil moisture in a groundnut crop. A 7-month study by an Australian apprentice found that *Heliothis armigera* larvae collected from two locations differed in their rate of development, survival, and pupal size. It was shown that it was important for adults to feed on sucrose for reproductive development and flight; and that pupal predation, mainly by ants, was an important mortality factor for *H. armigera* populations on chickpea and irrigated groundnut crops.

RESEARCH SUPPORT ACTIVITIES

Contents

Cover photo: ICRISAT statistician (left) and agroclimatologist (right) discussing an experimental design.

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RESEARCH SUPPORT ACTIVITIES

Plant Quarantine

During 1986 the Plant Quarantine Unit moved to a new building that has all the facilities of a modern plant quarantine laboratory, to facilitate rapid and effective clearance of seeds for export. From August 1986, the National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR) was designated as the inspecting authority for all incoming and outgoing ICRISAT seeds and given the responsibility for issuing phytosanitary certificates in place of Central Plant Protection Training Institute (CPPTI), Hyderabad.

A major highlight of our work was that we recorded a free-living nematode, *Panagrolaimus* sp, on pearl millet seeds. This nematode occurred in association with bacteria when the seeds were contaminated with soil, and was found to damage seed.

Plant Material Exports

During 1986 we exported 57 618 seed samples of ICRISAT mandate crops and minor millets, 3913 samples of plant material, and 95 units of rhizobial, mycorrhizal, and fungal cultures to scientists and cooperators in 102 countries (Table 1). Most of the seed exported was in the form of international trials and nurseries from the Cereals and Legumes programs. We also

Table 1. Seed material exports of ICRISAT mandate crops during 1986.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
AFRICA						
Botswana	362		10		14	
Burkina Faso	5863	836				
Burundi	108				101	
Cameroon	1199	134		24		
Canary Islands				7		
Cape Verde Islands	1					
Chad	72					
Egypt	106		146	32		
Ethiopia	212	2	1873	34	35	
Gabon					40	
Gambia	55	13		5	69	
Ghana	49	17		10	168	
Guinea	6					
Ivory Coast	792				4	
Kenya	1795	76	146	628		
Liberia				19		
Libya	72					
Malawi				230	240	
Mali	986	42			144	
Mauritius				15		
Morocco	4	7				

Continued.

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
Mozambique	192					
Niger	396	1059		33	304	
Nigeria	842					
Rwanda	202					
Senegal	200	85		44	30	
Sierra Leone				49	2	
Somalia	364	20	10	96	24	
Sudan	463	545	146	96	53	
Tanzania			55	57		
Togo	396			4		
Tunisia			296			
Uganda	96				130	
Zaire				30	72	
Zambia	559	133	120		208	
Zimbabwe	2313	4296		47	16	398
ASIA						
Bangladesh			834	8	25	
Bhutan	178					
Burma	76		512	126	24	
China	733		23	10	93	
Indonesia				157	85	
Iran			500			
Iraq	5	5	5	5	5	
Japan	82			3	38	
Korea	731	353	25	94	230	
Malaysia					124	
Nepal			849	428	38	
Oman		23				
Pakistan	1280	642	904	176	161	
Philippines	446		274	102	398	
Saudi Arabia					72	
Sri Lanka	59			57	180	
Syria	131		2			
Taiwan	57		1		181	
Thailand	414	5	240	214	197	
Vietnam		42				
Yemen (AR)	1151	124	146	4		
Yemen (PDR)				3		
THE AMERICAS						
Antigua				22		
Argentina	479					
Barbados				2		

Continued.

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
Belize				114		
Bolivia	24		5			
Brazil	2167	69	35		98	
Canada					11	
Chile			146			
Colombia	711	5				
Dominica				4		
Dominican Republic				38	27	
El Salvador	190					
Guatemala	209					
Guyana	100			8		
Haiti					35	
Honduras	88	70				
Jamaica				2		
Mexico	612	34	551	7	123	20
Nicaragua	6					
Peru			146	18		
Puerto Rico				8		
St. Lucia					43	
Surinam				3	51	
Trinidad				24		
USA	1635	111	1050	107	198	
Venezuela	140			16		
EUROPE						
Belgium	3					
Cyprus					52	
Denmark	7					
Federal Republic of Germany	362	60		9	7	
France	4			1		
Greece					96	
Italy	537		124	31	81	
Netherlands	3	3				
Poland			9			
Portugal					19	
Spain			142			
Switzerland	67	1	1	1	1	
Turkey	100					
UK	150	31	14	14	112	
AUSTRALASIA						
Australia	108		317	127	42	
Fiji				32	1	
Papua New Guinea					11	
Tonga		1		1		
Total	30750	8 844	9657	3436	4513	418

dispatched germplasm accessions from the ICRISAT gene bank, and all the material sent to collaborators and cooperators in ICRISAT's research in many universities and research institutions around the world.

Plant Material Imports

During 1986, ICRISAT received 5907 seed samples of its mandate crops, minor millets, *Atylosia* sp, *Rhyncosia* sp, *Flemingia* sp, and forest trees from 21 countries (Table 2). The seed samples of cereals and pulses were released after they had been thoroughly examined and treated against seed borne diseases where necessary, as were groundnut plants after growing on tests against viruses in the insect-proof screenhouse. Groundnut plants were also tested by the enzyme-linked immunosorbent assay (ELISA) technique for peanut stripe virus before they were sown in Post-Entry Quarantine Isolation Area (PEQIA).

Table 2. Seed material imports of ICRISAT mandate crops during 1986.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor Millets	Others
AFRICA							
Burkina Faso	22	26					
Cameroon	306	872			10		
Malawi					109		
Mali		4			29		
Niger		9					
Nigeria							9
Zimbabwe	345	1			68	184	
ASIA							
China	150						
Indonesia							31
Iran	7		123				
Korea	75				77	126	
Pakistan			15				
Syria			631				
Taiwan	1						
THE AMERICAS							
Jamaica				94			
USA	574	115	2		75		
Venezuela	7	1					
EUROPE							
Rumania	10						
UK	816	20		8	3	607	
USSR	139	9	24			134	
AUSTRALASIA							
Australia	26		4	9			
Total	2478	1057	799	111	371	1051	40

Post-Entry Quarantine Isolation Area (PEQIA)

As a precaution against the spread of infection, all seed and vegetative materials released by the National Quarantine Services are grown in isolation for one season before they are released to ICRISAT scientists. During 1986, 4494 samples of our mandate crops and wild legumes were grown under supervision of ICRISAT and CPPTI/NBPGR quarantine officials. The crops received adequate plant protection measures throughout the growing period, and any plants showing symptoms of exotic diseases were immediately rogued and incinerated. Healthy plants were harvested and their seeds released to ICRISAT scientists. Great care is taken to prevent spread or establishment of pests or diseases from the PEQIA.

Computer Services

The Computer Services Unit provides timesharing to ICRISAT researchers 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 systems. We develop interactive systems; provide data-entry services; install software packages, microcomputer hardware and software; conduct seminars; and provide individualized instruction on computer usage to all ICRISAT staff.

State of Development

The main focus of software development in 1986 was again on systems for administrative applications. Phase 1 of the Financial Accounting System was released for daily use in January, and the necessary refinements were made during the year. Phase II of the Financial Accounting System that will feature online enquiry by administrative offices, was completed and released for testing. Several maintenance functions were added to the personnel database system. An online leave management system and an employee medical records system, both of which integrate with the personnel database, were developed and released to the concerned user departments. The inventory management system, in use since late 1984, was completely redesigned to add more features and to improve its operating efficiency. A travel records management system was developed and released to the Travel Unit for testing. A system to manage the details of all locks and keys in the Institute was developed for the Security Unit, and a system to maintain details of visitors was developed for Visitors' Services.

We worked on an online system designed to keep track of the Editorial Committee review process for journal articles and conference papers, and to maintain a permanent database of all ICRISAT publications. We developed database system to manage details of all seeds exported by the Plant Quarantine Unit. We worked on software to interface microcomputer-based documents to the phototypesetter, using the VAX as an intermediary.

The research VAX-11/780 computer system was improved with the installation of 10 Megabytes of memory. The additional memory permits the use of the most recent version of the VMS operating system, and experimentation with a network between the two VAX systems. A laser printer was added to each of the VAX systems to provide faster letter-quality document printing.

Thirty-five DEC Rainbow microcomputers and three IBM PC/XT microcomputers were installed during 1986 for word processing, spreadsheet applications, small database management, specialized applications, and training. Many of these systems are able to gain access to one of the central computers for data exchange. A long-term goal is to place at least one microcomputer in each Program Office and provide network-based access to each of the two VAX computers. Over 100 staff members were trained in the use of microcomputer software at ICRISAT Center. Additionally, five Rainbow microcomputers were installed for the SADCC / ICRISAT Regional Sorghum and Millet Improvement Program in Bulawayo, Zimbabwe. Three staff members from

ICRISAT Center trained the staff in Bulawayo on the use of word processing, spreadsheet, database, communications, and statistical analysis software.

ICRISAT is a member of the electronic messaging and data communications system (CGNET) that links the Technical Advisory Committee (TAC) and the Consultative Group on International Agricultural Research (CGIAR) secretariats, with eight of the CGIAR centers and with each other. CGNET is implemented using the Dialcom Electronic Mail Service and also permits contact with several other institutions throughout the world. In March 1986, the SADCC/ICRISAT Program was added to CGNET using a DEC Rainbow, a modem, and an international telephone link to the UK. The CGNET access to the ICRISAT Sahelian Center in Niamey, Niger, initially established in 1985, was improved using a high-quality modem and a telephone link to the UK in May.

Looking Ahead

Despite the addition of many microcomputers, the demand for central computer resources increased substantially in 1986. This increased load has had an adverse effect on software development scheduled for 1986. Much effort will be expended in 1987 to improve the efficiency of the existing applications, to establish guidelines for software development that assure the most efficient use of existing resources, and to assess the best method of increasing computer resources. A consulting firm will be retained to help with this study. High-speed networking hardware that permits the use of microcomputers in the VAX network will be installed, and the distribution of applications between microcomputers and the central VAX computers will be explored.

Statistics Unit

The Statistics Unit provides consultancy services to ICRISAT staff and scientists from collaborative projects at various stages of their research; this service includes planning experiments, analyzing data, and drawing inferences. We review scientific papers for the Editorial Committee and reports for programs. We also lecture to the trainees on design and analysis of experiments and biometrical genetics. We participate in Inhouse Reviews, program planning meetings, and visit experimental trials.

In 1986, we supervised students from the Andhra Pradesh Agricultural University (APAU) in their dissertation work. Our Principal Statistician was transferred to ISC, Niamey, Niger, following recommendations of the External Program Review. One staff member received training on microcomputers at the University of Kiel, Federal Republic of Germany.

We consulted three experts on topics of our current research interest. These include applications of robust statistical techniques, estimation of variance components, and nonlinear functional relationships. We used several data sets to examine these methods. Our consultancies with scientific staff and collaborators during 1986 averaged over 85 per month.

These consultancies encouraged us to examine the following:

- Generation mean analysis. A number of methods suitable for non-normal data and combining means with heterogenous variances were examined to estimate components of generation means in plants. The comparison was made with the help of sorghum data. More data sets are now being examined.
- Variability studies. Using pearl millet data we examined methods to account for variability due to competition between neighboring rows. In a few cases we found that some genotypes competed with others when grown adjacently. Two nearest neighbor (NN) techniques due to Papadakis and Wilkinson were also found to be successful in accounting for variability due to local trends in the field.

Looking Ahead

We plan to examine the behavior of coefficient of variation (CV), noniterative robust methods for analyzing data from designed experiments, and to follow up visits from consultants invited during this past year.

Library and Documentation Services

Acquisition

During 1986 we developed a microcomputer-based serials data system; this will improve the library's capability to inventory and disseminate information on its serial holdings.

We added more than 2000 documents to our collection (Table 1).

In continuing to provide assistance in developing the ICRISAT Sahelian Center (ISC) library we acquired, processed, and transferred 262 titles to ISC. A staff member visited ISC as a consultant and to train the ISC Assistant Librarian in library techniques and procedures. This 3-week consultancy resulted in the classification and cataloging of the ISC collection, and the establishment of procedures for acquisition, technical processing, and circulation of documents.

Table 1. Status of acquisition, ICRISAT Library, 1986.

Documents	Additions during 1986	Total holdings (Dec 1986)
Books and reports	1313	21 358
Bound volumes of periodicals	394	12479
Annual Reports	256	1317
Reprints, photocopies, etc.	170	5 793
Microforms	33	796

Documentation Services

Our Selective Dissemination of Information (SDI) service continues to be popular with recipients. It now goes to 176 scientists in 35 countries; 36 of these are new recipients in 1986 representing a 26% growth over last year.

We conducted 98 literature searches, including 10 on-line searches to meet specific requests for comprehensive and problem-oriented information. The availability of search results was announced through the Institute's Newsletter, At ICRISAT, enabling more users to benefit from the service.

The Central Reprography Unit attached to the Library provides Institute-wide photocopying, microcopying, and offset printing services. In 1986, the unit produced 892 874 pages of photocopies and 10 742 of the masters used to print program-level publications. A modest beginning was also made on microfiching out-of-print ICRISAT publications.

During the year, we continued to input conventional and nonconventional literature produced at ICRISAT to the Information System for Agricultural Sciences and Technology (AGRIS) database, of the Food and Agriculture Organization of the United Nations (FAO).

Sorghum and Millets Information Center (SMIC)

Bibliographies. We published an annotated Sorghum Bibliography for 1983 (1558 entries) and compiled the Millets Bibliography for 1983 (1036 entries). Both were produced on computer.

BASIS. Phase II of the SMIC Project ended in September 1986 after an 18-month extension by the International Development Research Centre (IDRC), Canada. Under the IDRC grant we acquired a versatile Information Retrieval Software Package, BASIS, and held an intensive workshop on the package during September 1986. The workshop, funded in part by IDRC, provided hands-on training on the capabilities of the package and its use for database creation and maintenance. It was attended by 10 participants from the Library, Computer Services, Information Services, and the Genetic Resources Unit. BASIS will be used to put the SMIC database on the VAX-11/780 computer system and will enable interactive access to the database by scientists at ICRISAT Center.

Document Delivery Services. Following requests from scientists from all over the world we provided copies of 3086 papers and literature searches in the SMIC collection.

Computerization. The software package developed in 1985 to integrate bibliography data entry, updating, index generation, and production of formatted, camera-ready copy of bibliographies, was extended to produce SDI fascicules and the current literature sections of the SMIC Newsletter.

Looking Ahead

A project to expand SMIC's information resources and services to all five of ICRISAT's mandate crops has been approved and will be funded by IDRC. In 1987 we will begin to work on this new project, to be called the Semi-Arid Tropical Crops Information Service (SATCRIS). The project aims to develop a database on our mandate crops using machine-readable subsets of Commonwealth Agricultural Bureaux International (CABI) and AGRIS databases. It also envisages closer cooperation between ICRISAT and CABI, in the dissemination of information on the five crops to scientists working at ICRISAT and in national and regional programs of the SAT.

Information Services

Information Services is responsible for the publication and dissemination of information about ICRISAT's research to a wide audience of national scientists and policymakers in developing countries, the international scientific community, donors, and informed readers. In addition, it provides support services to scientists in the preparation of tables, figures, posters, photographs, and slides. It also provides a French-language translation service to ICRISAT administrative and scientific staff.

This year ICRISAT produced 32 institute-level publications including 5 workshop pro-

President Seyni Kountche of Niger (right), and a member of his staff discussing ICRISAT publications during a visit to ISC, Sadore, 1986.

ceedings, 2 bibliographies, and 15 issues of various newsletters. All these publications are produced in-house, and the majority of them are printed at ICRISAT Center. Two issues of Nouvelles de l'ICRISAT were published and distributed from the ICRISAT Sahelian Center, which also produced annual reports in English and French for the ISC and ICRISAT's sorghum program based in Burkina Faso for distribution in the West African region.

Information Services is responsible for publicizing scientific achievements through news releases and, with film and video presentations made by external agencies, to act as a link between ICRISAT scientists and the agencies concerned. During September 1986, a letter of understanding was signed between the Educational Media Research Centre (EMRC) of the Central Institute of English and Foreign Languages (CIEFL) to work on video presentations outlining various aspects of ICRISAT's work in India. Also, consultants from the USA conferred with staff and gave seminars on the use of graphics in writing reports, and on science writing for the public and the media.

During the year the Composing Unit installed a new-generation phototypesetter, the Comp/Edit 6400, to augment existing equipment. This has increased composition capacity by 50% and cut production time. Some 4600 m of phototypesetting paper were exposed and processed for publications, slides, and other typographic requirements. Because the phototypesetting equipment is electronically linked with the Institute's VAX mainframe computer, Composing Unit staff have trained text inputters in other programs to facilitate the interfacing and simplify the formatting work done within the Division. Computer graphics are increasingly used to illustrate ICRISAT publications.

The Art Unit handled more than 1200 pieces of artwork, in addition to their graphic and design work on Institute-level publications. This included line figures, photo page layouts, poster presentations, maps, forms, overlays, page paste-ups, and brochures. The Photographic Unit handled 1808 jobs, comprising about 39 518 exposures. The Printshop ran 3.32 million impressions during 1986; this includes the major Institute-level publications printed in-house. The Distribution Unit dispatched 20 383 copies of publications, 88% of which were sent gratis to libraries and scientists engaged in agricultural research pertaining to the SAT; the remainder were sold.

Information Services also provides the Secretariat to the Editorial Committee, which operates an internal peer-review system for manuscripts authored by Institute staff for the international scientific press. During 1986, 198 manuscripts were submitted to the Committee. Of them, 150 were approved for submission to journals, workshop or conference proceedings, and multiauthored books, or published as Institute serials. Information Services staff edited 40 of these during the review process, and 28 of them received statistical review. Thirty-eight journal articles and 44 conference papers previously approved by ICRISAT were published in the scientific press. These are listed at the end of concerned sections in this Report, and reprints can be obtained on request from relevant Program Offices.

Looking Ahead

Information Services has investigated presently available machine translation systems to meet the increasing demand for accurate technical translation from and into French and Spanish. It is hoped such aids will facilitate the production of more publications in these languages.

Further improvements will be made in the combined use of typesetting and computerized pen-plotted graphics in producing line figures. A communication program is being created to permit interfacing of both French and English texts from the mainframe computer to the new-generation phototypesetter.

Publications

Institute Publications

Annual Progress Reports

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Research Highlights 1985. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2532.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Progres de la recherche 1985. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2494.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2478.

Bibliographies

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Sorghum and Millets Information Center. 1986. Sorghum Bibliography 1982. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-117-8.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Sorghum and Millets Information Center. 1986. Sorghum Bibliography 1983. Patancheru, A.P. 502 324, India: ICRISAT. ISBN 92-9066-118-6.

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. At ICRISAT nos. 13, 14,15, and 16. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2486.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Nouvelles de TICRISAT nos. 7 and 8. Niamey, Niger: ICRISAT Sahelian Center. ISSN 0257-2524.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Sorghum and Millets Information Center. 1986. SMIC Newsletter nos. 18, 19, and 20. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2540.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. La Lettre du SMIC nos. 16, 17, and 18. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2516.

ICRISAT R&D Leaflets

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. ICRISAT R&D Leaflet. Crop improvement in India: varieties, hybrids, and lines developed by ICRISAT. Patancheru, A.P. 502 324, India: ICRISAT.

Other Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. ICRISAT in Africa. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. L'ICRISAT en Afrique. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. ICRISAT Publications Catalog 1986. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Publications (price list) 1986. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Publications de 1TCRISAT. Patancheru, A.P. 502 324, India: ICRISAT.

Conference Papers

Dutta, S. 1986. AGRIS level two—a review. Pages 85-93 *in* In the library and information science horizon (Guha, B.. ed.). New Delhi, India: Allied Publishers. (CP 119)

Varma, B.K. 1985. Plant quarantine in the export of pulses and groundnut germplasm from ICRISAT. Pages 181 -186 in Proceedings of the Regional Conference on Plant Quarantine Support for Agricultural Development, 10-12 Dec 1985, Serdang, Selangor, Malaysia. Serdang, Selangor, Malaysia: Asean Plant Quarantine Center and Training Institute. (CP 249)

ICRISAT Governing Board—1986

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Dept. of Agricultural Economics
and Business Management
University of New England
Armidale, NSW.2351
Australia

Dr. F. V. MacHardy, Chairman (from March)
7817 Saskatchewan Drive
Edmonton, Alberta
Canada T6G 2L3.

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Director General, Indian Council of
Agricultural Research (ICAR) and
Secretary to the Government of India
Department of Agricultural Research
and Education
Krishi Bhavan
New Delhi 110 001
India

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Director General, ICRISAT
Patancheru
Andhra Pradesh 502 324
India

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Secretary to the Government of India
Ministry of Agriculture
Krishi Bhavan
New Delhi 110 001
India

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Secretary to the Government of India
Ministry of Agriculture
Krishi Bhavan
New Delhi 110 001
India

Mr. Shravan Kumar
Chief Secretary to the
Government of Andhra Pradesh
Secretariat
Hyderabad 500 022
India

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Chancellor
Texas A & M University System
College Station
Texas 77843
USA

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Director
Plant Production and Protection Division
Food and Agriculture Organization of the UN
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00100 Rome
Italy

Dr. C. Charreau
Director, IRAT
Centre de Coope'ration Internationale en Recherche
Agronomique pour le DeVeloppement (CIRAD)
45 bis Avenue de la Belle Gabrielle
94130 Nogent sur Marne
France

Dr. J. P. Eckebil (from May)
Director
Institut de la Recherche Agronomique
B.P. 2123
Yaounde - Messa
Cameroon

Dr. N. L. Innes
Deputy Director
Scottish Crop Research Institute
Invergowrie, Dundee
Scotland

Dr. J. Kabore (until May)
Program Officer
World Food Program
B.P. 620
Nouakchott
Mauritania

Dr. K. Kumazawa
Professor of Plant Nutrition and Fertilizer
Faculty of Agriculture
University of Tokyo
Bunkyo-ku, Tokyo
Japan

ICRISAT Senior Staff—as of December 1986

ICRISAT Center

Administration

L.D. Swindale, Director General
J.S. Kanwar, Deputy Director General
M. Goon, Assistant Director General (Administration)
S.P. Ambrose, Principal Government Liaison Officer (until May)
K.B. Srinivasan, Assistant Director General (Liaison) (from Jun)
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 in Research Management Systems (from Aug)
V. Balasubramanian, Sr Executive Officer (Director General's Office)
Joyce Gay, Sr Adm Secretary to the DG
M.S.S. Reddy, Scientist (on contract)
Sunetra Sagar, Sr Adm Secretary to the DDG
S. Krishnan, Asst Manager (Admn), Office of Adviser to the DG for Donor Relations
S. Ramachandran, Adm Officer, Office of Adviser to the DG for Donor Relations (until Aug)
C. Geetha, Sr Secretary, Office of the ADG (Admn)
P. Sosamma Nair, Sr Secretary, Office of the ADG (Liaison)
D. Mitra, Fiscal Manager
A. Banerji, Asst Manager (Fiscal)
V.S. Swaminathan, Sr Accounts Officer
A.N. Venkataswamy, 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
B.K. Johri, Personnel Manager
P.M. Menon, Asst Personnel Manager (from Feb)
N.S.L. Kumar, Sr Personnel Officer
P. Suryanarayana, Sr Personnel Officer
A.J. Rama Rao, Sr Secretary (Personnel)
R. Vaidyanathan, Purchase and Stores Manager (on sabbatic until Apr)
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 (Admn)
N. Surya Prakash Rao, Sr Resident Medical Officer
R. Narsing Reddy, Transport Officer (until Sep)
G. Vijayakumar, Transport Officer
K. Jagannadham, Adm Officer (Transport)
A. Rama Murthy, Travel Officer

Research Programs

Cereals

Program Office

J.M.J. de Wet, Program Director, Cereals (from Jun)
K. Santhanam, Asst Manager (Admn) (from Aug)
S.P. Jaya Kumar, Adm Officer (until Aug)
Nirmala Kumar, Adm Officer

Sorghum Group

S.Z. Mukuru, Principal Plant Breeder (Program Leader until May) (on sabbatic)
L.K. Mughogho, Principal Plant Pathologist
J.M. Peacock, Principal Plant Physiologist
K. Leuschner, Principal Cereals Entomologist (until Nov)
D.S. Murty, Plant Breeder (on leave from Jul)
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
R. Bandyopadhyay, Plant Pathologist
S.L. Taneja, Entomologist
H.C. Sharma, Entomologist (on sabbatic from Nov)
H.D. Patil, Sr Research Associate
K. David Nicodemus, Sr Research Associate
P. Ramesh, Research Fellow
N.F. Beninati, International Intern (until Nov)
D.J. Flower, International Intern (from Feb)

Pearl Millet Group

S.B. King, Principal Plant Pathologist (Program Leader until May)

F.R. Bidinger, Principal Plant Physiologist
J.R. Witcombe, Principal Plant Breeder
K.K. Lee, Principal Cereals Microbiologist
K.N. Rai, Plant Breeder
B.S. Talukdar, Plant Breeder
Pheru Singh, Plant Breeder
S.B. Chavan, Plant Breeder
G. Alagarswamy, Plant Physiologist (on secondment)
V. Mahalakshmi, Plant Physiologist
S.D. Singh, Plant Pathologist
R.P. Thakur, Plant Pathologist (on sabbatic from Jul)
S.P. Wani, Microbiologist
K.R. Krishna, Microbiologist
P.Q. Craufurd, International Intern
C.T. Hash Jr., International Intern (from Mar)

Kenya

Brhane Gebrekidan, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern and Southern Africa (until Apr)
V.Y. Guiragossian, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa (from Jun)

Sudan

R.P. Jain, Principal Millet Breeder (until Sep)

Mexico

V.Y. Guiragossian, Principal Sorghum Breeder (until May)
C.L. Paul, Principal Sorghum Agronomist
R. Clara, Scientist, Sorghum Breeder

Legumes

Program Office

Y.L. Nene, Principal Plant Pathologist and Acting Program Director, Legumes
D.G. Faris, Principal Coordinator, Asian Grain Legumes Network
D.M. Pawar, Sr Agricultural Officer (Cooperative Trials)
P. Subrahmanyam, Sr Adm Officer (until Aug)
Surendra Mohan, Sr Adm Officer (from Aug)
P. Rama Murthy, Adm Officer, Legumes
G.J. Michael, Adm Officer (AGLN) (from Aug)

Pulses Group

W. Reed, Principal Entomologist
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/TDRI (from Apr)
J. Arihara, Associate Physiologist
N. Ae, Associate Microbiologist
H.J. Hansen, Asst Plant Pathologist, ICRISAT/DANIDA (from Jun)
K. Okada, Asst Microbiologist (from Dec)
D. Sharma, Sr Plant Breeder, Pigeonpea (from May)
K.C. Jain, Plant Breeder, Pigeonpea
Onkar Singh, Plant Breeder, Chickpea
K.B. Saxena, Plant Breeder, Pigeonpea
S.S. Lateef, Entomologist
M.P. Haware, Plant Pathologist (on leave from Nov)
S.C. Sethi, Plant Breeder, Chickpea
N.P. Saxena, Agronomist
C.L.L. Gowda, Plant Breeder, Chickpea
O.P. Rupela, Agronomist (Microbiology)
J.V.D.K. Kumar Rao, Agronomist (Microbiology)
A.M. Ghanekar, Plant Pathologist
Jagdish Kumar, Plant Breeder, Chickpea
S. Sithanantham, Entomologist
S.C. Gupta, Plant Breeder, Pigeonpea
M.V. Reddy, Plant Pathologist
Y.S. Chauhan, Agronomist (Physiology)
S.B. Sharma, Plant Nematologist (from Nov)
M.D. Gupta, Sr Research Associate (on study leave until Sep)
N.V. Ratnam, Sr Research Associate
J.H. Miranda, Sr Research Associate, Chickpea
L. Krishna Murthy, Sr Research Associate
I.S. Dundas, International Intern (until Oct)
P.K. Anand Rao, Postdoctoral Fellow
Nandita Sarkar, Postdoctoral Fellow (from Jun)

Groundnut Group

R.W. Gibbons, Principal Plant Breeder (Program Leader until May)
D. McDonald, Principal Plant Pathologist
J.P. Moss, Principal Cytogeneticist
D.V.R. Reddy, Principal Plant Virologist
J.H. Williams, Principal Plant Physiologist
J.A. Wightman, Principal Entomologist
S.N. Nigam, Principal Plant Breeder (from Jun)
F. Waliyar, Asst Plant Pathologist (from Sep)
L.J. Reddy, Plant Breeder (on sabbatic until Jun)
P. Subrahmanyam, Plant Pathologist
P.T.C. Nambiar, Microbiologist
P.W. Amin, Entomologist
G.V. Ranga Rao, Entomologist
A.K. Singh, Cytogeneticist (on sabbatic from Jul)
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
H.A. Hobbs, International Intern (until Feb)

K.M. Dick, International Intern (until Dec)
S. Nahdi, Research Fellow (until Mar)

Syria

K.B. Singh, Principal Chickpea Breeder
M.P. Haware, Principal Chickpea Pathologist (from Nov)

Pakistan

M.S. Rahman, Principal Chickpea Breeder/Plant Pathologist

Resource Management

Program Office

M. von Oppen, Program Director
D. Sharma, Coordinator, On-farm Research (until May)
S.K. Sharma, Sr Research Associate
R.S. Aiyer, Sr Adm Officer
Surendra Mohan, Sr Adm Officer (until Aug)
S. Ramachandran, Adm Officer (from Aug)

Agronomy Group

S.M. Virmani, Principal Agroclimatologist
J.R. Burford, Principal Soil Chemist (on sabbatic from Jun)
C.W. Hong, Principal Soil Scientist (ICRISAT/IFDC) (until May)
C.K. Ong, Principal Agronomist, Cropping Systems
A.B.S. King, Cropping Systems Entomologist (ICRISAT/TDRI) (until Apr)
R.J. Van Den Beldt, Principal Agronomist, Agroforestry
A. Schutt, Asst 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.R. Rao, Agronomist (until Jul)
M.S. Reddy, Agronomist (on leave)
M. Natarajan, Agronomist (on sabbatic from Mar)
A. Ramakrishna, Agronomist (from Oct)
C.S. Pawar, Entomologist
A.A.H. Khan, Engineer
R. Tabo, Postdoctoral Fellow (from Jul)

Engineering Group

K.B. Laryea, Principal Soil Physicist
T. Takenaga, Principal Agricultural Engineer
Sardar Singh, Soil Scientist
K.L. Srivastava, Agricultural Engineer
R.K. Bansal, Agricultural Engineer (on sabbatic from Oct)
R.C. Sachan, Agricultural Engineer
Prabhakar Pathak, Agricultural Engineer
N.K. Awadhwal, Agricultural Engineer/Soil Physicist
V.M. Mayande, Engineer (on study leave until Aug)

Economics Group

T.S. Walker, Principal Economist
P.J. Matlon, Principal Economist (from Sep)
R.A.E. Muller, Principal Economist
Karen Ann Dvorak, International Intern (until Nov) and Principal Economist (ICRISAT/IFDC) (from Nov)
N.S. Jodha, Sr Economist
R.N. Athavale, Sr Hydrologist (on contract)
R.D. Ghodake, Economist (on leave until Dec)
R.P. Singh, Economist
K.G. Kshirsagar, Sr Research Associate
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
N.V. Narasimham, Research Fellow (until Aug)
V. Ballabh, Research Fellow (until Jan)

Support Programs

Biochemistry

R. Jambunathan, Principal Biochemist
Umaid Singh, Biochemist
V. Subramanian, Biochemist
T.A. Krishnamurthi, Sr Adm Officer (until Aug)
P. Subrahmanyam, Sr Adm Officer (from Aug)
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
W.H. Skrdla, Germplasm Botanist (until Feb)
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, Adm Officer

Plant Quarantine

B.K. Varma, Chief Plant Quarantine Officer
Upendra Ravi, Sr Research Associate
N. Rajamani, Sr Adm Officer

Fellowships and Training

D.L. Oswalt, Principal Training Officer
A.S. Murthy, Sr Training Officer (until Mar)
B. Diwakar, Sr Training Officer
T. Nagur, Sr Training Officer (on sabbatic until May)
S.K. Dasgupta, Sr Training Officer (on sabbatic from Nov)
Faujdar Singh, Training Officer
V.S. Raju, Sr Secretary

Information Services

H.L. Thompson, Head (until Mar)
D.A. Fuccillo, Head (from Jun)
J.B. Wills, Research Editor (Acting Head Mar-Jun)
Susan D. Feakin, Research Editor
S.M. Sinha, Asst Manager, Art and Production
D.R. Mohan Raj, Editor
Madhu Reddy, Editor
J.J. Abraham, Editor
H.S. Duggal, Sr Photographic Supervisor
G.K. Guglani, Sr Art Visualizer
T.R. Kapoor, Sr Composing Supervisor
A. Antonisamy, Printshop Supervisor
N.V.N. Chari, Adm Officer

Statistics

B. Gilliver, Principal Statistician (until Oct)
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, Sr Computer Programmer/Analyst
C. Kameswara Rao, Computer Programmer/Analyst
S.V. Nanda Kishore, Computer Programmer/Analyst
J. Gnanasekharan, Computer Programmer/ Analyst

Library and Documentation Services

L.J. Haravu, Manager
P.K. Sinha, Sr Documentation Officer
P.S. Jadhav, Sr Library Officer
S. Prasannalakshmi, Library Officer

Housing and Food Services

G.W. Conover, Manager
S. Mazumdar, Asst Manager (Food Services)
B.R. Revathi Rao, Asst Manager (Housing)
D.V. Subba Rao, Asst Manager (Warehouse)

Physical Plant Services

V.P. McGough, Manager
P.M. Menon, Asst Manager (Admn) (until Feb)
Sudhir Rakhra, Chief Engineer (Civil)
D. Subramaniam, Chief Engineer (Electrical)
C.K. Belliappa, Asst Manager (Workshop)
S.K.V.K. Chari, Sr Engineer (Electronics and Instrumentation) (on study leave)
N.S.S. Prasad, Sr Engineer (Electronics and Instrumentation)
A.R. Das Gupta, Sr Engineer (Communication)
D.C. Raizada, Sr Engineer (Airconditioning)
D.V.S. Verma, Engineer (Machineshop) (until Feb)
R. Thiyagarajan, Engineer (Automobiles)
A.N. Singh, Engineer (Heavy Equipment and Tractors)
S.W. Quadar, Engineer (Office Equipment)
K.R.C. Bose, Engineer (Civil)
S.P. Jaya Kumar, Adm Officer (from Aug)

Farm Development and Operations

S.N. Kapoor, Acting Farm Manager
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
K. Santhanam, Asst Manager (Admn) (until Aug)
T.A. Krishnamurthi, Sr Adm Officer (from Aug)

West Africa Programs

ICRISAT Sahelian Center, Niger

C.R. Jackson, Director, ISC (until Mar)
R.W. Gibbons, Executive Director, West African Programs and Director,ISC (from May)
K.F. Nwanze, Principal Millet Entomologist (on sabbatic until Oct)
C. Renard, Principal Agronomist and Team Leader, Resource Management Program
K. Anand Kumar, Principal Millet Breeder and Team Leader, Millet Improvement Program
S.O. Okiror, Principal Millet Breeder/ Regional Trials Officer
B.B. Singh, Principal Millet Breeder, (Maradi) (until Mar)
J. Werder, Principal Millet Pathologist
M.V.K. Sivakumar, Principal Agroclimatologist
D.C.S. Spencer, Principal Economist (until May)
M.C. Klaij, Principal Soil and Water Management Scientist
C.A. Giroux, French Writer/Editor
B.D. Marvaldi, Project Development Officer
P.O. Serafini, Research Farm Manager
D.C. Goodman Jr., Regional Adm Officer
L.K. Fussell, Principal Millet Agronomist (on sabbatic from Oct)
B. Ndunguru, Principal Groundnut Agronomist (from Sep)
B. Gilliver, Principal Statistician (from Nov)
A. Bationo, Principal Soil Chemist (ICRISAT/IFDC)
Maimouna S. Dicko, Principal Animal Nutritionist (ICRISAT/ILCA) (on sabbatic from Apr)
B.R. N'tare, Principal Cowpea Breeder/ Agronomist (ICRISAT/IITA)
L. Marchais, Principal Geneticist (ORSTOM)
S. Tostain, Principal Geneticist (ORSTOM)
A. Tekete, Principal Agronomist (University of Hohenheim)
T.J. Stomph, Sr Research Asst
P. Ouedraogo, Sr Research Asst
Solange Delanne, Executive Asst, Liaison
K.A. Moussa, Personel and Transport Officer
I.J. Cachalo, Bilingual Secretary
G. Ouoba, Computer Programmer
P. Koudogbo, Chief Mechanic

Burkina Faso

C M . Pattanayak, Principal Sorghum Breeder and SAFGRAD/ICRISAT Coordinator
K.V. Ramaiah, Principal Cereal Breeder—*Striga* (on sabbatic until Aug)
S.N. Lohani, Principal Millet Breeder
P.J. Matlon, Principal Production Economist (until Aug)
M.D. Thomas, Principal Sorghum Pathologist
D.S. Murty, Principal Sorghum Breeder (from Jul)
S. Lingani, Adm Asst, Accounts
B. Ouedraogo, Adm Asst, General Services

Mali

J.F. Scheuring, Principal Cereals Breeder (until May)
S.V.R. Shetty, Principal Agronomist and Team Leader
N.F. Beninati, Principal Sorghum Breeder (from Nov)
S. Toure, Adm Asst
I. Kassambara, Research Associate (Sotuba)
A. Coulibaly, Research Associate (Cinzana)

Southern Africa Programs

SADCC Regional Sorghum and Millet Improvement Program, Zimbabwe

L.R. House, Executive Director, Southern Africa (from Sep) and Project Manager, SADCC/ICRISAT Program
W. Williams, Adm Officer (until Jun)
S.P. Ambrose, Regional Adm Officer (from May)
A.B. Obilana, Principal Sorghum Breeder
S.C. Gupta, Principal Millet Breeder
D.S. Bisht, Station Development and Operations Officer
W.A.J, de Milliano, Principal Cereals Pathologist
M. Osmanzai, Principal Cereals Agronomist (from Sep)
K. Leuschner, Principal Cereals Entomologist (from Dec)
F. York, Farm Manager
W.K. Morgan, Asst Adm Officer

Regional Groundnut Improvement Program, Malawi

K.R. Bock, Principal Groundnut Pathologist and Team Leader
S.N. Nigam, Principal Groundnut Breeder (until May)

Acronyms and Abbreviations Used in this Annual Report

ACIAR	Australian Centre for International Agricultural Research
ACT 3	Late Maturity Arhar Coordinated Trial
AGLN	Asian Grain Legume Network
AGLP	Asian Grain Legume Program
AGRHYMET	Centre regional de formation et d'application en agrometeorologie et hydrologie operationnelle (Niger)
AGRIS	Information System for Agricultural Sciences and Technology
AICMIP	All India Coordinated Millets Improvement Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICPIP	All India Coordinated Pulses Improvement Project
AICRPA	All India Coordinated Research Project on Agroforestry
AICSIP	All India Coordinated Sorghum Improvement Project
ANRC	Animal Nutrition Research Council (USA)
APAU	Andhra Pradesh Agricultural University (India)
APSDC	Andhra Pradesh Seed Development Corporation
ARC	Agricultural Research Center (Ethiopia)
ARC	Agriculture Research Center (Syria)
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
BCTP	Batan Cold Tolerant Population
BLRV	Bean Leaf-Roll Virus
BND	Bud Necrosis Disease
BNDRVT	Bud Necrosis Disease Resistant Varietal Trial
BSD	Bulk Seed Descent
BSEC	Bold Seeded Early Composite
CABI	Commonwealth Agricultural Bureaux International (UK)
CAN	Calcium Ammonium Nitrate
CDA	Cooperation for Development in Africa
CGIAR	Consultative Group on International Agricultural Research
CGNET	Consultative Group Network
CGPRT	Regional Co-ordination Center for Research and Development of Coarse Grains, Pulses, Roots, and Tuber crops in the Humid Tropics of Asia and the Pacific (Indonesia)
CIBC	Commonwealth Institute of Biological Control (Trinidad)
CIEFL	Central Institute of English and Foreign Languages (India)
CILSS	Comite permanent interetats de lutte contre la secheresse dans le Sahel (Mali)
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico)
CIRAD	Centre de cooperation internationale en recherche agronomique pour le developpement (France)
CMI	Commonwealth Mycological Institute (UK)

CMS	Cytoplasmic Male-Sterility
CPPTI	Central Plant Protection and Training Institute (India)
CPR	Common Property Resource
CR1DA	Central Research Institute for Dryland Agriculture (India)
CRSP	Collaborative Research Support Program (USA)
CTA	Technical Centre for Agricultural and Rural Co-operation (The Netherlands)
CV	Coefficient of Variation
cv	cultivar
CVRC	Central Varietal Release Committee (India)
D_2C	Dwarf Composite
DAE	Days After Emergence
DAS	Days After Sowing
DCP	Desi Chickpea
DCP	Dilution and Plate Counting Technique
DEC	Digital Equipment Corporation (USA)
DM	Downy Mildew
DRI	Drought Response Index
EACT	Extra-early Arhar Coordinated Trial
EARSAM	East African Regional Sorghum and Millet (Network; and Advisory Committee)
EC	Electrical Conductivity
EC	Early Composite
ELC	Elite Composite
ELISA	Enzyme-Linked Immunosorbent Assay
ELPN	Elite Products Nursery
EMBC	Early Maturing Backup Composite
EMRC	Educational Media Research Centre (India)
EPAY	Early-maturity Pigeonpea Adaptation Yield Trial
EPIT	Early-maturity Pigeonpea International Trial
ER	Ergot-Resistant
ERC	Ergot-Resistant Composite
ESD	Equal Seed Descent
EVPIT	Early Vegetable Pigeonpea International Trial
FAO	Food and Agriculture Organization of the United Nations (Italy)
FLIP	Food Legumes Improvement Program
FSR	Farming Systems Research
GCVT	Gram Coordinated Varietal Trial
GLM	Groundnut Leaf Miner
GRAV	Groundnut Rosette Assistor Virus
GRU	Genetic Resources Unit
GRV	Groundnut Rosette Virus
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (Federal Republic of Germany)
HAU	Haryana Agricultural University (India)
HPSVT	Hand Picked Selection Varietal Trial
HV	High Volume (sprayer)
HYV	High Yielding Variety
IAR	Institute for Agricultural Research, Ahmadu Bello University (Nigeria)
IARC	International Agricultural Research Center

IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources (Italy)
IBRAZ	Institut burkinabe de recherches agronomiques et zootechniques (Burkina Faso)
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas (Syria)
ICAT	International Chickpea Adaptation Trial
ICCT-DL	International Chickpea Cooperative Trial - Desi Long-duration
ICCT-K	International Chickpea Cooperative Trial - Kabuli
ICHRN	International Chickpea *Heliothis* Resistance Nursery
ICIPE	International Centre of Insect Physiology and Ecology (Kenya)
ICMPES	ICRISAT Millet Pathology Ergot Sib-bulk
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
ICRRWN	International Chickpea Root Rots and Wilt Nursery
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
IDRC	International Development Research Centre (Canada)
IER	Institut d'economie rurale (Mali)
IFDC	International Fertilizer Development Center (USA)
IFFCO	Indian Farmers Fertilizer Cooperative Organisation
IITA	International Institute of Tropical Agriculture (Nigeria)
IIUCRRWN	ICAR/ICRISAT Uniform Chickpea Root Rots and Wilt Nursery
IIUTPSMR	ICAR/ICRISAT Uniform Trials of Pigeonpea Sterility Mosaic Resistance
IIUTPWR	ICAR/ICRISAT Uniform Trial for Pigeonpea Wilt Resistance
ILCA	International Livestock Centre for Africa (Ethiopia)
IMZAT	ICRISAT Pearl Millet African Zone-A Trial
INERA	Institut national d'etudes et de recherches agricoles (Burkina Faso)
INRAN	Institut national de recherches agronomiques du Niger
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMAT	International Pearl Millet Adaptation Trial
IPMEN	International Pearl Millet Ergot Nursery
IPMRN	International Pearl Millet Rust Nursery
IPMSN	International Pearl Millet Smut Nursery
IPWN	International Pigeonpea Wilt Nursery
IRAT	Institut de recherches agronomiques tropicales et des cultures vivriferes (France)
IRHO	Institut de recherches pour les huiles et oleagineaux (France)
IRRI	International Rice Research Institute (The Philippines)
ISC	ICRISAT Sahelian Center (Niger)
ISHAT	International Sorghum Hybrid Adaptation Trial
ISMN	International Sorghum Midge Nursery
ISRA	Institut senegalais de recherches agricoles (Senegal)
ISSFN	International Sorghum Shoot Fly Nursery
ISSN	International Sorghum *Striga* Nursery
ISVAT	International Sorghum Variety Adaptation Trial

IVC	Inter Varietal Composite
IVSCAF	In Vitro Seed Colonization by *Aspergillus flavus*
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya (India)
LAI	Leaf Area Index
LARSVYT	Latin American Rainfed Sorghum Variety Yield Trial
LER	Land Equivalent Ratio
LMBC	Late Maturing Backup Composite
LV	Low Volume (sprayer)
LVP	Long-duration Vegetative Phase
MC	Medium Composite
MFR	Multifactor Resistant
MLT	Multinational Trial
MOU	Memorandum of Understanding
MPAY	Medium Pigeonpea Adaptation Yield Trial
MPN	Most Probable Number
MPSMWRY	Medium-duration Pigeonpea Sterility Mosaic Wilt Resistant Yield Trial
N	Nitrogen
NAA	Naphthalene Acetic Acid
NARC	National Agricultural Research Centre (Pakistan)
NBPGR	National Bureau of Plant Genetic Resources (India)
NDFRS	National Dryland Farming Research Station (Kenya)
NELC	New Elite Composite
NIAB	Nuclear Institute of Agriculture and Biology (Pakistan)
NN	Nearest Neighbor
NRA	Nitrate Reductase Activity
OAU	Organization for African Unity (Burkina Faso)
ODA	Overseas Development Administration (UK)
ORD	Organisme regional de developpement (Burkina Faso)
ORSTOM	Institut francais de recherche scientifique pour le developpement en cooperation (France)
P	Phosphorus
PARP	Partially Acidulated Rock Phosphate
PCV	Peanut Clump Virus
PE	Potential Evapotranspiration
PEQIA	Post-Entry Quarantine Isolation Area
PER	Protein Efficiency Ratio
PGRC/E	Plant Genetic Resources Center (Ethiopia)
PMAHT	Pearl Millet Advanced Hybrid Trial
PMAVT	Pearl Millet Advanced Variety Trial
PMIHT	Pearl Millet Initial Hybrid Trial
PMIVT	Pearl Millet Initial Variety Trial
PMV	Peanut Mottle Virus
PON	Pigeonpea Observation Nursery
PRL	Prairie Research Laboratory (Canada)
PRLN	Potential R-Lines Nursery
PRP	Parc-W Rock Phosphate
PStV	Peanut Stripe Virus Disease
PYSV	Peanut Yellow Spot Virus

PVT	Preliminary Variety Trial
PYT	Preliminary Yield Trial
RBD	Randomized-Block Design
RC	Restorer Composite
RH	Relative Humidity
RLWC	Relative Leaf-Water Content
RMP	Resource Management Program
RSPVT	Regional Sorghum Preliminary Varietal Trial
S	Sulfur
SADCC	Southern African Development Coordination Conference (Botswana)
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
SM	Sterility Mosaic
SMIC	Sorghum and Millets Information Center (ICRISAT)
SMK	Sound Mature Kernel
SR	Smut-Resistant
SRC	Smut-Resistant Composite
SSP	Single Superphosphate
SVP	Short-duration Vegetative Phase
TAC	Technical Advisory Committee (CGIAR)
TADD	Tangential Abrasive Dehulling Device
TDM	Total Dry Matter
TDRI	Tropical Development and Research Institute (UK)
TGMR	Threshed Grain Mold Rating
TRP	Tahoua Rock Phosphate
TSP	Triple Superphosphate
TSWV	Tomato Spotted Wilt Virus
ULV	Ultra-Low Volume (sprayer)
UNDP	United Nations Development Programme (USA)
UNEP	United Nations Environment Programme (USA)
UNESCO	United Nations Education, Scientific and Cultural Organization (France)
UPN	Uniform Progeny Nursery
USAID	United States Agency for International Development
VAM	Vesicular Arbuscular Mycorrhizae
VLP	Virus-Like Particle
VLS	Village-Level Studies
WADMON	West African Downy Mildew Observation Nursery
WADMVN	West African Downy Mildew Variability Nursery
WASHAT	West African Sorghum Hybrid Adaptation Trial
WASVAT	West African Sorghum Variety Adaptation Trial
WMO	World Meteorological Organization (Switzerland)
WTC	Wheeled Tool Carrier
WU	Water Use
WUE	Water-Use Efficiency

List of elite ICRISAT plant material issued in 1986 by the Plant Material Identification Committee (PMIC).

Original name	ICRISAT name	Release name	Justification/Present status	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). Prerelease in India.	86/1
PM 11344	ICSV 197	-	Resistant to sorghum midge (*Contarinia sorghicola*).	86/2
Sorghum hybrid				
CSH 11 (SPH 221)	ICSH 153	CSH 11	Released cultivar in India (1986).	86/3
Pearl millet cultivars/varieties				
WC-C75	ICMV 1	VVC-C75	Released cultivar in India (1982).	84/1
IBV 8001	ICMV 2	-	High-yielding cultivars in prerelease stage in Senegal.	84/2
1BV 8004	ICMV 3	-		84/2
ICMS 7703	ICMV 4	ICMS 7703	Released variety in India (1985).	86/4
ITMV 8001	ICMV 5	ITMV 8001	Released cultivars in Niger (1985).	86/5
ITMV 8002	ICMV 6	ITMV 8002		86/6
ITMV 8304	ICMV 7	ITMV 8304		86/7
Pearl millet male-sterile lines				
81A	ICMA 1	-	New male-sterile lines for the production of new hybrids.	86/8
81B	ICMB 1	-		86/8
843 A	ICMA 2	-		84/3
843 B	ICMB 2	-		84/3
842A	ICMA 3	-		84/3
842 B	ICMB 3	-		84/3
834A	ICMA 4	-		84/3
834 B	ICMB 4	-		84/3
Pearl millet inbred lines				
ICMPE 13-6-27	ICML 1	-	Sources of resistance to ergot (*Claviceps fusiformis*).	84/4
ICMPE 13-6-30	iCML 2	-		84/4
ICMPE 134-6-25	ICML 3	-		84/4
ICMPE 134-6-34	ICML 4	-		84/4

Continued.

Original name	ICRISAT name	Release name	Justification/Present status	Notice
SSC FS 252-S-4	ICML 5		Sources of resistance to smut (*Tolyposporium penicillariae*).	84/5
ICI 7517-S-1	ICML 6	-		84/5
EBS 46-1-2-S-2	ICML 7	-		84/5
EB 112-1-S-1-1	ICML 8	-		84/5
NEP 588-5690-S-8-4	ICML 9	-		84/5
P 489-S-3	ICML 10	-		84/5
IP 2696-1-4	ICML 11	-	Source of resistance to rust (*Puccinia penniseti*) controlled by a single dominant gene.	84/7
P7	ICML 12	-	Sources of resistance to downy mildew (*Sclerospora graminicola*).	84/13
SDN 503	ICML 13	-		84/13
700251	ICML 14	-		84/13
700516	ICML 15	-		84/13
700651	ICML 16	-		84/13
700481-21-8	ICML 17	-	Sources of resistance to rust (*Puccinia penniseti*).	84/14
IP 537 B	ICML 18	-		84/14
IP 11776 (Souna Mali)	ICML 19	-		84/14
IP 2084-1	ICML 20	-		84/14
P 24	ICML 21	-		84/14
D 212-P1	ICML 22	-		84/14
Pearl millet populations (sibs of sister lines)				
ICMPES 1	ICMP 1	-	Sources of combined resistance to ergot (*Claviceps fusiformis*), smut (*Tolyposporium penicillariae*), and downy mildew (*Sclerospora graminicola*).	84/6
ICMPES 2	ICMP 2	-		84/6
ICMPES 28	ICMP 3	-		84/6
ICMPES 32	ICMP 4	-		84/6
Chickpea cultivars/varieties				
ICCC 4	ICCV 1	ICCC 4	Released cultivar in Gujarat State, India (1983).	84/9
ICCL 82001	ICCV 2	-	Combine acceptable kabuli seed type with wilt resistance and short-duration.	84/10
ICCL 83006	ICCV 3	-		84/10
ICCL 83004	ICCV 4	-		84/10
ICCL 83009	ICCV 5	-		84/10
ICCC 32	ICCV 6	-	Prerelease in Central and Northwest Plain Zones of India.	86/11
ICCX 730008-8-1-1P -BP-8EB	ICCV 7	-	Identified by AICPIP as donor parent for *Helothis armigera* resistance.	86/12

Continued

Original name	ICRISAT name	Release name	Justification/ Present status	Notice
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
Pigeonpea male-sterile line				
MS4A	ICPM 1	-	Source of transluscent anther type of genetic male sterile.	84/12
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

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