ICRISAT Annual Report 1988

ICRISAT ANNUAL REPORT 1988

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

1989

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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;

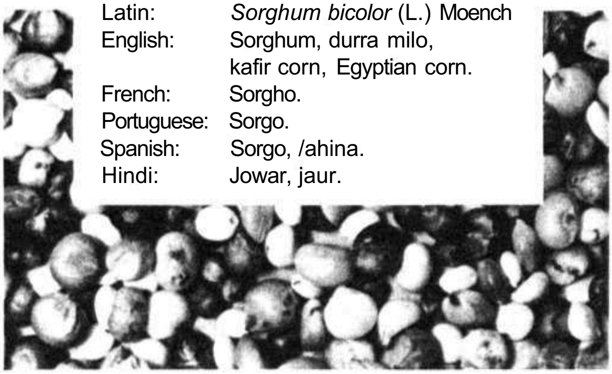
3. Identify constraints to agricultural development in the semi-arid tropics and evaluate means of alleviating them through technological and institutional changes; and

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.

ICRISAT'S FIVE CROPS

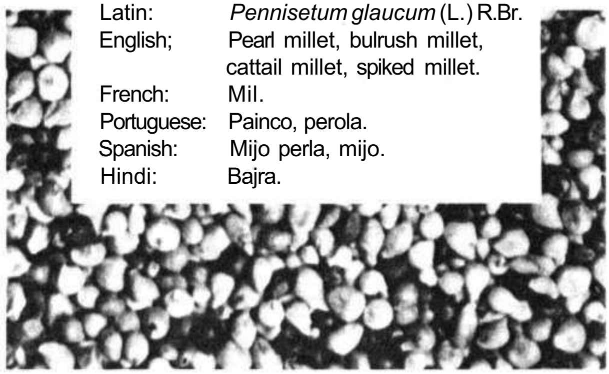
CEREALS

SORGHUM



Latin:	*Sorghum bicolor* (L.) Moench
English:	Sorghum, durra milo, kafir corn, Egyptian corn.
French:	Sorgho.
Portuguese:	Sorgo.
Spanish:	Sorgo, /ahina.
Hindi:	Jowar, jaur.

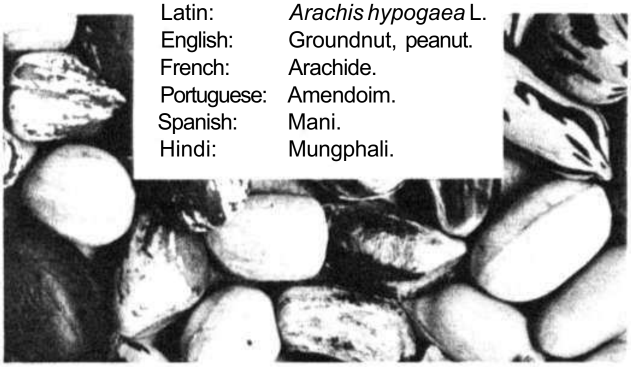
PEARL MILLET



Latin:	*Pennisetum glaucum* (L.) R.Br.
English;	Pearl millet, bulrush millet, cattail millet, spiked millet.
French:	Mil.
Portuguese:	Painco, perola.
Spanish:	Mijo perla, mijo.
Hindi:	Bajra.

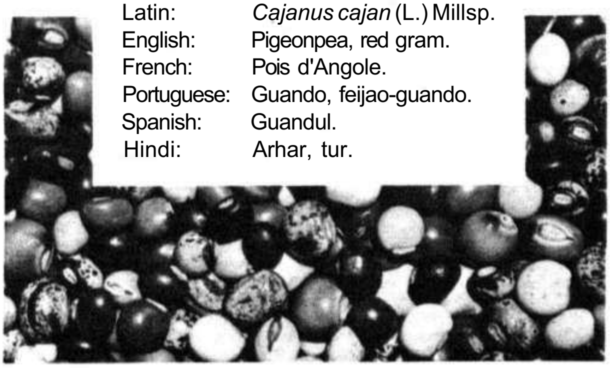
LEGUMES

GROUNDNUT



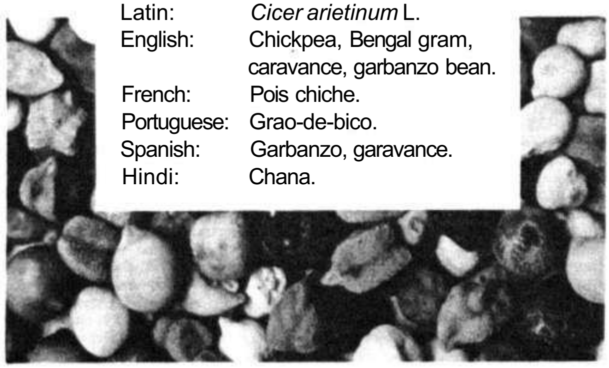
Latin:	*Arachis hypogaea* L.
English:	Groundnut, peanut.
French:	Arachide.
Portuguese:	Amendoim.
Spanish:	Mani.
Hindi:	Mungphali.

PIGEONPEA



Latin:	*Cajanus cajan* (L.) Millsp.
English:	Pigeonpea, red gram.
French:	Pois d'Angole.
Portuguese:	Guando, feijao-guando.
Spanish:	Guandul.
Hindi:	Arhar, tur.

CHICKPEA



Latin:	*Cicer arietinum* L.
English:	Chickpea, Bengal gram, caravance, garbanzo bean.
French:	Pois chiche.
Portuguese:	Grao-de-bico.
Spanish:	Garbanzo, garavance.
Hindi:	Chana.

ABOUT THIS REPORT

This Annual Report covers the 1988 calendar year. It includes work done at 1CRISAT Center near Hyderabad, India, at research stations on the campuses of agricultural universities in different climatic regions of India, and at national and international research facilities in six countries of Africa, and in Mexico, Syria, and Pakistan, where ICRISAT scientists are posted. Pertinent agroclimatic information is presented in the Agroclimatic Environment section.

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

Research by ICRISAT scientists in cooperative programs outside India is reported under relevant crop or discipline headings. Detailed reporting of the extensive activities of ICRISAT's research support units is precluded by the space available in this volume, but comprehensive coverage of ICRISAT's core research programs is given. This year we have added a new section on ICRISAT's activities fulfilling its mandate on technology transfer, which includes human resource development, network activities, workshops, and library, documentation, and information services. Further information about the work reported here is provided in individual program publications, available from the research programs concerned. Offprints of sections of this Report are also available on request from program offices.

ICRISAT uses the 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.

The latin name for the pod borer of legume crops, previously referred to as *Heliothis armigera* (Hubner), has been changed to *Helicoverpa armigera* (Hubner) in this Report and in other ICRISAT publications. (For authority, see Hardwick, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40:1-247.) Also, the latin name of the tree *Acacia albida* is given as *Faidherbia albida* (authority (Del.) A. Chev.), subject to international confirmation of this nomenclature change.

A list of elite ICRISAT plant materials issued by the Institute's Plant Material Identification Committee during 1988 appears at the end of this Report, together with a listing of previously named material that are now in cultivation.

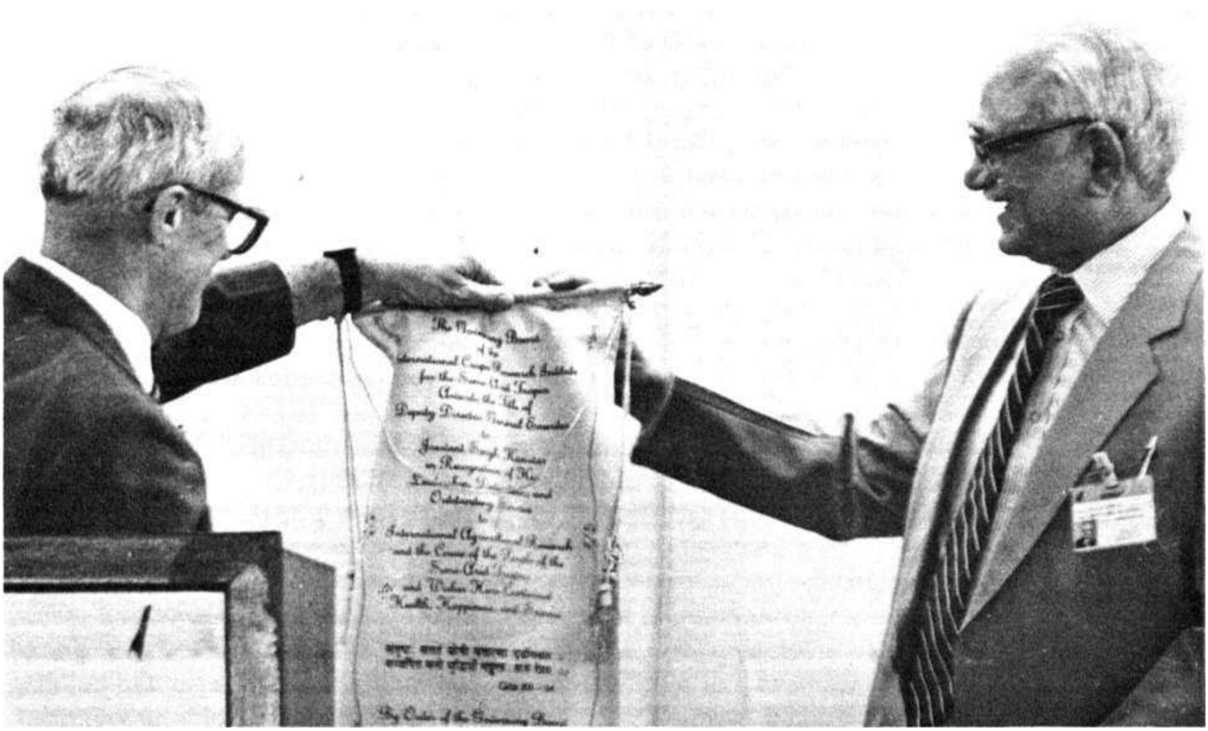
I N T R O D U C T I O N

The year 1988 proved to be eventful for ICRISAT; it was one with good rains in the semi-arid tropics (SAT). In India a spell of several dry years was broken, in southern Africa the rains were generally satisfactory, and in West Africa rains have generally been good. The good rains have allowed the improved technology that had been slowly disseminated to the farmers to be utilized adequately for the first time in the past 4 to 5 years—with excellent results.

This year ICRISAT Center had the privilege to host the 46th Meeting of the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) and a meeting of the Directors of the 13 International Agricultural Research Centers (including ICRISAT). These events brought together the 15 eminent scientists drawn from the developed and the developing world, who together constitute the TAC, with Center Directors, Chairmen of Boards, and donor observers.

Early this year, ICRISAT's Deputy Director General Dr J.S. Kanwar retired after 15 years of distinguished service at the Institute. We are glad that he will continue to be associated with ICRISAT as Deputy Director General Emeritus, an honor bestowed on him by ICRISAT's Governing Board.

Dr Kanwar (right,) *receives a scroll from Dr Swindale honoring him with the title of Deputy Director General Emeritus.*



Burkina Faso operations close

ICRISAT, after many years of fruitful work in Burkina Faso, this year drew its operations there to a close. The Institute's work there had commenced in 1975. ICRISAT established necesssary physical facilities at Kamboinse, near Ouagadougou. By 1979, the ICRISAT team had grown to five multidisciplinary researchers working on sorghum improvement and one millet breeder.

In addition to carrying out research, the ICRISAT team spent considerable time training national agricultural scientists and technicians. These scientists and technicians are contributing significantly to sorghum and millet research in Burkina Faso within the Institut national d'etudes et de recherches agricoles (INERA). The ICRISAT team at Burkina Faso was successful in identifying a dozen very promising sorghum varieties, more than a dozen breeding lines with high levels of resistance to *Striga,* and several millet lines with resistance to downy mildew and ergot, and developed joint agronomic research activities with the national program to stabilize grain production.

In 1984, ICRISAT helped initiate the West African Sorghum Research Network with the support of 17 nations in the region. As the needs of the INERA scientists at Kamboinse for more experimental plots grew, and Kamboise became INERA's main station, it became necessary for ICRISAT's West African Sorghum Improvement Program (WASIP) to seek another location to provide effective technical support to the national agricultural systems in the Network. Since there was no scope for expansion at Kamboinse and no other suitable site was identified in Burkina Faso, it became necessary to look for alternative options in West Africa. It was felt that ICRISAT could best serve the Network member-countries, spread over three agroclimatic zones of the region, by relocating its research scientists in two teams, located at Kano, Nigeria (<900 mm annual rainfall), and Bamako, Mali (>900 mm annual rainfall), instead of operating from one location. These moves were completed in 1988. But ICRISAT continues its cooperative research activities with INERA at the Farako-Ba and Kamboinse research stations. As a token of our cordial working relationship, we left behind for use by INERA staff the laboratory and field equipment brought to Kamboinse for ICRISAT staff, as well as office and laboratory equipment at Farako-Ba.

Food production and crop utilization

As part of our evolving global strategy in food production and crop utilization, we held this year a highly successful international workshop on uses of sorghum and millets at Bulawayo, Zimbabwe, attended by over 50 participants from five continents. Discussions focused on present and potential uses of these crops, including the use of sorghum and millet flours in combination with flour from maize, wheat, and legumes, to make traditional foods, baked products, and special foods (snacks, weaning food, etc.). The importance of animal feed was recognized and exploratory uses of sorghum and millet cellulose to make paper and building board and sweet stem sorghum for production of alcohol were suggested.

Diversification of uses of sorghum and pearl millet can be beneficial to the dryland farmer in India as well. Sorghum productivity in India has grown at the rate of 2.2% since the early 1960s. This may seem low but it exceeds the increase in productivity for rice in India over the same period and in recent years matches that of wheat. Because demand for sorghum in traditional foods is limited, real prices are declining steadily as productivity increases. The use of prepared breakfast foods is likely to increase in India, albeit more slowly than it has in other countries. Sorghum and pearl millet could find a niche in this market just as oats, once used only in porridges and as feed for horses, has made a spectacular comeback in the USA in the last few years. In Burundi, for instance, where the average per capita income is much lower than that of millions of Indians, sorghum is successfully used in commercially produced weaning foods for children. However, the most promising avenue for sorghum and pearl millet in India is as animal feed. Studies have shown a potential for increased small-animal production that will in turn increase the income of small farmers and provide additional employment. Therefore, the possibilities of increased utilization of rainfed cereals grown in the semi-arid tropics can have a substantially positive impact on income-earning prospects and on improvements in nutrition through greater use of animal products, as well as generating rural employment.

Good progress in Zimbabwe

An external evaluation team concluded in its report this year that the SADCC/ICRISAT Regional Program in Zimbabwe "had made excellent progress in addressing most of the objectives anticipated in the project design, and is ahead of schedule and has produced results earlier than expected in a number of areas". This follows a similar positive external evaluation in 1987 of ICRISAT's work in Mali, which is integrated closely with that of the national program there.

In Asia, ICRISAT's Asian Grain Legumes Network (AGLN) evolved beyond the bilateral stage as scientists from national, regional, and international research organizations met in Indonesia to suggest ways to improve groundnut production in the Asian region. Priorities for research were identified and recommendations made for continued research collaboration and increased training of scientists within the region. Similar efforts are on the anvil for chickpea and pigeonpea in the region.

Biotechnology laboratory

Following the recommendations of the biotechnology workshop in 1987, plans are being made to establish a biotechnology laboratory at ICRISAT Center with funds promised by the Asian Development Bank, and to apply biotechnological techniques as some selected ones were found to be of possible immediate use. Work in this area has already begun with two postdoctoral fellows working on virology while another is working on cell biology. The new laboratory will complement the existing work on tissue culture and use of wild species.

Consequent to a meeting in Rome held in 1987, ICRISAT and the University of Milan initiated collaborative research this year. Under the agreement, an Italian scientist was employed at ICRISAT to conduct research that will complement the research on sorghum by scientists at the University of Milan on selection for heat tolerance using molecular markers.

Systems of sustainable agriculture

Although sustainability has been implicit in much that we have always done, explicit attention has been paid to it this year as needs and increasing aspirations of expanding numbers of people compel a more dynamic view. Sustainability and concerns for the environment cover much the same ground. If there is a difference between them it is perhaps that the term 'sustainability' conveys the idea of a balance between human needs and preservation of the environment. The Chairman of the CGIAR has set up a CGIAR working group charged with spelling out the research implications of the CGIAR's decision to approach future programs from a sustainability perspective. The use of high-input agriculture in the developing world is increasing. The International Agricultural Research Centers, however, focus primarily on improving agriculture at a lower level of productivity, using far fewer commercial inputs. Research that emphasizes the recycling of nutrients, the incorporation of crop residues, and the use of intercropping systems—including agroforestry—and the combination of cereals and legumes are contributions to the sustainability of low-input agriculture. So too is the development of crop varieties tolerant of environmental stresses and resistant to existing pests and diseases. Farming systems approaches are used to incorporate these components into systems of sustainable agriculture.

Noting the importance of the issue, the CGIAR decided to consider this year the need to broaden its focus, admit new institutes, and prepare itself dynamically for the future. We hope these changes can be made without adverse impact on the existing CGIAR Centers. Certainly there is need for more emphasis on environment-related research. With this perspective ICRISAT launched its agroforestry program in West Africa in 1987 at the ICRISAT Sahelian Center (ISC) on the effect of neem windbreaks on pearl millet. Expanded work on agroforestry in the Sahel by ICRISAT scientists could help reverse the trend of desertification and contribute substantially to agriculture development in the SAT. At ICRISAT Center, agroforestry experiments with *Leucaena leucocephala,* which began in 1984, showed that this species competed too vigorously with crops in alley-cropping systems. Perennial pigeonpea is proving to be a much more suitable woody species for agroforestry in an environment where rainfall limits productivity.

ICRISAT's suggestions tested and assessed

ICRISAT's suggestions for improved cropping systems were tested and assessed in West Africa and in India. The initial results have been very encouraging. In an operational scale research (OPSCAR) project, ISC in partnership with the Institut national de recherches agronomiques du Niger (INRAN) and, more recently, with Institut d'economie rurale (IER) of Mali—has been testing components and combinations of technologies that researchers hope will have a role in producing more stable and sustainable agriculture in the drier regions of West Africa. A combination of superior treatments was tested for 3 years at the ISC and, in partnership with INRAN, at the INRAN Station at Birni N'Konni in 1987. The trial at Birni N'Konni is being repeated this year and a modified trial is being conducted by IER at the Cinzana Station in northern Mali as well. Also encouraging were results of the groundnut trials conducted by several Indian state Departments of Agriculture and monitored by the Legumes On-Farm Testing and Nursery (LEGOFTEN) Unit in several Indian states during the rainy seasons of 1987 and 1988 and postrainy season of 1987/88. As a result of these trials, the improved cultivation practices include utilization of ICRISAT-developed varieties where they are available. These practices have been widely adopted in the Indian states of Maharashtra, Karnataka, Tamil Nadu, and Orissa. At the request of the Government of India's Ministry of Agriculture, ICRISAT is extending this approach to pigeonpea and chickpea as well.

ICRISAT plant materials reach farmers

This year more ICRISAT plant materials reached farmers. ICRISAT's high-yielding sorghum variety ICSV 112 (SPV 475) was released as CSV 13 by India's Central Sub-committee on Crop Standards, Notification and Release of Varieties for general cultivation in this country. ICRISAT's open-pollinated pearl millet variety ICTP 8203 was identified for release in the Maharashtra and Andhra Pradesh states of India by the All India Coordinated Pearl Millet Project. This variety performs well under drought conditions and has large seeds. Two ICRISAT/ICARDA chickpea varieties, ILC 482 (ICARDA) and ILC 3279 (ICARDA), were released in Algeria. These were also released in Syria under the names Ghab 1 and Ghab 2. ILC 3279, resistant to ascochyta blight and low temperatures, has been released in Tunisia, also as Sultano for winter sowing in Italy, and as Yilousa in Cyprus. Another chickpea variety, ILC 464 (ICARDA), tolerant of ascochyta blight was released under the name Kyrenia in Cyprus. In Nepal, ICRISAT's chickpea ICCV 1 (ICCC 4) was released under the name Sita. A new pigeonpea variety, Quest, selected from a ICRISAT four-way cross, was released in Australia, the third pigeonpea cultivar selected from ICRISAT material to be released there. Another pigeonpea line ICP 9145, resistant to fusarium wilt and having large white seeds, has been released in Malawi by its Agriculture Ministry. India's Central Sub-committee on Crop Standards, Notification Release of Varieties also released the groundnut ICGS 44 (ICGV 87128) for postrainy-season/summer cultivation in Gujarat.

ICRISAT developed human resources in specialized areas by providing long-term training to 172 participants from 86 countries during 1988. Another 52 continue their training into 1989. Courses at ICRISAT Center served special groups such as a group concerned with evaluation of grain and food quality of sorghum and pearl millet, and another from West Africa concerned with pathology. Other such courses were held elsewhere, such as one in Indonesia, where a regional groundnut virology course was held for Asian participants.

Prof Liu Zhicheng (extreme right), *Vice President of the Chinese Academy of Agricultural Sciences, and members of the Chinese delegation he led, view germplasm accessions at ICRISAT Center.*

Apart from progress in research, ICRISAT this year improved its communication capabilities. The East African Regional Sorghum and Millet (EARSAM) network program office in Nairobi obtained access to the CGNET via a dial-up link to London. ICRISAT's West African Sorghum Improvement Program in Mali also joined the CGNET using a dial-up link via USA and later via UK. We also installed new high-speed modems with error-correction and data-compression facilities that will save cost on the increasing volume of messages. Soon ICRISAT locations in Africa will have access to INFONET services in the UK and southern Africa while ICRISAT Center will have access to INDONET's international gateway services, thus improving further the existing electronic messaging facilities.

Many dignitaries visited ICRISAT Center in 1988. Prominent among them were Mr Amarsinh Chaudhary, Chief Minister of Gujarat state, India; Mr Sabeti Yabesi, Deputy Minister of Agriculture, Uganda; Prof Liu Zhicheng, Vice President, Chinese Academy of Agricultural Sciences;
Mr B.G. Deshmukh, Cabinet Secretary, Government of India; and Sir Edmund Hillary, High Commissioner of New Zealand in India.
Mr C. Cundiff, the U.S. Ambassador to Niger, and Mr P.R. Sood, the Indian Ambassador to Niger, were among the important visitors to ISC.

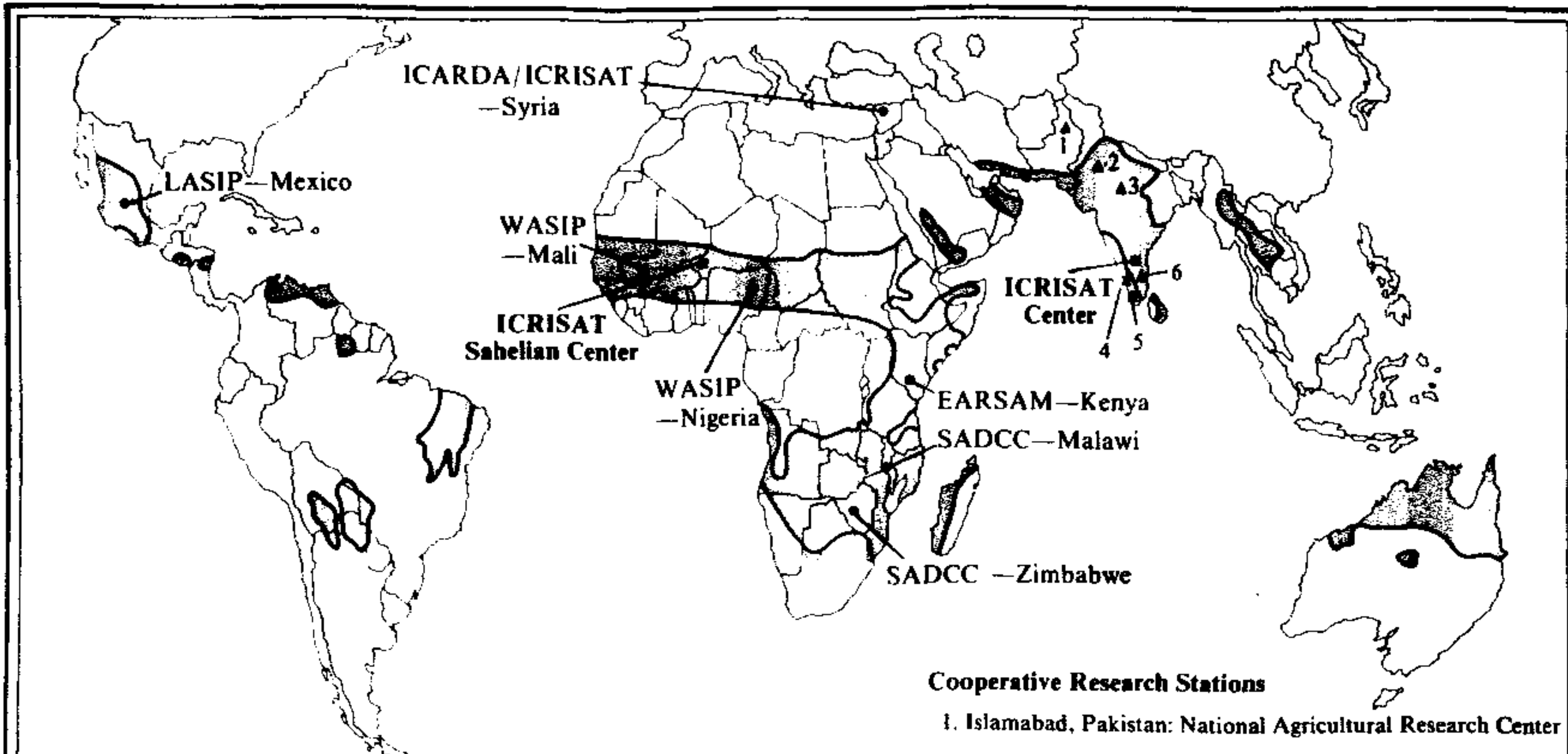
We look forward to the future with renewed strength in our efforts to help the resource-poor farmer gainfully grow more food and feed in the SAT, keeping in view overall environmental concerns.

F.V. MacHardy
Chairman, Governing Board

L.D. Swindale
Director General

AGROCLIMATIC ENVIRONMENT

Locations of ICRISAT Centers, Teams, Network Bases, and Cooperative Research Stations, 1988.



= Semi-Arid Tropics
LASIP = Latin American Sorghum Improvement Program
ICARDA = International Center for Agricultural Research in Dry Areas
WASIP = West African Sorghum Improvement Program
EARSAM = Eastern African Regional Sorghum and Millets network program
SADCC = Southern African Development Coordination Conference

Cooperative Research Stations

1. Islamabad, Pakistan: National Agricultural Research Center

India:

2. Hisar
3. Gwalior
4. Dharwad
5. Bhavanisagar
6. Anantapur

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AGROCLIMATIC ENVIRONMENT

Most of the research covered in this report was done at ICRISAT Center, the Institute's main research facility located near Hyderabad, in India, and at ICRISAT Sahelian Center in Niamey, Niger, with important contributions from ICRISAT scientists posted at cooperative stations in India, in six African countries, and in Mexico, Syria, and Pakistan. Material in this section is intended to serve as a background to our research reports. It presents a brief description of agroclimatic environments and includes monthly rainfall and temperature for most locations observed during 1988.

ICRISAT Center, Patancheru

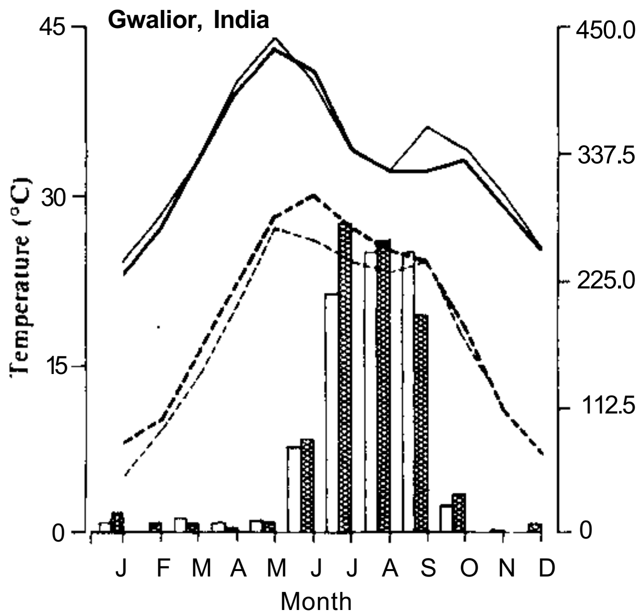
The Institute is located at 18°N, 78°E in Patancheru, 26 km northwest of Hyderabad in Andhra Pradesh. The experimental farm, extending over 1400 ha, includes two major soil types found in the semi-arid tropics (SAT): Alfisols (red soils), which are light and drought-prone, with an available water-holding capacity (AWHC) of 60-100 mm, and Vertisols (black soils), which have an AWHC of 180-230 mm. Access to both soil types provides an opportunity to conduct experimental work on our mandate and other crops under conditions representative of many SAT areas.

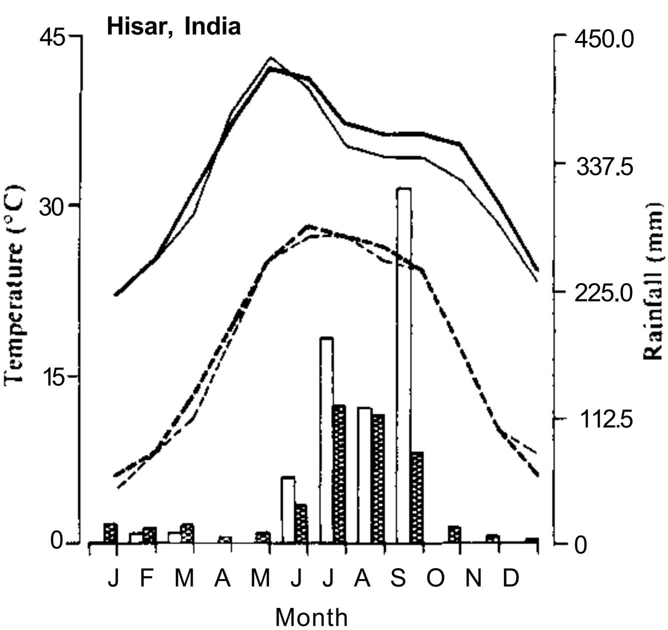
Seasons. Three distinct seasons characterize the Indian SAT. In the Hyderabad area the rainy season, also known as the monsoon or *kharif,* usually begins in June and extends into early October. On an average, more than 80% of the annual rainfall (764 mm) is received in those months, during which rainfed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

Crops. The five ICRISAT crops have different environmental requirements that determine when and where 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 under irrigation in the postrainy and summer seasons. 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 practices, two sorghum crops a year can be grown at the Center, one on Alfisols during the rainy season and the other on Vertisols in the postrainy season. Chickpea, a single-season crop, is grown during the postrainy season on residual moisture in Vertisols. At ICRISAT, as in normal farming practices, intercropping and relay cropping of our mandate crops are common.

Weather. In 1988, annual rainfall at Patancheru was 1027 mm, 31% above average. Rainfall during the rainy season was 34% above average but because October was exceptionally dry, prospects for establishing postrainy season crops were not good. Daily maximum and minimum air temperatures were within ±2°C of the average for all months.

Gwalior (26° N, 78° E, 899 mm rainfall). An area on Inceptisols (AWHC 150 mm), where most of India's long-duration pigeonpea crop is grown. Annual rainfall was 682 mm, 24% below average. Total rain during the rainy season (June-October) was 641 mm, which was 24% below average. Minimum temperatures during the rainy season were 2-4°C below average. Crop performance during the rainy season was good.





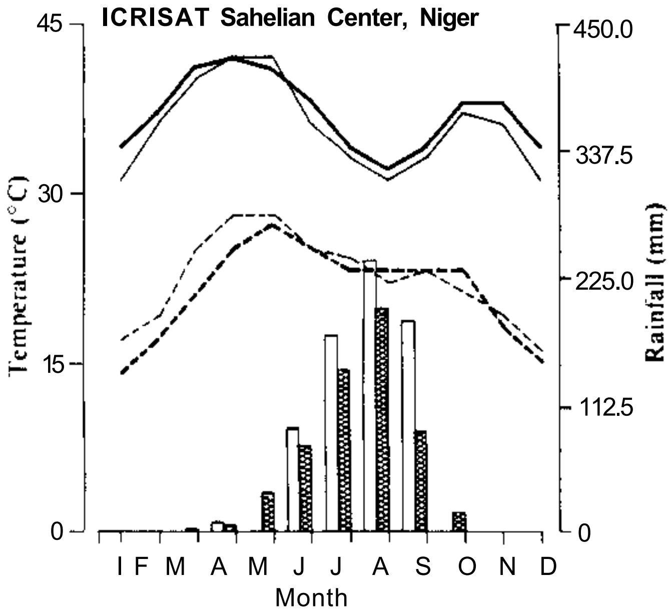
Hisar (29°N, 75°E, 447 mm rainfall). Here chickpea and pearl millet are tested under the climatic conditions in which they are mostly grown, and short-duration pigeonpeas are tested in a region where they are increasingly being grown in rotation with wheat. The soils are Entisols with 150-200 mm AWHC. Annual rainfall was 698 mm, 56% above average. Rainfall during June to September was 672 mm compared with the corresponding average of 351 mm. Daily maximum temperature during July to October was 2-3° C cooler than average. Pearl millet yields were badly affected by waterlogging following heavy rain (270 mm) between 23 and 26 September.

ICRISAT Sahelian Center, Niger

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

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

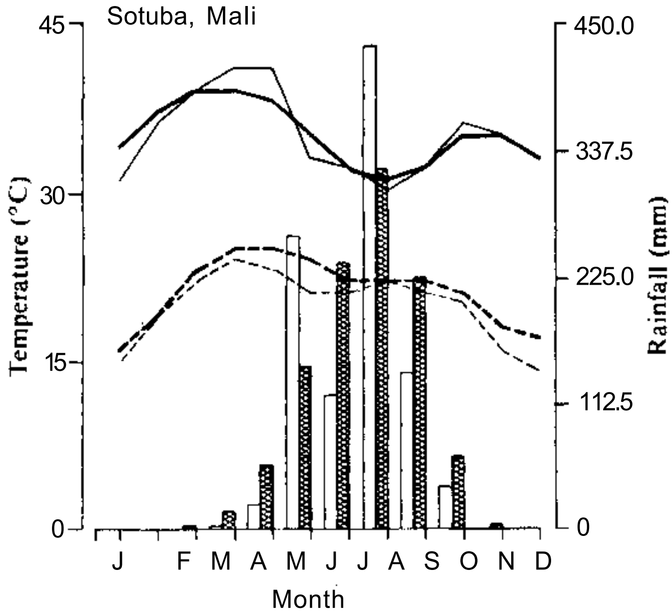
Crops. The main crop grown in the Niamey region is short-duration millet (90-110 days duration), which is sown with the first rains, towards the end of May until the end of June. To advance generations and to help in seed multiplication, an irrigated off-season nursery is grown from January to April.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

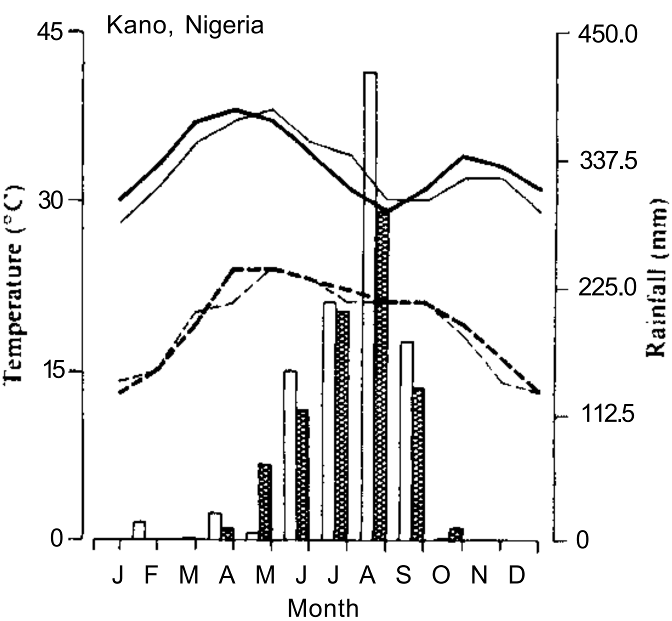


Weather. Annual rainfall at ISC was 700 mm, 23% above average. Rainfall during June to September was 690 mm against the average of 508 mm. Rainy days were frequent and we recorded more rain per day than the long-term average. Frequent rains during the vegetative period of crops increased disease particularly in groundnut and cowpea. Yields were fairly good. Daily maximum and minimum temperatures in January and December were 3° C cooler than average, while daily minimum temperatures from January to April were 3-4°C warmer than the average.

Mali

Sotuba near Bamako(13°N,8°W, 1075 mm rainfall). Here we are evaluating different crops and cropping systems to identify efficient land-use systems for the Sudanian bioclimatic zone. The cropping season extends to about 140 days from May/June to October/November. Sorghum, maize, groundnut, and pearl millet are the major crops. Soils are tropical ferruginous, leached to hydromorphic types (loam and clay loam), with an AWHC of 150-200 mm. Total rainfall in 1988 was 1013 mm, only 6% below average. Rainfall during the growing season (June-October) was 987 mm, which is very close to the average growing-season rainfall (991 mm). The crops yielded well in 1988.





Cinzana (13°N, 6° W, 700 mm rainfall). This is situated 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. Pearl millet, cowpea, groundnut, and sorghum are major crops. Soils are tropical ferruginous, humus-bearing hydromorphic loams, and sandy loams, (AWHC 120 150 mm).

Nigeria

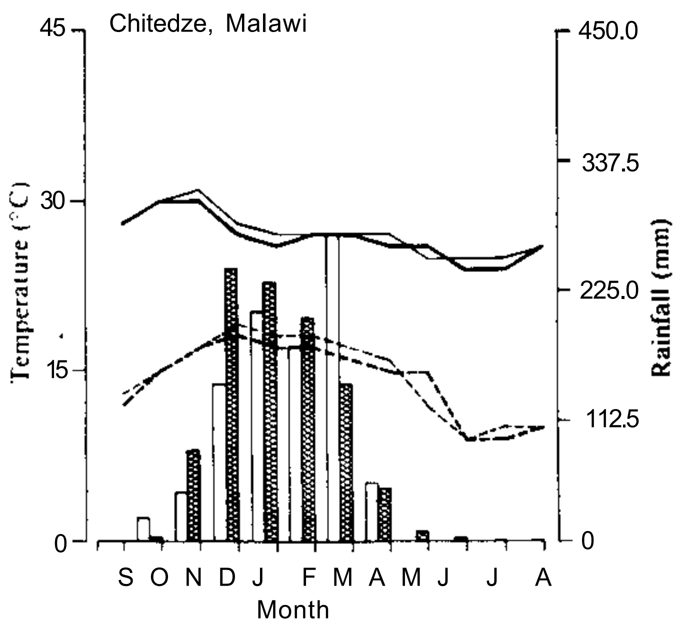
Kano (12°N, 9°E, 832 mm rainfall). Our WASIP base in Nigeria is located here. Annual rainfall was 998 mm, 20% above average. Rainfall during June to October was 951 mm (average 753 mm) and was said to be the highest rainfall recorded in the last 15 years. There was waterlogging during the cropping season, and crops showed symptoms of N deficiency. Weeds, mainly sedges, were a serious problem. The early-maturing varieties were affected by molds due to the high humidity. Daily maximum and minimum air temperatures were within ±2°C of the average for all months except in April when daily minimum temperatures were 3°C cooler than average.

Kenya

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

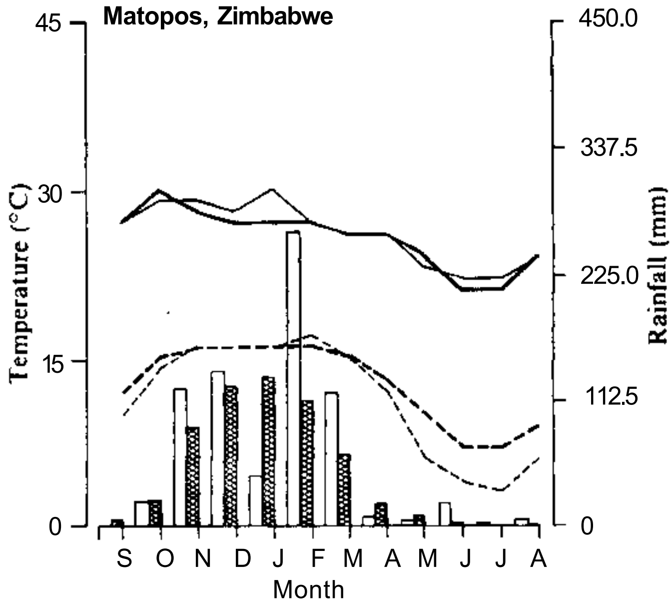
Malawi

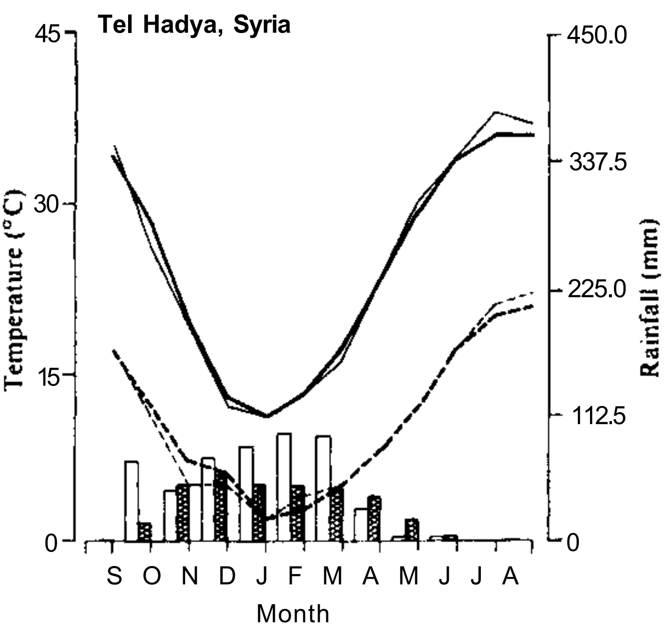
Chitedze (14° S, 34° E, 957 mm rainfall). Our Regional Groundnut Improvement Program for Southern and Eastern Africa is based here. Chitedze, located on the Lilongwe plain, has a tropical continental climate with one rainy season from October/November to March/April. Maize, tobacco, and groundnut are some of the important crops of the area. Annual rainfall during September 1987 to August 1988 was 908 mm, 5% below average. Rainfall during the growing season (November 1987 to April 1988) was 6% below the average (936 mm). Since rainfall at the beginning of the season was erratic and sowing was not possible before the end of the first week in December, yields were poor, particularly for the Virginia groundnut group. Daily minimum air temperature in May was 3°C cooler than the long-term average.



Zimbabwe

Matopos near Bulawayo (20°S, 29°E, 588 mm rainfall). Our cereals improvement program for the nine African countries of the SADCC region is based at Matopos Research Station. Sorghum, millet, maize, and cowpea are important crops in the region. The growing season is from October/November to March/April. Soils range from sandy types with an AWHC of 60 mm, to deep-clay types, with an AWHC of 180 mm. Annual rainfall (September 1987 to August 1988) was 754 mm, 28% above average. Rainfall in January was only 45 mm against the average of 134 mm, while rainfall during February and March was almost double the long-term average. Daily maximum temperature in January was 3°C warmer while daily minimum temperature during May to August was 3-4°C cooler. Crop performance was average to good.





Syria

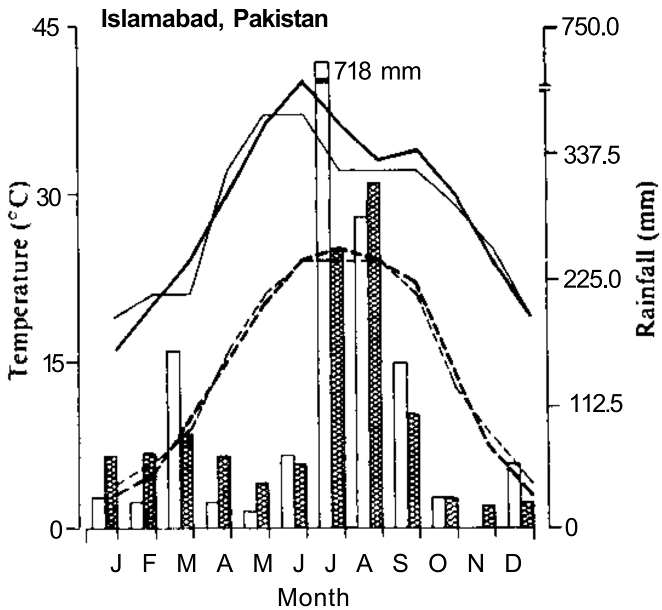
Tel Hadya near Aleppo (36°N, 37° E, 340 mm rainfall). Here our staff work with ICARDA on kabuli-type chickpea for spring or winter sowing in the Mediterranean region, and South and Central America. The crop season is from November to June. Soils are deep red to heavy black (AWHC 80-120 mm). Wheat, barley, chickpea, lentil, and faba bean are the important crops in this region. Rainfall in 1987/88 was 504 mm, 31 % below average. This season we received 50% more rainfall, which benefited the crop. Temperatures were favorable for chickpea production.

Pakistan

Islamabad (34° N, 73°E, 1116 mm rainfall). Here the research emphasis is on developing chickpeas resistant to ascochyta blight. Annual rainfall was 1551 mm, 39% above average. Rainfall from June to October was 1239 mm, 66% above average. July was the month of heaviest rainfall. Maximum temperatures during the rainy months were 1-4°C below average.

Mexico

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



CEREALS
SORGHUM

Contents

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SORGHUM

The objective of sorghum improvement is to develop, in collaboration with the national agricultural research systems (NARS), high-yielding, stable cultivars that have resistance to important pests and diseases, increased resistance to drought, and that are acceptable to consumers. Research is conducted by multidisciplinary teams of scientists located in Asia at ICRISAT Center (India), West Africa at Bamako (Mali) and Kano (Nigeria), eastern Africa at Nairobi (Kenya), southern Africa at Bulawayo (Zimbabwe), and Latin America at E1 Batan (Mexico). This decentralization of research is essential for the development of cultivars and technology for the diverse agroecological environments in which sorghum is grown.

Newly developed cultivars are widely distributed and tested in a network of multilocational trials in close collaboration with NARS. This year, through this network, two varieties were formally released for farmer use in India—one variety in Ecuador and one hybrid in E1 Salvador. A new unit, Cooperative Cereals Research Network (CCRN), was established at ICRISAT Center to coordinate and strengthen this network. CCRN will also assist NARS in on-farm testing of improved cultivars.

This report contains highlights of research conducted at ICRISAT Center and regional programs.

Physical Stresses

ICRISAT Center

Drought

The Role of Heat Shock Proteins in Seedling Heat Stress

We studied the production of heat shock proteins (HSPs) in sorghum genotypes with contrasting reaction to heat stress. Seed of IS 17820 and IS 23077, resistant to heat stress, and IS 83 and IS 14960, susceptible to heat stress, were grown at 35°C for 40 h. Seedlings of each genotype were given a heat shock by incubating at 45° C for 2 h in the presence of ^{35}S-methionine while the controls were kept at 35°C for 2 h. The seedlings were then homogenized in a buffer and centrifuged to obtain soluble proteins. These proteins were separated by electrophoresis and flurograms were developed. The major HSPs of molecular weights 65 and 62 kD were seen in all the genotypes tested. The pattern was similar when 24-, 48- or 72-h-old seedlings were tested. In contrast, heat-stress resistant pearl millet genotypes IP 14000 and IP 14085, and heat-stress susceptible genotypes IP 3120 and IP 3374 showed a higher number of HSPs (from 32 to 80 kD) under identical conditions. The significance of these differences between sorghum and pearl millet, and the role of HSPs in pearl millet are under investigation.

Factors Affecting Lodging Resistance in Terminal Drought

We previously reported the difference in lodging between two cultivars, CSH 6 being susceptible to, and E 36-1 being resistant to lodging (ICRISAT Annual Report 1984, p. 25). To better understand mechanisms of resistance to terminal drought stress and lodging, we compared these two cultivars for their patterns of growth and partitioning of recently formed photoassimilates (current assimilates) during the reproductive phase. The cultivars were grown during the 1987 postrainy season with adequate nutrients but without irrigation.

The grain yield of CSH 6 was 414 g m^{-2} (SE ± 61) and that of E 36-1 was 396 g m^{-2} (SE ± 61). However the harvest indices were different—40% for CSH 6, and 29% for E 36-1 (P= 0.10). In

CSH 6, a substantial part of the grain mass was obtained by remobilization of preanthesis reserves, as the biomass produced by the crop between anthesis and physiological maturity was lower ($P = 0.18$) than the mass needed to fill its grains. Conversely, E 36-1 relied primarily on current assimilates for grain filling.

We examined the partitioning of current assimilates into plant parts at different stages of panicle development. The penultimate leaf was exposed to $^{14}CO_2$ at mid-day during stages of reproductive growth from the boot to the late hard-dough growth stages. The labeled plants were harvested 48 h after feeding $^{14}CO_2$, and at physiological maturity. The radioactivity present in different plant parts was then determined. The results showed that 48 h after labeling, leaves of CSH 6 exported a greater proportion of the current assimilates to the panicles than E 36-1, especially during rapid grain-filling phase. For example, at 10 and 28 days after flowering (DAF), CSH 6 exported about 75% of the current assimilates to the panicle, whereas E 36-1 exported about 25%. The trend in accumulation of assimilates in the stem was the reverse. E 36-1 accumulated almost double the amount in its stem than CSH 6 during grain filling. Similar genotypic differences with respect to ^{14}C distribution were also observed when plants were analyzed at physiological maturity. These results suggest that in E 36-1, a greater proportion of current assimilates are first held in the stem, and gradually translocated to the developing grain, compared to CSH 6. This pattern of assimilate distribution in E 36-1 may be one of the factors that contribute to its lodging resistance.

Latin America

Low Temperature

The most consistent physical stress in the highlands of Mexico is low temperature. At E1 Batan Experiment Station (elevation 2240 m, 19° 31'N, 98° 50'W), an early first frost on 10 September effectively eliminated many of the later-maturing progenies from our nurseries and trials. A trial of 20 agronomically elite, cold-tolerant varieties at three highland sites (Tlayacapan, 1800 m; Las Trancas, 2240 m; Carretero, 2240 m) further demonstrated the importance of early maturity at the two higher-elevation sites, where accumulation of growing degree days was slower and early frost reduced the length of the growing season. An Eberhart and Russel stability analysis of this trial showed selections from the early-maturing varieties Valles Altos 110 and BTP 28 to have stable performance and high average grain yield (4.10 t ha^{-1}, SE ±0.60) across sites. Later-maturing varieties had lower yields (1.90-2.10 t ha^{-1}, SE ±0.60) and generally responded better at a lower- than at a higher-elevation, longer-growing season site, but were often inconsistent in their behavior. Early frost at the two higher-elevation sites prevented the later-maturing varieties from completing grain fill, resulting in a grain yield of 0.0-1.70 t ha^{-1} compared with 1.10-4.70 t ha^{-1} for the early-maturing selections from Valles Altos 110 and BTP 28. These experiments indicate that high and stable sorghum grain yields for the Mexican highlands will require early-maturing, cold-tolerant cultivars.

Biotic Stresses

Diseases

ICRISAT Center

Breeding for Resistance to Grain Mold

In two advanced screening trials, we evaluated 79 breeding lines identified with low susceptibility during the last 2 years. The test entries consisted of 42 advanced breeding lines derived from crosses (resistant x susceptible) involving colored-grain, mold-resistant sources and white-grain, mold-susceptible lines with high yield. The other 37 advanced breeding lines were derived from crosses (resistant x resistant) involving colored-grain, mold-resistant sources and white-grain, mold-resistant breeding derivatives. The postflowering period was favorable for grain mold development and all the entries that flowered before the end of August (70 days to 50% flowering) experienced severe grain mold pressure. We selected 35 entries (10 were from resistant x susceptible crosses and 25 were from resistant x resistant crosses) with threshed grain mold rating (TGMR) of 3 or less on a 1-5 rating scale, where 1 = no mold and 5 = more than 50% grain surface area molded.

We continued the conversion of tall mold-resistant breeding lines with lax panicles into dwarf lines with semi-compact panicles and other desirable agronomic traits (ICRISAT Annual Report 1987, p. 32). We evaluated 602 F_3 and F_4 progenies and made 100 white-grain, single plant selections less than 2.5 m-tall, with semi-loose panicles, and TGMR of up to 3. To improve the mold resistance level in the breeding lines, we made multiple crosses, using male-sterile ms_3 gene, of mold-resistant breeding derivatives and resistant germplasm sources from 1984 to 1986. From this material, we screened F_2 progenies (involving 19 mold-resistant germplasm source lines) and selected 144 single plants that combined mold resistance with desired agronomic traits. Another 343 F_3 and F_4 progenies were also screened and 28 single plants were selected for further testing.

Ergot (*Sphacelia sorghi*)

Infection and colonization of florets, and spore production. We investigated the process of infection and colonization of sorghum florets by *S. sorghi.* Artificially inoculated pistils were collected from panicles of field-grown male-sterile line 296A at 12-24-h intervals up to 12 days after inoculation, and observed using standard histopathological techniques (ICRISAT Annual Report 1985, pp. 36-37) and the scanning electron microscope. Macroconidia germinated on the stigma within 12 h after inoculation, producing 1-4 germ tubes. Infection hyphae penetrated the stigmatic hairs and grew intercellulary through the stigmatic papillae and stigmatic rachis, and then through the transmitting cells of the style down to the ovary, where the hyphae grew through the inner and outer integument cell layers and reached the vascular bundles in the rachilla within 3 days after inoculation. Within the next 2 days, the fungus quickly colonized the ovary wall and the integuments, intercellularly at first and then destroyed the cells, to form a white stroma that replaced the ovary. Conidiogenous locules formed in the interior of the stroma by involulated fungal growth of hyphal bundles that formed the stroma. Macroconidia were produced on short conidiophores in these locules and on the surface of the stroma. Macroconidia were released in sweet, sticky honeydew, exuded 5-8 days after inoculation. The fungus destroyed all the tissues of the ovary, except the vascular bundles in the rachilla, essential for nutrient transport to support the stroma and honeydew production.

We also found, contrary to the situation in pearl millet ergot, that fertilized ovaries were colonized by *S. sorghi,* i.e., pollination did not exclude the fungus from infecting developing grain. Infected grain had a white fungal stroma at the base, and honeydew oozed from the stroma. Thin sections of infected developing grain showed fungal hyphae in a well-differentiated pericarp, aluerone layer, embryo, and endosperm.

We investigated the production of secondary conidia by Indian isolates of the pathogen. Freshly formed honeydew appeared as tiny, clear, shiny drops that increased in size and became cloudy as innumerable macroconidia were released in the honeydew. Later, at 15-28°C and over 90% humidity, the surface of the honeydew became firm and a whitish growth appeared. Microscopic examination of the surface revealed that the firmness of the honeydew was due to a fungal mat formed by intertwining germ tubes originating from germinated macroconidia on the surface of the honeydew. Some macroconidia in the mat germinated by producing erect conidiophores on which pear-shaped secondary conidia were produced outside the honeydew surface.

We also discovered in the honeydew, small (3 x 4 µm diameter), round to obovate microconidia. All the three conidial forms (macroconidia, secondary conidia, and microconidia) produced by the ergot fungus infected the stigmas of the male-sterile line 296A when artificially inoculated.

Sorghum Viruses in India

The two main types of virus symptoms observed on sorghum in the area around Hyderabad are chlorotic lines with interveinal streaks and chlorotic bands. These symptoms have been described for more than 50 years in India but their causal agents had never been identified. We identified a rhabdovirus, similar to maize mosaic virus, from sorghum with the first type of symptoms. The virus was transmitted by the plant hopper *Peregrinus maidis.* Its infection rate on maize was very low compared to that on sorghum. Pearl millet was not a host of this rhabdovirus.

We also identified, by serology, a virus related to the maize stripe virus found in Reunion Island as the cause of the chlorotic bands. A nucleoprotein was extracted from infected leaf material. Although more than three bands were observed in sucrose gradient, only one protein could be analyzed by polyacrylamide gel electrophoresis (PAGE). The virus was transmitted by *P. maidis* in greenhouse tests 15 days after acquisition on an infected plant. The best transmission rate, about 30%, was obtained when the last instar larvae or young adults were used for acquisition.

West Africa

Grey Leaf Spot (*Cercospora sorghi*)

We previously reported that symptoms of grey leaf spot first appeared on the top four leaves, several DAF, and that the disease progressed slowly and became severe towards grain maturity (ICRISAT Annual Report 1987, pp. 33-34). We obtained similar results at the same location (Niangoloko, Burkina Faso) this year. In order to further confirm our previous observations, we monitored the development of grey leaf spot in 10 plants from each of 12 genotypes known to have varying reactions to the disease. The genotypes were grown at Farako-Ba (Burkina Faso) in a randomized-block design (RBD) with three replications and a plot size of two rows 4-m long. At the end of 5 weeks of observations, 9 out of the 12 genotypes had disease severity ratings (DSR) between 3.2 and 6 on a 1-6 scale, where 1 = no symptoms and 6 = more than 75% leaf area infected (LAI). Symptoms first appeared 3-7 DAF in the nine genotypes. At the 4th week of observation, when all nine genotypes were between 28 and 37 DAF, only two had a DSR of more than 5.0. Thus, under natural infection conditions, grey leaf spot was severe (> 50% LAI) in the top four leaves of the most susceptible genotypes only when grains were approaching maturity. We intend to follow the implications of this with regard to the effect of grey leaf spot on grain yield.

Southern Africa

Screening for Resistance to Downy Mildew (*Peronosclerospora sorghi*)

In the downy mildew nurseries at Golden Valley, Zambia, and Matopos, Zimbabwe, several released varieties were resistant, e.g., ICSV 2 (ZSV 1) from Zambia, ICSV 112 (SV 1) from Zimbabwe, and Sandala from Tanzania. All tested local varieties from Botswana and Lesotho were susceptible. Fifty-nine percent of the 930 entries with resistance at Matopos were susceptible at Golden Valley. Some entries with resistance in India, such as IS 1331, IS 7179, IS 8065, IS 8276, IS 8864, IS 8906, IS 10710, IS 10244, and IS 24941, and in the USA, such as RTx430, 82 BDM 499, and SC 414-12E were susceptible in Zimbabwe. These results indicate that the downy mildew pathogen population at Golden Valley may be more virulent than that at Matopos or in India.

Anthracnose (*Colletotrichum sublineolum*)

We started collaboration with the Zambian national program to screen sorghum for resistance to anthracnose at Mansa, a hot spot for this disease. Out of 347 lines (303 from ICRISAT Center, 9 from the Southern African Development Coordination Conference (SADCC)/ ICRISAT program, and 35 from the Zambian program) only 22 from ICRISAT Center and one from the Zambian program were resistant. Among the resistant selections from ICRISAT Center were four lines (IS 3547, IS 8283, A-2443-1, and PH 2911), previously identified as resistant in 3-5 years of testing in India. The sorghum line IS 18442 (H 112), which is used as a susceptible control in India, was highly resistant at Mansa. This result supports the need for extensive multilocational testing in order to identify stable resistance to anthracnose, which is known to be pathogenically highly variable.

Insect Pests

ICRISAT Center

Shoot Fly (*Atherigona soccata*)

Insect-host plant interaction. Our initial studies on the role of leaf surface wetness (LSW) in shoot fly behavior (ICRISAT Annual Report 1987, pp. 39-40) led us to measure leaf wetness in the whorl leaves of 44 sorghum lines consisting of shoot-fly resistant sources, breeding lines, and susceptible controls. We observed that leaf wetness score (LWS) was generally low (<2, thin film of moisture on leaf surfaces) in resistant lines, e.g., IS 2146 and IS 18551, but high (>4, leaves densely covered with water droplets) in susceptible lines, e.g., IS 1046, IS 2193, and CSH 1 (Fig. 1). This may explain the difference, reported in 1987, between resistant and susceptible lines in relation to the speed of larval movement towards the growing point.

We also investigated the relationship between glossy leaf character and leaf wetness and found that the LWS was very low in glossy resistant lines but high in glossy susceptible lines. All the nonglossy genotypes evaluated were susceptible and had high LWS except IS 1034, IS 1057, IS 4224, IS 5072, and IS 5511.

Stem Borer (*Chilo partellus*)

Resistance screening method. The established method of artificially infesting sorghum plants in the field with larvae of *C. partellus* for resistance screening is consistent and reliable, but it requires several crop seasons and resources to evaluate large numbers of plants. We therefore developed a rapid screening method in which 5-day-old seedlings, sown in trays or in field microplots, were evaluated under artificial infestation. By modifying the "bazooka" applicator (ICRISAT Annual Report 1982, p. 23), the rapid method required 250 *C. partellus* egg masses in 15 g of carrier to infest 1000 plants, compared with 500 egg masses and 80 g of carrier for 1000 plants under field-screening conditions. Observations on leaf feeding damage and incidence of deadhearts were carried out at 7 and 14 days after infestation and the screening process was completed within 4 weeks of planting. Results obtained were comparable with those from field screening. Although recovery resistance is difficult to evaluate by this method, highly susceptible entries can be identified and discarded, initial plot requirements are drastically reduced, and large collections can easily be evaluated over a short period of time throughout the year.

Ovipositional preference/nonpreference and leaf feeding damage. We studied ovipositional preferences of C. *partellus* moths under field cages using 1-6-week-old resistant and susceptible genotypes. Four-week-old plants received the maximum number of egg masses while younger seedlings (1-3 weeks old) were least preferred. This trend was maintained on both resistant and susceptible genotypes tested.

We also investigated larval leaf feeding preferences on susceptible genotype ICSV I (CSV 11) and resistant genotypes IS 2205 and ICSV 700 at 16, 23, 30, and 37 days after emergence (DAE) using first instar larval densities of 2,4,8, and 16.

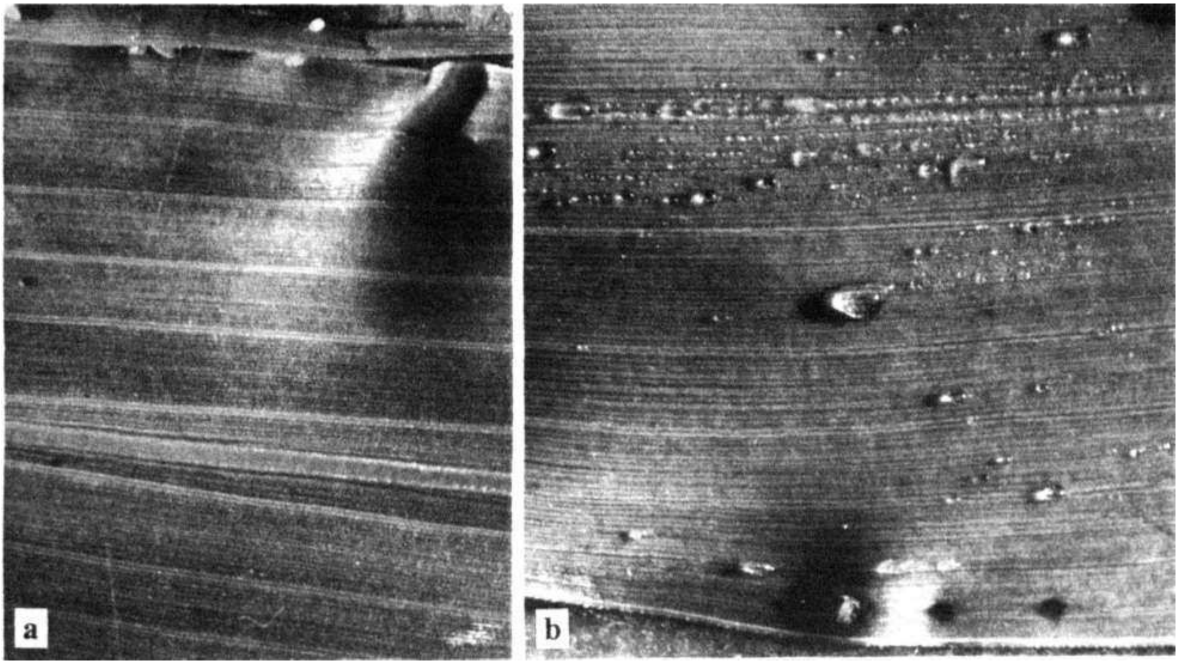

Figure 1. Leaf surface wetness (LSH) of central shoot leaves of 10-day-old sorghum seedlings; (a) 18551, glossr resistant and (b) CSH 1, nonglossy susceptible.

Leaf area damaged was significantly higher ($P = 0.01$) in ICSV 1 (CSV 11) at each infestation stage. Total leaf feeding per plant ranged from 27 mm^2 with 2 larvae per plant at 4 days after infestation, and 1337 mm^2 with 16 larvae per plant at 8 days after infestation.

Resistance screening. We evaluated 355 breeding lines for resistance. Over 60% of the lines selected under artificial infestation at ICRISAT Center did not correspond with those selected under natural infestation at Hisar. This implies that the resistance mechanisms operating under these two infestation conditions are different and require further investigation.

Midge (*Contarinia sorghicola*)

Sex pheromones. We investigated the presence of sex pheromones in midge females by using plastic sticky traps baited with midge females. Plastic containers (perforated with 5-mm holes) and smeared with Tanglefoot® were placed at a height of 1.5 m in the field. Five midge females, collected at 0800 from emergence cages, were placed in a perforated glass vial, which was placed inside the sticky trap. There were five replications. Five traps without females were maintained as controls. We recorded 30 males per trap in 5 days in midge-baited traps and 5 males per trap in 5 days in the control traps in March. In November, we recorded 12 males per trap in 5 days in the midge-baited traps and none in 5 days in the control traps.

Breeding for resistance. We evaluated 186 advanced midge-resistant breeding lines for yield at ICRISAT Center and for midge resistance at Dharwad. The highest-yielding lines were 1CSV 745 (3.53 t ha^{-1}), ICSV 747 (3.76 t ha^{-1}), [CSV 743 (3.76 t ha^{-1}), ICSV 88013 (3.79 t ha^{-1}), 1CSV 88014 (3.59 t ha^{-1}), ICSV 843 (3.67 t ha^{-1}), and ICSV 88032 (3.65 t ha^{-1}) (SE ± 0.12).

We produced 202 hybrids using midge-resistant and midge-susceptible female parents and midge-resistant male parents, and evaluated them for yield at ICRISAT Center and for midge resistance at Dharwad. We observed that the hybrids developed from midge-resistant female and male parents were more resistant to midge than those developed on susceptible female parents. We selected three hybrids (ICSH 88065, ICSH 88099, and ICSH 88100) with <10% chaffy florets compared with >90% in the control hybrid CSH 1.

Head Bug (*Calocoris angustatus*)

Biology. We studied the development of C. *angustatus* under laboratory conditions (30°C day temperature, 25°C night temperature, and about 80% relative humidity). Five nymphal stages were observed with a total developmental period of 8-10 days. Nymphal mortality was highest (15.3%) in the first instar. A 1:1 male to female ratio was recorded but there was no difference in the development of males and females. Adult longevity differed between the sexes: 12.1 days for males, 10 days for mated females, and 6.9 days for unmated females.

Mating occurred soon after adult emergence and lasted for 1-15 min and was characterized by crepuscular peaks. There was a 2 3-day preoviposition period. Females laid an average of 227 eggs (range of 99 404). Two oviposition peaks occurred, the first on the 2nd day (26 eggs) and the second between the 9th and 13th day (30 eggs).

Grain yield loss and economic injury level. We studied the economic injury levels for head bugs on cultivars CSH 1, ICSV 1 (CSV 11), and CSH 5 under artificial infestation. Maximum grain yield losses were recorded in ICSV 1 (CSV 11) (88.7%)), followed by CSH 1 (70.1%), and CSH 5 (54% in 1986 and 55.2% in 1987). Economic injury levels were 1.3-1.4 insects per panicle for CSH 1, 0.4-0.6 insects per panicle for ICSV 1 (CSV 11), and 0.2-0.6 insects per panicle for CSH 5.

Resistance screening. In the multilocational head bug nursery, 44 lines were tested under natural and artificial infestation in head cages, and 33 of these showed moderate resistance to head bugs (damage rating <5 compared with 9 in the control hybrid cultivar CSH 5).

West Africa

Breeding for Resistance to Midge (*Contarinia sorghicola*)

In 1985, we made several crosses to transfer midge resistance from ICSV 197 to high-yielding varieties adapted to West African conditions. This year we screened 50 F_6 progenies at Farako-Ba (Burkina Faso) under natural midge infestation. Midge infestation was very high (over 200 midges per panicle), and two progenies, 87 W 705 and 87 W 728, had damage scores of <5.0 on a 1-9 scale (where 1 = up to 10% chaffy florets and 9 = over 80% chaffy florets) compared with a score of 8 for the susceptible control cultivar ICSV 1001 BF(Framida).

Southern Africa

Stem Borer (*Chilo partellus*)

Grain yield loss assessment. Grain yield loss in two cultivars (a landrace variety Segaolane and a hybrid Red Swazi) caused by *C. partellus* was studied in trials conducted at the high- (Gwebe), middle- (Panmure), and low-veld (Mzarabani) research stations in Zimbabwe, and in a farmer's field at Chitedze, Malawi. Although natural occurring stem borer populations were low (20-30% plants infested), the trial results showed that early infestation (15-25 DAE) caused 60-70% of the yield loss.

Resistance screening. At Matopos, Zimbabwe, under artificial infestation conditions, we screened F_3, F_4, and F_5 SADCC/ICRISAT breeding lines together with the International Sorghum Shoot Fly Nursery (ISSFN) and other germplasm from various sources in the SADCC region. Out of the 1440 lines screened, we selected 226 lines with less than 50% deadhearts for further testing.

The SADCC/ICRISAT Sorghum Shoot Pest Nursery comprising 42 breeding lines from the sorghum shoot pest breeding program at ICRISAT Center and the Zimbabwe national program were tested in Tanzania, Malawi, Zambia, and Zimbabwe. A total of 22 lines were selected at Matopos (Zimbabwe), 12 at Golden Valley (Zambia), and 17 at Ngabu (Malawi) for further testing. In the International Sorghum Stem Borer Nursery (ISSBN) grown at Kasinthula (Malawi), Hombolo (Tanzania), Golden Valley (Zambia), and Aisleby (Zimbabwe), the lines PS 10723, IS 20643, IS 18584, and IS 18585 at Kasinthula, and IS 48573, IS 5571, and PB 10445 at Golden Valley had less than 50% plants infested and less than 50% dead hearts and were selected for further testing.

Grain Weevil (*Sitophilus* spp)

Postharvest losses due to storage insect pests are a serious problem in the SADCC region. *SitophUus oryzae* and *S. zeamais* are the predominant species found in rural storage bins. We developed a method for screening breeding material and germplasm for resistance: 10 g grain samples were infested with 30 unsexed weevils for 7 days at <70% relative humidity and 27°C. Thereafter, when eggs had been laid, all weevils were removed, and 27 days after infestation, samples were checked for 8 days for the presence of adult weevils. Out of 155 sorghum lines previously selected as resistant, 9 lines with <50% infestation were selected for further testing.

Plant Improvement

ICRISAT Center

Evaluation of Advanced Elite Varieties

We evaluated 33 advanced varieties in two separate trials, based on number of days to reach 50% flowering, at ICRISAT Center, Dharwad, and Bhavanisagar. Among the varieties that took <70 days to flower, we selected ICSV 233 with a grain yield of 4.38 t ha^{-1}, ICSV 210 with 3.74 t ha^{-1}, and ICSV 202 with 3.54 t ha^{-1} compared with 3.22 t ha^{-1} (SE ± 0.11) of the control variety, ICSV 1 (CSV 11). The trial mean was 2.72 t ha^{-1}. Among the varieties that took more than 70 days to flower, none produced grain yields higher than the control variety, ICSV 112 (SV 1) (3.78 t ha^{-1}).

Evaluation of Female Parents (Male Steriles) for Hybrids

We evaluated 22 newly developed male-sterile lines in two separate male-sterile x restorer (R) line trials, each with a different set of 4 R-lines, and selected 7 male-sterile lines (ICSA 82, ICSA 83, ICSA 84, ICSA 85, ICSA 92, ICSA 95, and ICSA 102) and two R-lines (ICSR 166 and ICSA 172) to make hybrids for the postrainy season in India. The selection was based on high general combining ability (GCA) for grain yield, threshability, plant height, and nonsenescence. The lines ICSA 82 and ICSA 84 were selected also for their earliness.

For the rainy season, we evaluated 15 lines for yield at three locations (ICRISAT Center, Dharwad, and Bhavanisagar). The control B-line 296B was highly susceptible to leaf blight and rust at Dharwad. We selected 10 B-lines that were resistant to these two diseases. The selected B-lines varied in flowering (65-72 days to 50% flowering), plant height (1.2-1.9 m), and grain yield (2.54-4.58 t ha^{-1}), while the control B-line, 296B took 71 days to 50% flowering, grew to a height of 1.2 m, and produced a grain yield of 2.78 t ha^{-1}.

A new set of 29 R-lines were also evaluated at the same locations and eight were selected for further yield testing. The selected lines varied for time to 50% flowering (67-76 days), plant height (1.6-2.2 m), and grain yield (2.32-4.14 t ha^{-1}), while the control R-line, CSV 4 took 71 days to 50% flowering, grew to a height of 1.5 m, and produced a grain yield of 1.30 t ha^{-1}.

Hybrid Evaluation

The 1987 advanced hybrid and variety trial for the postrainy season in India consisted of 35 hybrids and 23 varieties, and was conducted in a 8 x 8 triple lattice design at ICRISAT Center, Bijapur, and Nandyal. We selected 12 hybrids based on grain yield, seed size, and nonsenescence, for further testing. Grain yield of the selected hybrids ranged from 2.44 to 3.04 t ha^{-1} (SE± 0.18-0.32) compared with 2.08 t ha"^{1} for the commercial control, postrainy season hybrid, CSH 12R.

For the rainy season, we evaluated 20 early-maturing (< 100 days) and 22 medium-maturing (100-120 days) advanced hybrids in two separate trials at ICRISAT Center, Dharwad, and Bhavanisagar. We selected, from the early group, four hybrids (1CSH 401, ICSH 780, ICSH 798, and ICSH 444) that varied in plant height (1.9-2.3 m) and time to 50% flowering (61-64 days), and had grain yields of 4.58-4.65 t ha^{-1} (SE ± 0.12) compared with 3.37 t ha^{-1} of the control commercial hybrid CSH 6. The selected hybrids have male and female parents developed at ICRISAT Center.

From the medium-maturity group we selected five hybrids (ICSH 793, ICSH 807, ICSH 310, ICSH 566, and ICSH 205), which varied in plant height (1.7-2.5 m) and time to 50% flowering (66-67 days) and had grain yields of 4.31-4.71 t ha^{-1} (SE ±0.16) compared with 4.76 t ha^{-1} of the control hybrid ICSH 153 (CSH 11) (female parent 296A). These hybrids have new male and female parents developed at ICRISAT Center.

West Africa

Hybrid Evaluation

We evaluated 18 advanced hybrids in replicated yield trials at Bagauda farm near Kano, Nigeria. These hybrids were produced using seven male-sterile lines chosen for their superior performance and disease resistance in West Africa during the last 3 years (ICRISAT Annual Report 1987, p. 56). In the advanced hybrid trial, ICSH 507 gave the highest grain yield of 3.99 t ha^{-1}, followed by ICSH 780 (3.89 t ha^{-1}) while the local variety control Samsorg 17 (SK 5912) gave 1.41 t ha^{-1} (SE ±0.41).

Southern Africa

Variety Trials

We determined the performance of all existing commercial varieties and hybrids in southern Africa and selected derivatives from advanced introductions for 3 years at 5-10 locations in the region. Among commercial varieties, ICSV 1001 BF (Framida), Serena, Segaolane, and Red Swazi were most widely adapted, and gave an average yield of 2.04 t ha^{-1}; Red Swazi, Tenant White, and Mokhotlong I were earliest in maturity (90-100 days). Segaolane and Red Swazi were resistant to drought. Among commercial hybrids, DC 75, PNR 8544, PNR 8311, PNR 8384, and NK 300 had yields averaging 2.01-3.52 t ha^{-1}. We selected 13 lines with average yields ranging from 2.50 to 4.02 t ha^{-1} (SE ±0.70) from among the regional program selections. Several of these are being considered for release or are in prerelease testing in national programs.

Hybrid Breeding and Evaluation

We evaluated the performance of B-lines of 16 A-lines at Matopos and Mzarabani in Zimbabwe, and at Mount Makulu in Zambia. Five of them (ICSB 21, ICSB 12, SPL 109B, SPL 23B, and BTx 623) produced high grain yields averaging 3.72 t ha^{-1} compared with mean yields of 4.7 t ha^{-1} and 5.82 t ha^{-1} of the variety and hybrid controls. The lowest-yielding B-line was ICSB 20 with an average yield of 2.40 t ha^{-1} (SE ±0.90). The plant height of these B-lines ranged from 0.6 to 1.2 m at Matopos and 1.0 to 1.6 m at Mzarabani. ICSB 12, ICSB 19, D2B, and SPL 109 B had the best quality grains (2.0 on a scale of 1-5).

We evaluated 10 hybrids from ICRISAT Center and three commercial hybrids from the SADCC region at Matopos, Mzarabani, and Makoholi (Zimbabwe) and Pandamantenga (Botswana), The ICRISAT Center hybrids ICSH 162, ICSH 138, ICSH 281, and ICSH 106 gave grain yields of 4.10-4.53 t ha^{-1} whereas the local hybrids DC 99, PNR 8544, and PNR 8369 yielded 3.30-3.75 t ha^{-1} (SE ±0.85).

Population Breeding

We selected the best populations from 26 introduced random-mating populations (rmp) after 2 years of evaluation in the region. The selected populations are being merged to form one population for each of the three agroecological zones: the often droughted zone (ODZ), the hot dry zone (HDZ), and the cool dry zone (CDZ). A fourth population was formed by merging the best performing rmps across all locations in the three zones.

Yield of selected populations from each zone were highest from the ODZ at 4.04 t ha^{-1} (compared with the test entry mean of 3.12 t ha^{-1} and the control varieties mean of 2.30 t ha^{-1}), followed by those from the CDZ at 2.32 t ha^{-1} (compared with the test entry mean of 2.01 t ha^{-1}, and the control varieties mean of 1.40 t ha^{-1}), and the HDZ at 1.27 t ha^{-1} (compared with the test entry mean of 1.03 t ha^{-1} and the control varieties mean of 0.93 t ha^{-1}). The broadly adapted random-mating populations yielded, on average, 4.08 t ha^{-1} (SE ±0.71) in the ODZ, 2.13 t ha^{-1} (SE ±0.50) in CDZ and 1.26 t ha^{-1} (SE ±0.35) in the HDZ.

East Africa

Evaluation for Adaptation

Thirty-six sorghum varieties including 25 from ICRIS AT Center and 11 from the East African Regional Sorghum and Millet (EARSAM) network were evaluated for grain yield, drought, and disease resistance at Kiboko and Alupe research stations during the short rainy season (Sep-Jan) in Kenya. At Kiboko, the local variety Makueni was superior in grain yield (2.15 t ha^{-1}, SE ±2.92) to all the other varieties. Among the introductions from ICRISAT, ICSV 230 (2.12 t ha^{-1}) and ICSV 189 (1.95 t ha^{-1}) were selected for grain yield and drought resistance. At Alupe, the four highest-yielding varieties were Seredo (2.98 t ha^{-1}),MY146(2.24 t ha^{-1}),IS 8193(2.20 t ha^{-1}), and Serena (2.20 t ha^{-1}, SE ±3.09). Among the introductions from ICRISAT Center, ICSV 335 (1.86 t ha^{-1}) and ICSV 219 (1.84 t ha^{-1}) were selected for grain yield. Natural incidence of maize dwarf mosaic virus (MDMV) and leaf blight (*Exerohilum turcicum*) was high on susceptible cultivars, which allowed us to select for resistance. The four highest-yielding varieties were resistant to both MDMV and leaf blight, while ICSV 193 was free from both diseases.

Latin America

Breeding for the Highlands (1800-2500 m)

Pedigree breeding at the E1 Batan experiment station and in nearby farmers' fields resulted in the selection of 78 advanced-generation uniform lines for seed multiplication and evaluation in next year's preliminary yield trial.

Early frost badly damaged a late-sown trial of 15 F_1 hybrids (nine cold-susceptible A-line x cold-resistant (CR) pollen parent, and six CR A-line x CR pollen parent), all of which were pollen-fertile in an earlier lowland screening. However, pollen parent ICSV-LM 87005 produced two early-flowering, well-restored, cold-resistant hybrids.

In the preliminary yield trial of 70 new uniform lines identified in 1987, the best lines were ICSV-LM 88110 (a reselection from Valles Altos 110), ICSV-LM 88031, ICSV-LM 88117, ICSV-LM 88102, and ICSV-LM 88018, all with grain yields above 4.23 t ha^{-1} (SE ±0.57) despite a frost-shortened growing season.

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

In the 1987 regional trial (Mesoamerican Sorghum Variety Yield Trial, MASVYT-87) ICSV-LM 86513 had the best grain yield averaging 4.72 t ha^{-1} (SE ± 0.83) (range 1.94-6.67 t ha^{-1}, SE ±0.35-0.83) across eight rainfed locations.

Backcrossing was initiated to produce A-lines for recently identified B-lines having tan plant color and white or red grain without a testa. The best of these B-lines were PP 290, SCP 588-1, SCP-588-2, ICSV-LM 86553, and ICSV-LM 88510. All have excellent tropical adaptation and should be suitable for use as seed parents of hybrids for the region.

Breeding Photoperiod-sensitive Sorghums for Intercropping

In the 1987 regional trial, the best varieties at Texistepeque, El Salvador, were 85-EO-226 (grain yield 3.43 t ha^{-1}), ES-727 (3.25 t ha^{-1}), and EPR-127(3.21 t ha^{-1})(SE± 1.06), compared with 2.96 t ha^{-1} for the control variety Criollo Corona, despite severe terminal-drought stress caused by early cessation of the rains in late September. At Metalio, El Salvador, the best varieties were ES-727 (grain yield 2.48 t ha^{-1}), EPR-130 (2.07 t ha^{-1}), and Criollo Corona (2.01 t ha^{-1}) (SE ±0.37).

Grain and Food Quality

ICRISAT Center

Food Quality

We evaluated the quality of *injera,* a popular traditional food in Ethiopia, made from six sorghum cultivars. Various physiochemical analyses of flours were determined, including visco-amylography. Dehulled sorghum grain yielded the best *injera.* Among the physiochemical factors, grain hardness was correlated with the texture of *injera* while amylose content was correlated with taste and general acceptability.

West Africa

Grain Hardness

Grain samples from a multilocational adaptation trial of eight sorghum cultivars conducted at 11 locations in Burkina Faso in 1987 were observed for their grain mass [g (100 grains)$^{-1}$], grain hardness expressed as a percentage of floating grains in sodium nitrate of 1.3 specific gravity, percentage of grain protein, and percentage of lysine in the protein. Results indicated that mean grain mass per 100 grains varied between 2.16 (cv IS 6928) to 2.98 g (cv ICSV 111 IN) among the eight cultivars while mean percentage floaters ranged from 19 (cv Gnoflng, local control) to 89 (cv ICSV 126 IN). The grain hardness of cultivars varied over the 11 locations. The local control variety, Gnofing, exhibited the hardest grain at all the locations.

Research Collaboration with National Agricultural Research Systems (NARS)

Long smut (*Tolyposporium ehrenbergii*) in Kenya

In collaboration with the Kenya Agricultural Research Institute (KARI), we conducted surveys for long smut in farmers' fields in four districts of the Eastern Province of Kenya in 1987 and 1988. Long smut was found in Meru and Embu districts and disease incidence was 3.7% and 3.3%. At Marimanti experiment station in Meru district, disease incidence was 28.6% in the most susceptible genotypes.

In experiments conducted with KARI at Muguga, inoculating sorghums with sporidia just before heads emerged from the boot was found to be the most effective method of inducing infection. Over 200 lines were screened at Marimanti under natural-infection conditions, and 18 lines showed low smut incidence. These 18 lines were further screened using artificial inoculation with sporidia in the greenhouse at Muguga Research Station. One line, IS 8595 was free from smut infection. Although the line ICSV 212 had 30% disease incidence, the number of smut sori per panicle was <6. QL3, reported to be resistant in the Sudan, was susceptible to long smut in our tests.

Witchweed (*Striga*) Resistance Screening in Ethiopia

In collaboration with the Ethiopian Sorghum Improvement Program [East Africa Regional Cereals and Legumes (EARCAL) network's lead center for *Striga* research], we screened over 100 sorghum varieties for resistance to *Striga hermonthica* at Beles State Farm and Lower Birr and for resistance to S. *asiatica* at Gumaide. We identified two resistant varieties, ICSV 1007 and Seredo, to S. *hermonthica* at Lower Birr and to 5. *asiatica* at Gumaide. Seven varieties, SAR 24, Tetron, ICSV 1006, SR-5 (NJ-19892), UCHV, SR-9 (148), and Dobbs were resistant to *S. hermonthica* at Lower Birr and Beles State Farm, and six varieties [ICSV 1001 BF(Framida),N13, ICSV 1005, 76 TI 23, Dinkmash-86, and Short Kulisha] were resistant to 5. *asiatica* at Gumaide. All the selected varieties had at least 25% less *Striga* infestation than the susceptible control variety CK 60.

Ergot Resistance Screening in Ethiopia and Rwanda

We collaborate with Ethiopia and Rwanda national programs in research aimed at the identification of resistance to sorghum ergot in eastern Africa (ICRISAT Annual Report 1987, p. 36). We developed an artificial inoculation procedure based on our studies of the flowering biology of sorghum (ICRISAT Annual Report 1987, p. 32). The procedure was as follows:

1. All spikelets that underwent anthesis prior to inoculation were removed from the panicles.
2. The remaining spikelets were sprayed with a conidial suspension (1 x10^6 conidia mL^{-1}) prepared from fresh honeydew.
3. Inoculated panicles were covered with paper bags to enhance humidity.
4. Bags were removed 2 days after inoculation, panicles were reinoculated, and rebagged.
5. Bags were finally removed 7-10 days after first inoculation.

We evaluated five panicles of each genotype 20-25 days after first inoculation by counting infected spikelets in 100 spikelets borne on primary branches.

In Ethiopia, out of the 55 sorghum lines selected in the 1987 screening trial and retested at Arsi Negele, 12 entries had less than 10% infected spikelets compared with more than 90% infection in susceptible controls. In Rwanda at Rubona, the national program screened 245 germplasm accessions from ICRISAT Center and selected 34 entries with up to 10% infected spikelets; susceptible lines had more than 90% infected spikelets. The local cultivar Ikinyaruka was again free from ergot infection for the 2nd year.

Transfer of Downy Mildew Field Screening Technique to Zambia

The large-scale field screening technique for resistance to downy mildew, *Pewnosclerospora sorghi,* developed and used by ICRISAT at Dharwad, India, since 1981 (ICRISAT Annual Report 1982, pp. 28-29) was successfully established (in collaboration with the SADCC/ ICRISAT Regional Program) at Golden Valley, Zambia, for the Zambian national program. National program staff were trained in the establishment and use of the nursery. Of 2830 sorghum lines screened, 733 were identified as downy-mildew resistant (0-5% systemic disease).

Head Bug (*Eurystylus* sp) Research in Burkina Faso and Mali

We continued work on sorghum head bug in collaboration with NARS in Mali and Burkina Faso. We standardized the headcage technique to screen for resistance using cultivar S 34. Ten randomly selected panicles were infested with 0, 10, 20, 30, and 40 pairs (male and female adults) of head bugs per panicle enclosed in a headcage, when flowering was completed. Panicles infested with 10 pairs had a mean damage rating of 6.5 compared with 8.4 in those infested with 20 pairs and 8.7 in those infested with 40 pairs (on a 1-9 scale rating where 1 = grain with a few feeding punctures, and 9 = grain completely shrivelled).

We also compared population build up and grain damage in three resistant (CSM 388, Malisor 84-7, and Sakoika) and one susceptible (S 34) cultivars using 20 pairs of adults and 100 nymphs per panicle in headcages. CSM 388, Malisor 84-7, and Sakoika had a mean damage rating of 3.9 with 20 pairs per panicle compared, with 8.6 in S 34. The damage rating with nymphs was 3.9 in the resistant cultivars, and 8.2 in S 34. We recorded 7 bugs per panicle in CSM 388, and in Sakoika, 18 bugs per panicle in Malisor 84-7, and 82 bugs per panicle in S 34.

Crop Improvement in Botswana

We assisted the national program in Botswana to determine the crossability between cultivated sorghum, *Sorghum bicolor*(a staple cereal in the country) and columbus grass, *S. almum* (a potentially important forage grass in Botswana). Our 2-year genetic study indicated that there is 70% crossing between the two species with almost 50% fertility in the F,. The sterile heads in the F_1 segregated in a 35% full-sterility and 25% partial-sterility pattern. This implies that in contiguous fields, cultivated sorghum would cross with columbus grass resulting in gradual deterioration of the sorghum crop as the deleterious traits of seed shattering and disease susceptibility from the columbus grass would be transferred to the grain sorghum.

International Sorghum Variety Adaptation Trial (ISVAT 87)

ISVAT 87 consisted of 22 varieties and two ICRISAT-bred control cultivars [ICSV 1 (CSV 11), variety, and ICSH 153 (CSH 11), hybrid], and a local cultivar included by the cooperator at each location. It was grown at 9 locations in India, 3 in Pakistan, and 1 each in Burma, Thailand, the Philippines, Somalia, and Vietnam. Mean grain yields of selected high-yielding entries are presented in Tables 1 and 2.

The best varieties across Indian locations were ICSV 112 (SV 1) with an average grain yield of 3.91 t ha^{-1}, ICSV 273 with 3.83 t ha^{-1}, and ICSV 381 with 3.77 t ha^{-1} (Table 1). In Pakistan, ICSV 272 produced a grain yield of 3.33 t ha^{-1}, ICSV 381 produced 3.11 t ha^{-1}, and ICSV 298 produced 3.101 ha^{-1}. In Burma, ICSV 335 produced a grain yield of 5.87 t ha^{-1}, while the local control produced 3.55 t ha^{-1}. In Thailand, ICSV 361 was the top-yielder (5.46 t ha^{-1}) compared with the local 3.01 t ha^{-1}. In the Philippines, ICSV 110 gave the highest grain yield of 3.74 t ha^{-1}. ICSV 298 produced the highest grain yield (3.52 t ha^{-1}) in Vietnam. In Somalia, ICSV 193 produced a grain yield of 1.28 t ha^{-1} compared with 0.93 t ha^{-1} grain yield of the local control variety (Table 2).

In Pakistan and Vietnam, our varieties flowered 9-14 days later than at ICRISAT Center, whereas in Burma, they flowered 11 days earlier.

Table 1. Mean grain yield (t ha^{-1}) of highest-yielding entries in the 1987 International Sorghum Variety Adaptation Trial (ISVAT 87)[1] at nine locations in India[2].

Entry	1	2	3	4	5	6	7	8	9	Mean
ICSV 112 (SV 1)	5.11	6.92	3.99	2.06	1.71	4.61	3.85	3.98	2.98	3.91
ICSV 273	5.45	5.70	4.31	0.78	2.09	5.12	2.71	4.44	3.89	3.83
ICSV 381	5.32	5.95	4.05	0.51	2.21	5.21	3.17	5.00	2.54	3.77
ICSV 401	2.89	6.30	4.98	0.56	1.25	7.86	3.59	2.96	3.55	3.77
ICSV 197	5.46	8.07	2.53	0.59	2.21	4.82	0.45	5.09	4.27	3.72
ICSV 295	4.29	6.57	4.33	0.38	1.60	6.67	2.25	3.06	3.11	3.58
ICSV 234	4.17	6.46	3.48	1.66	1.27	5.13	2.59	2.87	4.19	3.53
Controls										
ICSH 153 (CSH 11)	6.28	6.53	5.34	2.01	1.20	3.63	4.43	4.72	3.81	4.22
ICSV 1 (CSV 11)	4.06	5.64	3.44	0.89	1.54	5.52	2.50	4.07	3.78	3.49
Local	4.97	5.61	5.54	1.88	1.66	4.16	2.70	3.33	4.03	3.77
SE	±0.61	±0.27	±0.53	±0.13	±0.15	±0.62	±0.57	±0.62	±0.21	±0.15
Trial mean (25 entries)	4.47	6.03	3.73	0.98	1.62	4.43	2.87	3.89	3.23	3.47
CV (%)	24	8	24	23	16	24	34	27	11	-
Efficiency (%)	101	119	103	107	144	100	244	100	100	-

1. 5 x 5 lattice, plot size ranged from 3.6 to 10.8 m^2.
2. Locations: 1 = Bhavanisagar, Tamil Nadu; 2 = Dharwad, Karnataka; 3 = Jalna, Maharashtra;4 = Kanpur, Uttar Pradesh; 5 - Kovilpatti, Tamil Nadu; 6 = Madras, Tamil Nadu; 7 = Patancheru, Andhra Pradesh; 8 = Pantnagar, Uttar Pradesh; and 9 = Surat, Gujarat.

Table 2. Mean grain yield (t ha^{-1}) of highest-yielding entries in the 1987 International Sorghum Variety Adaptation Trial (ISVAT 87)[1] at locations outside India.

	Pakistan							
Entry	Yousufwala	Islamabad	Dadu	Burma	Thailand	The Philippines	Vietnam	Somalia
ICSV 272	3.77	1.29	4.94	5.76	4.13	3.64	2.24	0.68
ICSV 381	4.25	0.52	4.56	1.97	5.30	3.30	2.47	0.86
ICSV 298	3.55	1.55	4.20	3.57	5.25	3.56	3.52	0.82
ICSV 335	4.04	1.17	3.51	5.87	4.89	3.45	2.18	0.49
ICSV 361	2.02	1.04	3.06	4.70	5.46	3.49	3.44	0.72
ICSV 110	2.47	0.97	3.25	4.10	4.83	3.74	1.70	0.35
ICSV 193	3.69	0.95	3.38	4.64	2.73	1.99	1.68	1.28
Controls								
ICSV 1 (CSV 11)	3.87	1.14	3.21	5.01	4.97	3.02	2.14	0.78
ICSH 153 (CSH 11)	5.43	1.06	4.03	5.49	6.23	4.36	3.46	1.12
Local	2.89	0.94	4.33	3.55	3.01	3.01	1.75	0.93
SE	±0.39	±0.09	±0.20	±0.53	±0.39	±0.41	±0.15	±0.12
Trial mean (25 entries)	3.47	1.00	3.90	4.52	4.56	3.15	2.22	0.77
CV(%)	19	15	9	20	15	23	12	26
Efficiency (%)	100	145	112	106	100	185	101	105

1. 5 x 5 lattice, plot size ranged from 5.2 to 7.5 m^2.

Table 3. Mean grain yield (t ha^{-1}) of highest-yielding entries in the 1987 International Sorghum Hybrid Adaptation Trial (ISHAT 87)[1] at eight locations in India[2].

Entry	1	2	3	4	5	6	7	8	Mean
ICSH 281	7.03	7.77	5.31	2.45	4.36	6.99	4.57	3.00	5.18
ICSH 106	7.33	7.32	6.65	1.72	3.17	7.28	4.17	3.67	5.16
ICSH 229	6.68	6.60	4.78	1.28	3.83	5.77	3.96	4.62	4.69
ICSH 110	5.25	6.29	5.99	1.23	3.43	7.38	4.30	3.06	4.62
ICSH 109	4.58	6.50	5.87	1.47	3.71	6.00	4.25	4.45	4.60
ICSH 233	6.04	6.39	4.14	1.87	3.80	6.09	4.72	3.62	4.59
ICSH 138	6.24	6.25	4.78	2.10	2.79	7.10	4.37	2.92	4.57
Controls									
ICSH 153 (CSH 11)	5.39	7.36	5.76	1.33	2.98	5.46	4.23	4.02	4.57
CSH 9	5.70	6.88	5.76	1.36	1.85	6.97	3.81	4.07	4.55
ICSV 112 (SV 1)	4.60	6.42	3.96	1.71	3.21	3.63	3.28	3.57	3.80
Local	4.58	7.99	6.27	1.60	3.51	5.34	2.34	4.73	4.54
ICSV 1 (CSV 11)	2.65	6.15	4.89	0.77	2.13	5.28	4.15	3.96	3.75
SE	±0.86	±0.41	±0.72	±0.17	±0.16	±0.61	±0.55	±0.31	±0.19
Trial mean (25 entries)	5.46	6.61	5.25	1.42	3.08	5.76	3.89	3.54	4.38
CV (%)	27	11	24	21	9	18	25	15	-
Efficiency (%)	100	115	100	100	101	100	109	102	-

1. 5 x 5 lattice, plot size ranged from 3.6 to 10.8 m^2.
2. Locations: 1 = Bhavanisagar, Tamil Nadu; 2 = Dharwad, Karnataka; 3 = Jalna, Maharashtra; 4 = Kanpur, Uttar Pradesh; 5 = Kovilpatti, Tamil Nadu; 6 = Patancheru, Andhra Pradesh; 7 = Pantnagar, Uttar Pradesh; and 8 = Sural, Gujarat.

Table 4. Mean grain yield (t ha^{-1}) of highest-yielding entries in the 1987 International Sorghum Hybrid Adaptation Trial (ISHAT 87)[1] at locations outside India.

	Pakistan							
Entry	Yousufwala	Islamabad	Dadu	Burma	Thailand	People's Republic of China	The Philippines	Somalia
ICSH 106	7.32	1.53	4.69	5.62	5.52	8.47	4.01	1.63
ICSH 281	7.18	1.75	4.26	6.45	5.47	8.09	2.48	1.61
ICSH 110	5.34	1.64	5.10	7.03	6.47	8.13	4.00	1.60
ICSH 138	6.61	1.90	4.67	6.11	5.30	8.39	4.00	1.52
ICSH 109	5.44	1.41	4.73	5.94	5.35	8.77	3.68	1.63
ICSH 162	5.71	1.41	4.45	4.04	5.90	8.28	4.21	1.27
ICSH 434	3.59	1.45	3.55	4.79	5.17	8.08	4.03	1.69
Controls								
ICSH 153 (CSH 11)	5.59	1.33	3.69	5.66	5.97	7.50	3.95	1.51
CSH 9	5.50	0.93	4.48	5.04	4.87	7.66	4.58	1.50
ICSV 112 (SV 1)	4.26	1.02	4.65	4.87	5.29	7.61	3.37	0.54
Local	3.00	0.83	5.18	4.10	3.03	5.72	2.49	0.81
ICSV 1 (CSV 11)	3.90	0.90	3.45	5.08	4.91	6.12	2.38	0.83
SE	±0.41	±0.14	±0.18	±0.49	±0.31	±0.39	±0.38	±0.15
Trial mean (25 entries)	5.06	1.36	4.28	5.37	5.36	7.72	3.55	1.36
CV (%)	14	18	7	16	10	9	18	20
Efficiency (%)	101	133	100	104	102	100	202	102

1. 5 x 5 lattice, plot size ranged from 3.0 to 7.5 m^2.

International Sorghum Hybrid Adaptation Trial (ISHAT 87)

ISHAT 87 consisted of 20 test and 5 control entries. It was grown at 8 locations in India, 3 in Pakistan, 1 each in Burma, Thailand, the People's Republic of China, the Philippines, and Somalia. Grain yield data are given in Tables 3 and 4. ICSH 281 produced a grain yield of 5.18 t ha^{-1} in India and 4.40 t ha^{-1} in Pakistan; and ICSH 106 produced 5.16 t ha^{-1} in India and 4.52

Table 5. Mean grain yield of ICRISAT-Center bred cultivars (IC) and of locally bred cultivars in the 1987 International Sorghum Trials and Nurseries (ISTN 87)[1].

			Grain yield				Time to 50% flowering (days)	
Country location	Entry	Source	(t ha^{-1})	SE	Superiority	CV (%)	Days	SE
Burkina Faso (Saria)	ICSV 273	IC	3.99	±0.51	19	36	67	±1
	ICSV 1078	Regional	3.35				68	
Burkina Faso (Farako-BS)	ICSV 295	IC	3.19	±0.30	13	21	70	±1
	ICSV 1002	Regional	2.82				74	
Mali (Sotuba)	ICSV 401	IC	1.92	±0.22	2	27	70	±0
	Sor 84-7	Regional	1.88				74	
Mali (Bema)	ICSV 401	IC	2.26	±0.36	18	46	63	±3
	Sor 84-5	Regional	1.91				61	
Kenya (Busia)	ICSV 335	IC	1.87	±0.31	-37	41	70	±1
	Seredo	Regional	2.98				71	
Kenya (Kiboko)	ICSV 230	IC	2.13	±0.29	- 1	40	63	±3
	Mukueni	Regional	2.15				70	
Sudan	ICSH 109	IC	5.89	±0.41	53	18	68	±1
	ICSV 112 (SV I)	IC	5.48		42		72	
	Hageen-Durra I	Regional	3.85				64	
Tanzania	ICSV 298	IC	0.87	±0.12	40	43	68	±3
	Serena	Regional	0.62				78	
Zimbabwe	ICSH 109	IC	3.61	±0.34	75	26	71	±1
	SDBP 46	Regional	2.06				67	
Zambia	ICSV 298	IC	4.44	±0.53	- 3	27	77	±3
	Local 7	Regional	4.56				66	
Mexico (Apatzingan)	ICSV 234	IC	6.69	±0.53	45	20	70	±2
	ICSV-LM-86-5021	Regional	4.60				64	
Mexico (Poza Rica)	ICSV 230	IC	4.44	±0.33	13	16	68	±1
	ICSV-LM-86-5014	Regional	3.93				72	

1. 6x6 lattice, plot size ranged from 6 to 10 m^2.
2. Superiority of the ICRISAT-Center bred cultivar expressed as a percentage increase above that of the highest-yielding locally bred cultivar.

t ha^{-1} in Pakistan. ICSH 110 produced the highest grain yield in Burma and Thailand, ICSH 109 in China, ICSH 162 in the Philippines, and ICSH 434 in Somalia.

Our hybrids flowered 12 days later in Pakistan and 9 days later in Burma than at ICRISAT Center.

International Sorghum Trials and Nurseries (ISTN 87)

ISTN 87 consisted of 36 entries (23 varieties and 2 hybrids from ICRISAT Center, and 11 varieties contributed by cooperators at each location. It was grown at 2 locations each in Burkina Faso, Kenya, Mali, and Mexico, and 1 location each in Sudan, Tanzania, Zambia, and Zimbabwe. Data in Table 5 show that ICRISAT-Center bred cultivars outyielded locally bred cultivars in Burkina Faso, Mali, Mexico, Sudan, Tanzania, and Zimbabwe. In Kenya, however, local cultivars had yields higher than those of ICRISAT-Center bred cultivars.

Seed Distribution

ICRISAT Center

In response to requests, we provided 8264 seed samples of our improved varieties, hybrids, parents of hybrids, and resistant sources to 37 countries as follows: Argentina (10), Bangladesh (24), Bhutan (24), Burkina Faso (44), Burma (71), Cameroon (38), Cdte dTvoire (38), Cuba (12), Denmark (5), Gambia (31), Ghana (19), Guinea (6), India (1371), Indonesia (96), Jordan (24), Kenya (3444), Malawi (3), Malaysia (30), Mali (44), Maldives (1), Mexico (96), Morocco (144), Nepal (2), Niger (135), Nigeria (145), Oman (3), Pakistan (81), the Philippines (242), Rwanda (24), Somalia (37), Sri Lanka (3), Sudan (94), Thailand (117), the People's Republic of China (447), Togo (19), Vietnam (24), and Zimbabwe (42).

Southern Africa

In response to requests for seeds, we dispatched breeding lines, improved varieties, hybrids and their parental lines to national programs and related institutions in different parts of the world. We supplied samples of seeds to Eastern Africa Regional Program (46), West Africa Sorghum Improvement Program (WASIP) in Mali (112), Ethiopia (41), Cameroon (112), Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Brazil (220), Purdue University, USA (5), Parbhani, India (11), Zambia (592). We also sent 30 kg of breeders seed of ICSV 112 (CSV 11) and 3 kg of ICSV 2 (ZSV1) to Malawi.

We received seed samples for inclusion in regional cooperative trials from Malawi (1), Zambia (6), and Zimbabwe (5),

East Africa

Seed of breeding lines, varieties, hybrids and their parental lines were provided by EARSAM to cooperators in Kenya (680), Ethiopia (320), Uganda (110), Burundi (90), Rwanda (122), and Somalia (220).

Latin America

In response to requests, we provided seed of breeding lines, varieties, and hybrids to the following countries: Colombia (22), Costa Rica (9), El Salvador (1081), Guatemala (405), Kenya (204), Mexico (588), Nicaragua (3), USA (408), and Zimbabwe (36).

ICRISAT Cultivars Released or in Prerelease Stage

India

- The ICRISAT variety, ICSV 112 (SV 1) was formally released as CSV 13 for general cultivation by the Government of India. Another ICRISAT variety, ICSV 145 (SAR 1), was released as SAR 1 for cultivation in *Striga*-endemic areas.

- The ICRISAT hybrid, ICSH 110, was in mini-kit testing in farmers' fields during the rainy season.
- Two ICRISAT varieties, ICSV 202 and ICSV 210, and a hybrid, ICSH 205 were included in the rainy-season All India Coordinated Sorghum Improvement Project (AICSIP) advanced trials.

Latin America

Ecuador:The variety [(GPR 148 x E35-1)-4-1 x (CS 3541 deriv.)]-I-I was released as INIAP 201. El Salvador : The hybrid, ATx 625 x Selection from M-90362, was released by the local private seed company Agroconsultores, S.A. de C.V., as AGROCONSA I.

Publications

Institute Publications

Plant Material Descriptions

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Sorghum hybrid ICSH 153. Plant Material Description no. 15. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-156-9. (PME 015)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Sorghum variety ICSV 112. Plant Material Description no. 16. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-157-7. (PME 016)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Sorghum variety ICSV 145. Plant Material Description no. 17. Patancheru, A.P. 502 324, India: ICRISAT. 4pp. ISBN 92-9066-158-5. (PME 017)

Workshop and Symposia Proceedings

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Uses of sorghum and millets: summary proceedings of an International Workshop on Policy, Practice, and Potential Relating to Uses of Sorghum and Millets, 8-12 Feb 1988, Bulawayo, Zimbabwe. Patancheru, A.P. 502 324, India: ICRISAT. 36 pp. ISBN 92-9066-159-3. (CPE 047)

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Nwanze, K.F. 1988. National agricultural research programmes in Sahelian countries of West Africa: problems and recommendations. Agricultural Administration and Extension 28(4):227-238. (JA 694)

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Sharma, H.C., Vidyasagar, P., and Leuschner, K. 1988. Field screening sorghum for resistance to sorghum midge (Diptera: Cecidomyiidae). Journal of Economic Entomology 81(1):327-334. (JA 558)

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Jambunathan, R., and Subramanian, V. 1988. Grain quality and utilization of sorghum and pearl millet. Pages 133-139 *in* Biotechnology in tropical crop improvement: proceedings of the International Biotechnology Workshop, 12-15 Jan 1987, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 394)

Nwanze, K.F., and Sivakumar, M.V.K. 1988. Effets des facteurs physiques du sol et climatiques sur la diapause et le cycle saisonnier de la chenille de l'epidu mil (*Raghuva albipunctella*). (In Fr.) Pages 99-109 *in* Compte rendu du cycle d'etudes sur l'Agrometeorologie et la protection des cultures dans les zones semi-arides, 8-12 Dec 1986, Niamey, Niger. Geneva, Switzerland: WMO. (CP 86-012)

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Taneja, S.L. 1987. Host-plant resistance in the management of sorghum stem borers. Pages 212-233 *in* Recent advances in entomology (Mathur, Y.K., Bhattacharya, A.K., Pandey, N.D., Upadhyaya, K.D., and Srivastava, J.P., eds.). Kanpur, Uttar Pradesh, India: Gopal Prakashan. (CP 309)

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CEREALS

PEARL MILLET

Contents

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PEARL MILLET

The global area sown to pearl millet (about 27 million ha) is primarily localized in two regions: the Indian subcontinent and Sahelian/ Sudanian Africa (Table 1). Because of ecological differences between these two regions, and to better address the specific needs of each, ICRISAT has pearl millet research programs in both.

In India, which alone has 43% of the global pearl millet area, ICRISAT has a team of nine scientists (three internationally recruited and six nationally recruited) who are mainly engaged in strategic research in breeding, pathology, and physiology. India has an extensive national research program on pearl millet—the All India Coordinated Pearl Millet Improvement Project (AICPMIP)—which brings together a large number of individual scientists into a single, coordinated, multidisciplinary pearl millet research program. In addition, there is, in India, a growing private-sector investment in pearl millet breeding by a number of seed companies. ICRISAT supports this extensive national effort by concentrating on the diversification of breeding material, the difficult task of breeding male-sterile lines for hybrid production, studies on breeding and screening methodologies, and research on crop and pathogen biology.

In Sahelian/Sudanian Africa, which has 53% of the global pearl millet area, ICRISAT has a team of six internationally recruited scientists who concentrate primarily on breeding new varieties for regional use. Research on pearl millet in this region is spread among the national programs of 12 independent countries, many of which do not have adequate resources to mount integrated research programs, and which are not members of an overall coordinated research program as are individual research stations in India. Research and breeding at the ICRISAT Sahelian Center (ISC) is therefore oriented to the production of new varieties for evaluation and use by national programs. These can be either directly released to farmers, or used as parents by national programs that have the resources. Scientists at the ISC thus concentrate on combining a superior yield potential with

Table 1. Ranking of pearl-millet growing countries (Africa), states (India), and provinces (Pakistan) by area sown to pearl millet.[1]

Country/ State/ Province	Area sown (million ha)
Rajasthan (India)	4.87
Nigeria	4.72
Niger	3.08
Maharashtra (India)	1.60
Gujarat (India)	1.42
Mali	1.36
Chad	1.15
Sudan	1.06
Uttar Pradesh (India)	1.01
Senegal	1.00
Burkina Faso	0.90
Haryana (India)	0.81
Karnataka (India)	0.55
Cameroon	0.50
Andhra Pradesh (India)	0.49
Tamil Nadu (India)	0.31
Punjab (Pakistan)	0.30
Zimbabwe	0.28
Tanzania	0.19
Madhya Pradesh (India)	0.18
Egypt	0.16
Togo	0.16
Sind (Pakistan)	0.15
Ghana	0.14
Mauritania	0.13
Others(12)	0.39
Total	26.90

1. Excludes countries where pearl millet is grown primarily as a forage crop.

Source: ICRISAT 1987. Looking ahead: a 10-year plan.

resistance to biotic and physical environmental stresses, to assure adaptation, especially to the Sahelian zone. Scientists at ISC also spend a significant portion of their time training national program staff, visiting their programs, and organizing workshops, to attempt to make available new methods and concepts to the national programs.

Three percent of the global pearl millet area lies in eastern and southern Africa, where pearl millet is a minor crop on a regional basis, but is an important crop in local areas of several countries. ICRISAT maintains a small effort on pearl millet through its regional cereal programs in both regions. This centers on the identification and regional evaluation of selected varieties from the programs at ICRISAT Center and ISC, individual national programs, and ICRISAT's small breeding program at the Southern African Development Coordination Conference (SADCC) regional headquarters in Zimbabwe. The latter also provides a finger millet and cereal forage germplasm and varieties for regional testing and use.

ICRISAT's research on biotic and physical stresses is presented jointly from all these programs in the following report. Breeding activities are reported in separate sections for the ICRISAT Center and ISC Programs, and the work of the SADCC Regional Program is reported in the section on Cooperation with National Programs.

Physical Stresses

Crop Establishment

Effects of Seed Quality on Emergence and Survival

We continued to examine the importance of seed quality in genotype differences in seedling establishment ability (ICRISAT Annual Report 1987, p. 79). We subjected seedlots of varieties of Sudanian (600-900 mm annual rainfall) and Sahelian (400-600 mm annual rainfall) origin with different seed qualities to seedling drought stress, using the seedling drought screen reported earlier (ICRISAT Annual Report 1986, p. 71). Seedlot quality was varied by rapidly ageing (at 14% moisture content and 50°C) certain seedlots, which reduced seed quality (vigor), but did not significantly lower the germination percentage. Reported here are the effects of seed quality in a typical Sudanian (ICTP 8202) and Sahelian (CIVT) genotype.

Genotypes of Sudanian origin were slower to emerge than those from the Sahelian zone, although final emergence did not differ (Fig. 1a). Furthermore, the lower seed quality of the aged seedlots delayed emergence and reduced the final percentage of emerged seedlings from 55 to 31%. Subsequent survival counts of the two seedlots of the Sudanian and Sahelian genotypes indicated that seedlots that had a slower emergence rate due to either seed quality or genotype differences, also had a lower percentage survival of emerged seedlings (Fig. 1b). These findings highlight the critical role both of seed quality and genetic background of the seedlot in understanding seedling survival under postsowing drought stress.

Comparative Importance of Heat and Drought Stresses in Seedling Mortality

Over the last 2 years, we have been attempting to determine the comparative importance of supraoptimal temperatures (i.e., heat stress) and moisture deficiency as causes of seedling mortality at the beginning of the season. In the research reported here, we monitored seedling survival over time, of three different seedlots of six pearl millet genotypes, subjected to adequate or inadequate root-zone soil moisture and two different soil-surface temperatures. The genotypes chosen were diverse and seed sources originated from Togo, Senegal, and Niger. The adequate soil moisture treatment received sufficient irrigation in the bottom of the furrows to wet the root-zone soil but not the soil surface. The inadequate moisture treatment received only the initial sprinkler irrigation generally given to germinate

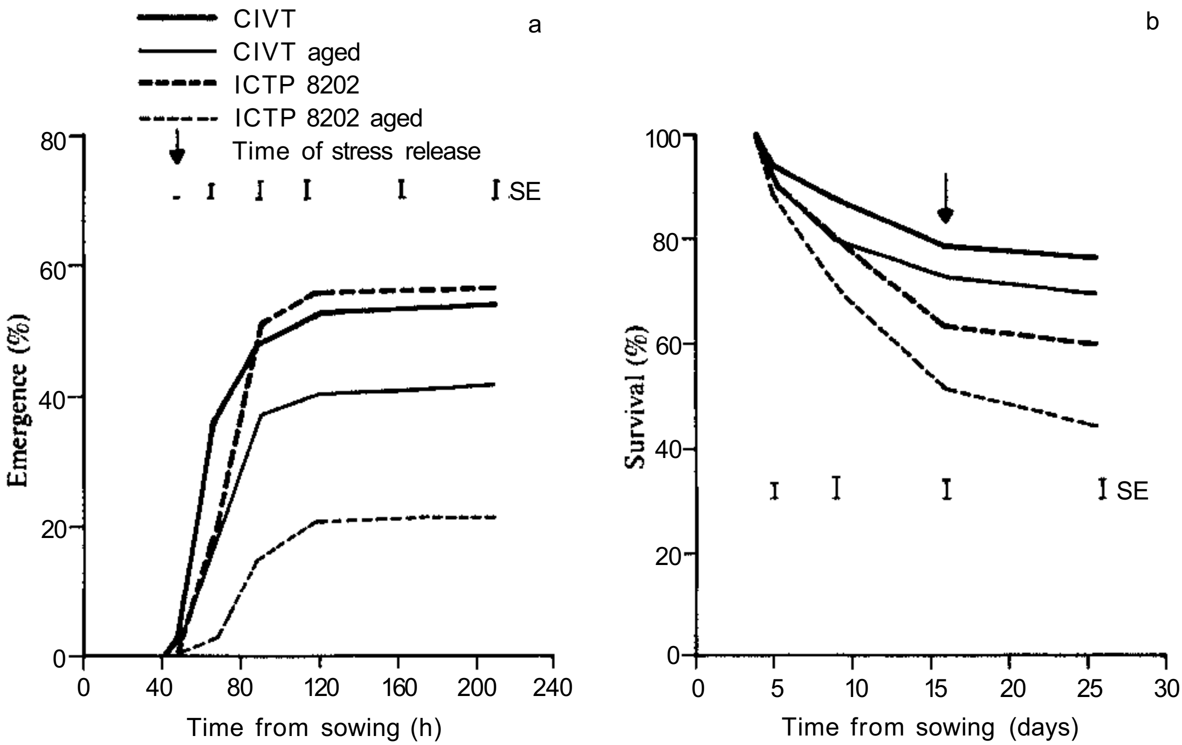

Figure 1. *The course of* (a) *field emergence and* (b) *seedling survival after emergence oft wo pearl millet genotypes, CIVT and ICTP 8202, with aged and normal seed qualities. ISC, dry season 1988.*

the crop. Differential soil-surface temperatures were created by allowing heating of the natural soil surface in the hot treatment and reducing this in the cooler (as compared with the hot) treatment by misting the soil surface with a small amount of water every 20 minutes between 1000 and 1600 each day during the treatment period. The combination of both these manipulations resulted in four treatments with different mean daily maximum temperatures (MDMT) and mean root-zone (5-10 cm) soil moisture (MRZSM):

- hot/wet treatment, MDMT = 54.3°C and MRZSM =1.36 mm;
- hot/dry treatment, MDMT = 54.3°C and MRZSM = 0.92 mm;
- cooler/wet treatment, MDMT = 49.4°C and MRZSM = 1.37 mm; and
- cooler/dry treatment, MDMT = 50.7°C and MRSZM = 0.97 mm.

There were no differences in soil surface (0-5 cm) moisture between the hot and cool treatment pairs for either the wet (0.50-0.56 mm) or the dry (0.34-0.35 mm) treatments.

Averaged across genotypes and seedlots, high soil-surface temperatures alone (hot/wet treatment) reduced seedling survival more (22%) at 16 days after sowing (DAS) (time of drought stress release) than the cooler/wet treatment (18%) (Fig. 2). However, seedling mortality was even higher (32%) in the presence of soil moisture deficiency alone (cooler/dry treatment). The combination of both heat stress and moisture deficiency (hot/dry treatment) was more than additive (45% mortality) in its effect on seedling survival These results demonstrate that seedlings can withstand better high soil temperatures where soil moisture is adequate, than they can moisture deficiency without temperature stress. The combination of the two stresses, a

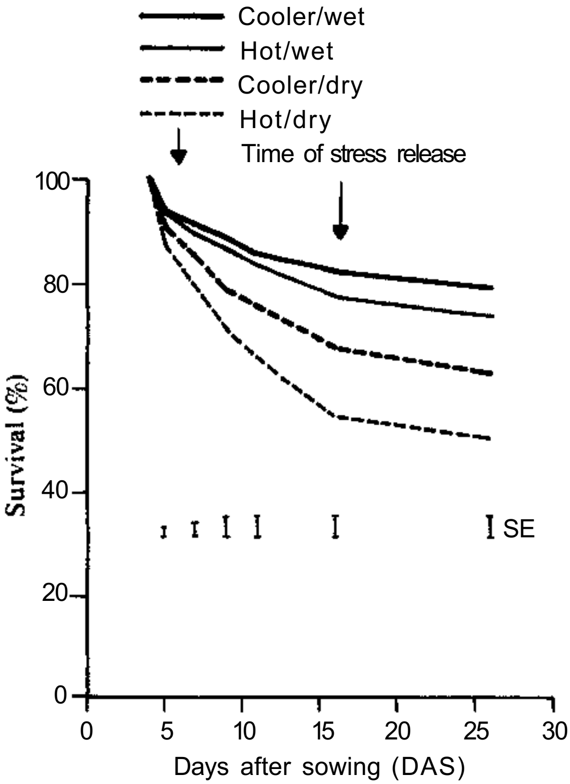

Figure 2. A comparison of the effects of four moisture-deficiency and temperature-stress treatments on the course of pearl millet seedling survival, ISC, dry season 1988.

common phenomenon at the beginning of the season in the southern Sahelian zone, is most detrimental to seedling survival and to achieving a good crop stand.

Drought Stress

Genotype Evaluation for Drought Response

To assess the repeatability and applicability of drought response screening in the dry season at ICRISAT Center, we conducted a trial of 25 diverse genotypes in six locations over a 3-year period (1985-88). The locations included fully irrigated sowings in the rainy and dry seasons at ICRISAT Center, midseason stress (panicle initiation to flowering) and terminal stress (flowering and grainfilling) in the dry season at ICRISAT Center, and early (Anantapur I), and late (Anantapur II) sowing at Anantapur. The Anantapur I and II sowings approximated midseason and terminal stresses under natural rainfall conditions, based on average rainfall patterns at this location.

For the dry-season screening of genotypes for drought response to be most effective, the controlled stress environments should:

- be more repeatable or stable in the ranking of genotypes than the rainy season, natural stress environments;
- effectively discriminate among genotypes by their yield or response to drought; and
- be more predictive of the yields or response to stress in natural stress conditions than are the nonstressed locations.

The experiment described above allowed us to test each of these requirements. We used:

1. analysis of variance (ANOVA) techniques to estimate the variances for genotypes, locations, years, and their interactions;
2. linear regression analysis to evaluate how well each location differentiated among genotypes; and
3. cluster analysis to measure the similarity of genotype evaluation among environments.

Besides the grain yield data, we also analyzed data for threshing percentage (ratio of grain yield to panicle yield), our proposed selection criterion for tolerance to terminal stress.

Stability of test location. We tested the stability of each location by calculating the percentage of the ANOVA model sums of squares (replication, year, and genotype effects), which were due to genotype x year interactions in each test location. The smaller this percentage, the more repeatable is the genotype ranking over years.

In general, irrigated locations were more stable than stress locations, as would be expected. The dry-season stress locations differed considerably in stability/terminal stress was comparable to the normal rainy-season selection environment for stability of grain yield and much more stable for threshing percentage, where midseason stress was the poorest of all the locations for grain yield, but average for threshing percentage (Table 2). The natural stress locations were somewhat less stable than the terminal stress for both variables, and therefore would make less useful selection locations.

Discrimination of genotypes. The effectiveness of each location in discriminating genotypes was tested by comparing the regressions of the genotype yields in the 18 individual year x location environments on the mean genotype yield across all 18 environments (best estimate of genotype performance). In this analysis, each location is described by the range (across years) in the regression coefficient (b value), which is a measure of how well the location differentiates among the high- and low-yielding genotypes. A desirable screening environment has a consistently high regression coefficient over years.

The irrigated locations were the most effective in distinguishing genotype differences in grain yield (Table 3). The terminal-stress location was also reasonably good (mean b value of 0.9), whereas both naturally droughted locations were very poor in distinguishing the mean genotype differences in grain yield (mean b value <0.5). To distinguish genotype differences in threshing percentage, the terminal-stress location was the best of the six locations. This was expected because of the control we can exert on the onset and severity of stress in the dry season. The terminal-stress location also appeared to be more consistent across years in the b values than most of the other locations.

Table 3. The ability to distinguish among genotypes for grain yield and threshing percentage differences for each of the six test locations. Data are the ranges in regression coefficients from the individual year by location regressions of genotype yield and threshing percentage against mean genotype yield and threshing percentage.

Location	Range in regression coefficients	
	Grain yield	Threshing percentage
Rainy season		
Patancheru	0.86-2.03	0.19-0.79
Anantapur I	0.14-0.62	0.28-0.72
Anantapur II	0.21-0.57	0.37-1.01
Dry season		
Irrigated	1.76-2.32	0.87-0.94
Midseason stress	0.55-1.36	0.10-1.15
Terminal stress	0.88-0.92	1.05-1.74

Table 2. The stability of genotype performance across years in different test locations. Data are the percentages of sum of squares due to genotype x year interaction from the analysis of variance of year and genotype effects for each location.

Location	Degrees of freedom	Percentages of sum of squares	
		Grain yield	Threshing percentage
Rainy season			
Patancheru	48	9.5	35.9
Anantapur I	48	9.2	38.2
Anantapur II	48	16.0	17.9
Dry season			
Irrigated	48	2.8	17.1
Midseason stress	48	34.0	22.8
Terminal stress	48	8.1	20.2

Grouping of environments. A two-way cluster analysis (genotype x environment) was done for all environments to see how well the controlled-stress locations compared with the naturally stressed and irrigated locations in terms of how they ranked genotype performance (data not presented).

On the basis of grain yield, the terminal stress and the natural stress environments (Anantapur I and II) grouped together in two clusters which did not overlap with the nonstressed environments. The latter also fall into two distinct clusters, on the basis of yield level, rather than on the basis of season. The midseason stress environments clustered inconsistently with both the stressed and nonstressed groups.

On the basis of threshing percentage, drought environments fell into three separate clusters, and the irrigated environments into a fourth cluster. The stressed clusters grouped environments mainly by degree of reduction in threshing percentage, which tended, therefore, to distinguish between the midseason and terminal-stress environments in the dry season but not necessarily between the early and late sowings at Anantapur, as the severity, as well as the timing of these environments varied from year to year. However, as in the case of yield, there was no overlap of the stressed and nonstressed locations.

These patterns indicate that genotype assessment on the basis of grain yield and threshing percentage is different in at least terminal stress and nonstressed environments, and that genotype evaluation in nonstressed locations is not necessarily valid for locations characterized by terminal stress. The case for midseason stress environments, both natural and managed, was less clear, as they clustered with both groups. This could possibly have been predicted, as a midseason stress is much less well-defined than a terminal stress.

This experiment provides evidence to support the case for at least the terminal-stress location in the dry season as a screening location, as it provides a relatively repeatable screening location which is capable of distinguishing genotype differences. Most importantly, it represents the natural stress environment, which we used in this experiment (Anantapur), better than do either of the nonstressed environments we used. We plan to extend our analysis of these data to the actual physical conditions (temperature, available soil water, etc.) of the 18 environments to determine if a direct analysis of the environments supports our conclusions from the analysis of genotype performance in them.

Biotic Stresses

We report here research on four major research areas: pathogenic variability in the downy mildew pathogen (*Sclerospora graminicola*) in India and West Africa, several studies in India relating to ergot, the identification of hot-spot locations for disease screening in southern Africa, and studies on the pearl millet stem borer conducted in Niger. We also conduct biotic stress research on smut, rust, *Striga hermonthica,* and headworm of pearl millet, but research projects in these areas are not reported this year.

Virulence of *Sclerospora graminicola*

Our major concern in pearl millet downy mildew research is the potential for pathogenic variability in 5. *graminicola* and the implications this has on breeding for resistance and vulnerability of resistant cultivars. We are conducting research on this problem both in India and West Africa. To a large extent, our research to date has emphasized the identification of virulence differences in 5. *graminicola* isolates from among and within regions, based on differential reactions of hosts in multilocational testing. International nurseries and trials, including the International Pearl Millet Downy Mildew Nursery (IPMDMN) in India and West Africa, and the West African Downy Mildew Variability Nursery (WADMVN) in West Africa,provide most of our information. Information has also been obtained through a recently completed collaborative project on pathogenic variability in *S. graminicola* with the University of Reading, UK. We realize that due to the dynamic nature of downy mildew, the results reported here may not be precisely repeatable in other tests in other years.

India

In India there have been several examples of the breakdown of resistance to downy mildew in pearl millet hybrids at the farmers' level. We believe that this is due to changes in virulence in the pathogen, which have been the result of the selection pressure exerted by continuous cultivation by farmers, of given genotypes, hybrids in these cases, over several years.

We observed in our multilocational testing, apparent differences in virulence on certain entries at some locations. These have especially been apparent in our nurseries grown in cooperation with the Indian national program at Mysore and Aurangabad. Isolates from these two locations were tested at ICRISAT Center on pearl millet at the seedling stage using the greenhouse inoculation technique (ICRISAT Annual Report 1987, pp. 85-86). They gave reactions distinctly different from each other, and from an isolate from Patancheru on several pearl millet entries (Table 4). The Aurangabad isolate caused 54% downy mildew incidence on the cultivar MBH 110, but none on cultivars ICMH 451 or 852B, whereas the Mysore isolate caused 75% incidence on 852B, but none on ICMH 451 or MBH 110. The isolate from Patancheru caused < 1 % incidence on all three cultivars. All three isolates caused >65% downy mildew incidence on the universal susceptible control, 7042. These data demonstrate distinct qualitative differences among the S. *graminicola* populations at these three locations, and we believe that more extensive testing would reveal the existence of other pathotypes at other locations in India.

Table 4. Downy mildew incidence (%) in seedlings of four pearl millet cultivars tested in the greenhouse for their reactions to isolates of *Sclerospora graminicola* from three locations in India, ICRISAT Center, 1988.

	Origin of isolate		
Cultivar	Aurangabad	Mysore	Patancheru
ICMH 451	0	0	1
MBH 110	54	0	0
852B	0	75	1
7042	68	66	83

Some of our pearl millet breeding nurseries, especially those containing hybrid parents, are being grown at several locations in India, with the objective of exposing them to potentially different populations of *S. graminicola.* One such location was in a farmer's field near Aurangabad, where the farmer had sown MBH 110 in the previous 3 consecutive years, experiencing downy mildew incidence levels of <5% in 1985, about 20% in 1986, and >75% in 1987. With assistance from the national program, we grew our nurseries in this field in 1988.

The overall downy mildew incidence was low, with most entries free from downy mildew and <10% of them having >10% incidence. In contrast, MBH 110 had about 50% downy mildew incidence. These data suggest that, for the pathotype to be able to parasitize MBH 110, the population of *S. graminicola* in the field had undergone very specific selection over the previous 3 years. Furthermore, they indicate that at present, our breeding material is generally resistant to this pathotype.

West Africa

We evaluated several pearl millet lines and cultivars for downy mildew reaction annually since 1986, in cooperation with the national programs in Burkina Faso, Mali, Niger, Nigeria, and Senegal. The same test entries have also been evaluated for their reaction to S. *graminicola* isolates from Burkina Faso, Niger, and Nigeria, in the collaborative project at the University of Reading, UK.

We found quantitative differences in the mean downy mildew incidence among the test locations. Mean incidence of 10 entries over 3 years was 35% at Cinzana (Mali) and 8% at Bambey (Senegal); the values for Samaru (Nigeria), Bengou (Niger), and Kamboinse (Burkina Faso) fail between these two extremes (Fig. 3a). These findings indicate that the *S. graminicola* pathotype at Cinzana is perhaps the most aggressive among those tested, and the pathotype from Senegal the least aggressive. Studies at the University of Reading (ICRISAT Annual Report

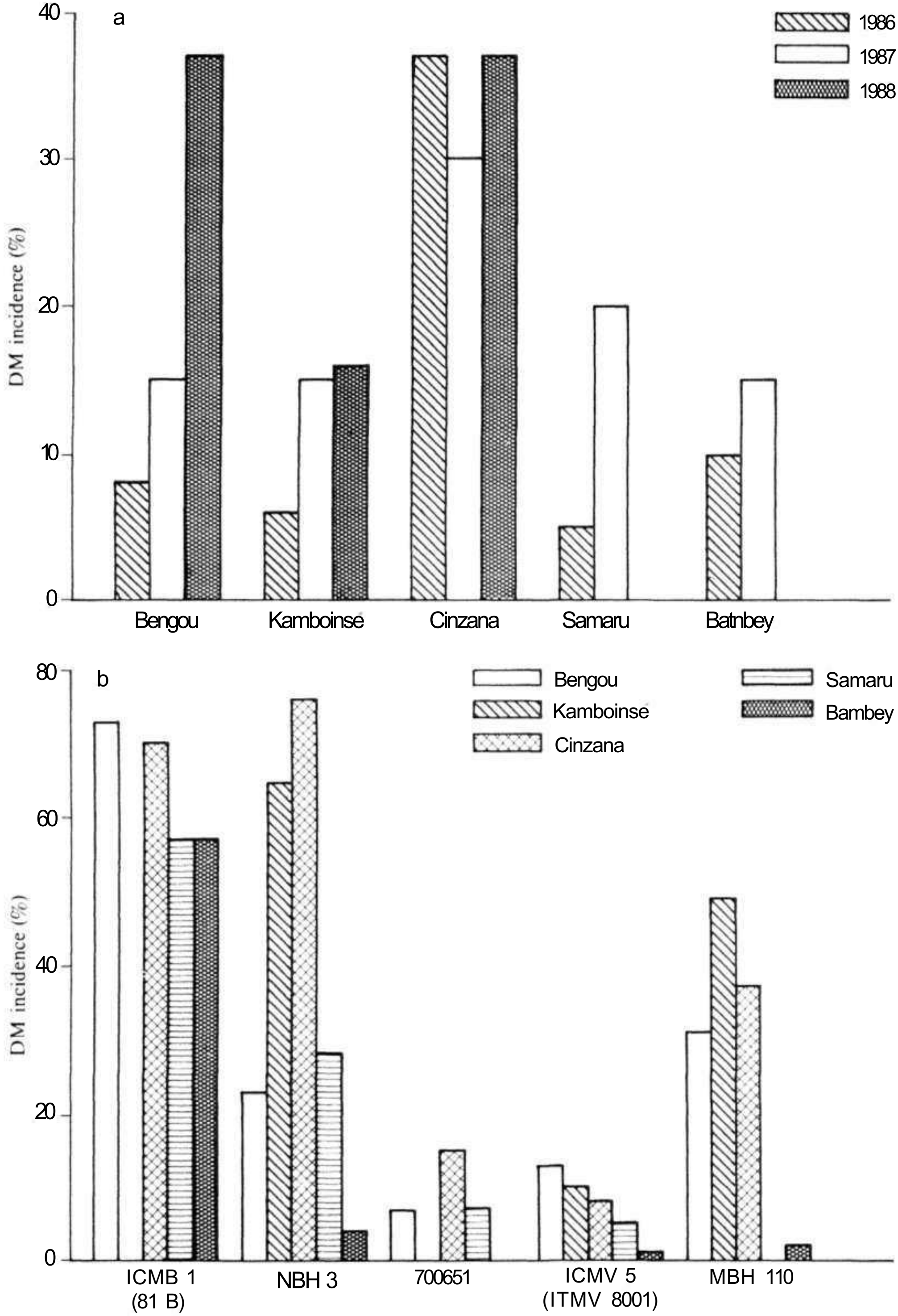

Figure 3. Downy mildew incidence (%) *in the West African Downy Mildew Variability Nursery* (*WA DM VN*) *at five locations in West Africa, 1986-1988:* (a) *mean incidence of the 10-entry nursery, by location and year, and* (b) *mean incidence over 2-3 years for five of the genotypes, by individual location.*

1986, p. 75) also found that isolates from Senegal were the least aggressive of those studied from West Africa.

Remarkable differences in virulence among isolates from some locations were expressed on some genotypes, especially 81B and MBH 110 (Fig. 3b). Genotype 81B was consistently resistant at Kamboinse but susceptible at all other locations over 3 years of testing. Scientists at the University of Reading also showed that 81B was less susceptible to the isolate they used from Burkina Faso than to the isolates from Niger and Nigeria. Similarly, NHB 3 showed a resistant reaction at Bambey (4% downy mildew incidence), a susceptible reaction at Cinzana (76%) and Kamboinse (65%), and an intermediate reaction at Bengou (23%) and Samaru (28%). A different contrasting reaction was found on hybrid MBH 110, which was resistant at Cinzana and Bambey but highly susceptible at all other locations. Breeding line 700651 and variety ICMV 5 (ITMV 8001) showed stable resistance over the 3 years and five locations.

These data clearly demonstrate the existence of different pathotypes of *S. gmminicola* in West Africa. Based on these findings, we recommend that breeders within the West Africa region test their advanced breeding material for stable resistance in at least three locations in the region for a 3-year period. Of the locations involved in this study, Cinzana appears to have the most aggressive pathotype followed by pathotypes at Bengou, Samaru, Kamboinse, and Bambey. However, observations by scientists of some national programs within West Africa suggest that different pathotypes are probably present in different parts of the same country. In 1989, scientists in some national programs in West Africa will begin to monitor pathogenic variability in *S. gmminicola* within their countries.

Ergot (*Claviceps fusiformis*)

We have conducted considerable research at ICRISAT Center on the biology of the pearl millet ergot disease, the identification and breeding of sources of resistance, and the utilization of resistant sources to breed ergot-resistant varieties and hybrids. Although we have generated considerable information on the biology of ergot and have a number of breeding lines and populations with stable resistance to ergot, we have not been as successful in our attempts to breed ergot-resistant varieties and hybrids for farmer use. Based on our findings, we believe that due to the nature of resistance (short protogyny and rapid self-pollination), its complex inheritance, and general association with lower yield potential and some undesirable agronomic traits, a program to breed high-yielding, agronomically elite, ergot-resistant cultivars (especially hybrids) would be extremely resource-consuming, with little assurance of success. Furthermore, it now appears that, relative to other disease problems ergot may not be as important in major pearl-millet growing areas as we once thought it was. Therefore, we propose to reduce our research on ergot in future.

We report here a number of studies on various aspects of ergot research that have recently been completed.

Expression of Ergot Resistance under Artificial Epidemic Conditions

Ergot-resistance screening at ICRISAT Center has, of necessity, been based on an inoculation technique that involves timely inoculation (at the protogyny stage) in a suitable environment (moderate temperature and high humidity) and eliminates interference with infection by pollen from other panicles (by bagging panicles). This screening technique is, to some extent, unnatural and it has not been possible to test resistance identified by this method for its effectiveness in natural ergot epidemics since these are infrequent and unpredictable in pearl-millet growing areas. Therefore, we attempted to create, in the greenhouse and in the field, the environmental conditions believed to prevail during ergot epidemics, and evaluated some of our resistant sources for their reaction to ergot under more natural conditions.

The epidemic conditions were created in a greenhouse by repeated misting of *C. fusiformis* conidia into the air surrounding protogynous panicles and maintaining conditions of high relative humidity (>90%) and panicle wetness (>80%) created by automatic misters controlled by relative-humidity and leaf-wetness sensors attached to a data logger (Fig. 4). In the field, we inoculated panicles in a similar manner, but used frequent sprinkler irrigations to maintain high humidity and panicle wetness.

Figure 4. Evaluation of ergot resistance of pearl millet in a greenhouse under artificial ergot epidemic conditions of high relative humidity and panicle wetness provided by a misting system controlled by humidity and leaf wetness sensors, ICRISAT Center 1988.

There were no significant differences in the classification of ergot reactions under artificial epidemic conditions (both greenhouse and field) and previous field screening for either ergot-resistant (<10% severity) or susceptible (>30% severity) lines. However, lines that had been identified as moderately resistant (10-30% ergot severity) in field screening showed low ergot levels (<2% severity) comparable to highly resistant lines, under artificial field epidemic conditions. Under the more severe conditions created in the greenhouse, moderately resistant lines generally showed slightly lower ergot levels than they did in field screening (Table 5). The results suggest that lines with moderate resistance are likely to show a higher level of functional resistance under natural ergot epidemic conditions than they do in ergot-resistance screening.

Several ICMPES lines (sib-bulk populations) that have moderate levels of ergot resistance in field screening and generally desirable agronomic traits may be suitable for cultivation in areas where ergot is economically important.

Ethrel as a Male Gametocide in Relation to Ergot Development

Ethrel (2-chloroethyl phosphonic acid), although not previously tested on pearl millet, has been reported to be a male gametocide when used on flowers of several crops. In an attempt to test the nature of ergot resistance, believed to be based on short protogyny leading to rapid self-pollination in bagged panicles, we tested Ethrel on pearl millet to determine if some mechanism other than short protogyny and rapid self-pollination may be involved in ergot resistance. In field and greenhouse experiments, we found that Ethrel was most effective in inducing male sterility when applied at 2000 mg kg^{-1} to panicles at late boot or early protogyny stages. However, since Ethrel did not induce complete sterility, and pollen from even a few fertile florets was enough for self-pollination in the bagged panicles, we

Table 5. Evaluation of selected pearl millet cultivars resistant(R), moderately resistant (MR), and susceptible(S), to ergot under field-screening, and artificial field- and greenhouse-epidemic conditions, ICRISAT Center, 1984-1988.

		Mean ergot severity (%)		
Cultivar	Known ergot reaction[1]	Field screening[2]	Artificial field epidemic[3]	Artificial green-house epidemic[4]
ICMPES 23	R	2 ±0.6	1 ±0.2	_[5]
ICMPES 29	R	5 ± 3.6	1 ±0.1	1 ±0.6
ICMPES 34	R	2± 1.5	1 ±0.2	6± 1.9
ICMPES 8	MR	21 ± 1.4	2± 1.2	14 ± 2.0
ICMPES 9	MR	23 ± 2.9	1 ±0.2	19 ± 2.4
ICMPES 32	MR	12 ± 1.5	1 ±0.2	-
Control				
ICMV 1 (WC-C75)	S	72 ± 6.9	24 ± 10.4	41 ±5.5

1. Based on several years of multilocational testing through the International Pearl Millet Ergot Nursery (1PMEN); R is <10% mean severity, MR=10-30% mean severity, and S is >30% mean severity.
2. Mean of 30-40 panicles from 2 3 replications with artificial inoculation in 1984, 1987, and 1988 rainy seasons.
3. Mean of 100-800 panicles from 3-4 replications in 1984, 1987, and 1988 rainy seasons.
4. Mean of 20-60 panicles in 1988.
5. - = Not tested.

were not able to effectively use this male gametocide as a tool to study the role of pollen in ergot resistance.

Ethrel treatment did not affect female fertility in male-sterile lines, but when applied at the late boot stage, it partially inhibited panicle exsertion and reduced plant height and panicle length. At 2000 mg kg^{-1}, Ethrel completely inhibited pollen germination in vitro, but did not affect conidial germination.

Ergot Susceptibility in Relation to Cytoplasmic Male Sterility

F_1 hybrids made from female parents with cytoplasmic male sterility are generally more suscept-ible to ergot than are varieties. To determine the association between cytoplasmic male sterility and susceptibility to ergot, we tested six cytoplasmic male-sterile lines(A-lines), 852A, 5054A, 81A, 834A, 843A, and ICMI 841 (841A); their corresponding maintainer lines (B-lines); 8 restorer lines (R-lines), ICMPES 1, ICMPES 2, ICMP 851009, J 104, ICMP 451, ICMP 501, ICMP 85417, and ICMP 423; and 36 A/B x R, F_1 hybrids. All the A-lines, except 81A and 843A, were significantly more susceptible (78-97% severity) than their corresponding B-lines (54-82% severity), and R-lines, except ICMP 85417 and ICMP 423, were significantly less susceptible (34-50% severity) than A- or B-lines. All A x R hybrids, except 834A x ICMP 501 and 843A x ICMP 85417, were significantly more susceptible than their corresponding B x R hybrids, indicating the positive association of sterile cytoplasm with ergot susceptibility. The higher ergot susceptibility of A-lines and AxR hybrids than B-lines and B x R hybrids can perhaps be attributed to the cytoplasmic, nuclear, or cytoplasmic x nuclear factors that may affect the flowering events (protogyny, fertility restoration) that influence ergot susceptibility.

The results suggest that if hybrids could be made without using cytoplasmic male sterility, they might be less susceptible to ergot. Another alternative for ergot control in hybrids might be to use topcross hybrids based on pollinators having asynchronous flowering that would increase the variability in time of flowering of the crop, thereby reducing vulnerability to ergot in a field situation.

A Mycoparasite on Ergot

We invariably observe a *Fusarium*-like growth on ergot-infected pearl millet panicles both under field and greenhouse conditions. The fungus could be consistently isolated from honeydew and sclerotia, and was identified as *Fusarium semitectum* var. *majus* Wollen by the International Mycological Institute, Kew, Surrey, UK. The parasitic potential of the fungus was determined in several field and greenhouse experiments. Inoculation of pearl millet panicles with the fungus at various times of ergot development resulted in 83-98% greater ovary colonization, 24-43% greater sclerotial colonization, 46-48% greater sclerotial disintegration, and 14-52% lower sclerotial formation than in the noninoculated, ergot-infected control panicles.

These studies suggest that *F. semitectum* var. *majus* might be biologically significant in some instances in reducing ergot damage under natural conditions. However, because of the relatively low value per hectare of the pearl millet crop and the lack of predictability of ergot epidemics, it is doubtful that this fungus could be successfully used as a biocontrol agent by farmers.

Identification of Major Diseases in Southern Africa

From 1986 to 1988, the SADCC Pearl Millet Disease Monitoring Nursery was grown at 17 locations (10 locations annually involving five countries). Disease severity was scored using a 0-9 scale (0 = disease absent, 9 = all plants severely affected). Ergot (*Claviceps fusiformis*), smut (*Tolyposporium penicillariae*), leaf spots (among others *Bipolaris uroehloae),* rust (*Puccinia penniseti*), and false mildew (*Beniowskia sphaeroidea*) reached severity levels above 3 at several locations, during at least 1 year. It is likely that screening for resistance to these diseases can be successful at these locations. Only one location in the region—Ngabu, Malawi, had disease levels high enough to enable screening in all 3 years of testing. Natural epidemics developed at this location for ergot in all years and for smut in 2 years.

Identification and verification of resistance to major diseases is slow and uncertain owing to the present lack of knowledge of disease hot-spot locations for screening. The search for disease hot-spot locations will continue in the ecologically diverse and large countries of Tanzania, Mozambique, and Angola. In addition, artifical inoculation, supplementary irrigation, and crop management are being used at a few locations where the major diseases are endemic.

Stem Borer [*Coniesta* (*Acigona*) *ignefusalis*]

The identification of genetic sources of resistance to the millet stem borer has the highest priority in pearl millet entomology research at ISC. However, before a screening program can be initiated, reliable and precise measurement techniques must be developed. Therefore, during the 1987 and 1988 growing seasons, we placed major emphasis on (1) sampling methods most suitable for assessing resistance/susceptibility in a screening program, (2) augmentation of natural populations for screening, and (3) understanding behavioral patterns of larvae and adults.

Sampling Methods

We assessed 20 different ways of assessing larval number to find out the best estimate of larval population densities. Data of 2 years show that larval exit holes in the stem made by the mature larvae gave a reliable estimate of larval numbers. In the 1987 rainy season, we conducted six different sampling trials in which the mean correlation between larval number and exit holes was r = 0.853 (range 0.711-0.955), while in 1988, the correlation from five field tests was r = 0.780. The actual ratio of exit holes to observed larvae was nearly 3:1 in all tests.

Not only is counting exit holes the fastest method of determining larval populations, but the stems can be examined and exit holes counted throughout the dry season. We will use this method to evaluate germplasm lines for stem borer resistance.

The 1987 and 1988 data show that four replications are needed to obtain a reliable evaluation and that a 5-m long, three-row plot is the minimum size that can be used to obtain reliable data.

Augmentation of Natural Stem Borer Populations

The pearl millet stem borer suffers a high mortality rate during the dry season. This results in an uneven spatial distribution of infestation, as well as delayed buildup of natural populations. Both these factors preclude an effective screening program that is dependent on natural populations alone. Beginning in 1987, we placed major effort on augmenting these low population levels and insuring a uniform infestation throughout test plots.

We found that survival of larvae in infested stems could be greatly enhanced if these are stored in a protected environment. Minimal shading and protection from rains resulted in more than 50% larval survival compared with 5% under natural conditions. Pupation of diapausing larvae could be regulated by withholding contact moisture. Therefore, timing of infestations can be controlled such that plots will be infested at desired stages of plant growth.

During the 1988 rainy season, we conducted several trials where we compared stem borer infestation in a group of four plots in which a bundle of infested stems was placed in the center of the group, to infestation in control groups of plots where no stems were placed. In three different tests, 98% of the plots which received infested stems, themselves became infested, compared with 78% of the control plots.

The results of these trials show that uniform infestations can now be achieved by placing infested stems in test areas and regulating the emergence pattern of adults by manipulating contact moisture and photoperiods.

Stem-borer Behavior Patterns

Pheromones are commonly used to monitor population densities of many different lepidopterous pests. It has been clearly demonstrated that virgin females of the pearl millet stem borer produce pheromone(s) that attract large numbers of males. A cooperative project was begun with the Overseas Development Natural Resources Institute (ODNRI) in UK to identify the active components of the stem-borer pheromone(s). Four components have been identified, but their biological activity has not yet been demonstrated in the field. However, through field-trapping studies, we have determined that 1-day-old virgin females are the most active (69%) producers of the pheromone and that yellow and green traps catch more males than do red, white, or blue ones. Seven different trap designs have been evaluated. Nocturnal observations also show that adults become active soon after dark, and feeding commences immediately, while the peak time for mating occurs shortly after midnight.

Plant Improvement: ICRISAT Center

Genetic Diversification

Evaluation of Rajasthan landraces. A successful pearl millet variety in the arid zones of northwestern India has to be adapted to drought, high soil temperatures at emergence, and high air temperatures during the grain-filling stage. Further requirements for such a variety are good fodder yield, and possibly, fodder quality. Assuming that this complex combination of traits would most likely be found in the local landrace material, we evaluated a large number of landrace populations from Rajasthan and its adjacent states to identify useful breeding material.

Initially we chose 304 landrace populations from the pearl millet collection in the ICRISAT Genetic Resources Unit gene bank, which were collected in the different agroclimatic zones of northwestern India. We evaluated these accessions in replicated trials in the 1988 dry season with full irrigation and under terminal (i.e., growth stage 3, GS3) drought stress. As controls, we used ICMH 451 and ICMV 1 (WC-C75) to represent ICRISAT material; RCB-2 and CZP 86, which are open-pollinated varieties from Rajasthan; and ICMH 88801, a topcross (A-line x population) hybrid having a Rajasthan population as pollinator, selected for its good performance under GS3 drought stress. We recorded early growth vigor (score), time to 50% flowering, plant height, yields of grain, panicles and straw, 100-seed mass, plant stand, panicle length and girth, and leaf width. In cooperation with germplasm botanists, we identified populations contaminated with alien genetic material, and then classified the noncontaminated populations into the six major traditional types of pearl millet found in Rajasthan: Desert type, Chadi, Barmer, Karauli, Jakharana, and Sulkhania.

For the trials in the following (1988) rainy season, we selected 153 noncontaminated populations, which represented the different traditional varieties, and which had a satisfactory yield in the dry season trials. The trial was grown at ICRISAT Center, Hisar in Haryana, and Fatehpur and Jodhpur in Rajasthan, and we evaluated the same traits and used the same controls as in the dry season.

The mean grain yields of the six test locations varied from 0.56 to 2.46 t ha^{-1} (Table 6); and the

Table 6. Grain yield of eight North Indian landrace groups at ICRISAT Center and in three North Indian locations, dry and rainy seasons 1988.

		Grain yield (t ha^{-1})					
		ICRISAT Center					
Landrace group	No. of entries	Full irrigation[1]	GS3 stress[1]	Rainy season	Hisar	Fatehpur	Jodhpur
Desert type	17	2.40	0.79	1.27	1.31	1.77	0.81
Chadi	46	2.04	0.84	1.28	1.51	1.93	0.76
Barmer	34	2.30	0.94	1.28	1.32	1.75	0.50
Karauli	12	2.44	0.99	1.36	1.24	1.35	0.27
Jakharana	6	2.39	0.98	1.41	1.26	1.73	0.36
Sulkhania	5	1.98	0.72	1.40	1.15	1.58	0.34
Punjab	11	2.60	0.93	1.36	2.11	1.71	0.48
Gujarat	22	2.44	0.50	1.35	1.35	1.38	0.32
Controls	15	3.51	1.17	2.04	2.83	2.36	0.58
SE[2]		±0.109	±0.058	±0.072	±0.123	±0.114	±0.063
Trial mean (168 entries)		2.46	0.90	1.38	1.53	1.77	0.58
CV (%)		17	25	20	24	25	53

1. Dry season.
2. Conservative estimate of SE of group means.

locations thus represented a broad range of environments. The very low yields at Jodhpur were caused primarily by drought and hot, desiccating winds starting towards the end of the flowering period. In Fatehpur, similar weather conditions occurred, but later in the growth cycle of the crop. The comparatively low yields at ICRISAT Center during the rainy season were probably due to high rainfall at flowering time, and waterlogging and leaching of nitrogen at the boot stage.

An analysis of grain yield data from all the locations revealed highly significant differences among the landrace populations. We summarized these results by grouping the landrace populations by type (Table 6). The superiority of the control cultivars at the highly productive sites and in the drought nursery was very clear, but not surprising, since the landraces have evolved under quite different environmental conditions. At these sites, most of the landrace groups were not very different. However, the landraces tended to yield comparatively better under conditions that resembled their origin; e.g., Punjab landraces at Hisar and Jakharana at Fatehpur. None of the landraces yield well at ICRISAT Center in the rainy season. At Jodhpur, the landraces originating from western Rajasthan, the Desert-type and Chadi, clearly outyielded both the controls and the other landrace populations. These results support our assumption that these are good parent material for starting a variety improvement programs targeted for this region. The variability among different populations is great, and thus progress from selection can be expected. However, genes for downy mildew resistance may have to be introduced into these landraces, which are quite susceptible to this disease.

Breeding Hybrids

Breeding Male-sterile Lines (A-lines)

Breeding methodology. In breeding A-lines, we usually begin by making crosses between adapted maintainer lines (B-lines) and advance generations from them by selfing, using bulk pedigree breeding. During these selfing generations, we evaluate the progenies for performance per se, combining ability, downy mildew resistance, reduced photoperiod sensitivity, and nonrestoration ability. We then backcross the B-lines we have finally selected, into a male-sterile cytoplasm (A-line) (Table 7).

Our methodology is designed to economize resources by selecting for highly heritable and important phenotypic characters in the early generations, before more extensive replicated trials in the later generations. We generally use dry-season sowings to advance the generations and to produce the testcrosses and topcrosses required in the selection scheme. We use the rainy season for progeny evaluation and replicated trials. We advance all generations after the F_2 by using the pedigree-bulk method, and screen for downy mildew resistance in the greenhouse at least each alternate generation from F_4 onwards. We describe below selection methods for male-sterile breeding line chosen from experience.

- Year 1: We cross selected parents, and grow F_1 plots to produce F_2 populations by selfing.
- Year 2: We sow with replication F_2 populations at ICRISAT Center and Hisar in the rainy season for evaluation and selfing. Sowing at Hisar (latitude 29°N) enables us to select plants of early maturity and reduced photoperiod sensitivity; sowing at ICRISAT Center (latitude 17°N) ensures against the risk of crop failures at Hisar and provides a further selection environment. In the following dry season, we replant at ICRISAT Center some of the very promising F_2 populations, which were also early at Hisar, for a larger-scale evaluation with more intensive selection.
- Year 3: We evaluate F_3 progenies at ICRISAT Center and at Hisar in small plots (single rows, 2-m long). We plant them at a 7-10-day interval in two different fields to provide different environmental conditions whilst reducing the risk of crop failure. At this stage, we do not self the F_3 progenies because a high proportion of this large number of lines will be rejected. In the next season, we regrow the

Table 7. Generation advance, Potential B-lines Trials (PBLT), and backcross procedures in male-sterile line breeding.

Year	Season[1]	Generation	Breeding operation/s
1	1	Parental	Cross parents to produce F_1s
	2	F_1	Self F_1s to produce F_2s
2	1	F_2	Evaluate F_2s and produce F_3 progenies
	2	F_2	Replant selected F_2s and produce F_3 progenies
3	1	F_3	Evaluate F_3s for yield, height, and maturity
	2	F_3	Replant selected F_3s for: • testcrossing on an A-line • producing F_4 progenies
4	1	F_4	Evaluate F_4s in PBLT-1 for: • grain yield, height, and maturity • downy mildew resistance and daylength response Produce F_5 progenies Evaluate testcrosses for sterility
	2	F_5	Evaluate F_5s for downy mildew resistance Produce F_6 progenies
5	1	F_6	Evaluate F_6s in PBLT-2 for: • grain yield, height, and maturity • seed set and seed size Produce F_7 progenies Cross on an A-line
	2	F_7	Evaluate F_7s for downy mildew resistance Produce F_8 progenies and topcrosses Make first backcross (BC_1)
6	1	F_8	Evaluate F_8s in PBLT-3 and their topcrosses in PBLT-3 topcross trial for: • grain yield, height, and maturity • *seed set* and seed size Make second backcross (BC_2).

Stop further setting of B-lines. Complete subsequent 4-5 backcrosses using rapid generation advance (three generations per year).

1. 1 = rainy season; 2 = dry season.

selected F_3 lines from remnant seed for selfing and a further evaluation.

- Years 4-6: We start replicated yield trials at the F_4 generation as the Potential B-lines Trial (PBLT series). PBLT-1 tests F_4 progenies in a single-row plot of 4 m, replicated twice at ICRISAT Center and at Hisar. PBLT-2, which consists of F_6 progenies, is grown at three locations in three replications with the same plot size as PBLT-1. PBLT-3 consists of F_8 progenies that are also topcrossed on three genetically diverse populations/varieties to constitute the PBLT-3 Topcross Trial (PBLT-3 TCT). We evaluate PBLT-3 and PBLT-3 TCT in adjacent blocks at three locations in two-row plots of 4 m, replicated three times.
- Years 5-6: At the F_7 stage, we begin to backcross selected PBLT-2 entries to initiate their conversion into A-lines. We follow line x line rather than plant * plant crossing throughout the conversion process as this is effective and less resource consuming.

Some variation in this method is required for certain crosses. In the case of crosses involving an unadapted parent, we continue selfing to the F_4 generation and then cross the selected progenies with adapted B-lines. Where the initial cross has a downy-mildew susceptible parent, greenhouse screening of F_3 progenies for downy mildew resistance precedes their field evaluation. For B-line x restorer line (R-line) crosses, where many of the progenies will be R-lines, the F_3 progenies are testcrossed on an A-line to identify and discard the R-lines before we test for yield and agronomic traits. This avoids unnecessarily advancing many progeny rows.

Combining ability of new, large-seeded male-sterile lines. To test a range of five new, large-seeded male-sterile lines for their ability to produce high-yielding hybrids, we crossed each of them, and the control male-sterile line ICMA 1 (81A), with 48 pollinators and evaluated the resultant F_1 hybrids.

All the large-seeded male-sterile lines were derived from the same germplasm originating from Togo; four lines (ICMA 88002 to ICMA

88005) are sister A-lines derived from a single S_7 progeny. These four lines have a characteristic yellowish green color that changes to green after flowering. This is a valuable character for maintaining the genetic purity of the lines.

In a yield trial of hybrids at ICRISAT Center, Bhavanisagar, and Hisar, yields of hybrids across locations made with all the large-seeded male-sterile lines were higher than the control hybrids made with ICMA1 (81A) (Table 8). Compared to the control hybrids, these hybrids flowered 2-3 days earlier at ICRISAT Center and Bhavanisagar, but had a similar flowering time at Hisar.

In another trial, we compared hybrids of 863A, a bulk of ICMA 88002 to ICMA 88004, and ICMA 1 (81A) made by crossing each with 20 genetically diverse pollinators, selected for their high combining ability on ICMA 1 (81A). At ICRISAT Center, hybrids made with large-seeded male-sterile lines outyielded those made with ICMA 1 (81A) by about 22%. At Hisar, they produced comparable grain yields and at Bhavanisagar, they yielded about 21% less. We therefore conclude that in most of the pearl-millet growing areas of India, these new male-sterile lines can produce higher-yielding hybrids than ICMA 1 (81A).

Of the new male-sterile lines, ICMA 88002 to ICMA 88005, ICMA 88004 has the greatest resistance to downy mildew; it has better seed set than 863A, and produces earlier hybrids than those on 863A but with equivalent yield potential. We have, therefore, selected this new male-sterile line for extensive use in our hybrid breeding program.

Yield potential of an F_1 male-sterile seed parent. Inbred male-sterile lines produce more uniform hybrids than the three-way hybrids produced by F_1 male-sterile seed parents. However, with the wide acceptance of more variable open-pollinated varieties by farmers, it is unlikely that the variability of a three-way hybrid on an F_1 male-sterile seed parent will be a significant barrier to its adoption. The use of F_1 male-sterile seed parents offers several potential advantages:

- An F_1 male sterile, because of its hybrid vigor, will produce more seed in hybrid seed production plots than an inbred male-sterile.
- A good male-sterile line that has become susceptible to downy mildew could still be used as a parent of an F_1 male-sterile seed parent. Because of the dominant inheritance of disease resistance, the F_1 male-sterile seed parent is likely to be resistant.

Table 8. Mean performance of hybrids on five large-seeded male-sterile lines at ICRISAT Center (IC), Bhavanisagar (Bsr), and Hisar (His), rainy season 1988.

	Grain yield (t ha^{-1})				Time to 50% flowering (days)			
Male-sterile line	Bsr	IC	His	Mean	Bsr	IC	His	Mean
863A	4.27	2.75	2.66	3.23	46	49	55	50
ICMA 88002	3.77	2.45	2.60	2.94	44	47	54	48
ICMA 88003	3.42	2.22	2.66	2.77	45	48	55	49
ICMA 88004	3.98	2.62	2.75	3.12	44	47	53	48
ICMA 88005	3.55	2.50	2.57	2.87	45	48	54	51
Control								
ICMA 1(81A)	3.52	1.96	2.39	2.62	48	51	54	51
SE	±0.065	±0.034	±0.054	±0.032	±0.1	±0.1	±0.2	±0.01
Trial mean (288 entries)	3.75	2.42	2.60	2.92	45	48	54	49
CV (%)	21	17	25		3	3	4	

- By judicious selection of parents, F_1 male-sterile seed parents could be produced, that combine the advantageous traits of both inbred parents without their disadvantages. For example, a male-sterile line with excellent downy mildew resistance and combining ability, but with poor seed set in the A-line could be used as the B-line parent in a cross to a susceptible A-line with excellent seed set. An F_1 male-sterile seed parent from this cross should have both downy mildew resistance and good seed set.

The yield potential of three-way hybrids has not been studied in pearl millet. We, therefore, compared the yields of three-way hybrids and single-cross hybrids. Male-sterile line 852A is a very good general combiner. However, it is tall, produces late hybrids, has variable seed set, and is downy-mildew susceptible in disease nurseries. It has medium-sized seeds. Male-sterile line 5054A matures early, is shorter in height, tillers profusely, is downy-mildew resistant, but has small seeds. We produced an F_1 male-sterile seed parent by crossing 852B on 5054A. We then crossed both this F_1 male-sterile seed parent and 852A with 24 genetically diverse restorer lines, and evaluated the hybrids at ICRISAT Center, Bhavanisagar, and Hisar. The three-way hybrids yielded 10% less at ICRISAT Center and 25% less at Bhavanisagar than the single-cross hybrids on 852A (Table 9). However, the three-way hybrids yielded about 6% more than the single-cross hybrids at Hisar, and were slightly earlier flowering and shorter in height, which was desirable. Our results show that the three-way hybrids on this F_1 male-sterile seed parent have a yield advantage only in one location over the single-cross hybrids, but the three-way hybrids were better adapted to areas in North India and had more desirable agronomic traits. The F_1 male-sterile seed parent was selected because of its superior phenotypic characteristics but 5054A is a much poorer combiner than 852A, and has clearly contributed this character to the F_1. These results are sufficiently encouraging for us to continue this research using different F_1 male-sterile seed parents to see if three-way hybrids can be obtained, which are higher yielding than those with the 5054A x 852B cross.

Hybrid Testing

Topcross hybrids. Topcross hybrids (A-line x open-pollinated variety) may have many advantages over single-cross hybrids (A-line x inbred restorer line).

- The more variable pollinator of the topcross hybrid can be constantly selected to maintain downy mildew resistance.

Table 9. Performance of hybrids on an inbred male-sterile line (8S2A) and an F_1 male-sterile seed parent (5054A x 852B) at ICRISAT Center (IC), Bhavanisagar (Bsr), and Hisar (His), rainy season 1988.

	Grain yield ($t\ ha^{-1}$)				Time to 50% flowering (days)				Plant height (m)			
Male-sterile line	Bsr	IC	His	Mean	Bsr	IC	His	Mean	Bsr	IC	His	Mean
852A	5.64	2.77	2.52	3.64	50	52	55	52	2.2	2.2	2.9	2.5
5054A x 852B	4.19	2.48	2.68	3.12	49	50	50	49	2.1	2.1	2.7	2.3
SE	±0.110	±0.034	±0.049		±0.5	±0.2	±0.3		±0.01	±0.01	±0.03	
Trial mean (48 entries)	4.92	2.63	2.60		50	51	53	51	2.2	2.2	2.8	2.4
CV (%)	18	11	16		8	3	6		5	5	10	

- The pollinator is more vigorous, as it does not suffer from inbreeding depression, making production of seed of both hybrids and pollinators easier.
- It is less likely that there will be nicking problems in producing the hybrid due to the greater spread of flowering in a variety.
- It does not take as many generations to breed as an inbred pollinator, and seed of experimental hybrids is easily produced as part of a topcross pollinator breeding scheme.
- Because of the expected durable disease resistance of the topcross pollinator, there is time to specifically breed A-lines for high combining ability with the pollinator.
- The more variable topcross hybrid will be less susceptible to diseases, such as downy mildew, than the single-cross hybrid.

We conducted two experiments to examine the yield potential of topcross hybrids. In one experiment, three high-yielding open-pollinated varieties, ICMV 1 (WC-C75), ICMV 87901 and ICMV 87902 from the Bold Seeded Early Composite (BSEC), and the High Protein Composite (HPC), were crossed in a nonsystematic way onto the male-sterile lines, ICMA 1 (81 A), 843 A, 852A, 863 A, ICMA 87002, and ICMA 87003, to produce 12 topcross hybrids. We evaluated these, along with three control hybrids, at three locations—ICRISAT Center, Bhavanisagar, and Hisar (Table 10). On average, the topcross hybrids did not show any improvement over their pollinator parents for grain yield, but HPC and ICMV 1 (WC-C75) topcross hybrids flowered earlier than their pollinators. However, when individual topcross hybrids were considered, some showed heterosis for grain yield over their pollinators. Topcross hybrid ICMA 1 (81A) x ICMV 87901 was significantly higher yielding than its high-yielding, open-pollinated variety pollinator (13% heterosis). The topcross hybrid, ICMH 87088, yielded about the same as ICMH 451 but flowered 4 days earlier. Other topcross hybrids with BSEC pollinators, e.g.,

Table 10. Summary of performance of selected topcross hybrids and their pollinator parents across three locations (ICRISAT Center, Bhavanisagar, and Hisar), rainy season 1988.

	Pollinator or control		Mean of topcross hybrids		Highest-yielding topcross hybrid			Lowest-yielding topcross hybrid		
Material[1]	Yield (t ha^{-1})	Time to 50% flowering (days)	Yield (t ha^{-1})	Time to 50% flowering (days)	Male sterile	Yield (t ha^{-1})	Time to 50% flowering (days)	Male sterile	Yield (t ha^{-1})	Time to 50% flowering (days)
HPC	2.57	54	2.61	51	863A	2.79	51	ICMA 87002	2.42	48
BSEC	2.7	45	2.77	47	ICMA1(81A)	3.13	48	863A	2.35	47
ICMV 1 (WC-C75)	2.76	52	2.71	48	863A	2.76	52	ICMA 87003	2.66	48
Control										
MBH 110	2.94	45								
ICMH451	2.79	52								
ICMH423	2.46	46								
SE	±0.171	±0.5								
Trial mean (48 entries)	2.71	48								

1. HPC = High Protein Composite; BSEC = Bold Seeded Early Composite.

863A x ICMV 87902, were significantly lower yielding than the pollinator, indicating large male sterile x pollinator interactions. None of the topcross hybrids having ICMV 1 (WC-C75) as the pollinator differed greatly in yield from ICMV 1 (WC-C75), but in the case of the HPC, its topcross hybrid on 863A was higher yielding (9% heterosis) and flowered earlier.

In the second experiment, three groups of materials were individually crossed onto the male-sterile lines 842A and 843A; (1) five landrace accessions, (2) five landrace open-pollinated varieties (improved landrace populations), and (3) five modern varieties (four high-yielding open-pollinated varieties and a composite). These 15 pollinators and 30 hybrids were evaluated across two nonstressed and three stressed environments at ICRISAT Center, Fatehpur, and Anantapur. The topcross hybrids differed significantly from the pollinators in time to 50% flowering, grain yield, and harvest index in all the three groups (Table 11). Grain yield heterosis varied from 18 to 33% across the groups. The highest-yielding topcross hybrids had modern varieties as pollinators, but the greatest heterosis of hybrid over pollinator was 33% in the case of the lowest-yielding improved landraces. The significant gain in yield found in the topcross hybrids can largely be attributed to improved harvest index, as there were no significant differences in biomass. Improved yield may also be attributed to the earliness of the topcross hybrids, which avoided terminal drought stress better than the later pollinators. The two male-sterile lines used, 842A and 843A, had equal combining abilities.

We conclude from the results of both these trials that topcross hybrids can provide a desirable alternative to single cross hybrids. As expected, large interactions occur between the topcross pollinators and the male-sterile lines used.

From encouraging trial results in 1987, we entered two topcross hybrids into the AICPMIP trials. These were ICMH 88088 (ICMA 1 (81A) x a BSEC population) and ICMH 88951 (843A x a BSEC population). ICMH 88088 displays significant heterosis over its pollinator and has a similar performance to its related hybrid ICMH 87088, i.e., it yields about the same as ICMH 451 but is earlier to flower and mature. In the case of ICMH 88951, we have not observed significant heterosis for grain yield over the pollinator. However, the hybrid flowers earlier than the pollinator (an advantage in terminal-drought stress) and has a more uniform appearance than the variety. This illustrates an important advantage of a topcross hybrid, its greatly improved appearance over the more variable variety.

As in the case of single-cross hybrids, the pollinator needs to be a restorer, so varieties or populations that have only been selected for yield require improvement for restoration ability. We have, therefore, started recurrent selection for combining ability and restoration ability

Table 11. Heterosis of topcross hybrids over their pollinator parent and performance of their pollinators across five environments, rainy season 1988.

Pollinator/group	Time to 50% flowering (days)	Heterosis[1] (%)	Grain yield (t ha^{-1})	Heterosis (%)	Biomass (t ha^{-1})	Heterosis (%)	Harvest index (%)	Heterosis (%)
Landrace accession	47	6***	2.36	26***	8.12	4NS[2]	29.5	21***
Landrace variety	48	6***	2.14	33***	8.17	3NS	26.9	27***
Modern variety	47	9***	2.60	18***	8.08	2NS	32.1	17***

1. Heterosis expressed as % earlier than pollinator;

*** $P < 0.001$ for difference between topcross and pollinator means.

2. NS = Not significant.

to breed topcross pollinators from four populations, BSEC, Early Composite 87 (EC 87), the High Tillering Population 88 (HiTiP 88), and the Bristled Early Composite 88 (BEC 88). We self single plants of the pollinator to produce S_1 seed, and also cross them onto an A-line. We then test the resultant hybrids for fertility and performance. We then sow, in an isolation, a range of A-lines and the selfed seed of only those plants that gave the best fertile hybrids to produce both the next cycle bulk of the topcross pollinator and topcross hybrids. In the case of BEC 88, the cytoplasm is A_1 so there is no need to make testcrosses to determine fertility restoration. This simplifies the breeding procedure at the expense of cytoplasmic diversity.

Plant Improvement: ICRISAT Sahelian Center

Breeding is one of the three pearl millet research units located at ISC, and is responsible for breeding pearl millet suitable for the southern Sahelian zone (300-700 mm annual rainfall). This unit deals with breeding male-sterile lines and assessment of the potential of pearl millet hybrids in this region, among other research projects. The following is a report of results of research conducted with this objective over the last 2 years.

Breeding Male-sterile Lines for West Africa

Evaluation of Existing Male-sterile Lines

We previously measured yield advantages of F_1 hybrids (male-sterile line x inbred restorer line or variety) of as much as 60% over our improved variety controls (ICRISAT Annual Report 1985, pp. 116-117). However, the limited range of male-sterile lines that we evaluated for producing hybrids were all susceptible to downy mildew. Over the last 2 years, we evaluated a large number of available pearl millet male steriles for their reaction to downy mildew at ISC. These included 23 A and B pairs obtained from ICRISAT Center, the Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM), and the Coastal Plains Experiment Station, Tifton, Georgia, USA (Table 12). Several of these male-sterile lines originate from West Africa: N 86-287/288 A has cytoplasm from *Pennisetum violaceum* in the landrace Tiotande (originating from Mauritania); Tift 85D2 incorporates genes for rust and *Pyricularia* sp resistance from *P. monodii* (from Senegal) in the Tift 23D background; and the DSA and PMC series of male-sterile lines were identified by the GRU from accessions from Ghana and Botswana.

Two years of evaluation data at Sadore indicates a very high level of susceptibility to downy mildew in nearly all these A/B pairs (Table 12). Only five pairs [833 A/B, ICMA/B 4 (834 A/B), ICMA841 (841A)/ICMB841 (841B), DSA 144-1 A/B, and PMC 23 A/B] had less than 50% incidence in both the A- and B-lines. In previous years, we also found A and B pairs of 842, 843, and 852 to be susceptible to downy mildew. Thus all available male-sterile lines from West Africa and ICRISAT Center are too susceptible to be used directly at Sadore in breeding hybrids.

Breeding New Male-sterile Lines

We are attempting to select downy-mildew resistant versions of five of the existing less susceptible male-sterile lines (833, 841, 863, DSA 134, PMC 23), by making plant x plant crosses between A/B pairs, using downy-mildew free plants. Forty-two such crosses were evaluated in the downy mildew nursery in 1988, from which we have generated 35 new plant x plant pairs (downy-mildew free plants) to continue selection for downy mildew resistance.

In previous years, we reported incorporation of sterile cytoplasms into lines with West African backgrounds to develop adapted male-sterile lines (ICRISAT Annual Reports 1986, p. 111;

and 1987, p. 115). In 1987, we identified two pairs of ICMA 1(81 A) x Souna Mali$_5$ that were free of downy mildew in the postrainy season.

Table 12. Reaction to downy mildew of 23 A and B pairs of pearl millet, ISC, Niger, postrainy seasons 1987 and 1988.

A and B pair	Origin[1]	Downy mildew incidence (% hills)[2] A-line	B-line
ICMA/B1 (81A/B)	IC	95	100
833 A/B	IC	13	27
ICMA/B 4 (834A/B)	IC	36	36
ICMA 841 (841A)/ ICMB 841 (841B)	IC	50	18
861A/B	IC	100	100
862 A/ B	IC	94	88
863 A/ B	IC	81	72
ICMA/B 87001	IC	100	100
ICMA/B 87002	IC	100	100
ICMA/B 87003	IC	95	81
Pb 1IIA/B	PAU	100	100
5054 A/B	IARI	100	100
5I41A/B	IARI	65	54
DSA 105 A/B	GRU	100	100
DSA 118A/B	GRU	100	100
DSA 134A/B	GRU	27	63
DSA 144-1A/ B	GRU	40	18
DSA 501A/B	GRU	100	100
PMC 23A/B	GRU	9	0
PMC 30A/B	GRU	50	90
N 86-287/288A/B	ORSTQM	86	95
85D2A/B	Tifton	69[3]	83
ICMA 88001	IC	96[3]	-

1. IC = ICRISAT Center; PAU = Punjab Agricultural University; IARI = Indian Agricultural Research Institute; GRU = ICRISAT Genetic Resources Unit; Tifton = Coastal Plains Research Station, Tifton GA, USA.
2. Hill population (2 plants hill^{-1}) ranged from 10 to 54 hills per entry, downy mildew as natural incidence.
3. Downy mildew incidence, as percentage of plants, plant population varied from 24-51 per entry. Mean incidence on the NHB-3 indicator was 73%. Results from downy mildew nursery, ISC, postrainy season 1988.

We generated 29 plant x plant pairs from this cross and screened them for downy mildew reaction in the 1988 postrainy season at Sadore. A-lines of 4 pairs were sterile, 13 were segregating for sterility and fertility, and the remaining 12 were fertile. Mean downy-mildew incidence was 3% in the steriles and 6% in the fertiles, which was markedly lower than that in A/B pairs generated from the existing male steriles (Table 13). We generated a further 18 plant x plant crosses using pairs in which the A-line was sterile. These will be planted in the 1989 dry season for assessing uniformity, confirming sterility status of the A-line, and seed increase.

The ORSTOM team continued their research on male-sterility maintainers of P. *violaceum*(V) cytoplasm. Thirty accessions of diverse geographical origins and different maturities have been identified as maintainers of sterility of V cytoplasm (ICRISAT Annual Report 1987, p. 116). These were crossed with an A, male-sterile line. There were frequent cases of partial restoration of A, sterile cytoplasm but no case of complete male fertility restoration in these crosses, indicating that A_1 and V cytoplasms are not very different. This confirms work at ICRISAT Center (ICRISAT Annual Report 1987, p. 109). Some of these maintainer lines will be included in our male-sterile breeding project.

Experience gained thus far in breeding male-steriles for West Africa indicates that it is important to select for the required adaptative traits-resistance to downy mildew, early plant vigor, and maturity similar to improved varieties. We can effectively select for maturity and downy mildew resistance at Sadore. The next step is to select for durable resistances by multilocational selection.

Inbred x Variety Hybrids

Results obtained indicate that non A-line inbred x variety hybrids (a form of topcross hybrids) offer a better potential than single-cross hybrids. These hybrids are not morphologically uniform, but should have higher levels of downy mildew resistance, and could be rapidly produced because

Table 13. Summary of reaction to downy mildew of plant x plant crosses of five A and B pairs of pearl millet, ISC, Niger, postrainy season 1988.

		Downy mildew incidence (%)[1]				
		Mean		Range		
A/B pair	No. of pairs tested	A-line	B-line	A-line	B-line	No. of new pairs generated
833	4	22	36	0 47	0-64	4
863	19	56	49	4 100	0-100	15
DSA 134	17	36	42	8-77	10-80	12
PMC 23	1	0	77			4
841	1	62	92			0
81A x Souna (Mali)	29	3	6	0-18	0-13	18
Controls						
NHB 3		54				
HB 3		63				
7042		99				

1. Screening in the downy mildew nursery; mean plant populations ranged from 12-24 plants per entry.

of the possibility of directly using new inbred lines as seed parents without the tedious procedure of first identifying maintainer lines. We conducted a yield trial of 32 such topcross hybrids in 1988. These were derived using four partial inbreds (originally selected as pollinators, ICRISAT Annual Report 1987, p. 116) as seed parents and eight improved varieties as pollen parents. Preliminary results indicated yield advantages of these topcross hybrids over the best controls of 2-24% (Table 14). We selected four of these topcross hybrids for further evaluation. In addition, we selected from our genetic diversification project, over 100 progenies combining a high tiller number, short plant stature, and synchronous tillering for use as female parents in the production of new, similar topcross hybrids.

In the near future, we will place equal emphasis on breeding downy-mildew resistant male-sterile lines and such inbred x variety topcross hybrids in the development of hybrids for West Africa.

Table 14. Mean performance of pearl millet topcross hybrids for grain yield and downy mildew, ISC, Niger, rainy season 1988.

Entries	Grain yield ($t\ ha^{-1}$)	Downy mildew incidence (%)[1]
Female parents (4)	1.04	38
Hybrids (32)	2.24	39
Male parents (8)	1.87	33
Controls		
C1VT		60
HKP		57
P_3Kolo		47
SE	±0.23	-
Trial mean (44 entries)	2.07	37
CV (%)	22	-

1. Recorded in the downy mildew nursery in the postrainy season 1988. Plant population ranged from 14-24 plants.

Cooperation with National Programs

ICRISAT Center

Supply of Breeding Materials

In 1988 we sent 7692 seed samples to 21 countries (Table 15). Most of these lines were nursery or trial entries. The trials were the Pearl Millet Bulk Progeny Nursery (PMBPN) and our two Elite Products Nurseries (ELPN-1 and ELPN-2). ELPN-1 consists of 11 ICRISAT hybrids and ELPN-2 has 17 ICRISAT varieties; all these hybrids and varieties are released or are in AICPMIP trials. These two nurseries are preliminary trials for scientists who wish to test a limited range of elite material. The PMBPN is a set of variable progenies selected from our Potential R-lines Nursery. This nursery was widely grown by cooperating scientists in India to select, by selfing, promising lines adapted to their locations.

Varieties for National Trials

Eight varieties and six hybrids from ICRISAT Center were tested in the 1988 AICPMIP trials.

Table 15. Pearl millet seed samples dispatched from ICRISAT Center to various countries during 1988.

Country	Breeder seed	No.of sets of trials/ nurseries	Trial entries	Breeding lines	Total samples[1]
Bangladesh	0	2	28	0	28
Burma	0	0	0	7	7
Federal Republic of Germany	0	0	0	6	6
Gambia	0	2	28	6	34
Ghana	0	0	0	3	3
Guinea	0	2	28	3	31
India	507	115	4618	970	6095
Indonesia	0	6	102	0	102
Jordan	0	I	17	0	17
Mexico	0	3	64	13	77
Niger	0	12[2]	72	239	311
Pakistan	0	7	296	17	313
Panama	0	1	17	0	17
People's Republic of China	0	1	17	0	17
Swaziland	0	0	0	13	13
Thailand	0	2	28	0	28
UK	0	0	0	6	6
USA	0	0	0	1	1
Yemen Arab Republic	0	1	17	0	17
Zambia	0	0	0	267	267
Zimbabwe	0	23	151	151	302
Total samples	507	178	5483	1702	7692

1. Excludes replications in trials and nurseries.
2. Some samples were further distributed by ISC from Niger to other SAT countries in West Africa.

Two of the six hybrids were topcross hybrids; this is the first time we have entered topcross hybrids in AICPMIP trials. In addition, five varieties were jointly entered by cooperators and by ICRISAT Center. We contributed three restorer lines and 12 A/B pairs to parental line trials, and also provided several entries as standard controls including ICMV 1 (WC-C75) and ICMH 451.

Of the seven hybrids only one (ICMH 84122) was retained for a 3rd year of testing, and one (ICMH 87004) was moved from the early- to the normal-duration hybrid trial. We withdrew two hybrids even though they were second and third ranked for grain yield in the trial (after ICMH 451, which ranked first), because of downy-mildew susceptibility in the male-sterile line, 852A. The remaining three hybrids were dropped because they were not sufficiently high yielding.

Of the eight varieties, six were retained. The most promising of the varieties that have been in the trials for more than 1 year is ICMV 84400. Over 2 years, it yielded 112% of the grain yield of ICMV 1 (WC-C75)and 114% of its fodder yield. It has the same maturity as ICMV 1 (WC-C75). The four cooperator/ICRISAT entries were also retained.

International Pearl Millet Adaptation Trial (IPMAT)

The International Pearl Millet Adaptation Trial 1988 had 19 entries including 1 local control (9 hybrids and 9 varieties). It was sent to 15 locations in India and Pakistan. Five entries were from our cooperators. ICMH 87030, a hybrid on male-sterile line 863A, was the highest-yielding entry (2.69 t ha^{-1}). It yielded 6% more grain than ICMH 451 and was 4 days earlier to bloom. The highest-yielding open-pollinated varieties were from the Inter-Varietal Composite (IVC), the Early Composite II (EC II), and the Medium Composite (MC). All these varieties yielded about 2.26 t ha^{-1},17% more than WC-C75. The early open-pollinated variety ICMV 87901 from the Bold Seeded Early Composite (BSEC) yielded 2.18 t ha^{-1}, 13% more than WG-C75 and 10% more than the large-seeded released variety ICTP 8203.

Disease Nurseries

We evaluated 179 entries in seven AICPMIP trials and nurseries at ICRISAT Center for their reactions to downy mildew and rust, and some of these entries for reactions to ergot and smut. In the advanced hybrid and variety trials, half the entries had <5% downy mildew and relatively few entries >20% downy mildew; downy mildew levels were somewhat higher in the initial hybrid and variety trials. In contrast, considerably higher levels of downy-mildew susceptibility were found in the A/ B nursery where almost half the entries had >20% downy mildew, emphasizing the generally high degree of vulnerability to downy mildew in this important component of hybrid breeding in India.

We also evaluated materials from other programs in our downy mildew nursery as a service to these programs. These included 47 pearl millet entries for an AICPMIP breeder engaged in a study on inheritance of resistance to downy mildew, and 54 breeding lines for a private seed company that is producing hybrids for cultivation by Indian farmers.

The International Pearl Millet Downy Mildew Nursery (IPMDMN) with 30 test entries (25 of them breeding lines) was grown at six locations in India and five locations in West Africa. High levels of downy mildew occurred on at least some entries at all locations; ail West African locations had higher mean downy mildew levels than any Indian location. Two genetic resources accessions, P 310-17 and P1449-3, again showed a high level of resistance to downy mildew (<5% across-location mean severity). Remarkable differential response to downy mildew was noted in several entries among Indian and West African locations, confirming our earlier findings suggesting the existence of distinct pathotypes of *S. graminicola.*

We obtained data on the International Pearl Millet Rust Nursery (IPMRN) grown at three locations, all in India. All 21 test entries are genetic resources accessions that have undergone at least some selection pressure for resistance to pearl millet rust. Most entries showed considerable resistance to rust compared with the susceptible controls. Three entries, 7042-1-4-4, P 24-1, and 700481-21-8, had rust severities of ⩽ 10% on upper leaves at all locations, confirming results obtained in previous years.

Results from the 1988 International Pearl Millet Smut Nursery (IPMSN), grown and evaluated at two locations in India and two locations in Niger, confirmed the smut resistance (<5% severity) of the eight smut-resistant lines tested. However, smut severity scores ranged from 19 to 47% (except one with 1%) for the eight B-lines that are undergoing selection and breeding for smut resistance and for seven restorer lines. Though these severities are still high, it is encouraging that several of these lines had smut severity values considerably lower than the smut severities (>55%) of the susceptible controls.

Release and Adoption of ICRISAT Materials

ICRISAT has two hybrids, ICMH 451 and ICMH 423, under cultivation in India. Of these, ICMH 451 is now grown on a large scale, while ICMH 423 is still mainly in the seed multiplication stage. HHB 50 of Haryana Agricultural University (HAU), which has ICRISAT's ICMA 1 (81 A) as the seed parent, is being marketed in Haryana, and Pusa 23 of the Indian Agricultural Research Institute (IARI), which has ICRISAT's ICMA 841 (841 A) as the seed parent, is under multiplication.

ICMV 1 (WC-C75) continues to be grown on a large scale in India (at least 1 million ha) and ICMV 4 (ICMS 7703) has widespread adoption in Tamil Nadu. The area of ICTP 8203 increased in 1988 in Maharashtra over 1987, its 1st year of cultivation. This early-maturing, large-grained variety is proving very popular with the farmers as judged by the high demand for breeder seed. ICTP 8203 was notified by the Indian Ministry in December 1988, and is recommended for cultivation in Maharashtra and Andhra Pradesh. A second hybrid of HAU, HHB 60, was notified in December 1988 for cultivation in Haryana. As in the case of HHB 50, the seed parent is ICMA 1 (81A).

Supply of Breeder Seed

We supplied 446 samples of breeder seed to seed producers in India. In terms of seed quantity, this amounted to 1427 kg for hybrid parents and 1390 kg for varieties (Table 16). Parents of ICMH 451 accounted for 77% of the total seed supplies of all the hybrid parents, and ICMV 1 (WC-C75) accounted for 61% of the total seed supplies of all the varieties.

In all cases, supply of breeder seed increased considerably over that in 1987, with the exception of ICMS 7704 which, after many years of testing, was not released. Total supply of breeder seed is, however, only an indication of certified seed production. In the case of open-pollinated

Table 16. Quantities of breeder seed supplied by ICRISAT Center to various seed producers during 1988.

Material	Quantity (kg) '	No. of requests
Parents of ICMH 451		
ICMA(8IA)	540	71
ICMB(81B)	233	71
ICMP451	322	70
Parents of ICMH 501		
834A	90	8
834B	45	8
ICMP 501	4	2
Parents of ICMH 423		
ICMA 841 (841A)	88	36
ICMB 841 (841B)	48	36
ICMP 423	57	29
Open-pollinated varieties		
ICMV 1 (WC-C75)	847	67
ICMS 7703	255	32
ICMS 7704	2	1
ICTP 8203	286	45
Total	2817	446

varieties, for example, breeder seed may sometimes be used for direct production of certified seed, but is usually used to produce foundation seed. Such foundation seed may or may not have a further generation of multiplication (to foundation seed 2) before it is used for certified seed production. The requirement for breeder seed varies greatly depending on the multiplication scheme that is followed.

ICRISAT Center Field Day for Pearl Millet Seed Producers

This event, the first of its kind for pearl millet, was held to facilitate information and technology transfer between pearl millet improvement at ICRISAT Center and the private and public sector pearl millet seed producers in India. A total of 29 people attended, representing 20 private seed companies, 5 state seed corporations, and the National Seeds Corporation. The Coordinator of AICPMIP also attended. During a tour of our research fields, we showed participants hybrids and varieties that have been released or are in advanced testing, B-line F_3 progenies, the pollinator collection, dwarf hybrids, and the downy mildew nursery (Fig. 5). A discussion session was held during which we obtained feedback from producers on the performance and problems associated with our released materials. The Economics Unit (Resource Management Program) presented a preliminary report on sorghum and pearl millet research and seed production by private seed companies in India. The participants commented favorably on our research program, although private sector producers expressed concern about the occasional difficulty in obtaining seed of hybrid parents.

ICRISAT Sahelian Center

Supply of Breeding Materials

We supply improved breeding material to national and regional programs in the form of breeder seed, elite breeding lines, progenies at various levels of inbreeding, and varieties, as well as meeting specific seed requests. During the year, we supplied over 700 seed samples to eight countries not including our regional, advanced, and initial trials, and seed supplied in bulk for large-scale evaluations. In particular, we sent large numbers of elite breeding lines to Burkina Faso, Mali, and Senegal.

Regional and International Yield Trials

Results of the 1987 Pearl Millet Zone A Adaptation Trial (IMZAT-87) are reported this year. This trial consisted of 15 test entries—three contributed by Institut national de recherches agronomiques du Niger (INRAN), three by the Institute for Agricultural Research (IAR), Nigeria, and nine by ISC. Locally chosen, improved varieties were used as controls at each of the 13 locations in eight countries of West Africa to which the trial was distributed. At five locations (Kolo, Sadore, Bengou, Kamboinse, and Samaru) from which usable data are available, the cultivar differences in grain yield were significant ($P < 0.05$) only at Bengou, Kamboinse, and Sadore. The test entries yielding 100% or more of the controls at these locations included: SE 360, SE 2124, and INMV 8298 at Bengou; ICMV 7 (ITMV 8304), ICMV IS 85327, and IKMV 8201 at Kamboinse; and INMV 8298 and CT-2 at Sadore. We plan to include these seven entries in IMZAT-1988.

We now screen new varieties bred at ICRISAT Center for adaptation to the Sahelian zone—first all varieties for downy mildew reaction and then those entries that show low levels of downy mildew for stand establishment. During this year, we have grown 87 test entries of Center-coordinated yield trials in the downy mildew nursery in the postrainy season. Mean downy mildew incidence was 57%, only five varieties had a downy mildew incidence lower than 10%. These five varieties will be screened for seedling establishment by the agronomist during the dry season and better entries will be included in our preliminary variety trials. Two varieties in

Figure 5. ICRISAT scientists showing a hybrid breeding demonstration to participants in the Field Pay held for pearl millet seed producers from the private and public sectors in India.

the ICRISAT Center Early Varieties Trial, ICMV-E 8313 and ICMV-D85307 (ICRISAT Annual Report 1987, p. 124) yielded as much as the improved early control variety HKB Tif at Sadore (1.20 t ha^{-1}, compared with the trial mean of 1.11 ±0.13 t ha^{-1}). These two varieties will also be included in the preliminary variety trial of 1989.

Regional Disease Nurseries

The West African Downy Mildew Observation Nursery (WADMON) was grown and evaluated in 1988 by national programs and the ISC at nine locations in eight countries (Benin, Burkina Faso, Ghana, Guinea 3issau, Mali, Niger, Nigeria, and Senegal). The purpose of this nursery is to give national programs and the ISC scientists an opportunity to test the effectiveness of downy mildew resistance across locations in elite materials, including released cultivars, varieties at the prerelease stage, advanced breeding materials, and in some cases, local unimproved material (landraces). At the time of reporting, we had received data from six locations. The lowest mean downy mildew incidence was recorded at Ina (Benin) with 1.6% and at Bambey (Senegal) with 1.9% and the highest incidence at Bengou (Niger) with 28.1% and at Bawku Manga (Ghana) with 17.9%. Out of the 32 entries tested, 22 had less than 10% downy mildew incidence. SE 13 and Ex-Bornu from Nigeria had the least downy mildew incidence (less than 2%); the downy-mildew susceptible control 7042 had 68% and control NHB 3 had 36% across all six locations.

The WADMVN was sent to 10 locations in eight countries in West Africa, and results were received from seven locations. This nursery aims to study variability of virulence of the downy mildew pathogen in West Africa. Details are reported in the 'Biotic Stresses' section of this report, under 'Virulence of *Sclerospora graminicola'* (West Africa).

Varieties for National Testing

Six varieties have been in large-scale tests in Burkina Faso since 1987, or have been recommended for general cultivation (ICRISAT Annual Report 1987, p. 125). During 1988, we supplied over 200 kg of breeder and foundation seed of varieties IKMP 1, IKMP 2, IKMP 3, IKMP 5, IKMV 8201, and IKMC 1 to the Organisme regional de developpement (ORD), Yetanga, Accelerated Agricultural Development Project, Semi-Arid Food Grain Research and Development (SAFGRAD), and to the Institut national d'etudes et de recherches agricoles (INERA) of Burkina Faso, for on-farm tests and seed multiplication. In 1986, we supplied large quantities of seed to the Projet production de semences en zone Sahelienne of the Programme des Nations Unies pour le developpement (PNUD)/Food and Agricultural Organization of the United Nations (FAO) of varieties ICMV 5 (ITMV 8001) and ICMV 7 (ITMV 8304) developed by ICRISAT/INRAN. We are informed that during 1986-88, about 80 t of seed of ICMV 5 (ITMV 8001) was produced and that the variety is now grown on an estimated 16 000 ha. Variety IBMV 8001 developed by ICRISAT/Institut senegalais de recherches agricoles (ISRA) is being multiplied in Mali by the Section de reglementation et de controle des semences selectionnees of Institut d'economie rurale (IER) and distributed to extension agencies for seed production and distribution to farmers. However, accurate figures on actual seed quantities are not available.

This year we supplied 2 kg each of three varieties developed at the ISC (ICMV-IS- 85333, ICMV-IS 85327, ICMV-IS 88201), and IKMV 8201 to Projet Keita of FAO; 40 kg of ICMV 7 (ITMV 8304), 4 kg each of four ISC-bred varieties and 2 kg each of ICTP 8203 and ICMV 87901 for on-farm testing to Projet Productivite de Niamey, Niger. To IER, Mali, we supplied 2-3 kg seed of five ISC-bred varieties for on-station evaluation. We supplied seed of nine early varieties to Aide de l'Eglise norwegienne in Mali for tests on farmers' fields.

SADCC/ICRISAT Regional Program

ICRISAT's millet program in southern Africa seeks to breed or introduce superior genotypes of pearl millet, finger millet, and several cereal forage species adapted to the different agroclimatic zones of the SADCC region. This includes organization of regional trials and selection nurseries for all these crops, organization of regional workshops, field tours, etc., and specific support activities for individual national programs as requested.

Pearl Millet Breeding

Breeding material. We collected 541 pearl millet accessions from Zimbabwe with the assistance of ICRISAT's GRU, to add to our collection of 1764 accessions from the millet-growing areas of the SADCC countries. All the accessions were multiplied in the offseason at Mzarabani this year, to have them ready for systematic evaluation and characterization. This season we shall evaluate the collections from Tanzania and Zimbabwe. There is still a need to collect from the western province of Zambia, northern Botswana, Mozambique, and the southern parts of Angola.

The genetic base of the four composites constituted in 1985, early, medium, dwarf, and bristled (ICRISAT Annual Report 1985, pp. 132-133), was further diversified by merging the early and medium composites, and including new materials in the dwarf and in the bristled composites. We identified two hybrids from our hybrid trials: ICMH-SD 88001 (81A x SDPC 8) and ICMH-SD 88002 (81A x SDPC 7), which yielded 80% more grain than RMP1, the only released variety in Zimbabwe. These hybrids are being evaluated in the Regional Advanced Hybrid Trial during the 1988/89 rainy season.

Regional trials. This year, five pearl millet regional trials were conducted in three to six locations. The trials were the Early-Maturing Varieties Trial (EMVT), the Medium-Maturing Varieties Trial (MMVT), the Dwarf Entries Trial (DET), the Hybrid Trial, and the Pearl Millet Regional Cooperative Initial Trial. ICMV 84421, ICMS 8359, and ICMV 82132 from the EMVT, ICMV-SD 87014 from the MMVT, and NC(d_2) from the DET were selected for large-scale testing throughout the SADCC region. All these were 15-49% superior in grain yield to RMP1, the improved control entry from Zimbabwe. All the selected entries, except ICMV-SD 87014, are direct introductions from ICRISAT Center.

Results from several years of regional pearl millet trials indicate that varieties introduced from ICRISAT Center perform well in most of the SADCC countries, with the exception of Tanzania. Most materials from Tanzania and northern parts of Zambia, Malawi, and Mozambique are later maturing than ICRISAT Center materials and are more photoperiod sensitive. The regional program is collaborating with the Tanzanian national program to develop a composite based on elite, late-maturing accessions from Tanzania and elsewhere. The composite is currently in its fourth generation of random mating.

Forage Crop Breeding

The improvement of sorghum and millets for forage was started in late 1987. The major activity this year has been the introduction and evaluation of germplasm: we have so far acquired 147 accessions of forage sorghums, 106 of sudan grass, 107 of pearl millet, 35 of *Pennisetum monodii,* 65 of minor millets (5 species), 20 of napier grass (*P. purpurenum*), and 5 hybrids between pearl millet and napier grass (known as bana grass in this region). We have also acquired 85 accessions of forage cereals, legumes, and browse trees from the International Livestock Centre for Africa (ILCA) for use in crop-association studies.

From an initial cereal forage introduction trial consisting of 81 entries, planted in Zimbabwe, Botswana, Mozambique, Lesotho, and Swaziland during the 1986/87 rainy season, 25 entries were advanced into a Cereal Forage Yield Trial in 1987/88. Results were obtained from 11 locations in seven countries. However, none of the introduced entries was superior to the pearl millet control variety 'Babala'from South Africa, which produced 12.5 t ha^{-1} of dry fodder.

A crossing program has been initiated between selected sorghum and sudan grass accessions and among pearl millet and napier grass. Attempts are being made to transfer brown-midrib genes for forage quality into agronomically superior backgrounds. A forage pearl millet composite is being constituted by recombining the 38 best pearl millet lines.

Finger Millet Breeding

During 1988, we collected 150 accessions of finger millet from Zimbabwe and added 403 accessions from the ICRISAT's GRU. We now have a total of 1708 accessions, but there is still a need to collect from Tanzania and several East African countries.

The program organized and distributed three regional finger millet trials, each of which was sent to about 3-6 locations in the region. The highest-ranked entries in each of the early, medium, and late variety trials had mean yields between 1.9 and 2.3 t ha^{-1} across locations. Forty-three of the total of 107 entries were selected for further testing. Several additional entries were selected for specific characters: white seed, long spikes or fingers, large glumes, and branched spikes.

Publications

Institute Publications

Plant Material Description

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Pearl millet hybrid ICMH 451. Plant Material Description no. 14. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-133-X. (PME 014)

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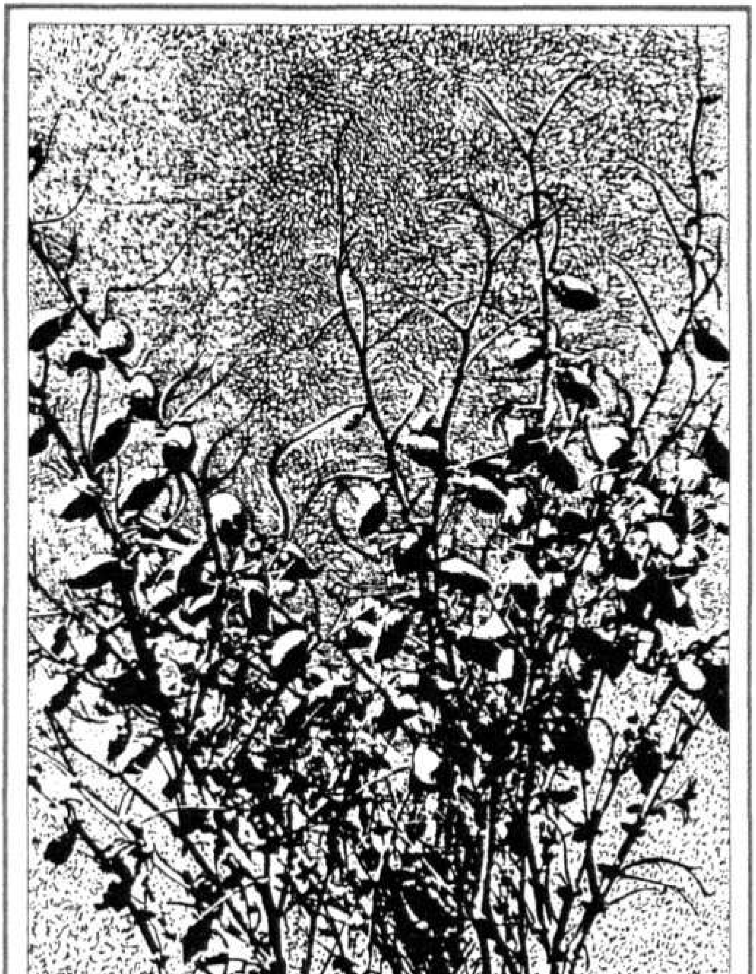
LEGUMES

CHICKPEA



Contents

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CHICKPEA

Chickpea is an ancient, well-established crop in many countries, and a new, rapidly expanding species in several others, e.g., Australia. The largest producer of the crop is India, followed by Turkey, and not far behind is Pakistan. The seed yield per unit area of land differs considerably from country to country. Pakistan, for instance, reports average yields of 0.56 t ha^{-1}, while Turkey averages 1.20 t ha^{-1}. This underscores the large ecological variations between the 45° N and S latitudes in which the crop is produced. This report, therefore, covers not only work conducted at ICRISAT Center, but also collaborative research with the International Center for Agricultural Research in Dry Areas (ICARDA), Syria; the National Agricultural Research Centre (NARC), Pakistan; the All India Coordinated Pulses Improvement Project (AICPIP); and national programs of several countries.

Chickpea, when grown under optimal conditions, can give yields of over 4 t ha^{-1}, but deviations from such conditions may decrease yields drastically. Therefore, this report pays considerable attention to factors that reduce yield. These can be abiotic, such as drought and low temperature, or biotic, where fungal and viral diseases, nematodes, and pests reduce yield. We observed that the drought-tolerant variety, ICC 4958, had a 30% greater root length and volume than Annigeri, a widely used high-yielding control cultivar, and attempts are being made to combine the root characters of ICC 4958 with the canopy characters of Annigeri. The identification of genotypes that form pods under low temperatures, ranging from -1°C to 7°C, may have important implications for chickpea improvement. The multiple-disease resistance screening work was intensified. Tests over two to three seasons enabled us to identify nine high-yielding lines with less than 20% mortality under multiple-disease infestation. Pod borers caused serious damage to chickpea in many areas. It was, therefore, of practical interest to learn from ovipositional studies that ICCL 86102 (ICRISAT Annual Report 1986, pp. 139-140) and other lines had 28-33% fewer eggs than the control cultivar, Annigeri, this year. It was also gratifying to note that short-duration varieties (e.g., ICCV 2) were in great demand by farmers in peninsular India.

Protein quality is of increasing importance in grain legumes, and interestingly, our biochemists observed that the biological value of the kabuli-type chickpeas was higher than that of the desi-type chickpeas, resulting in higher values for utilizable protein.

The genetic improvement program concentrated on combining high yield with resistance to stress factors. Combined low ratings for wilt, stunt, ascochyta blight, and pod-borer damage were given to a selection made in a 1983 cross, which was tested in the relevant screening nurseries. The data compiled over the past 5 years for the early-sowing trials (ICRISAT Annual Reports, 1983, p. 136; 1984, p. 149; 1985, pp. 160-161; 1986, pp.154-155; 1987, pp. 163-165) revealed that an average yield advantage of 25% over normal sowing was achieved by this practice. Combination breeding had given some remarkable results of yield increase, while mutation breeding enabled plant selection for significantly increased seed masses. We began some work on cell and tissue culture, mainly to standardize techniques for micropropagation, plant regeneration by somatic embryogenesis, and embryo rescue for interspecific crosses.

The ICARDA/ICRISAT Chickpea Improvement Program in Syria had a major thrust on breeding for combined resistance to stress factors, such as ascochyta blight and cold temperatures, while an increase in varietal releases was the result of its sustained efforts at crop improvement. The National Chickpea Improvement Project of Pakistan pursued its breeding work for ascochyta blight resistance, and capitalized on its success of previous seasons by off-season seed multiplication of resistant material with acceptable agronomic performance.

A key factor in all future improvement work is the availability or development of appropriate screening techniques to stabilize seed yield with the required quality characteristics, so that improved products of early or more advanced generations can be made available to any interested program.

Physical Stresses

Major emphasis in our work has been to improve the understanding of factors that affect yield and adaptation of chickpea in tropical and subtropical environments. This has enabled us to identify genotypes with higher harvest indices for subtropical environments and genotypes better adapted to drought in tropical climates.

Physiological Basis of Drought Tolerance

We have reported earlier (ICRISAT Annual Report 1987, pp. 134-135) that ICC 4958, a germplasm accession, has consistently proved its drought tolerance. During the 1987/88 postrainy season, we studied the mechanisms of adaptation of this genotype to droughted environments at ICRISAT Center, both on an Alfisol and a Vertisol. We grew genotypes ICC 4958, ICC 10448, ICC 10985, and Annigeri with and without irrigation as described earlier (ICRISAT Annual Report 1982, pp. 110-111).

High rainfall (390 mm) from October to December 1987 resulted in an unusually high mean yield of 1.6 t ha^{-1} in the drought treatment. This masked the genotypic differences, which are generally well expressed when the stress yield is <1.0 t ha^{-1}. However, we monitored the physiological shoot characters known to be associated with drought tolerance, such as midday shoot water potential, canopy temperature, and relative water content of leaves. We also measured rates of water loss of uprooted plants. We brought the uprooted plants to full turgor by keeping them overnight at 5°C, with roots immersed in water. The next day, we applied four treatments in a factorial combination. The treatments consisted of either laying the roots on a bench or keeping them immersed in water and placing the plants either in direct sunlight or in the shade. The rates of water loss during the day, measured by weighing the plants at hourly intervals between 0900 and 1600, were not significantly different for ICC 4958 and Annigeri. There was also no significant difference between ICC 4958 and Annigeri in any of the shoot characters mentioned. The roots of ICC 4958, however, had a 30% greater root length and volume than Annigeri. The root/ shoot ratio was smaller for ICC 4958. We conducted these studies on plants grown in pots, using both sand and solution culture, as well as in the field.

We screened a segregating F_4 population of a cross between ICC 4958 and Annigeri for root characters described above (Fig. 1). We repotted the selected F_4 plants and harvested the F_5 seed. The remaining F_4 seed, from which promising selections were made, will be used to test for drought tolerance by the field screening method described earlier (ICRISAT Annual Report 1982, pp. 110-111) and the F_5 seed will be multiplied.

Tolerance to Low Temperature during Flowering and Pod Set

We have earlier described failure in chickpea to set pods because of low night temperatures. We have reported preliminary data on the genotypic variation in cold tolerance and its effect of increasing the harvest index (ICRISAT Annual Report 1987, pp. 136-137). We separated the single plant progenies from the 1986/87 postrainy season trial into 12 groups, based on time to 50% flowering and pod set. We selected the 10 highest-yielding progenies in each group and conducted a replicated yield test on an Entisol at Hisar in the 1987/88 postrainy season. The daily minimum temperature, when the early groups of genotypes were podding, ranged from -1° to 7°C (with temperatures falling below 5°C on most nights).

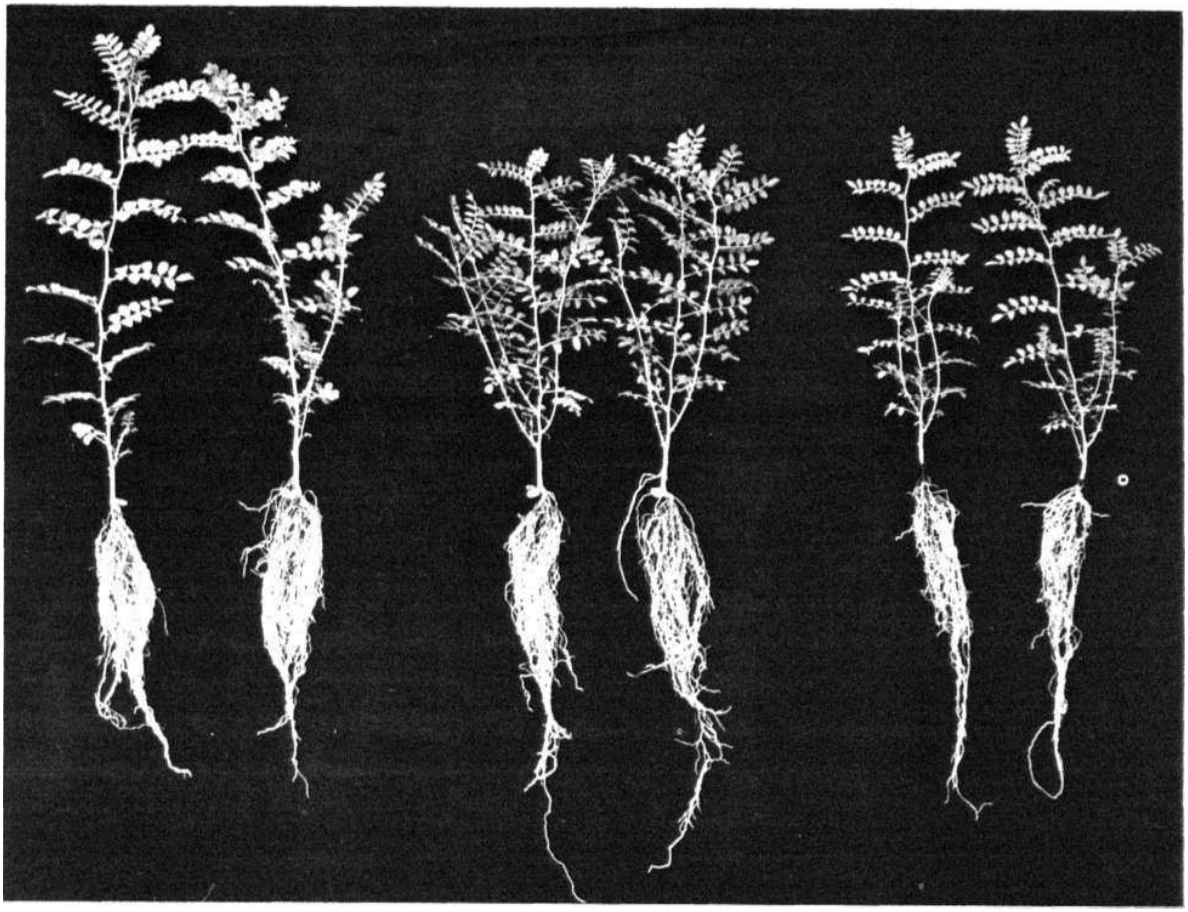

Figure 1. Differences in root growth of chickpea germplasm accession ICC 4958 (drought tolerance) (left) *and cv Annigeri (response to irrigation)* (right) *used as parents, and of the F_4 plant (longer root and branched shoot characters)* (center) *derived from their cross, ICRISAT Center, rainy season 1988.*

The material with early flowering and podding during the low-temperature period had indeed high harvest indices, as hypothesized (Table 1). Harvest indices for the early groups of genotypes were 50-54%, compared with 39-42% for the late-flowering and late-podding selections. The later groups flowered and set pods at the same time as conventional cultivars, such as Pant G 114. The cold-tolerant early-podding selections (Groups 1-5) produced lower mean yields than the genotypes in Group 9. However, there were some progenies in the early groups that had a mean yield of 1.95 t ha^{-1} (average of three replications), very near to the highest mean yield of 2.19 t ha^{-1} in the entire test. Contrary to our expectations, the genotypes of Groups 1-7 tended to have a shorter flowering and podding duration, than those of Groups 9-11. We are now investigating the agronomic practices appropriate to realize the yield potential of the cold-tolerant genotypes. We are also exploring utility of these in other environments.

Effects of Canopy Modifications in Chickpea Crops

In a Special Project supported by the Government of Japan on responsiveness of chickpea to phosphorus, we examined the extent to which

Table 1. Flowering and podding initiation and duration, shoot mass, grain yield, and harvest index in 120 cold-tolerant chickpea selections, Hisar, postrainy season 1987/88.

Group[1]	Flowering Initiation (DAS)[2]	Flowering Duration (days)	Podding Initiation (DAS)	Podding Duration (days)	Shoot mass ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Harvest index (%)
1	42	39	50	38	2.24	1.19	54.4
2	46	40	53	38	2.65	1.33	50.4
3	46	40	53	40	2.72	1.34	49.7
4	46	45	54	43	2.58	1.36	53.8
5	48	38	55	38	2.69	1.35	52.1
6	51	40	58	39	2.94	1.28	44.5
7	54	36	61	36	2.81	1.32	47.4
8	54	44	62	42	3.15	1.31	40.7
9	65	49	72	46	4.06	1.67	42.0
10	70	45	79	41	3.67	1.49	41.3
11	73	37	81	35	3.27	1.36	41.1
12	76	39	82	38	3.46	1.44	38.9
SE	±1	±2	±1	±2	±0.18	±0.08	±1.7
CV(%)	12	23	11	24	33	33	20

1. Values for each group are a mean of 10 selections.
2. DAS = Days after sowing.

chickpea canopies utilize light, setting upper limits to growth and yield for nonlimiting phosphorus and moisture supply. We grew two genotypes of contrasting growth habit—ICCC 42 with a bushy habit, and K 850 with a semierect habit—at 30 cm x 10 cm plant spacing. Canopies were modified by superimposing four treatments; the factorial combination of A and B:

A) ridging (support of lower branches by compacting soil against plants) vs flat bed;

B) tying up branches of each plant to increase light penetration vs undisturbed (natural) canopy.

Canopy light-extinction coefficients (k) in natural canopies were lower for K 850 than ICCC 42, indicating better usage of light by K 850 (Table 2). Tying up of the branches of ICCC 42 significantly lowered k in ridged plots and resulted in a significant yield increase (Table 2). The treatment effects on K 850 were not significant. These results suggest that there is scope to improve the canopy structure of chickpea genotypes with a bushy habit and that the erect canopy is best suited to most efficient light utilization.

Biotic Stresses

Diseases

Disease Situation

Botrytis gray mold (*Botrytis cinerea*) epiphytotic in Nepal. A severe epiphytotic of botrytis gray mold occurred in the Terai region of central and western Nepal in the 1987/88 postrainy season. We found the highest levels of disease and the most severe yield losses (66%) on experimental-station crops. The loss in farmers' fields was about 15%. High plant populations in exper-

Table 2. Effects of canopy modification on light-extinction coefficients and grain yield of bushy (ICCC 42) and erect (K 850) chickpea genotypes, on a Vertisol, ICRISAT Center, postrainy season 1987/88.

	Flat bed		Ridge		
Genotype	Natural	Tied	Natural	Tied	Mean
	Canopy light-extinction coefficient (k)				
ICCC 42	1.12	0.99	1.20	0.82	1.03
K 850	1.00	0.98	1.14	0.91	1.03
SE		±0.13			±0.07
Mean	1.06	1.02	1.17	0.86	1.03
SE		±0.09			
CV (%)		22			
	Grain yield (t ha^{-1})				
ICCC 42	2.80	3.12	2.46	3.54	2.98
K 850	3.16	3.09	2.69	3.17	3.03
SE		±0.27			±0.13
Mean	2.98	3.11	2.58	3.36	3.01
SE		±0.19			
CV (%)		18			

imental station crops had a denser canopy than the farmers' crops. It is assumed that as the humidity within the canopy was higher on research stations, the incidence and severity of the disease increased accordingly.

Disease survey in Kenya. We surveyed the eastern and central provinces of Kenya for diseases during 4-14 July. We surveyed 26 roadside chickpea fields at every 7-10 km in the two provinces. In each field, we recorded data on total plant stand and the number of diseased plants at three random locations, each of 3 m^2 area. The diseases recorded were dry root rot (*Rhizoctonia bataticola*) (15%), wilt (*Fusarium oxysporum* f.sp *ciceri*) (12%), collar rot (*Sclerotium rolfsii*) (10%), and stunt (6%).

Fusarium Wilt (*Fusarium oxysporum* f.sp *ciceri*)

Wilt inoculum threshold. We conducted a greenhouse experiment to investigate the interaction between fusarium wilt inoculum in the soil and disease incidence in three chickpea cultivars. We mixed soil from a wilt-sick plot with sterilized soil to give eight levels of inoculum ranging from 33 to 3283 propagules (g of soil)$^{-1}$. In a replicated trial, we grew the resistant cultivar WR 315, the tolerant cultivar K 850, and the susceptible cultivar JG 62 in pots of the eight soil mixtures. In the susceptible cultivar, JG 62, we saw wilt at all the inoculum levels tested between 90 and 110 days after sowing (DAS) (Table 3). In the tolerant cultivar, K 850, wilt incidence increased with increasing initial inocu-

Table 3. Effects of inoculum density of *Fusarium oxysporum* f.sp *ciceri* on wilt incidence in three chickpea cultivars (JG 62, K 850, and WR 315), greenhouse trials, ICRISAT Center, 1988.

Intitial *Fusarium* propagules (g of soil)$^{-1}$	Wilt incidence (%)[1,2]			Final *Fusarium* propagules (g of soil)$^{-1}$		
	JG62	K850	WR315	JG62	K850	WR315
3283	100	43 (40.8)	0	3167	3033	2900
1517	too	33 (30.0)	0	1442	3050	2058
867	100	23 (23.9)	0	1550	1925	1575
483	100	10 (17.7)	0	1575	1908	1717
267	87 (76.9)	0	0	1642	2008	1233
133	67 (60.0)	0	0	1867	1892	1500
67	65 (58.9)	0	0	1425	1400	842
33	30 (28.1)	0	0	1025	1842	383
0	0	0	0	0	0	0
SB[3]	(±15.2)	(±11.7)			±118	
CV(%)	(47)	(72)			11	

1. Average of three replications.
2. Angular transformed values are shown in parentheses.
3. Hundreds and zeros are not included in calculating SE.

lum levels. A minimum of 483 propagules (g of soil)$^{-1}$ was required to produce wilt in this cultivar. There was no wilt disease in the resistant cultivar at any of the inoculum levels tested. There was a significant increase in the number of *Fusarium* propagules after growing these cultivars. The highest increase was for the tolerant cultivar, K 850 [1400-3050 propagules (g of soil)$^{-1}$].

Effect of mycorrhiza on wilt. We studied the interaction between vesicular-arbascular mycorrhizae (VAM) and the wilt pathogen (*F. oxysporum* f.sp *ciceri*) under greenhouse conditions. We used a mixture of three *Glomus* spp (*G. mosseae, G. contrictum,* and *G. monosporum*) to inoculate the soil alone or in combination with *Fusarium.* We used sterilized soil as control. There was no effect of VAM on wilt incidence in the susceptible (JG 62) or resistant (WR 315) cultivars. However, in the wilt-tolerant cultivar (K 850) it significantly (P <0.05) reduced the wilt incidence (Table 4).

Table 4. Effect of vesicular-arbuscular mycorrhizae (VAM) on fusarium-wilt incidence in three chickpea cultivars (JG 62, K 850, and WR 315), greenhouse trial, ICRISAT Center, 1988.

Inoculation treatment	Percentage of wilt		
	JG62	K850	WR315
Fusarium alone	100	35±7.5	0
VAM alone	0	0	0
Fusarium + VAM	100	25±7.5	0
Control (sterilized soil)	0	0	0

Dry Root Rot (*Rhizoctonia bataticola*)

Effect of plant age on susceptibility to dry root rot. In a blotter test, five chickpea cultivars, when inoculated at 7 and 15 DAS with *R. bataticola,* showed differential reactions, but at 30 or more days all were susceptible, indicating the higher susceptibility of older chickpeas to dry root rot caused by *R. bataticola* than the younger plants.

Viruses

Characterization. We isolated a potyvirus from chickpea plants with bushy appearance and small leaflets. The virus infected several plants belonging to Chenopodiaceae, Leguminosae, and Solanaceae. We found *Chenopodium amaranticolor* to be a good local lesion host. Virus identification was based on electron microscopy and physico-chemical properties. We purified the virus and produced an antiserum. It was serologically related to soybean mosaic, adzuki bean mosaic, and peanut mottle viruses but not to bean yellow mosaic virus.

Nematodes

Surveys. Our surveys in the Terai region of Nepal revealed that the root-knot disease caused by *Meloidogyne* spp on chickpea was widespread. The disease was recorded in Bhairahawa (Rupandehi district), Hardinath (Dhanusha district), Gadari and Nawalpur (Sarlahi district), Gopalkoti (Louthat district), Rampur (Chitwan district), Nepalgunj (Banke district), and Parwanipur (Bara district).

Disease Resistance

Evaluation of chickpea lines for wilt and root rot resistance. We evaluated the entries in the All India Coordinated Varietal Trials and ICRISAT elite lines in the wilt and root-rot nursery at ICRISAT Center, during the 1985/86,1986/87, and 1987/88 postrainy seasons to seek material with wilt and root rot resistance and high-yield potential. There was 100% mortality in the susceptible control JG 62 in the three seasons. Nine varieties that were tested for two to three seasons had <20% mortality (Table 5). These varieties have good yield potential and can be considered for release in areas where wilt and root rot are endemic.

Table 5. Chickpea varieties in the All India Coordinated Varietal Trials with less than 20% mortality because of wilt and root rots, in a sick plot, ICRISAT Center, postrainy seasons 1985/86 to 1987/88.

	Percentage of mortality		
Variety	1985/86	1986/87	1987/88
Avrodhi	8	9	12
ICCC 48	14	12	3
PDG 83-33	12	17	4
H 83-18	12	-[1]	19
GCP6	-	6	6
GCP 28	-	7	14
ICCV 10	-	7	5
JG317	-	4	3
BG313	18	18	7
Control (susceptible)			
JG62	100	100	100

1. - = Not tested.

Insect Pests

Pest incidence. The pod borer, *Helicoverpa armigera,* was again the dominant insect pest on chickpea in the 1987/88 postrainy season at ICRISAT Center and at all other locations where chickpea selections were grown unprotected. At ICRISAT Center, the attack of this pest at the seedling stage was less severe than in previous years. In the 1987/88 season, the number of *H. armigera* moths caught in the light and pheromone traps at ICRISAT Center was high, particularly from December 1987 to March 1988. However, moth activity started much earlier than normal, i.e., from mid-August 1987. At Gwalior, we caught many moths in pheromone traps from February to March 1988. The numbers caught were also higher than those in previous years. At Hisar, we first recorded the peak activity of *Helicoverpa* moths in October/

November 1987 and after the cold weather period from February to April 1988.

Aphis craccivora, the vector of bean leaf-roll virus, which causes the stunt disease of chickpea, was prevalent at Hisar. *Spodoptera exigua* was a minor pest at ICRISAT Center. The ICARDA entomologist reported a high incidence of *Helicoverpa* in chickpea in southern Syria, but the leaf miner (*Liriomyza cicerina*) was the most widespread pest in the Mediterranean region.

Pod borer (*Helicoverpa armigera*)

Host-plant resistance. We have evaluated 409 new germplasm accessions in nonreplicated plots in the pesticide-free Vertisol area at ICRISAT Center for borer damage, by scoring for damage and weighing the seed yield. We screened lines bred for resistance to *Helicoverpa* and wilt as well as the breeders' elite material for borer damage under unprotected conditions at ICRISAT Center and at Hisar. At ICRISAT Center, *Helicoverpa* damage to pods ranged from 3.4% to 59.5% in the short-duration, from 4.0% to 23.0% in the medium-duration, and from 12.0% to 32.0% in the long-duration material, under unprotected conditions. We recorded the highest yields from ICCX 730094-18-2-IP-BP-EB(1.56 t ha^{-1}) in the short-duration and 1.39±0.14t ha^{-1} in ICCC 13 of the medium-duration group. At Hisar, water stress, dry root rot, and stunt diseases, led to poor and uneven plant growth in our trials. Under unprotected conditions, borer damage to pods ranged from 20.7% to 61.5±6.3% with yields of 0.33 t to 1.30±0.19 t ha^{-1}. In the kabuli selections, only one entry, ICCC 34, gave a high yield (2.04±0.14 t ha^{-1}). In another trial, where the yields of 15 moderately resistant selections were compared with susceptible lines under unprotected and protected conditions, there was a significant yield increase, with pesticide protection, for three selections GL 1002-2EB, ICCX 730020-11-2-IH-B-10EB, and ICCX 790203-38PLB-11PLB-1HLB-1HLB-2EB. This indicates a good level of tolerance to pests at podding stages in these selections.

We supplied seeds for International Chickpea *Helicoverpa* (*Heliothis*) Resistance Nursery (ICHRN) trials to 11 cooperators in India and to 9 in other countries to determine the relative importance of insect pests at different locations.

Mechanisms of resistance. We intensified studies on mechanisms of resistance to *Helicoverpa* in chickpea genotypes by conducting field and laboratory tests, using moths and larvae produced in our rearing facility. We had reported earlier (ICRISAT Annual Report 1986, pp. 139-140) that chickpea genotypes differ in susceptibility to *H. armigera* because of differences in oviposition, larval retention, and antibiosis. In studies on oviposition, using flowering twigs of resistant and susceptible genotypes, we found that there was, on an average, 25% fewer eggs on ICCV 7, 28% fewer on ICCL 86102, 33% fewer on ICCL 86101, and 63% fewer on ICC 506 compared to the control, Annigeri. We conducted studies on oviposition and larval retention under field conditions in large (7.5 m x 7.2 m x 2.5 m) field cages covered with nylon fish net of 5-mm mesh (Fig. 2). In these cages, we conducted trials with five resistant and susceptible genotypes of short- and medium-duration material grown in a latin-square trial, with five replications in each cage. At the tender pod stage, we released three laboratory-bred *Helicoverpa* larvae (newly hatched) per plant on all the plants in a row of all test entries. We left the adjacent row noninfested. At maturity, we made pod-damage assessments on two plants per row. We recorded pod damage on both rows because of larval migration from the infested plants to noninfested ones (Table 6). Resistant genotypes showed comparatively lower damage on both rows, compared with the control cultivars, Annigeri and K 850, which remained susceptible.

Plant Nutrition

We are continuing efforts to develop appropriate strategies for enhancing nitrogen (N)fixa-

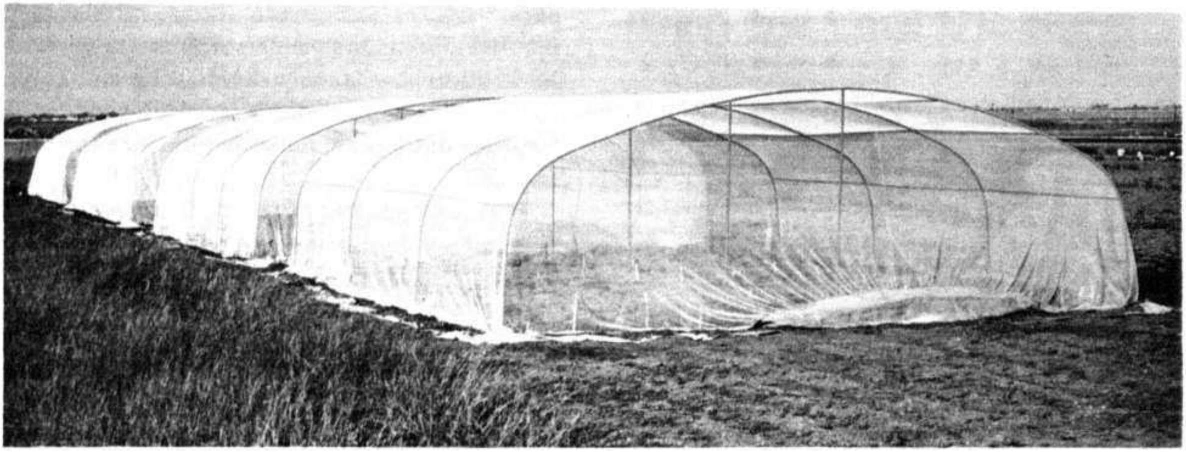

Figure 2. Field arch-cages, covered with 5-mm mesh nylon fish net, used for mechanisms of resistance field studies, ICRISAT Center, post rainy season 1987/88.

Table 6. Mean percentage of pod damage on artificially infested and noninfested chickpea genotypes tested in field arch-cages, ICRISAT Center, January 1988.

	Pod damage (%)	
Genotype	On infested	On noninfested
Short-duration		
Borer resistant		
ICC 505	4.9(11.5)[1]	2.2 (7.2)
ICCV 7	2.6 (7.9)	3.4(10.3)
ICCL 86101	2.5 (8.7)	5.9(13.3)
ICCL 86102	2.8 (8.5)	5.3(11.9)
Control		
Annigeri	6.9(13.7)	9.5(17.6)
SE	(±2.0)	(±2.3)
Medium-/long-duration		
Borer resistant		
ICCL 86106	5.0(11.0)	5.2(11.4)
ICCX 730020-11-1-1H	5.6(12.5)	1.3 (4.6)
ICCL 86105	10.1(17.9)	5.1(12.9)
ICCX 730041-8-1-1P	3.9(10.5)	3.3 (9.9)
Control		
K850	14.3(21.8)	12.2(20.1)
SE	(±3.0)	(±1.7)

1. Angular transformed values are shown in parentheses.

tion, and also to examine interactions between phosphorus nutrition and soil-moisture availability in chickpea, as part of the Government of Japan Special Project.

Nitrogen Response of Chickpea Genotypes

We are trying to identify genotypes that are self-sufficient in their N requirements through symbiotic N fixation in soils of low and moderate N status. Chickpea often responds to N fertilizers, indicating inadequacy of the symbiosis. We thus compared, at ICRISAT Center during the 1987/88 postrainy season, the N-fertilizer response of 18 chickpea genotypes on a Vertisol, which had been depleted of soil N by prior cropping with cereals. We irrigated the experiment to avoid growth limitation by drought stress.

Six contrasting responses of above-ground dry-matter production are illustrated in Figure 3. The greater response to N fertilizer of Annigeri compared with K 850 is consistent with the previously documented lower nodulating and N-fixing capacity of Annigeri. Among recently developed cultivars, ICCC 42 appears more responsive to N fertilizer than ICCV 2 (ICCL 82001). As expected, the nonnodulating mutant, ICC 435M, responds to N fertilizer more than its

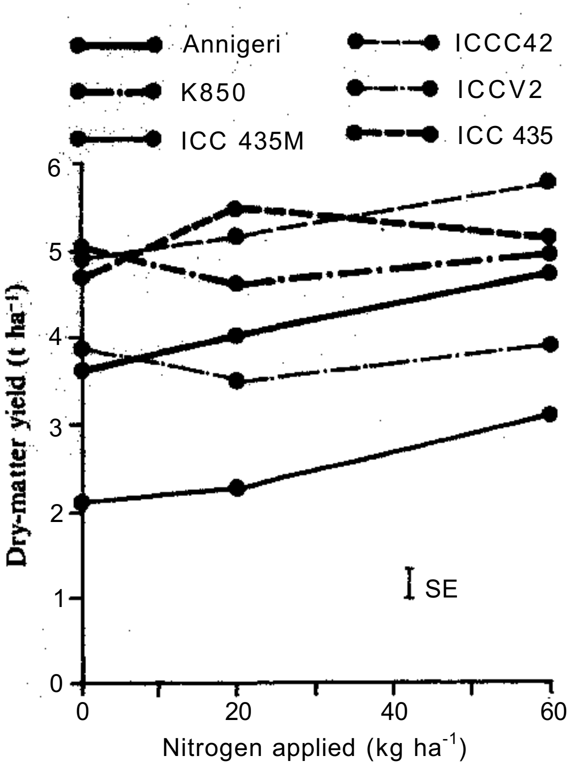

Figure 3. Response of six chickpea genotypes to nitrogen fertilizer on a Vertisol, ICRISAT Center, postrainy season 1987/88.

parent, ICC 435. Previous studies have shown that the mutant can yield as well as its parent at N fertilizer levels of over 100 kg ha^{-1}. We obtained similar responses for grain yield, as N fertilizer did not appreciably influence the harvest index.

We are continuing these studies, in conjunction with experiments using ^{15}N isotope and natural-abundance techniques.

Success of Inoculation and Survival of the Inoculant Strain

Last year we reported (ICRISAT Annual Report 1987, p. 156) that inoculation with *Rhizobium* strain IC 59 increased nodulation, shoot dry matter, and grain yield of chickpea (cv Annigeri) in plots where native rhizobial populations had been reduced by solarization. At 51 DAS, we sampled and serotyped the nodules. In solarized plots, significantly more nodules were formed by the inoculant strain, when it was introduced by dual inoculation, first with a sorghum crop at 3 weeks after cessation of solarization, and second at the time of sowing of chickpea 4.5 months

Table 7. Effect of soil solarization on nodule number and percentage of nodules formed by the inoculant strain on chickpea (cv Annigeri), on a Vertisol, ICRISAT Center, postrainy seasons 1986/87 and 1987/88.

	Number of nodules plant^{-1} at 51 DAS[1]						Nodules formed by inoculant strain (%)					
	1986/87			1987/88			1986/87			1987/88		
Inoculation treatment	+sol[3]	-sol	Mean	+sol	-sol	Mean	+sol	-sol	Mean	+sol	-sol	Mean
Dual inoculation (sorghum and chickpea)	27	32	29	39	41	40	47.0 (43.0)[3]	6.2 (14.2)	26.6 (28.6)	68.3 (56.2)	2.0 (6.6)	35.2 (31.4)
Single inoculation (chickpea only)	24	31	28	36	36	36	13.2 (20.7)	6.6 (11.9)	9.9 (16.3)	9.3 (16.0)	1.9 (7.7)	5.6 (11.9)
Noninoculated control	20	31	26	35	35	35	1.0 (3.2)	0.0 (00)	0.5 (1.6)	1.0 (3.2)	0.6 (3.2)	0.8 (3.2)
SE	±2		±1	±1		±1	±(3.7)		±(2.6)	±(4.8)		±(3.4)
CV(%)	18			9			(58)			(75)		

1. DAS = Days after sowing.
2. sol = Solarization.
3. Angular transformed values are shown in parentheses.

after solarization. This treatment also resulted in the highest nodule occupancy by IC 59, as compared with either the single inoculation at chickpea sowing or the noninoculated control (Table 7).

In the 2nd year of the experiment (1987/ 88 postrainy season), there was no further solarization, but a noninoculated crop of Annigeri was grown on the experimental area. The treatment differences in nodulation, growth, and yield apparent in the 1st year were not reflected in the 2nd year. However, nodule occupancy by the inoculant strain had increased by about 20% in the dual-inoculation treatment but had marginally decreased with a single inoculation (Table 7).

Although it has been often reported that it is very difficult to displace native rhizobia with introduced strains, this procedure of solarization and immediate inoculation of the crop grown prior to chickpea seems to be effective in this regard.

Grain and Food Quality

Cooking Quality and Consumer Acceptance

We continued to monitor the cooking quality and consumer acceptance of some newly developed chickpea genotypes. We determined the cooking time, water absorption, and organoleptic properties such as color, texture, flavor, taste, and general acceptability using whole seeds of five desi [ICCV 1 (ICCC 4), ICCC 37, ICCC 42, K 850, and Annigeri], and five kabuli [ICCV 2 (ICCL 82001), ICCV 3 (ICCL 83006), ICCV 4 (ICCL 83004), ICCV 5 (ICCL 83009), and ICCV 6 (ICCC 32)] genotypes. We noticed significant ($P < 0.01$) differences in cooking time of these genotypes, whereas water absorption revealed no noticeable differences (Table 8). Of the various

Table 8. Cooking quality and physico-chemical properties of newly developed and control chickpeas, ICRISAT Center, postrainy season 1987/88.

Genotype	Cooking time (min)[1]	Water absorption (g of sample)$^{-1}$	General acceptability[2]	Gelatinization temperature (°C)[3]	Viscosity (Brabender units)[3]
Desi					
ICCV 1 (ICCC 4)	76	0.9	2.7	70.0	390
ICCC 37	72	1.0	2.8	68.0	335
ICCC 42	81	0.9	2.5	71.0	385
Controls					
K850	96	0.9	2.8	71.8	315
Annigeri	82	1.0	2.6	66.8	358
Kabul,					
ICCV 2 (ICCL 82001)	75	1.0	2.9	67.7	435
ICCV 3 (ICCL 83006)	73	0.9	3.1	65.5	515
ICCV 4 (ICCL 83004)	72	1.0	3.2	65.7	430
ICCV 5 (ICCL 83009)	72	0.9	3.4	68.0	458
ICCV 6 (ICCC 32)	76	1.0	2.9	67.5	495
SE	±1.4	±0.01	±0.14	±0.35	±8.3
CV(%)	2.5	1.8	6.7	0.7	2.9

1. Based on two determinations for each genotype, using whole-seed sample.
2. Based on whole-seed evaluation by 10 panel members. Rating score: 1 = Poor; 2 = Fair; 3 = Good; and 4 = Excellent.
3. Based on two determinations for each genotype, using dhal sample.

organoleptic properties, the sensory evaluation score on color was considerably higher in kabuli than in desi genotypes, whereas texture, flavor, and taste revealed only minor differences between the two groups. To prepare boiled chickpea products, such as *chole,* both desi and kabuli types may be used. Our results show that kabuli types may be preferred on the basis of cooking time and general acceptability of the product (Table 8).

Besan Quality of Desi and Kabuli Types

Besan is the flour prepared from decorticated chickpea and is used in several preparations in India, Pakistan, and Bangladesh. Desi types are preferred in the preparation of *besan* and as an ingredient in the *besan*-based deep-fried product, *pakora,* which is a common snack food in India. Using a viscoamylograph, we examined the paste viscosity patterns of *besan* made from five desi and five kabuli genotypes. We also determined the gelatinization temperature of these. The results of this study are presented in Table 8. These indicate that the *besan* of the kabuli types was more viscous than that of the desi types, and there were clear-cut and significant (P <0.01) differences between the two groups. This observation could be of practical importance in understanding the difference in food-product quality of the two chickpea groups. The starch gelatinization temperature was slightly higher in desi than in kabuli types (Table 8).

Biological Evaluation of Protein Quality

Chemical analysis does not always reveal how much of a protein is biologically available to the body. Therefore, the biological evaluation of proteins is important and commonly carried out by conducting rat-feeding trials. We examined the protein quality of each of the newly developed desi and kabuli genotypes by feeding five rats on cooked whole seeds. Interestingly, we observed that the biological value of the kabuli types was higher than that of the desi types, which resulted in higher values of utilizable protein (Table 9). Protein digestibility is of increasing importance in grain legumes. The protein digestibility of the genotypes varied between 80.0% and 86.0%, with a mean of 83.1%. The protein digestibility and net protein utilization of desi and kabuli types are similar/Though these desi and kabuli genotypes reveal no noticeable difference in protein content, the differences in protein quality (in terms of biological value) and utilizable proteins are apparent. We suspect that the relatively higher biological value of kabuli types is because of a higher biological availability of sulfur amino acids, methionine, and cystine than those in desi types. The biological availability of the sulfur amino acids play an important role in determining the nutritive value of legume proteins.

Effect of Defaulting on Nutrient Losses

Minerals and trace elements are important dietary nutrients. It has been observed that calcium and iron are often deficient in the diets of people with low income, particularly infants, preschool children, and pregnant and lactating women. We examined the effect of scarification on the losses of calcium, iron, zinc, and manganese by analyzing dhal and powder fractions of chickpea (cv Annigeri) dehulled for 0,2,4,8, and 12 min in a Tangential Abrasive Dehulling Device (TADD). In the control (0 min dehulling), we removed the seed coat manually. The concentration of these minerals decreased as the dehulling time increased (Table 10). The powder fraction of the samples contained considerably more of the minerals. This shows that these nutritionally important minerals are located in the outer layers of the cotyledons, which are lost by dehulling.

Protein Content and Amino Acids

Earlier (ICRISAT Annual Report 1986, p. 147), we reported that the protein content of the chickpea (cv Annigeri) showed a large variation when grown in different fields at ICRISAT Gen-

Table 9. Biological value (BY), true digestibility (TD), net protein utilization (NPU), and utilizable protein (UP) of cooked whole-seed samples of newly developed and control chickpeas, ICRISAT Center, postrainy season 1987/88[1].

Genotype	Protein[2] (%)	BV (%)	TD (%)	NPU (%)	UP (%)
Desi					
ICCV 1 (ICCC4)	21.0	77.7	80.4	62.4	12.2
ICCC37	20.6	76.2	85.1	64.7	12.6
ICCC42	19.2	74.7	80.0	59.7	10.6
Controls					
K850	20.4	78.6	84.3	66.3	12.6
Annigeri	19.4	72.7	80.1	58.3	10.5
Kabuli					
ICCV 2 (ICCL 82001)	23.4	79.0	83.8	66.2	14.3
ICCV 3 (ICCL 83006)	18.3	89.6	82.9	74.3	12.7
ICCV 4 (ICCL 83004)	21.2	83.8	82.1	68.8	13.4
ICCV 5 (ICCL 83009)	19.5	83.7	85.9	72.0	13.1
ICCV 6 (ICCC 32)	19.6	86.6	86.0	74.4	13.5
SE	±0.1	±2.1	±1.2	±2.0	±0.4
CV (%)	0.9	5.8	3.2	6.7	6.7

1. Based on five determinations for each treatment.
2. Based on two determinations for each genotype.

Table 10. Mineral content [mg (100 g of sample)$^{-1}$] of chickpea dhal and powder fractions, ICRISAT Center, postrainy season 1986/87[1].

Dehulling time (min)	Dhal				Powder			
	Calcium	Iron	Zinc	Manganese	Calcium	Iron	Zinc	Manganese
0[2]	43.0	5.7	3.6	1.3	-	-	-	-
2	39.5	5.0	3.0	1.2	85.0	12.0	8.2	2.4
4	38.0	4.8	2.7	1.1	65.5	10.5	7.4	2.2
8	35.5	4.3	2.6	1.0	45.0	8.5	6.7	1.9
12	35.0	3.8	2.5	1.0	45.0	7.0	5.8	1.6
SE	±1.8	±0.4	±0.2	±0.1	±2.9	±0.3	±0.2	±0.1
CV(%)	4.3	7.1	6.6	6.5	4.2	3.4	2.4	1.8

1. Fractions obtained by using Tangential Abrasive Dehulling Device (TADD).
2. This treatment was dehulled by hand and not subjected to abrasion in TADD; hence, no powder.

ter. During the 1987/88 postrainy season, we analyzed 60 seed samples each of Pant-G 114 and H 208, which were grown in different fields at Hisar. We noticed that the protein content of Pant-G 114 ranged from 23.8% to 29.2% with a mean of 26.9% and that of H 208 from 24.6% to 29.3% with a mean of 27.3%. This suggests that chickpea genotypes can show considerable variation in protein content, if grown in different fields at a particular location. We estimated the protein content in 355 whole-seed samples, received from our breeding program. The protein content of these samples varied widely, namely, from 15.5% to 29.3%. In addition, we analyzed 829 seed samples of germplasm accessions and found that protein content varied from 16.3% to 25.5%. Amino-acid analyses of five desi and five kabuli genotypes did not reveal large differences, which confirm our earlier results.

Plant Improvement

Breeding Short- and Medium-duration Desi Types

We continued our efforts to breed short- and medium-duration chickpeas for high yield, with resistance to biotic and abiotic stresses. We tested the material selected from among advanced generations in yield trials conducted in two environments at ICRISAT Center. The best entry yielded 3.1 t ha^{-1} on an average and exceeded the yield of the control (cv Annigeri) by 22%. We contributed 24 entries to the International Chickpea Screening Nurseries of Short and Medium Durations (ICSN-DS and ICSN-DM).

Breeding Long-duration Desi Types

We continued our thrust against the major biotic and abiotic stress factors. We crossed carefully selected parents, intercrossed F_1s to combine resistance factors, and screened segregating populations in disease and pest nurseries. We identified genotypes that set pods at low temperatures. This is a character considered useful to check excessive vegetative growth and to safeguard a crop against foliar diseases. The yield levels were low because of drought, yet lines performing well could be identified. In a combined wilt and stunt nursery, 20 breeding lines recorded <10% incidence of both diseases and we selected these for yield evaluation. We identified breeding lines that had resistance to more than two biotic stress factors and also had a good yielding ability. An example is ICCX 830677-10H-BH-BH, which recorded 0% wilt, 11% stunt, a rating of 5 both for ascochyta blight and pod borer damage on a 1-9 rating scale (where 1 = Highly resistant, and 9 = Highly susceptible), and yielded 2.13±0.19 t ha^{-1} compared with 2.34±0.19 t ha^{-1} of Pant G 114, the control.

Breeding Kabuli Chickpea

Stress factors, considered important for kabulis in the higher latitudes, are the same as those for long-duration desis. However, for the lower latitudes, where the interest in kabulis is increasing, dry root rot also assumes significance. Kabulis are generally valued for their large seeds and we, therefore, continued to select for this character. The goal set is to have a seed mass not below that of L 550 [about 20 g $(100\ seeds)^{-1}$]. We detected moderate levels of resistance to diseases and *Helicoverpa.* Yields were low because of drought but we identified lines performing better than the control cultivar (L 550). With the breeding of short-duration kabuli genotypes, such as ICCV 2 (ICCL 82001) and ICCV 5 (ICCL 83009), the kabuli adaptation has been extended to areas of lower latitudes. ICCV 2 (ICCL 82001), growing in the shortest duration, fits well in drought-prone environments. There is considerable demand for these two varieties and we supplied 173 kg of seed through organized trials to 19 cooperators on individual requests.

Extending Chickpea Adaptation

Where drought conditions prevent the production of most crops, chickpea may still be able to give the farmer a reasonable return. This is because few crops can grow successfully on residual moisture alone, and few can complete a growth cycle, if necessary, in 70-80 days while chickpea can. Chickpea is thus a flexible crop, a trait that invites us to try to extend its adaptation to unusual conditions.

Early Sowing at Lower Latitudes

We initiated early sowing experiments during the 1978/ 79 postrainy season (ICRISAT Annual Report 1985, p. 161; 1986, p. 155; 1987, p. 163). Since then, we have screened about 1500 germplasm lines to select genotypes adapted to mid-September sowing, and we have used these in yield trials and in crosses. Over the years, early sowing has given a yield advantage of 25% over normal sowing (Table 11). The 1987/88 postrainy season was an exception when early sowing did not give a yield advantage because of excessive rainfall in October and November. In the 1981/82 and 1983/84 postrainy seasons either excessive rains in September prevented sowing or the seed was damaged by waterlogging; and the 1986/87 postrainy season was a drought year, when no chickpea, neither early nor normal, could be sown. This illustrates that early sowing has its advantages, but risks as well.

Late Sowing at Higher Latitudes

In many parts of Bangladesh, Burma, northern India, Nepal, and Pakistan, there is an increasing trend to grow chickpeas after rice, maize, or cotton. These crops are often harvested late in November or December, thus delaying the sowing of a succeeding crop of chickpea beyond its optimum sowing date.

During the past 10 years, we have screened many late-sown germplasm lines and segregating populations, and have conducted trials with selected genotypes under normal and late-sowing conditions. Though we had been able to identify genotypes that performed consistently better than others under these conditions, we have failed so far to detect genotype x sowing date interactions. However, during the 1987/88 postrainy season, in the normal vs late-sown trials conducted at Hisar and Gwalior, we observed for the first time significant interactions between genotypes and sowing dates, namely for grain yield, days to 50% flowering, and seed size. We continued our breeding, and testing program, trying to combine adaptation to late sowing with resistance to ascochyta blight. The highest-yielding entry of an advanced yield trial (AYT) gave 1.95±0.21 t ha^{-1} average in the 1988/89

Table 11. Mean seed yield (t ha^{-1}) of early-sown (mid-September) and normal-sown (mid-October) chickpea trials, ICRISAT Center, postrainy seasons 1980/81 to 1987/88.

Sowing time	Season					Mean over seasons	Percentage increase
	1980/81	1982/83	1984/85	1985/86	1987/88		
Early	0.80	2.39	1.84	1.11	1.36	1.50	24.6
Normal	0	1.77	1.09	0.74	2.42	1.20	-
SE	±0.03	±0.04	±0.04	±0.02	±0.03		
CV (%)	20	12	18	10	6		

postrainy season; the control yielded 1.48±0.21 t ha^{-1}.

Breeding for Adaptation to High Inputs

One of the major constraints that limits the chickpea productivity is its failure to respond to high inputs. Chickpea tends to put on excessive vegetative growth and lodge, when grown under moist, high-fertility conditions particularly in long-duration environments, such as those found in northern India. We screened 360 germplasm and advanced breeding lines for tolerance of lodging at our subcenter at Hisar and at a sewage farm near Gwalior. The crop was lush and showed excessive vegetative growth, particularly at the latter site. Some of the lines were more than 1-m tall, and more than 60% of the plants lodged badly. We selected for further evaluation 38 lines having a rating of 1 or 2 (1 = No lodging, and 5 = Complete lodging).

Breeding and Genetic Studies

Recombination Breeding among Selected Parents

A procedure to combine desirable characters of chosen parents is to cross these in all possible combinations, and intercross segregants with desirable characters. Lines from the derived recombinants are then compared for their performance. We initiated such a program in the 1981/82 postrainy season. The parental cultivars were: Annigeri (high yielding and wilt resistant); K 850 (high yielding, wide adaptation, large seed size, and strong nodulation); JG 62 (high yielding and double podded); and ICC 506 (resistant to *Helicoverpa*). In the 1987/88 postrainy season, we made selections and intercrosses in different recombination cycles, and evaluated F_5 progenies derived from the first cycle for grain yield and other characteristics in a preliminary yield trial (PYT) under irrigated and nonirrigated environments at ICRISAT Center. The best entry gave a mean yield of 3.83±0.24 t ha^{-1}, while Annigeri yielded 2.95±0.24 t ha^{-1}.

Single- vs Double-podded Chickpea

Chickpeas normally produce one flower per peduncle, but genotypes with two flowers on the same peduncle also occur. To assess the value of the double-podded character in chickpea improvement, we compared a single-podded cultivar (Annigeri) and its double-podded mutant in a 2^3 factorial experiment with five replications. Other factors were: two dates of sowing (mid-October and mid-November) and two irrigation treatments (with and without postsowing irrigation). The single-podded type, sown in October with postsowing irrigation, produced the highest grain yield (Table 12). Interestingly, significant interaction effects of cultivars with sowing dates occurred. As compared with October, the November sowing was 52% lower in grain yield for Annigeri, whereas the grain yield of the double-podded mutant was only 28% lower, suggesting that the double-podded character has a more positive effect on yield as the growth cycle gets shorter.

Mutation Breeding

We subjected seed batches of two kabulis, ICCV 2 (ICCL 82001) and ICCV 6 (ICCC 32), to gamma radiation treatments in 1986 (ICRISAT Annual Report 1987, pp. 166-167). We passed the seed produced by the M, populations through screens to select the largest and smallest seeds (4%) of ICCV 2 (ICCL 82001) and the largest and smallest seeds (1%) of ICCV 6 (ICCC 32). The different varietal x radiation x seed size combinations were sown in a trial with 42 entries and three replications. The experiment had plot sizes of 4 rows of 4-m length, the plant spacing was 30 cm * 10 cm, and the design was a randomized complete block (RCB). The results showed that the differences in seed size were not maintained for ICCV 6 (ICCC 32), but they were for ICCV 2 (ICCL 82001). We sowed part of the seed, which was not used in the trial, in October 1987 in a 1-ha selection block. We carefully inspected the plants for increased pod and seed sizes and we made and tested 122 single-plant selections in

Table 12. Effect of sowing dates (mid-October and mid-November) and no irrigation (no postsowing irrigation and two postsowing irrigations) on grain yield of chickpea cv Annigeri and its double-podded mutant, ICRISAT Center, postrainy season 1986/87.

		Grain yield (t ha^{-1})		
		Sowing date		
Cultivar	Irrigation	October	November	Mean
Annigeri	N[1]	2.82	1.38	2.10
	P	4.13	1.89	3.01
SE			±0.17	
Mean		3.48	1.64	2.56
Mutant	N	2.20	1.48	1.84
	I	3.02	2.26	2.64
SE			±0.12	
Mean		2.61	1.87	2.24
	N	2.51	1.43	1.97
	I	3.58	2.08	2.83
SE			±0.09	
Mean		3.04	1.75	2.40
CV (%)			23	

1. N = No postsowing irrigation, I = Two postsowing irrigations.

small 1-m rows, during the 1988 rainy season. The selections reproduced a significant increase in seed mass for ICCV 6 (ICCC 32), but not for ICCV 2 (ICCL 82001) (Table 13 and Fig. 4).

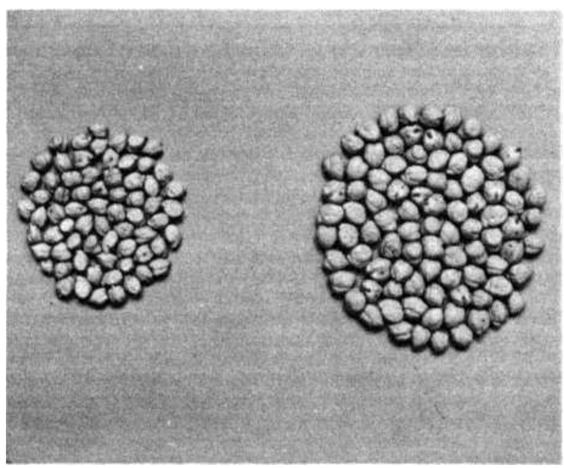

Figure 4. M_2 seed-mass increase for chickpea variety, ICCV6 (ICCC32), exposed to gamma-ray mutagenic treatment (right) compared with nontreated seed (left), ICRISAT Center, postrainy season 1987/88.

Cell and Tissue Culture

We conducted experiments to standardize tissue-culture techniques for micropropagation, plant regeneration by somatic embryogenesis, and embryo rescue for chickpea improvement.

Micropropagation

Multiple-shoot production. We used for multiple-shoot production shoot tips from 15-day-old

Table 13. Chickpea selections made for seed mass in M_2 populations and their performance in M_3 progenies as compared with the parents as control, ICRISAT Center, postrainy season 1987/88 and rainy season 1988.

Variety	Single-plant selections	Mean 100-seed mass (g)	
		1987/88	1988
ICCV2(ICCL82001)	62	29.1 ±0.4	19.6±0.2
Control	-	25.9±0.1	19.1±0.6
ICCV 6 (ICCC 32)	60	31.1±0.4	23.0±0.5
Control	-	18.4±0.1	14.7±0.5

in vitro grown seedlings of four genotypes: L 550, K 850, ICCV 6 (ICCC 32), and ICC 12237, raised on Murashige and Skoog medium (MS). The explants were cultured on MS and Legumes (L-6) media containing different hormone combinations: S1, S2, S3, S4, S5, S6, and S7 (Table 14). We incubated the cultures at 25±2°C under 16-h daylength. All four genotypes produced multiple shoots; the base of the explants produced calluses. We observed a good response on SI, S3, and S6 media, but callus growth was more abundant on S6.

Shoots produced from one explant each on S1 and S3 media were excised individually and transferred on to the same medium at 6-week intervals. K 850 gave the best results on S3 medium. From one initial explant of K 850 on S3 medium after two subcultures 51 shoots were produced, while the other genotypes produced more calluses. Only K 850 shoots continued to produce multiple shoots even after the third transfer.

Root induction. We excised multiple shoots produced from shoot-tip explants individually and transferred these to a rooting medium based on a reduced strength of MS salts. Rooting response was better in a medium containing 0.1 mg L^{-1} naphthalene acetic acid (NAA) than in a medium containing 0.2 mg L^{-1} indole butyric acid (IBA) or NAA. Although there were interactions between genotypes and media, K 850 and L 550 responded generally better than ICCV 6 (ICCC 32) and ICC 12237.

Table 14. Number of shoots produced per explant[1] from shoot tips[2] of four chickpea genotypes (L 550, K 850, ICCC 32, ICCC 12237) on media with different hormone combinations, ICRISAT Center, 1988.

	L550		K850		ICCC 32		ICCC 12237[3]	
Medium	Average[4]	Range	Average	Range	Average	Range	Average	Range
MS[5] + 2.0 mg L^{-1} BA[5] + 0.5 mg L^{-1} IAA[5] (S1)	5.0	3-7	6.2	2-10	5.3	3-10	4.8	4-6
MS + 2.0 mg L^{-1} ZEA[5] + 0.5 mg L^{-1} IAA (S2)	1.3	1-3	3.8	1-7	1.8	1-3	3.2	1-7
L-6 + 2.0 mg L^{-1} BA + 0.5 mg L^{-1} IAA (S3)	5.8	4-9	4.9	2-9	5.5	3-9	8.8	8-10
L-6 + 2.0 mg L^{-1} ZEA + 0.5 mg L^{-1} IAA (S4)	1.4	1-2	2.9	1-5	2.2	2-3	1.8	1-3
MS + 0.5 mg L^{-1} BA + 0.1 mg L^{-1} IAA (S5)	3.1	1-7	-[6]	-	1.2	1-2	1.7	1-2
L-6 + 0.5 mg L^{-1} BA + 0.1 mg L^{-1} NAA (S6)	4.0	2-6	5.3	2-7	4.1	1-9	6.0	1-10
MS + 0.5 mg L^{-1} ZEA + 0.1 mg L^{-1} IAA (S7)	1.1	1-2	1.1	1-2	1.2	1-2	1.1	1-2

1. Ten explants per genotype were cultured.
2. Shoot tips from 15-day-old in vitro seedlings.
3. Only five explants were tested on S1, S2, S3, and S4.
4. Observations recorded 6 weeks after culturing.
5. MS = Murashige and Skoog, BA = Benzyladenine, IAA = Indole acetic acid, ZEA = Zeatin.
6. - = Data not available.

Cooperative Activities

International Trials and Nurseries

In the 1987/88 postrainy season, we had seven types of international trials and nurseries and we despatched 124 sets to cooperators in 13 different countries. As in the two previous seasons, we sent F_2 populations against specific request for disease resistance, maturity periods, and high yield only. Along with the trials and nurseries, we sent 241 samples of F_2 populations.

Genotype x environment interactions, especially for yield, were very high in all types of trials. The best entries of the various trial types yielded an average of 1.88±0.16 t ha^{-1} and exceeded the control by 24%.

Distribution of Breeders' Material

In addition to the trial sets and F_2 populations, we distributed 683 samples of breeding materials to cooperators in 13 countries against specific requests.

Cooperation with AICPIP

We contributed two new desi lines (ICCV 88105 and ICCV 88111) to AICPIP for testing in the Indian national trial series. Many entries from our breeding programs were promoted or retained for further testing in the 1988/89 postrainy season. In the Gram Coordinated Varietal Trial (GCVT), ICCC 36, ICCC 42, ICCC 48, and ICCC 37 were among the good performers in the South Zone during the 1987/88 postrainy season. In the GCVT (Late Sown), ICCC 42 performed well in the North West Plain Zone and Central Zone. In the GCVT (Kabuli), ICCV 14 and ICCV 13 were outstanding in the North East Plain Zone, and ICCV 14 in the South East Zone and South Zone. In the Gram Initial Evaluation Trial (GIET), ICCV 19 yielded well in the West Zone, and ICCV 10 and ICCV 19 in the South Zone.

We supplied 100 kg of seed of three varieties each ICCC 37, ICCV 6 (ICCC 32), and ICCC 42—to Maharashtra state and 50 kg of seed of two varieties—ICCV 2 (ICCL 82001) and ICCC 37—each to Orissa state for large-scale multiplication.

Cooperation with Nepal

An ICRISAT Chickpea Breeder has been posted with the National Grain Legume Improvement Programme of Nepal to further strengthen our chickpea collaborative research work in that country. Several ICRISAT lines included in replicated yield tests produced over 3 t ha^{-1}, the highest (ICCL 86316) giving 3.50±0.33 t ha^{-1}. In a multilocational on-farm trial, an ICRISAT line, ICCL 82108, yielded 1.89 t ha^{-1}, compared with 1.54 t ha^{-1} produced by the control. An ICRISAT chickpea cultivar, ICCV 1 (ICCC 4), released in Nepal in 1987, continued to do well particularly in the western part of that country. In maximization plots, it gave a seed yield of 3.46 t ha^{-1} compared with 2.55 t ha^{-1} of the control.

Cooperation with ICARDA

Screening for Multiple Stresses

Evaluation of cultivated species. We initiated screening of germplasm accessions for resistance to ascochyta blight (*Ascochyta rabiei*) in 1978 and now we also screen for resistances to low temperatures, leaf miner (*Liriomyza cicerina* and *Phytomyza lathri*), wilt (*Fusarium oxysporum*), bruchid (*Callosobruchus chincnsis*), and cyst nematode (*Heterodera ciceri*). We have sources of resistance to ascochyta blight, low temperatures, leaf miner, and fusarium wilt, but to date we have found no sources of high-level resistance to cyst nematode or to bruchid (Table 15).

Evaluation of wild species. We evaluated ICARDA's 137 accessions of eight wild species against five stresses (Table 16). We found high

Table 15. Resistance sources to different biotic and abiotic stresses in chickpea identified at ICARDA, Syria, 1978-88.

Stress	Number of lines screened	Resistance sources among ICARDA accessions (ILC numbers)
Ascochyta blight	15 000	182, 200, 2506, 2956, 3274, 3866, 3856, 3870, 4421, 5586, 5921, 6188.
Low temperatures	5 200	794, 1071, 1251, 1256, 1444, 1455, 1464, 1875, 3465, 3598, 3746, 3747, 3791, 3857, 3861.
Leaf miner	6 200	5901.
Fusarium wilt	2 500	848, 850, 851, 857, 858, 860, 871, 904, 911, 5032, 5411.

Table 16. Evaluation of eight *Cicer* species resistance to biotic and abiotic stresses at Tel Hadya, Syria, winter 1987/88.

Cicer species	Lines tested[1]	Ascochyta blight R[2]	Ascochyta blight S[3]	Leaf miner R	Leaf miner S	Cyst nematode R	Cyst nematode S	Bruchid R	Bruchid S	Low temperatures R	Low temperatures S
C. bijugum	23	16	6	0	16	22	1	18	3	23	0
C. chorassanicum	5	0	1	1	0	0	5	0	4	0	5
C. cuneatum	3	2	1	1	0	0	3	2	1	0	3
C. echinospermum	4	0	2	1	0	0	4	3	0	4	0
C. judaicum	47	32	11	40	5	0	47	11	36	19	28
C. pirmatifidum	30	26	4	30	0	0	30	2	28	30	0
C. reticulatum	23	0	12	0	2	0	23	5	15	22	1
C. yamashitae	2	0	2	0	0	0	2	0	2	0	2
Total	137	76	39	73	23	22	115	41	89	98	39

1. The number of lines evaluated was not 137 for each stress because of shortage of seed or failure of germination.
2. R = Resistant.
3. S = Susceptible.

levels of resistance to ascochyta blight, leaf miner, cyst nematode, bruchid, and low temperatures.

Response to irrigation. We grew 48 selected genotypes in two trials of 24 each for 3 years, 1985/86 to 1987/88 postrainy seasons, with and without supplemental irrigation. For supplemental irrigation, we added different quantities of water in the three seasons as scheduled by daily water balance computations of rainfall and pan evaporation, and verified by soil-moisture measurements using neutron moisture meters. The mean yield under rainfed conditions was 2.0±0.13 t ha^{-1} as against 3.0±0.26 t ha^{-1} with supplemental irrigation. We were thus able to select lines better adapted to well-watered environments.

Resistance to seed shattering. Harvesting by combine harvesters requires lines that do not shatter at maturity. We evaluated 6224 kabuli germplasm accessions for seed shattering 1 month after complete maturity during the winter of 1987/88 and spring of 1988. We observed no seed shattering in most of the lines suggesting that chickpeas like cereals are suitable for machine harvesting.

Screening for resistance to five pathotypes of *A. rabiei.* We screened 740 breeding lines against five pathotypes of *A. rabiei* in the plastichouse (greenhouse) at the seedling stage. We inoculated promising lines at both seedling and reproductive stages. Several lines were resistant at the vegetative stage but had reduced resistance to some pathotypes at the reproductive stage.

Pathogenic variability in *A. rabiei.* We collected several isolates of *A. rabiei* from the Tel Hadya farm and elsewhere in Syria. Isolates from Tel Hadya could be placed in one of six groups by their morphological characters. However, when we studied the reaction of 25 lines, they could be differentiated by their capacity to infect the plants and placed in two distinct groups: namely, mild and aggressive.

Yield performance of newly bred lines. We evaluated between 226 and 387 lines for yield during winter and spring at Jindiress and Tel Hadya in Syria, and Terbol in Lebanon. Several lines exceeded the control in yield. Many high-yielding lines had large seed, tall stature, or early maturity.

Selection of pure lines for cold tolerance. We selected 500 cold-tolerant plants from a population of 650 000 plants each of ILC 482 (ICARDA) and ILC 3279 (ICARDA) during the 1984/85 winter, which was the coldest of the past 20 winters in Syria. We screened these plants against low temperatures in the subsequent three seasons. Two plant selections from ILC 482 and four from ILC 3279 had much higher tolerance levels of low temperatures than their respective parents. This study shows that genetic diversity for tolerance of low temperatures existed in the original populations of ILC 482 and ILC 3279. The cold-tolerant versions of ILC 482 and ILC 3279 will be useful wherever the original parents are cultivated commercially.

Release of cultivars by national programs. A major objective of the program is to strengthen the national agricultural research systems (NARSs) by providing diverse nurseries to enable them to develop and release cultivars for their farmers. In 10 countries, 21 lines have been released from materials supplied through our international nurseries (Table 17). Eighteen of these have been released for winter sowing and two for spring sowing in the Mediterranean region and one in the subtropics.

Algeria has selected 2 lines (FLIP 84-145C, ILC 190), Cyprus 4 (FLIP 85-16C, FLIP 85-17C, FLIP 85-55C, FLIP 85-12C), France I (FLIP 81-293C), Jordan 2 (ILC 482, ILC 3279), Lebanon 2 (ILC 482, FLIP 85-5C), Morocco 6 (FLIP 81-293C, FLIP 82-91C, FLIP 82-92C, FLIP 82-127C, FLIP 82-128C, FLIP 82-161C), Syria 6 (FLIP 82-150C, FLIP 83-47C, FLIP 83-48C, FLIP 83-71C, FLIP 83-98C, FLIP 84-15C), Tunisia 2 (FLIP 83-93C, FLIP 84-145C), and Turkey 12 (87 AK 71112, 87 AK 71113, 87 AK 71114, 87 AK 71115, FLIP 83-47C, FLIP 83-77C, FLIP 85-4C, FLIP 85-63C, FLIP 85-92C, FLIP 85-118C, FLIP 85-134C, FLIP 86-11C) from the international nurseries and identified them for prerelease multiplication and/or on-farm trials. For winter sowing 24 cultivars have been selected, and 13 for spring sowing.

Cooperation with Pakistan

One ICRISAT Plant Breeder/ Pathologist has been assigned to NARC in Islamabad (34°N,

Table 17. Kabuli chickpea lines selected from international nurseries and released as cultivars by 10 national programs[1].

Country	ICARDA accession/ line	Name of released cultivar	Year of release	Special features of cultivars
Algeria	ILC 482		1988	High yield, wide adaptation
	ILC 3279		1988	Tall, high yield
Cyprus	ILC 3279	Yialousa	1984	Tall
	ILC 464	Kyrenia	1987	Large seeds
Italy	ILC 72	Califfo	1987	Tall, high yield
	ILC 3279	Sultano	1987	Tall
Morocco	ILC 195		1987	Tall
	ILC 482		1987	High yield, wide adaptation
Spain	ILC 72	Fardan	1985	Tall, high yield
	ILC 200	Zegri	1985	Mid-tall, high yield
	ILC 2548	Almena	1985	Tall, high yield
	ILC 2555	Alcazaba	1985	Tall, high yield
	ILC 200	Atalaya	1985	Mid-tall, high yield
Sudan	ILC 1335	Shendi	1987	High yield
Syria	ILC 482	Ghab 1	1982	High yield, wide adaptation
	ILC 3279	Ghab2	1986	Tall, cold tolerant
Tunisia	ILC 3279	Chetoui	1986	Tall
Turkey	ILC 195		1986	Tall, cold tolerant, medium-sized seed
	ILC 482	Gunej Sarisi 482	1986	High yield, wide adaptation
Tunisia	FLIP 83-46C	Kassab	1986	Large seeds, high yield
	Be-sel-81-48	Amdoun	1986	Large seeds, fusarium wilt resistant

1. All cultivars are resistant to ascochyta blight and released for winter sowing, with the exception of Arndoun 1, which is resistant to fusarium wilt and released for spring sowing. Gunej Sarisi 482 is also released for spring sowing in Turkey.

73°E) to work on the National Chickpea Improvement Project of Pakistan. The major objective is to stabilize yield of the crop and improve it further.

Screening for Resistance to Ascochyta Blight

We grew varying numbers of F_3 single-plant progenies (SPPs) in the Pathology Block at NARC to screen progenies against induced blight disease. We selected SPPs of 11 crosses that showed ratings of 3-5 on a 1-9 scale for further studies. The parents involved in these crosses were: C 44, C 141, CM 72, E 100 Ym, E 101, ICC 7770, ICC 11514, ILC 72, ILC 482, ILC 3279, NEC 138-2, and PK 51814.

Seed Increase during Off-season

We sowed about 0.5 ha to increase seed of single-plant progenies selected in four F_4s and four F_5 bulks, which over 2 years had proved to be moderately resistant to blight in the blight-screening nursery at NARC. We harvested a sizeable amount of bulked seeds of two F_5s and three F_6s, enabling us to include these in the Adaptation Trial, sown at five places in November 1988.

Cooperation with Provincial Units

We cooperated with the Chickpea Research Units of the four Provinces in Pakistan by supplying them with segregating materials, nurseries, or trials developed at NARC or brought from ICRISAT/ICARDA Chickpea Improvement Program, and also by frequent visits.

Publications

Institute Publications

Plant Material Descriptions

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Chickpea kabuli variety ICCV 6. Plant Material Description no. 12. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. ISBN 92-9066-131-3. (PME 012)

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Research Bulletin

Chauhan, Y.S., Nene, Y.L., Johansen, C., Haware, M.P., Saxena, N.P., Sardar Singh, Sharma, S.B., Sahrawat, K.L., Burford, J.R., Rupela, O.P., Kumar Rao, J.V.D.K., and Sithanantham, S. 1988. Effects of soil solarization on pigeonpea and chickpea. (Summary in Fr.) Research Bulletin no. 11. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 20 pp. ISBN 92-9066-167-4. (RBE 011)

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. International Chickpea Newsletter no. 18. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2508. (NCE)

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Nene, Y.L., Hanounik, S.B., Qureshi, and Sen, B. 1988. Fungal and bacterial foliar diseases of pea, lentil, faba bean and chickpea. Pages 577-590 in World crops: cool season food legumes: proceedings of the International Food Legume Research Conference on Pea, Lentil, Faba Bean and Chickpea, 6-11 Jul 1986,

Spokane, Washington, USA (Summerfield, R.J., ed.). Dordrecht, Netherlands: Kluwer Academic Publishers. (CP 286)

Sharma, S.B. 1988. Nematology in the year 2000 A.D. as I see it in relation to dryland farming. Pages 44-52 *in* Nematology in 2000 A.D.: proceedings of the Symposium on Nematology in the Year 2000 A.D. as I see it, 28 May 1988, New Delhi, India: Indian Agricultural Research Institute. (CP 427)

van Rheenen, H.A., Bond, D.A., Erskine, W. and Sharma, B. 1988. Future breeding strategies for pea, lentil, faba bean and chickpea. Pages 1013-1030 *in* World crops: cool season food legumes: proceedings of the International Food Legume Research Conference on Pea, Lentil, Faba Bean and Chickpea, 6-11 Jul 1986, Spokane, Washington, USA (Summerfield, R.J.,ed.), Dordrecht, Netherlands: Kluwer Academic Publishers. (CP 264)

LEGUMES

PIGEONPEA

Contents

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PIGEONPEA

Pigeonpea (*Cajanus cajan* (L.) Millsp.) has multiple uses (food, fodder, and fuel) and is adaptable to diverse production systems (short-duration sole crops to perennial types in agroforestry). This makes research in pigeonpea improvement a multidisciplinary endeavor at ICRISAT. Our research aims to improve the productivity per unit area and over time, with stability across environments and resistances to major stresses. Geographically, we have enhanced our cooperative work in southeast Asia through the Asian Grain Legumes Network (AGLN) and in Africa through network initiatives.

At ICRISAT Center (18°N, 78°E, 760 mm annual rainfall), we conduct research on short-duration, medium-duration, and perennial pigeonpea. Maintenance and evaluation of germplasm, operational-scale testing of improved genotypes in different production systems, and screening for biotic and abiotic stresses are also largely done at the Center. Most short-duration breeding material is bred and tested at Hisar (29°N, 75°E, 450 mm rainfall), in cooperation with Haryana Agricultural University (HAU). We concentrate on developing improved long-duration types and on better agronomic management of advanced short-duration material at Gwalior (26°N, 78°E, 840 mm rainfall), in cooperation with Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) College of Agriculture.

Next year, we plan to strengthen our work on short-statured (dwarf) plant types in the three major phenological groups, on genetic improvement, and on agronomic management. We will continue germplasm enhancement, using random-mating populations with genetic male-sterile genes, for tolerance of pod borer, podfly, and phytophthora blight disease.

We will strengthen cooperative networking to determine the major pests in extra-short- and short-duration pigeonpea when extended to non-traditional regions and cropping systems and develop integrated pest management practices.

Our cooperative hybrid pigeonpea breeding program, initiated in 1987 with the All India Coordinated Pulses Improvement Project (AICPIP), will continue. We will continue studies to develop plant ideotypes, to better understand drought and salinity response in pigeonpea, and to identify and confirm sources of tolerance. We will also strengthen our research into problems of pigeonpea growth on soils of high clay content when soil-moisture levels are high.

Physical Stresses

We are continuing to screen pigeonpea for tolerance of drought, waterlogging, and salinity. The drier-than-normal rainy season of 1987 permitted good screening of short-duration lines for drought response but the heavy rains during October and November that year interfered with our screening of medium-duration genotypes for tolerance of terminal drought stress. In 1987, we began studies on adaptation of newly evolved extra-short-duration pigeonpea to various cropping systems. We report about these below, and these studies were continued in 1988.

Screening of Short-duration Pigeonpea for Drought Tolerance

Short-duration pigeonpea can escape drought stress in regions where terminal drought stress reduces yields of medium- or long-duration genotypes. However, the short-duration genotypes are still subjected to intermittent water deficits during the rainy season, and we are seeking tolerance against this stress. We began screening short-duration genotypes for their moisture response, using a line-source sprinkler system in 1986 (ICRISAT Annual Report 1987, pp. 183-184). In 1987, we screened 23 determinate and 23 indeterminate genotypes, using the line-source sprinkler system.

The response pattern of yield and dry matter to moisture was curvilinear for most of the genotypes, as observed in the previous season. Yields of the indeterminate genotypes were relatively less affected by moisture stress than those of the determinate group. For genotypes tested in both the 1986 and 1987 rainy seasons, genotypic differences in response were generally similar. For example, ICPH 9 was particularly drought tolerant and ICPL151 more susceptible to drought stress than ICPL 87. However, an exception was ICPL 161, which was rated sensitive to drought stress in 1986 but relatively tolerant in 1987; further confirmation of relative responses across seasons is warranted. Other genotypes showing drought tolerance in 1987 were ICPLs 83024, 84031, and 86012 in the determinate group, and ICPLs 288, 84045, 84059, 85045, 85051, and 87023 and ICPH 8 in the indeterminate group.

Soil-aeration Effects

During the rainy season, temporary waterlogging can inhibit pigeonpea growth, and thus we have a continuing program to screen for waterlogging tolerance. However, better soil management to maintain good aeration conditions in the soil after periods of heavy rainfall is also an option to overcome this stress. The Government of Japan Special Project is studying this.

In the 1987 rainy season, we grew a medium-duration pigeonpea cultivar, C11, under rainfed conditions, either on ridges spaced at 75 cm or on flat beds, on both a Vertisol and an Alfisol at ICRISAT Center. After major rainfall events, we monitored soil-oxygen concentrations by extracting samples of soil air from tubes placed at different soil depths and measuring oxygen concentrations in a solid-electrolyte oxygen electrode. At 15-cm depth in the Alfisol, following heavy rain, oxygen concentrations fell to as low as 10% in flat beds but only to 15% in ridges. At 15-cm depth in the Vertisol, the comparative values were 17% and 18%. At 30-cm depth, oxygen concentrations fell below 10% after heavy rainfall in both types of plots and on both soil types, although lower levels were generally recorded for the Vertisol.

The reduced soil-oxygen concentrations were reflected by reduced plant growth of pigeonpea, but the experimental variability was large (Table 1). The largest effects were at early plant-growth stages. It is surprising that the largest beneficial effect of ridging is obtained on Alfisols as it is generally considered that Vertisols are more prone to waterlogging limitations. There were indications that good aeration at early-growth stages facilitated deeper root penetration, thus permitting plants to better cope with terminal drought stress. We are continuing studies to further clarify these effects.

Salinity Tolerance in Wild Species and Hybrids with Pigeonpea

We have previously reported (ICRISAT Annual Report 1987, pp. 184-185) that some wild relatives of cultivated pigeonpea possess consider-

Table 1. Effect of land-preparation methods on above-ground dry matter of medium-duration pigeonpea (cv C 11), ICRISAT Center, sown in rainy season 1987.

	Above-ground dry matter (g m^{-2})					
	Vertisol			Alfisol		
Days after sowing	Rat bed	Ridge and furrow	SE	Flat bed	Ridge and furrow	SE
62	69	81	±9	55	84	±11
131	544	541	±101	340	423	±62
179	572	631	±49	609	723	±101

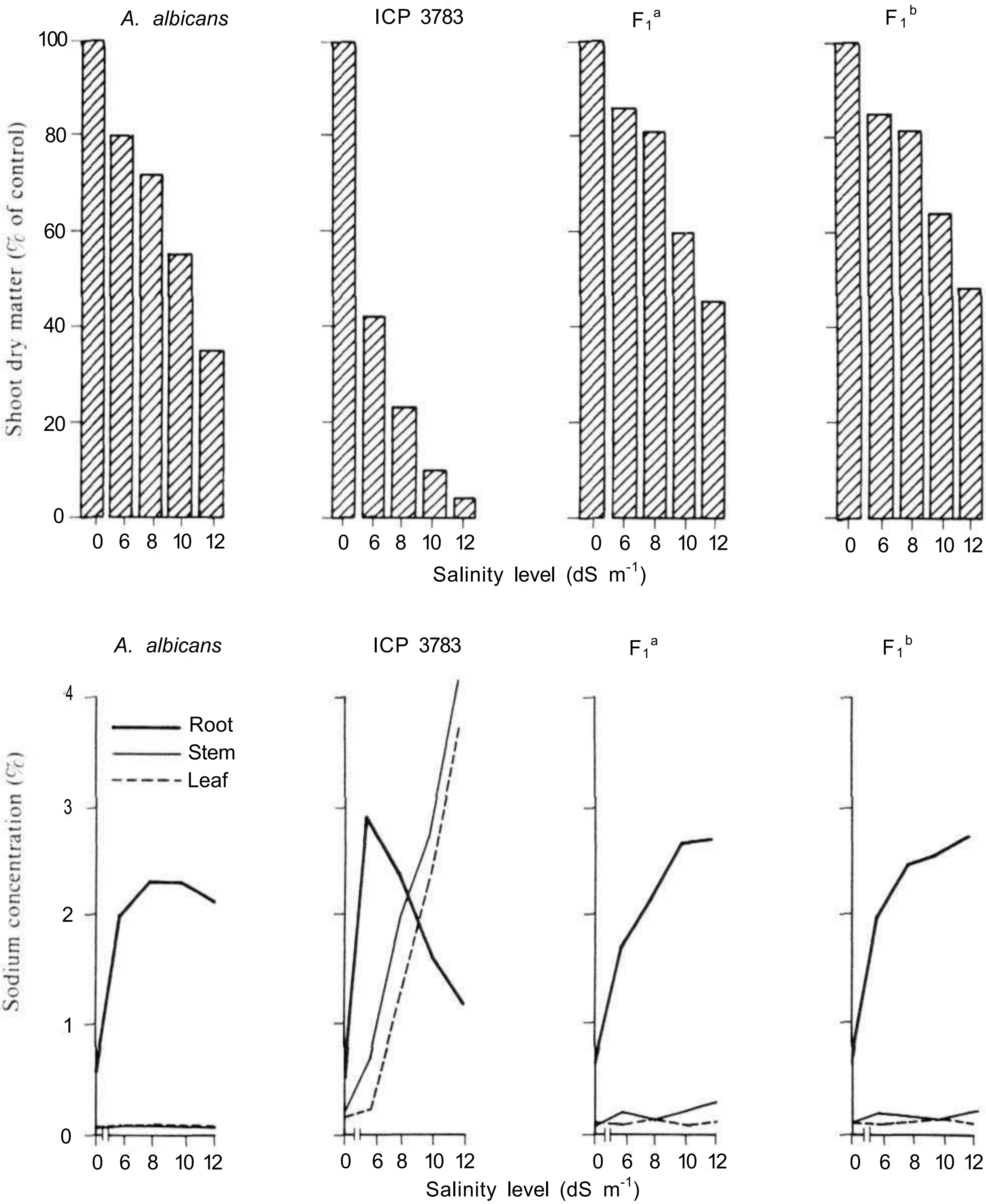


Figure 1. Effect of salinity on shoot dry matter and tissue sodium concentration of Atylosia albicans (*tolerant*), *on pigeonpea line ICP 3783* (*sensitive*) *and their F, hybrids* (F_1^a = A. albicans x *ICP 3783 and* F_1^b = *ICP3783 x* A. albicans), *ICRISAT Center*, *1988.*

able salinity tolerance. We examined the salinity response of F_1 hybrids of a cross between one of these wild types, *Atylosia albicans,* and pigeonpea genotype ICP 3783, as a first step to examine the genetic control of salinity tolerance in pigeonpea. We grew hybrids of reciprocal crosses, along with their respective parents, in sand culture, flushed with a nutrient solution, which included nitrogen. We treated these with salt ($NaCl$ + $CaCl_2$) concentrations that varied in electrical conductivity (EC) up to 12 dS m^{-1}.

Figure 1 shows that the salinity response of hybrids of both reciprocal crosses is similar to that of the salt-tolerant parent, A *albicans,* rather than that of the sensitive, cultivated pigeonpea. Further, the mechanism of salt tolerance is similar for these plants, namely, they have an ability to exclude salt from the shoots and retain it in the roots at high salt levels (Fig. 1). In contrast with this, the salt-sensitive ICP 3783 is unable to exclude sodium from the shoot when the EC of the external solution exceeds 6 dS m^{-1}. Figure 1 gives data for sodium only, but we measured similar patterns for chloride.

Thus, the salt-tolerance trait in pigeonpea, attributable to salt exclusion from shoots, appears to be inherited as a dominant trait, which should facilitate its transfer into cultivated pigeonpea. Studies are planned to further understand the genetic control of the salt-tolerance trait, to incorporate it most efficiently into agronomically desirable types of cultivated pigeonpea.

Table 2. Grain yield of six extra-short-duration pigeonpea genotypes (ICPLs 83015, 84023, 85015, 85037,86020, and 4) at two sowing dates and three plant populations, under rainfed conditions, Alfisol, ICRISAT Center, sown in rainy season 1987.

	Grain yield (t ha^{-1})							
Plant population nr^{2}	ICPL 83015	ICPL 84023	ICPL 85015	ICPL 85037	ICPL 86020	ICPL 4	Mean	Mean
	25 June sowing							
16	1.55	1.57	1.42	1.21	1.19	1.48	1.40	
33	1.52	1.64	1.28	1.31	1.20	1.75	1.45	1.39
66	1.32	1.65	1.35	1.16	0.97	1.42	1.31	
SE							±0.03	
	7 August sowing							
16	1.18	1.09	1.26	1.19	1.08	1.02	1.14	
33	1.50	1.17	1.28	1.26	1.12	1.27	1.27	1.21
66	1.57	1.37	1.00	1.18	0.95	1.23	1.22	
SE							±0.03	±0.01
	Mean							
16	1.37	1.33	1.34	1.20	1.13	1.25	1.27	
33	1.51	1.41	1.28	1.29	1.16	1.51	1.36	
66	1.45	1.51	1.17	1.17	0.96	1.33	1.26	
SE			±0.08				±0.02	
Mean	1.44	1.42	1.26	1.22	1.08	1.36		
SE			±0.06					

Adaptation of Extra-short-duration Pigeonpea

We envisaged that the newly evolved extra-short-duration genotypes could be used as contingency crops in environments where soil moisture is available for only short periods; i.e., they could potentially escape drought. Thus, a range of promising genotypes, together with a control of similar duration (ICPL 4), was grown under rainfed conditions on an Alfisol at ICRISAT Center in 1987. We conducted a split-split-plot experiment with two sowing dates in main plots, with six genotypes in subplots, and with three plant populations in sub-subplots.

All genotypes matured in 95-102 days in the June sowing and in 85-101 days in the August sowing. Severe drought stress during September affected the reproductive phase of the June-sown crop and the vegetative phase of the August-sown crop. Nevertheless, mean yields for both the first sowing (1.39 t ha^{-1}) and the second sowing (1.21 t ha^{-1}) were reasonable (Table 2). The sowing date x genotype interaction was not significant and genotypes ICPLs 83015 and 84023 yielded well at both sowings. The genotype x spacing interaction was significant with 16 plants m^{-2} being optimum for ICPL 85015, 66 plants m^{-2} for ICPL 84023, and 33 plants m^{-2} for the other genotypes.

Such trials were continued in 1988 to verify these promising results, and collaborative multilocational trials are underway to compare extra-short-duration pigeonpea with other short-season legumes for contingency cropping situations.

Biotic Stresses

Diseases

Macrophomina stem canker in Nepal

A visit to pigeonpea plots at experimental stations (Nawalpur, Rampur, and Nepalgunj) and farmers' fields near Nepalgunj in Nepal, during the last week of March 1988, revealed that stem canker caused by *Macrophomina phaseolina* was a very common and serious disease. The disease symptoms ranged from restricted spindle-shaped lesions on stems without any apparent damage to extended lesions causing drying of the whole plant (Figs. 2 and 3). This is the first report of the disease on pigeonpea occurring in Nepal. The high humidity that prevails in the Terai during the pigeonpea-growing season seems to favor the development of the disease. This stem canker disease was possibly wrongly diagnosed earlier as fusarium wilt (*Fusarium udum* Butler).

Phytophthora Blight (*Phytophthora drechsleri* f.sp *cajani*)

Evaluation of fungicides for control. Phytophthora blight (PB) is more prevalent in short-duration pigeonpea as the crop is grown at a close spacing, which encourages disease buildup. At present no cultivars with high and stable resistance to this disease are available. We eval-

Figure 2. A pigeonpea plant showing spindle-shaped lesions caused by Macrophomina phaeseolina *on stem, in a farmer's field, Nepal, 1988.*

Figure 3. A pigeonpea line, dried because of Macrophomina phaeseolina, *growing in afield near Nepalgunj, Nepal, 1988.*

uated seven fungicidal treatments in a field trial using ICPL 87 on an Alfisol PB-sick plot at ICRISAT Center, during the 1988 rainy season. We treated the seed with respective fungicides, and we gave two foliar sprays at 15-day intervals from 15 days after sowing (DAS). Of the six fungicides evaluated, fosetyl-Al (Aliette®) and metalaxyl (Ridomil®) were more effective in reducing disease incidence and plant mortality. Fungicide fosetyl-AL reduced mortality by 57% and metalaxyl by 42% as compared with the nonsprayed control, and significantly increased yield (Table 3). However, the yields were low because of late sowing (1st week of July) and lack of irrigation.

Sterility Mosaic

Investigations of the agent causing sterility mosaic (SM) disease. Although the disease has long been known to be mite-transmitted, the etiologic agent remains elusive. Much evidence suggests, however, that the disease is not because of mite toxemia but rather that a pathogen is involved. We sought to identify the agent, both by conventional means and by comparison of nucleic acids present in healthy and infected tissues. We used a variety of buffers at different stages in many viral purification protocols. None of these procedures yielded structures specific to infected tissue on examination by electron microscopy. Tissue extracts and nucleic-acid preparations, with and without bentonite, failed to transmit the causal agent on mechanical inoculation of several plant species. Analysis of total nucleic acids was ham-

Table 3. Effect of seed dressing (3 g kg^{-1}) and foliar spraying (3 g L^{-1}) of fungicides on phytophthora blight incidence, mortality, and yield in short-duration pigeonpea (cv ICPL 87), ICRISAT Center, rainy season 1988.

Fungicide	Percentage of incidence	Percentage of mortality	Yield (kg ha^{-1})
Carbendazim (Bavistin®)	100	92	57± 11
Captan	100	67	119± 95
Captafol (Difolatan®)	100	88	53± 43
Mancozeb (Dithane M 45®)	100	92	87± 41
Fosetyl-Al (Aliette®)	82	43	650± 88
Metalaxyl (Ridomil®)	84	58	546±214
Metalaxyl (Ridomil®) + mancozeb (Dithane M 45®)	92	78	128± 44
Control	100	98	9± 9

pered by the large quantities of ribosomal ribonucleic acid (RNA) and interfering material present in pigeonpea tissue, e.g., polysaccharides. Several fractionation techniques failed to remedy this situation. When we successfully resolved RNA species, we did not identify any disease-specific species. However, when we subjected nucleic acids, extracted from large quantities of tissue, to CF-11® chromatography, we identified disease-specific double-stranded species. Subsequently, we identified several single-stranded species in the high-speed pellet of infected-tissue extracts. Further characterization revealed that these species were in fact host species, undetectable in very young tissue, but prominent in more mature tissue. We are currently reassessing the nature of the double-stranded species we had identified earlier, as well as our assumption that the etiologic agent is in fact viral. We are also exploring the possible involvement of membranous bodies of uniform size, recently found to be associated with two mite-transmitted diseases.

Multiple Disease Resistance

Evaluation of lines in the All India Arhar (pigeonpea) Coordinated Trials for wilt, SM, and PB resistance. To identify high-yielding lines with resistance to major diseases, we evaluated short-, medium-, and long-duration lines in the different Arhar Coordinated Yield Trials against wilt, SM, and PB in field and greenhouse trials at ICRISAT Center, during the previous 10 years (1977-86). The source of the seeds was the All India Coordinated Pulses Improvement Project (AICPIP), Kanpur.

We carried out evaluation for wilt resistance in wilt-sick plots that were developed and maintained at ICRISAT Center since 1977. We evaluated 509 lines for wilt susceptibility. The wilt incidence in the susceptible controls in all the tests was very high (72-100%). ICPL 87 was tested for two seasons and showed less than 10% wilt during both the seasons.

We carried out evaluation for SM resistance in the field by following either infector-hedge or leaf-stapling techniques. We evaluated 568 lines. The SM incidence in the susceptible controls was almost 100% in all the tests. We tested the lines MA 165, MA 166, ICPL 86, ICPL 146, and PDA 2 during two seasons and these were found resistant. We tested lines DA 11, DA 13, PDA 10, and ICPL 366 during three seasons and these were found resistant. We tested lines MA 97 and DA 15 during four seasons and these were found resistant. We tested the line Bahar during six seasons and it was found resistant in all the seasons.

We carried out screening for PB resistance in the field, and in pots in the greenhouse. We evaluated 322 lines. The blight incidence in the susceptible control in both field and pot screening was very high (76-100%). We tested two lines, BDN 1 and HY 4, during two seasons and these were found resistant in field screenings. However, we did not find any line resistant in pot screening in the greenhouse.

The lines AL 1, H 76-51, H 76-65, ICPL 267, and DA 12 showed less than 10% wilt and SM. In the field screening, however, three lines, NP(WR) 15, 1234, and Bahar (1258) showed resistance to SM and PB. ICPL 227, grown in a wilt- and SM-disease nursery at ICRISAT Center, showed good resistance to both diseases (Fig. 4).

Nematodes

Response to a questionnaire on nematode-caused diseases of ICRISAT's mandate legumes. We sent a questionnaire covering many aspects of research on nematode problems of chickpea, pigeonpea, and groundnut to nematologists and plant-protection workers concerned with these crops. We received responses from nematologists working in 13 countries including those in seven Indian states (Table 4). The root-knot nematodes (*Meloidogyne* spp), the lesion nematodes (*Pratylenchus* spp), and the reniform nematode (*Rotylenchulus reniformis*) are considered important in many countries. Among seven Indian states, pigeonpea cyst nematode (*Heterodera cajani*) is considered most important nema-

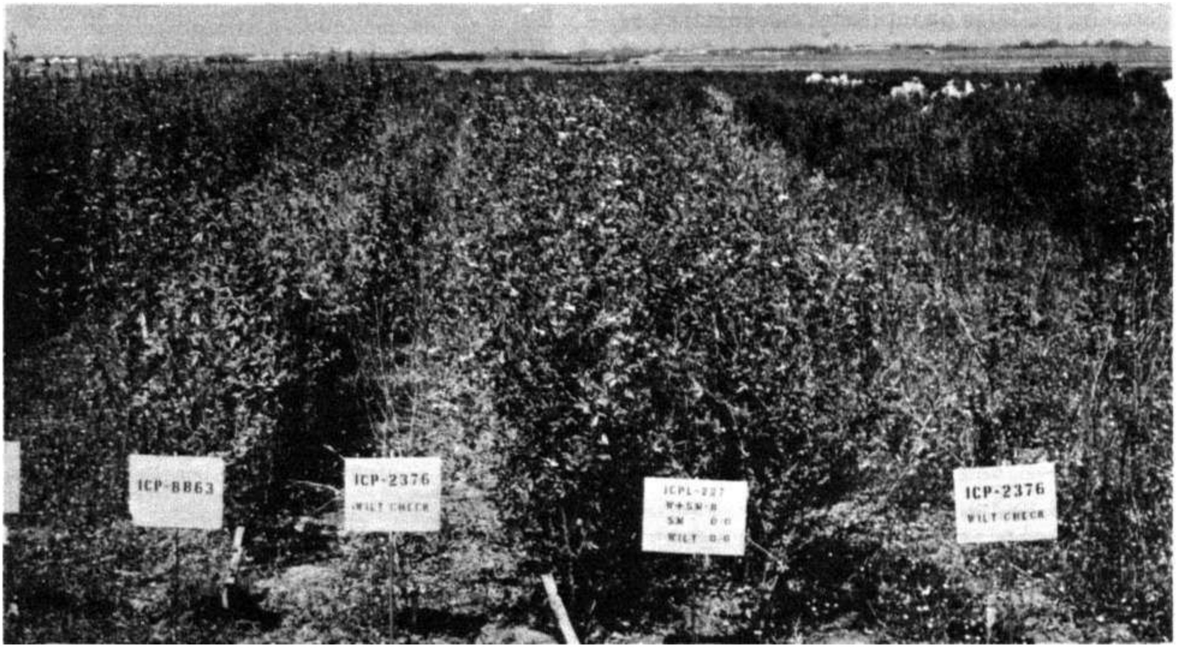


Figure 4. The pigeonpea multiple-disease nursery at ICRISAT Center during 1987/88 season. The line ICPL 227 (two-row plot) shows resistance to wilt and sterility mosaic while the neighboring wilt (ICP 2376) and sterility mosaic (ICP 8863) susceptible controls show 100% disease incidence.

Table 4. Important nematode pests of pigeonpea in 13 countries.

Country	Most important	Very important	Important
Brazil	*Meloidogyne javanica*	*Pratylenchus brachyurus*	*Helicotylenchus dihystera*
Egypt	*Heterodera cajani*	*M. incognita*	
Ethiopia	*Meloidogyne* sp		
Fiji	*Rotylenchulus reniformis*	*Meloidogyne* sp	*Radopholus similis*
India (states)			
Andhra Pradesh	*H. cajani*	*Meloidogyne incognita*	*Pratylenchus* sp
Bihar	*H. cajani*	*Meloidogyne* sp	*Hoplolaimus* sp
Gujarat	*Meloidogyne* sp	*R. reniformis*	*Tylenchorhynchus vulgaris*
Haryana	*H. cajani*	*Meloidogyne* sp	*R. reniformis*
Karnataka	*H. cajani*	*Meloidogyne* sp	*R. reniformis*
Maharashtra	*M. incognita*	*R. reniformis*	
Rajasthan	*R. reniformis*	*H. cajani*	*Tylenchorhynchus* sp
Jamaica	*R. reniformis*	*Pratylenchus* sp	*Helicotylenchus* sp
Malawi	*M. javanica*		
Nepal	*Meloidogyne* sp		
Sudan	*P. sudanensis*	*Tylenchorhynchus* sp	*Ditylenchus* sp
Trinidad	*R. reniformis*	*Pratylenchus zeae*	*H. dihystera*
USA	*Meloidogyne* sp	*Pratylenchus* sp	
Zambia	*Meloidogyne* sp		
Zimbabwe	*Meloidogyne* sp	*Pratylenchus* sp	*Helicotylenchus* sp

tode pest in four: Andhra Pradesh, Bihar, Haryana, and Karnataka. The respondents from India, Jamaica, Sudan, Trinidad, Zambia, and Zimbabwe indicated that only 10% or less of their total pigeonpea-growing areas have been surveyed for nematode-caused diseases.

Survival. We studied survival of plant-parasitic nematodes without hosts in Alfisol and Vertisol fields. The reniform nematode, *R. reniformis,* in Alfisol and in Vertisol, the lance nematode, *Hoplolaimus seinhorsti,* in Alfisol, and the cyst nematode *H. cajani* in Vertisol could survive for more than 300 days without host plants.

Parasitism of *H. cajani* and *Meloidogyne javanica* by a bacterium, *Pasteuria penetrans.* We observed that 24% of white females of *H. cajani* collected from a field where pigeonpea had been cultivated for more than 10 years, were filled with spores of a bacterium (*Pasteuria penetrans*). The female nematodes were devoid of eggs and larvae. We also observed the bacterial infection in second-stage larvae collected from soil samples. The root-knot nematode (*M.javanica*) collected from the same field was also infected with *P. penetrans,* and larvae had endospores attached to their cuticles. Infected larvae of these nematodes, when placed in water, formed loosely woven masses because of adhesion of endospores attached to their cuticles. Initially two to three larvae were seen clinging to each other and gradually more and more larvae joined them to form the loosely woven 'sticky swarm'. The bacterium is not host specific, as it could also infect larvae of *R. reniformis.*

Insect Pests

Pest Incidence

In the 1987/88 growing season, the pod borer, *Helicoverpa* (formerly *Heliothis) armigera,* was the major pest of pigeonpea in peninsular India and also at Hisar. At ICRISAT Center, the borer populations increased first in September and again in December 1987. At Hisar, we first recorded peak populations of *Helicoverpa* moths in October/ November 1987, and then soon after the cold-weather period in February continuing up to April 1988. At Gwalior, we noticed moth abundance during February/March 1988. The spotted borer, *Maruca testulalis,* which is usually a pest of short-duration cultivars common in the northern Indian pigeonpea-growing areas, was not a major pest during 1987-88, particularly at Hisar.

Of the other lepidopteran pests, the leaf webber (*Cydia critica*) was more common than usual at ICRISAT Center and in other pigeonpea-growing areas but relatively rare at Hisar. The infestation of this pest begins at the early-seedling stage. The larvae then web the terminal leaves together and can cause damage to buds, flowers, and tender pods (Fig. 5).

Podfly (*Melanagrowyza obtusa*) incidence was generally low, but this pest severely damaged the long-duration cultivars at Gwalior.

Blister beetle *(Mylabris pustulata)* was very common again at ICRISAT Center from August to November and we received reports from several areas of India that this pest was a serious yield reducer of short-duration pigeonpea.

Pod borer (*Helicoverpa armigera*)

Host-plant resistance. We tested selections from breeders' material of extra-short-duration pigeonpea with tolerance of *Helicoverpa* damage at ICRISAT Center and at Hisar on small plots of twp 4-m long rows to assess their borer-, resistance levels and yields under unprotected conditions. The results of the outstanding genotypes from such a test at Hisar are given in Table 5. Genotypes ICPLs 187-1-1-6EB, 2-2EB, 269, and 288 have performed well in our tests so far at ICRISAT Center.

As most of our pest-resistant material is susceptible to wilt and other diseases, we have developed a combined wilt and *Helicoverpa* resistance screening nursery at ICRISAT Center. The test material is planted on two 4-m long rows with a wilt-susceptible control on every third row. No plant-protection measures are

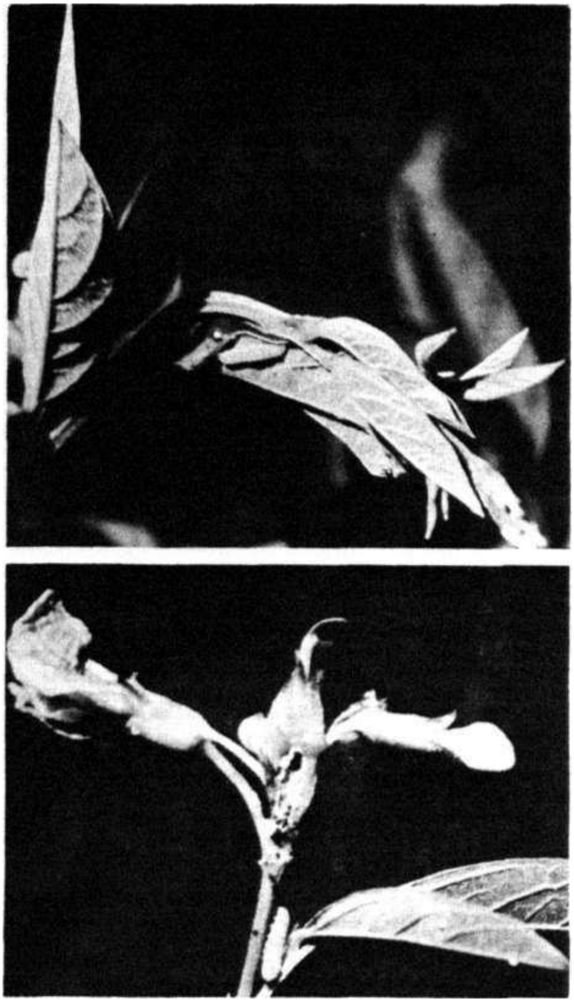


Figure 5. Cydia critica *damage in pigeonpea: webbed leaves with caterpillar* (top), *and damaged buds and flowers* (bottom).

Table 5. Performance of some extra-short-duration, pest-tolerant pigeonpea genotypes grown in a pesticide-free field, plot size 2.1 m^2, Hisar, rainy season 1987.

Genotype	Time to 50% flowering (days)	Borer-damaged pods (%)	Grain yields (t ha^{-1})
1CPL 85059 E2	82	16	3.70
ICPL 86016-E2	84	28	4.59
ICPH 22	84	24	4.44
ICPL 85048-E1	84	29	3.38
ICPL 85059-2EB	86	24	2.15
ICPL 85057-E2	87	33	3.71
ICPL 187-1-1-6EB	88	33	4.57
Controls			
UPAS 120	82	61	1.56
Pant A1	85	63	2.40
SE		±8.3	±0.53
Trial mean (20 genotypes)		41	2.82
CV (%)		20	19

used. Borer incidence is augmented, if necessary, by introducing laboratory-bred *Helicoverpa* moths. At maturity, the surviving plants are checked and lines showing reduced susceptibility are selected for further testing.

Chemical Basis of Host-plant Resistance

We found in previous experiments of the cooperative project with the Max-Planck Institute for Biochemistry, Munich, Federal Republic of Germany, that pigeonpea volatiles play an important role in host-plant recognition by *H. armigera.* We used a new method to sample head-space volatiles, under field conditions, during the 1987/88 postrainy season. We collected samples from individual plants of various pigeonpea cultivars from the gaseous phase without using a solvent. Analyses by gas chromatography and comparison with 23 reference compounds revealed a high amount of terpenoids and volatiles in the sesquiterpenoid range. Some compounds were tested individually as well as in mixture. Recently we found linalool, which is abundant in less-susceptible genotypes, to be a very effective repellent for *H. armigera* larvae in olfactometer bioassays. Further refinements of the sampling procedure now provide a facility to sample individual living plants repeatedly.

Podfly (*Melanagromyza obtusa*)

Host-plant resistance. We intensified our efforts to screen for resistance to podfly at Gwalior and at ICRISAT Center. We grew several trials and identified less-susceptible genotypes, the most promising of which are shown in Table 6.

Collaboration with Overseas Development Natural Resources Institute (ODNRI), UK

The upsurge of *Helicoverpa* resistance to synthetic pyrethroids at the end of 1987 and the dispersal of resistant insects were elements of the main focus of research this year. We first suspected pyrethroid resistance when insecticides used on cotton crops failed in coastal Andhra Pradesh. Resistance testing was undertaken at Reading University, UK (under extramural contract to ODNRI). We confirmed a high level of resistance to cypermethrin, a representative pyrethroid insecticide, in samples of *Helicoverpa* from Juzzuru (Andhra Pradesh) collected at the end of October 1987. At ICRISAT Center, control of *Helicoverpa* on pigeonpea and chickpea was poor, during the 1987/88 postrainy season. Many samples taken from late October 1987 to March 1988 showed increasing levels of pyrethroid resistance during the season. This contrasts with the complete susceptibility to a pyrethroid in *Helicoverpafrom* the 1986 rainy season (Table 7). Further tests on *Helicoverpa* samples from ICRISAT Center and from Aurepalle, some 100 km to the south, collected in September 1988, showed that pyrethroid resistance had again fallen to the 1986 levels. Resistance to endosulfan and monocrotophos had also increased slightly during the 1987/88 postrainy season. In March 1988, *Helicoverpa* was again fully susceptible to endosulfan.

Table 6. Pod damage by podfly (*Melanagromyza obtusa*) on pigeonpea genotypes grown in 12-row plots of 4-m length, ICRISAT Center and Gwalior, sown in rainy season 1987.

Genotype	Mean (n = 4) pod damage (%) ICRISAT Center	Gwalior
1CPL 8362-EB	12	26
PI 39457I-S2-2EB	20	35
ICP 8094-2-1-S1-SB-EB	14	22
1CP 7176-5-E1-5EB	10	38
ICP8102-5-S1-10-EB	16	34
Controls		
Gwalior 3	21	48
Bahar	25	61
1CPL 366	21	38
NP(WR) 15	20	33
SE	±2.9	±4.8
CV (%)	33	24

The increasing severity of pyrethroid resistance during the 1987/88 postrainy season at ICRISAT Center, where previously no resistance had been recorded, strongly suggests that resistant insects had invaded from elsewhere. Tethered flight studies in 1987 showed that flights of up to 80 km in a night were possible. Radar observations confirmed that dispersal was at a low elevation and downwind, beginning soon after dusk. Strong circumstantial evidence therefore exists for repeated influxes of resistant insects from the cotton-growing region, some 250 km distant, flying with the prevailing southeasterly winds. The subsequent decline of resistance in the 1988 rainy season further supports this.

Plant Nutrition

The bulk of our work on this subject this year has been done within the Government of Japan Special Project, which is primarily examining phosphorus nutrition and its interaction with soil-moisture availability. However, work is continuing on nitrogen (N) fixation in pigeonpea, an example of which is reported below.

Table 7. Toxicity of synthetic pyrethroids, cypermethrin and fenvalerate, on strains of *Helicoverpa armigera* from Andhra Pradesh, India[1].

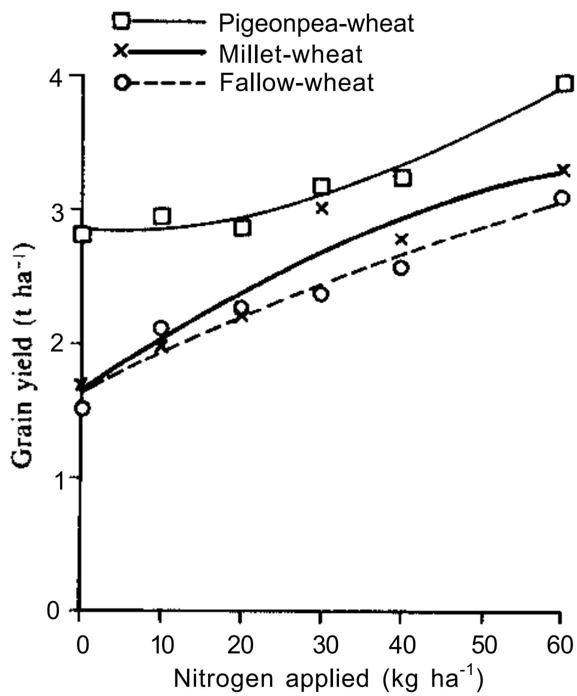
Insecticide	Month collected	Location	Crop	LD 50[2]	Resistance ratio[3]
Fenvalerate	Aug 1987	ICRISAT Center	Chickpea	0.012	0.8
Cypermethrin	Oct 1987	Juzzuru	Cotton	6.5	325
Cypermethrin	Oct 1987	ICRISAT Center	Pigeonpea	0.8	40
Fenvalerate	Oct 1987	ICRISAT Center	Pigeonpea	1.8	120
Cypermethrin	Nov 1987	ICRISAT Center	Pigeonpea	2.5	125
Cypermethrin	Nov 1987	ICRISAT Center	Chickpea	1.7	85
Cypermethrin	Mar 1988	ICRISAT Center	Pigeonpea	1.5	750
Fenvalerate	Mar 1988	ICRISAT Center	Pigeonpea	4.3	287
Cypermethrin	Sep 1988	ICRISAT Center	Sorghum	0.012	0.6
Cypermethrin	Sep 1988	ICRISAT Center	Pigeonpea	0.036	1.8
Cypermethrin	Sep 1988	Aurepalle	Pigeonpea	0.016	0.8

1. Topical application to third instar larvae; comparison with standard reading susceptible strain.
2. Expressed as μg $larva^{-1}$.
3. Ratio of LD 50 of resistant strain to LD 50 of susceptible strain.

Residual Effect of Short-duration Pigeonpea

In the 1987 rainy season, we began an experiment at Gwalior to calibrate the residual effect of short-duration pigeonpea genotype ICPL 151 on a subsequent wheat crop. This genotype is proving to be particularly suited to the short-duration pigeonpea-wheat rotation of northern India, because of its high yields, lesser crop height than those of commonly used indeterminate short-duration cultivars, and shorter duration. There have been conflicting reports of the effects of pigeonpea on subsequent crops, ranging from detrimental to beneficial.

Thus, during the rainy season, we grew four replications of three main plot treatments, ICPL 151, pearl millet (cv GV 1) and fallow (weed free). The growth of these crops was normal. After their harvest, we divided the main plots into six subplots on which N-fertilizer treatments were imposed. We sowed wheat (cv HDM 1553) on all subplots in early December. Differential N-responses between main-plot treatments were visually apparent during wheat growth, by both apparent biomass and foliage greenness. Figure 6 shows that there was a lesser N response



Pigeonpea-wheat $y = 2.84 - 0.00135x + 0.00033x^2$ ($r^2 = 0.96$)
Millet-wheat $y = 1.62 + 0.04270x - 0.00025x^2$ ($r^2 = 0.87$)
Fallow-wheat $y = 1.62 + 0.03040x - 0.00011x^2$ ($r^2 = 0.92$)

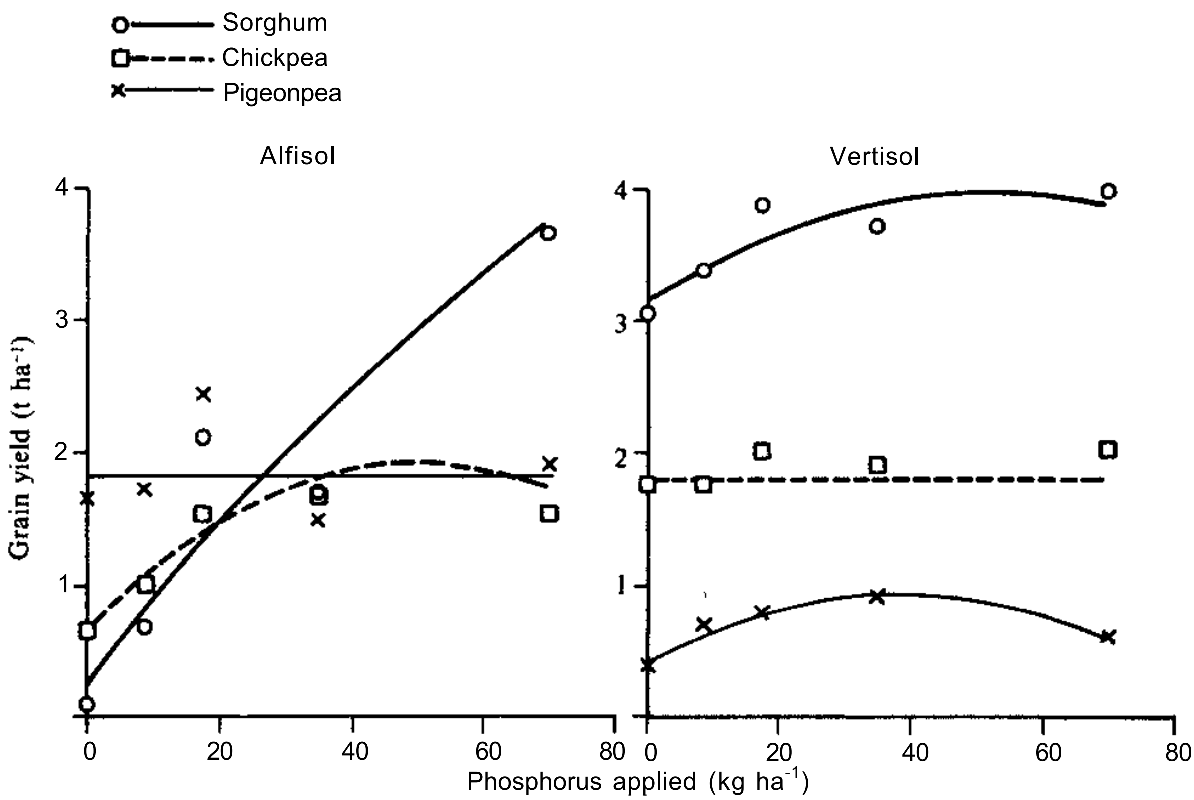
Figure 6. Effect of previous crop treatments on response of grain yield ($t\ ha^{-1}$) of wheat to nitrogen fertilizer, Gwalior, postrainy season 1987/88.

of wheat on pigeonpea main plots than on either millet or fallow main plots. The pigeonpea was worth in excess of 40 kg ha^{-1} N when compared with fallow plots and about 30 kg ha^{-1} N when compared with millet plots. We obtained a similar advantage in respect of N responses of total dry-matter production of wheat.

Thus, it appears that ICPL 151 can appreciably improve the N nutrition of a following wheat crop. This is perhaps surprising because few nodules could be detected on pigeonpea roots during its growth and because of the short period between crops, suggesting a rapid breakdown and release of N from decomposing pigeonpea material.

Phosphorus-solubilizing Root Exudates

We have previously shown that pigeonpea is better able than other crop species to absorb phosphorus (P) from iron-bound P, which is the predominant form of P in Alfisols (ICRISAT Annual Report 1987, pp. 199-201). Pot studies showed that pigeonpea could survive on an Alfisol at low-P status without mycorrhizae (sterilized soil) or P fertilizer, whereas sorghum died at an early stage (ICRISAT Annual Report 1987, pp. 198-200). Field experiments have also clearly shown differences in P response between pigeonpea and other crops on an Alfisol (4 mg kg^{-1} Olsen's P) and a Vertisol (1 mg kg^{-1} Olsen's



	Alfisol	Vertisol
Sorghum	$y = 0.284 + 0.0635x - 0.00024x^2$ ($r^2 = 0.75$)	$y = 3.129 + 0.0315x - 0.00031x^2$ ($r^2 = 0.62$)
Chickpea	$y = 0.664 + 0.0498x - 0.00054x^2$ ($r^2 = 0.90$)	$y = 1.79$
Pigeonpea	$y = 1.81$	$y = 0.405 + 0.0268x - 0.00034x^2$ ($r^2 = 0.91$)

Figure 7. Response of pigeonpea (ICPL 87), chickpea (K 850), and sorghum (CSH 5) to phosphorus in field experiments, on an Alfisol and a Vertisol, ICRISAT Center, rainy season 1987 (pigeonpea, sorghum) and postrainy season 1987/88 (chickpea).

P), the latter soil type containing a large fraction of calcium-bound P (Fig. 7). Pigeonpea was much less responsive than chickpea or sorghum on the Alfisol, and yielded much higher than these crops on this soil without P application. Thus, pigeonpea appears to be better utilizing iron-bound P, whereas chickpea and sorghum better utilize calcium-bound P. These results suggest that pigeonpea root exudates are able to solubilize iron-bound P.

We collected root exudates, from pigeonpea cultivars—C 11 and ICPL 87—grown in sand culture, up to the flowering stage. We fractionated the exudates by ion-exchange chromatography into cationic, anionic, and neutral fractions. The ability of these fractions to solubilize P from ferric phosphate was: cationic, 14.5 ± 4.8 $\mu g\ pot^{-1}$; anionic, 40.8 ± 11.3 $\mu g\ pot^{-1}$; neutral, nil. The activity of these fractions varied depending on the plant-growth stage and nutritional status but the anionic fraction always had the highest activity.

We further fractionated anionic fractions, collected from pigeonpea root exudates, using charcoal-column chromatography. By eluting with water, methyl alcohol, acetone, and benzene, 10 fractions were recovered. The first water-soluble fraction comprised large amounts of citric acid and small amounts of malic, malonic, and succinic acids. We also found these proportions of organic acids in chickpea root exudates and thus the special ability of pigeonpea to utilize iron-bound P may not be explained by these organic acids. The fourth fraction, soluble in 75% methyl alcohol, contained unidentified compounds that could solubilize ferric phosphate, react strongly with Folin-Denis reagent, and reduce ferric-ion. These compounds could not be found in the root exudates of chickpea, sorghum, or soybean; they are now being characterized.

Grain and Food Quality

Starch Properties and Noodle Quality

We investigated the feasibility of using pigeonpea starch to prepare noodles and compared it with mung-bean noodles, commonly used in Thailand. Using whole-seed and dhal samples of these two legumes, we isolated the starches. We observed that the starch-extraction rate from

Table 8. Starch-extraction rates, swelling power, and viscosity patterns of isolated starches of pigeonpea (C 11) and mung bean (PS 16), ICRISAT Center, rainy season 1987[1].

Legume	Starch extraction (%)	Isolated starch: Swelling power[2] g (g sample)$^{-1}$	Viscosity (Brabender units)[3] Initial	Viscosity (Brabender units)[3] Final
Pigeonpea				
Whole seed	49.3	7.8	305	322
Dhal	71.2	10.1	277	302
Mung bean				
Whole seed	59.3	8.9	372	402
Dhal	78.3	9.2	300	315
SE	±3.8	±0.4	±6	±9

1. Based on two determinations for each treatment.
2. Determined at 80° C.
3. Determined at 95°C. Final reading was taken after holding for 60 min.

both the whole-seed and dhal samples of rnung bean was higher than that of pigeonpea (Table 8). Differences in whole-seed samples were more pronounced, which may be because of the differences in their seed coat and fiber contents. However, the isolated starch fractions of both whole-seed and dhal of these legumes contained very low amounts of protein, ash, and crude fiber, and this reflected the purity of the isolated starch fraction (Table 8). Pigeonpea starch contained slightly more protein than mung-bean starch. We observed no large difference in the amylose content of pigeonpea and mung-bean starches.

We noticed that both mung-bean and pigeonpea starches were exemplified by a two-stage swelling process, i.e., restricted swelling at lower temperatures (60°C and 70°C) and then an increased swelling at higher temperatures (80°C and 90°C). However, at different temperatures, we observed marked differences in viscosity patterns of pigeonpea and mung-bean starches. The Brabender viscosity measurement of 6% starch pastes of pigeonpea and mung bean showed a stable graph, indicating that there was no breakdown of the hot paste; the values are shown in Table 8. The viscosity patterns of these legumes appeared to be related to their swelling power.

For noodle-quality evaluation, we prepared both soft and hard noodles of pigeonpea and mung-bean starches, and evaluated freshly cooked noodles for various quality characteristics (Table 9). Soft noodles prepared from whole-seed and dhal samples are shown in Figure 8. The whole-seed starch isolated from pigeonpea produced noodles of poor to fair quality, with an average score of 1.9 on general acceptability, (scale 1-4, where 1 = Poor, and 4 = Excellent), whereas the noodles of whole-seed starches of mung bean were rated as fair to good, with an average score of 2.8 (Table 9). The score on noodle clarity and color from whole-seed starch of pigeonpea was lower than that of mung bean. On the other hand, dhal starch of pigeonpea produced noodles of better quality than that of mung bean, as revealed by various organoleptic properties (Table 9) and noodle color (Fig. 8). We observed no marked differences in the quality of hard noodles of mung bean and pigeonpea starches. These results indicate that noodle quality of whole seed of mung bean is better than that of pigeonpea, while pigeonpea dhal noodles were better than mung-bean dhal noodles.

Tempeh, a Fermented Product

Tempeh, traditionally prepared from soybean, is an important food in Indonesia. Pigeonpea utilization in *tempeh* in Indonesia has often been suggested. We prepared *tempeh,* using the cul-

Table 9. Organoleptic properties of soft noodle starches of pigeonpea (C 11) and mung bean (PS 16), ICRISAT Center, rainy season 1987.

Type of noodle	Color	Texture	Clarity	Uniform appearance	General acceptability
Pigeonpea noodle					
Whole seed	1.6[1]	2.0	1.7	2.3	1.9
Dhal	3.6	2.6	3.5	3.4	3.4
Mung-bean noodle					
Whole seed	2.5	3.2	2.5	2.8	2.8
Dhal	2.8	2.9	2.6	2.3	2.6
SE	±0.3	±0.3	±0.3	±0.3	±0.3

1. Average score values of 10 panel members. Scored on a 1-4 scale, where: 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent.

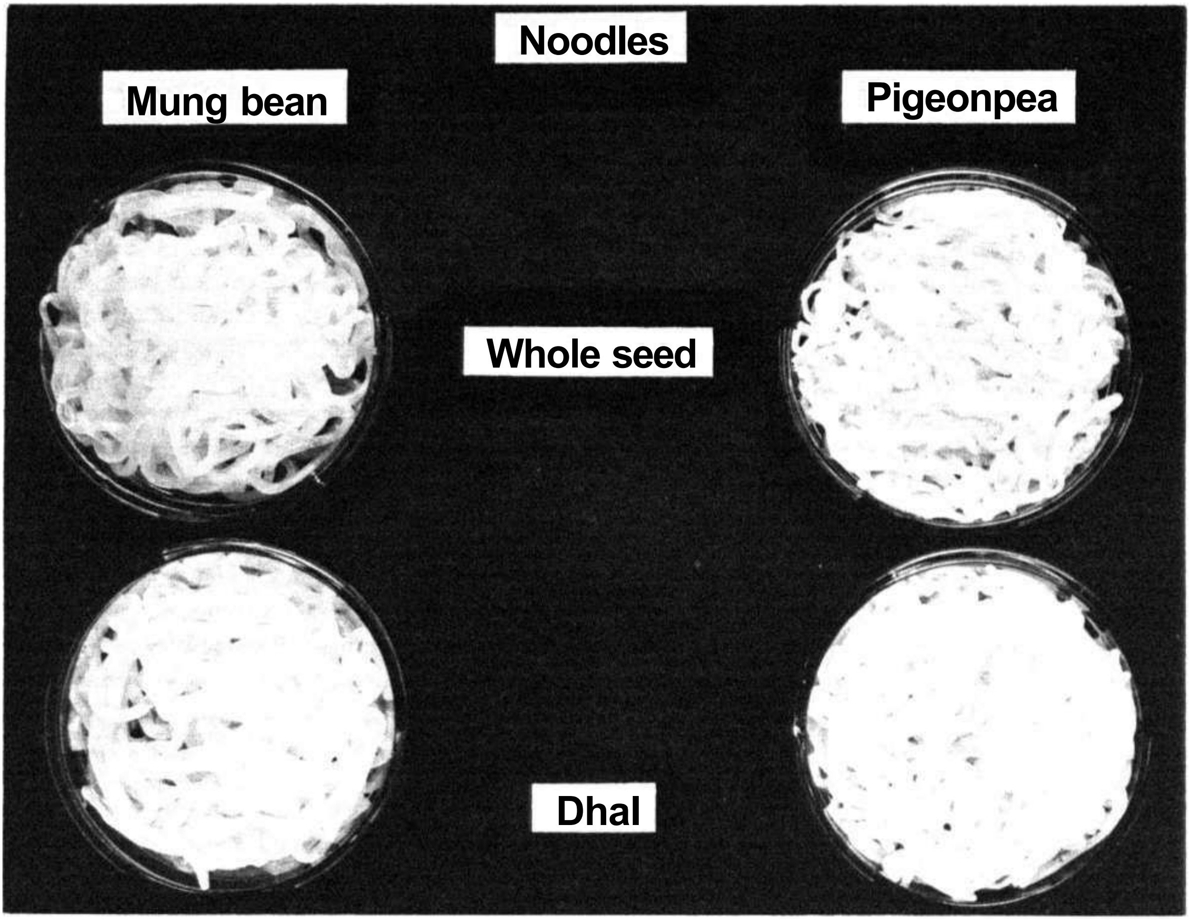


Figure 8. Starch noodles of whole seed and dhal samples of pigeonpea (C 11) and mung bean (PS 16), ICRISAT Center, 1988.

ture *Rhizopus oligosporus* obtained from Indonesia, and compared it with soybean *tempeh* prepared in a similar way. We standardized the fermentation conditions of *tempeh* preparation and fermentation carried out at 30°C for 24 h. The organoleptic properties, such as color, taste, texture, and flavor in *tempeh* of pigeonpea and soybean were similar, suggesting that pigeonpea can substitute soybean in *tempeh* preparation. Preliminary studies also indicated that pigeonpea genotype C 11 (brown seed coat) required more time to ferment for *tempeh* preparation compared with variety Nylon (white seed coat). We also noticed that addition of salt before fermentation delayed fermentation.

Plant Improvement

Short-duration Pigeonpea

We continued with increased emphasis our work on the improvement of extra-short- [<100 days after sowing (DAS) at Hisar in normal end-of-June sowing] and short-duration (101-130 DAS) pigeonpea to suit different cropping systems.

We identified an extra-short-duration pigeonpea line, ICPL 85010, for the AICPIP multilocational trials in 1988. This line is shorter in plant height and has larger seeds, than the control cultivar, ICPL 4 (Prabhat). It has produced higher grain yields than the control cultivar, ICPL4(Prabhat), both in 1986 and 1987 at three dates of sowing at Hisar (Table 10). The short-statured extra-short-duration lines are suitable for mechanized cultivation. At Hisar, a combine harvester successfully harvested two extra-short-duration lines, ICPLs 84023 and 83015, (Fig. 9). Because of their relative insensitivity to photoperiod and temperature variations, they are comparatively stable in phenology and can be successfully grown at higher latitudes and altitudes.

In rainfed semi-arid environments planting time varies depending on when the rainy season begins. Further, availability of irrigation permits sowing earlier than would otherwise be possible, as in parts of northern India, where farmers

Table 10. Performance of an extra-short-duration pigeonpea line (ICPL 85010), Hisar, 1986-87.

	Grain yield (t ha^{-1})			
Date sown	ICPL 85010	Control ICPL 4 (Prabhat)	SE	CV (%)
1986				
7 April	3.76	2.50	±0.18	11
25 June	2.56	2.13	±0.26	20
28 July	2.12	1.72	±0.18	16
1987				
1 May	2.81	1.86	±0.22	12
30 June	2.91	2.78	±0.19	12
28 July	3.05	2.82	±0.30	22

Figure 9. An extra-short-duration line, ICPL 84023, being harvested by a combine harvester, Hisar, rainy season 1987.

prefer to sow pigeonpeas soon after harvesting and threshing of wheat, in May. Hence, we made an attempt to identify short-duration pigeonpea lines, stable in production, across different sowing times. We thus tested advanced extra-short - and short-duration lines at three dates of sowing at Hisar.

Of the extra-short-duration lines, ICPLs 86009 and 83015 were among the three highest-yielding lines at all sowings, indicating their stability in production at different sowing times (Table 11). Both consistently produced higher grain yields and had bigger seeds than the control, ICPL 4 (Prabhat). During 1987, these lines were also tested in a multilocational Extra-early Pigeonpea Adaptation Yield Trial (EXPAY 87) along with 16 other entries including controls. At seven acceptable locations in North Plains West Zone, ICPL 86009 was among the five highest-yielding lines at six locations and ICPL 83015 among the five highest-yielding lines at five locations, with mean grain yields of 2.63 t ha^{-1} (ICPL 86009) and 2.48 t ha^{-1} (ICPL 83015) as compared with 2.06 t ha^{-1} in the control (ICPL 4).

Among the short-duration determinate lines, ICPLs 86012, 85012, and 86007 consistently produced higher grain yield than the control cultivars, ICPLs 151 and 87, in all the three sowings at Hisar during the 1987 rainy season (Table 12). They were among the six highest-yielding lines at all sowings indicating their relative stability of production over sowing-time variations. These lines have large white seeds and have shown resistance to SM disease.

One of the promising short-duration pigeonpea lines, ICPL 84031, was entered in AICPIP multilocational trials and was also tested in an ICR1SAT multilocational Early Pigeonpea Adaptation Yield 87 Determinate Trial (EPAY 87 DT) in 1987. At the AICPIP Kharif Pulses Workshop held at Udaipur, India, 23-26 May 1988, the line was identified as promising in North East Hill and North West Plains Zones. In EPAY 87 DT, out of 18 locations, it was found to be one among the five highest-yielding lines at 11 locations with a mean grain yield of 1.93 t ha^{-1}, as compared with the control cultivars yield of 1.78 t ha^{-1} (ICPL 87) and 1.83 t ha^{-1} of ICPL 151. The line has shown resistance to SM disease.

Table 11. Performance of some promising extra-short-duration pigeonpea lines in early (1 May), normal (30 June), and late (28 July) sowings, Hisar, rainy season 1987.

Line	Grain yield (t ha^{-1})				100-seed mass (g)
	1 May	30 June	28 July	Mean	
ICPL 86009	3.29 (2)[1]	3.91 (1)	3.45(1)	3.55	9.4
ICPL 83015	3.39 (1)	3.20 (3)	3.25 (2)	3.28	9.7
ICPL 83006	2.78 (6)	3.16 (5)	3.20 (3)	3.05	7.6
ICPL 84023	3.02 (4)	3.18 (4)	2.93 (6)	3.04	8.1
Control					
ICPL 4 (Prabhat)	1.86(16)	2.78(11)	2.82 (8)	2.48	6.1
SE	±0.22	±0.19	±0.30		
Trial mean (16 entries)	2.54	2.88	2.34	2.59	
CV (%)	12	11	22		

1. Values in parentheses are ranks at each sowing.

Table 12. Performance of some promising short-duration pigeonpea lines in early (1 May), normal (30 June), and late (28 July) sowings, Hisar, rainy season 1987.

Line	Grain yield (t ha^{-1})				100-seed mass (g)	Seed color[1]
	I May	30 June	28 July	Mean		
1CPL 86012	3.09 (2)[2]	4.08 (1)	3.76 (4)	3.64	12.4	W
ICPL 85012	2.85 (6)	3.71 (2)	3.97 (2)	3.51	12.4	W
1CPL 86007	3.19 (1)	3.61 (4)	3.07 (6)	3.29	11.5	w
ICPL 84031	3.04 (3)	3.47 (5)	2.91 (8)	3.14	10.4	B
Controls						
ICPL 151	2.67 (9)	3.22(11)	2.56(12)	2.82	10.7	C
ICPL 87	2.29(11)	3.14(14)	2.72 (10)	2.72	11.3	B
SE	±0.27	±0.16	±0.42			
Trial mean (18 entries)	2.55	3.29	2.85	2.90		
CV (%)	18	8	25			

1. B = Brown, C = Cream, W = White.
2. Values in parentheses are ranks at each sowing.

Hybrids

This year we evaluated 252 short-duration hybrids of determinate (45) and indeterminate (207) growth habit at Hisar and 1CRISAT Center. Some short-duration hybrids, namely, ICPHs 253, 267, 281, 289, and 140, were outstanding. On an average, these hybrids yielded 3.35 t ha"[1] in comparison with 2.15 t ha^{-1} for the control cultivar, UPAS 120. These hybrids matured a week earlier and produced 15% more grain yield than the hybrid ICPH 8.

In the AICPIP Kharif Pulses Workshop at Bangalore in May 1987, ICRISAT's proposed cooperative program to produce and to evaluate experimental hybrids was accepted. As a follow-up, a cooperative network involving some Indian agricultural universities and Indian Council of Agricultural Research (ICAR) centres was developed to produce and to evaluate experimental hybrids of short and long duration. We also trained scientists and technicians of private seed companies and universities in hybrid pigeonpea seed production.

Vegetable Pigeonpea

We are developing medium-maturing, disease-resistant pigeonpea lines suitable for vegetable and dry-seed consumption. ICPL 87048, which has larger seeds than the control, C 11, performed well at ICRISAT Center (ICRISAT Annual Report 1987, p. 211). This line is tolerant of wilt and has large, brown seeds. We have now developed high-yielding, disease-resistant lines with white, bold seeds suitable for both dry seed and vegetable purposes. Among such lines, ICPL 87066 yielded 1.79 t ha^{-1} of dry seed and ICPL 87067 yielded 1.73 t ha^{-1} of dry seed compared with 1.41 t ha^{-1} yield of the control, BDN 2 (Table 13). These lines had significantly larger seeds than the control. Both the lines have shown resistance to wilt and sterility mosaic in a disease nursery at ICRISAT Center. In the Indian state of Gujarat and in the northern part of another state, Karnataka, where white, bold-seeded lines are preferred and fusarium wilt is a major yield reducer, these lines are likely to find a place on farmers'fields. Seed multiplication for large plot

Table 13. Performance of disease-resistant, white, bold-seeded, medium-duration pigeonpea lines at two locations in India, sown in rainy seasons 1986 and 1987.

	Grain yield (t ha^{-1})			100-seed mass (g)		
	1986	1987		1986	1987	
Entry	ICRISAT Center	ICRISAT Center	Gulbarga	ICRISAT Center	ICRISAT Center	Gulbarga
ICPL 87066	1.88	1.67	1.82	14.8	13.4	13.2
ICPL 87067	1.73	1.54	1.93	15.1	14.0	13.2
Controls						
BDN2	1.63	1.39	1.21	10.4	10.5	10.3
Maruti	-	1.48	1.58	-	10.2	8.7
SE	±0.17	±0.30	±0.12	±0.3	±0.3	-
Trial mean	1.56	1.41	1.51	13.6	13.4	12.8
(No. of entries)	(25)	(10)	(10)	(25)	(10)	(10)
CV (%)	19	37	13	4	5	-

production-potential trials has been undertaken.

Long-duration Pigeonpea

To stabilize crop productivity of long-duration pigeonpea, we continued to breed lines with resistance to major diseases. We evaluated, in the Terai region of Nepal, in collaboration with the Grain Legume Improvement Programme (GLIP) of Nepal, a SM and alternaria-blight resistant line, ICPL 366, which performed well in northern Madhya Pradesh (ICRISAT Annual Report 1987, p. 211). ICPL 366 had a mean yield of 2.86 t ha^{-1} in five on-farm trials compared with 2.52 t ha^{-1} for the local control (Table 14). ICPL 366 was free from SM disease both on farmers' fields as well as at the experiment station. We have supplied 150 kg seed of this variety for large-scale trials in the 1988 rainy season. This variety stands a good chance for release in Nepal because of its high yield, good adaptation, and SM resistance.

This year we identified another long-duration line, ICPL 83072, for inclusion in AICPIP multilocational trials. Besides having a high level of SM resistance, this line has a good yield potential and large seeds (Table 15).

Table 14. Yield of pigeonpea line ICPL 366 in on-farm trials, Nepal, rainy season 1987.

	Grain yield (t ha^{-1})	
Village	ICPL 366	Nepalgunj local
Mankamnapur	2.60	2.55
Urarapur	3.36	2,88
Bageshwari	3.41	2.53
Khajura Khurd	1.62	1.75
Nepalgunj	3.30	2.91
Mean	2.86	2.52
Sterility mosaic reaction	Resistant	Susceptible

Breeding for Disease Resistance

In medium-duration pigeonpea, our main emphasis is to develop lines stable in yield by incorporating resistance to or tolerance of different

Table 15. Performance of pigeonpea line ICPL 83072, Gwalior and Morena, India, rainy seasons 1982-86.

Year	Location	ICPL 83072	Control (GW 3)	SE	Trial mean	CV (%)
		Yield (t ha^{-1})				
1982	Gwalior	2.58	2.51	±0.18	2.37	16
1983	Gwalior	2.29	2.78	±0.35	2.42	28
1983	Morena	3.22	2.39	±0.38	2.64	25
1984	Gwalior	1.56	2.11	±0.22	1.45	31
1985	Morena	1.33	1.39	±0.29	1.30	46
1986	Gwalior	1.99	1.06	±0.31	1.49	41
Mean		2.16	2.04			
		100-seed mass (g)				
1982	Gwalior	10.7	8.0	±0.3	9.4	6
1983	Gwalior	10.6	7.8	±0.3	8.4	6
1983	Morena	11.2	8,3	±0.4	8.9	8
1984	Gwalior	11.5	7.7	±0.4	7.5	10
1985	Morena	11.7	9.3	±0.6	10.0	11
1986	Gwalior	11.9	8.2	±0.3	8.9	6
Mean		11.3	8.2			
		Sterility mosaic (%) (disease nursery)				
1987		0.2	100			
1988		2.0	100			

biotic factors (diseases/pests).

To incorporate SM resistance, we crossed a high-yielding line, BDN 1, with a SM-resistant F_6 line from the cross ICPX 73054 (ICRISAT Annual Report 1986, p. 180) and backcrossed three times with BDN 1. We evaluated 35 SM-resistant BDN 1 backcross progenies (BC_3F_6) for SM resistance in a SM nursery and for agronomic traits under disease-free conditions at ICRISAT Center; trials were sown during the 1987 rainy season and harvested in 1988. Although the coefficient of variation for grain yield was high (31%) because of differential *Helicoverpa* damage, the potential of several progenies was encouraging. Of these, 10 progenies produced about 1 t ha^{-1} more grain yield than the 1.19 ± 0.33 t ha^{-1} yield of the control cultivar, BDN 1. They have comparatively larger seeds than BDN 1. From these progenies, we selected the two highest-yielding lines for further multilocational testing in the 1988 rainy season.

To incorporate wilt resistance, we irradiated LRG 30 and screened its M_3 single-plant progenies for wilt resistance (ICRISAT Annual Report 1987, p. 190). Of the 16 resistant progenies evaluated for resistance in the SM + wilt nursery and for agronomic traits under disease-free conditions, during the 1987 rainy season, we selected three highest-yielding wilt-resistant progenies for multilocational testing. In addition to higher grain yield (1.9 ± 0.18 t ha^{-1}) than the control (1.5 ± 0.18 t ha^{-1}), and higher wilt resistance than the control, these have also shown resistance to or tolerance of SM disease.

Breeding for *Helicoverpa* Resistance

We evaluated two *Helicoverpa* tolerant lines, ICPLs 87088 and 87089, for their yield potential in different yield trials with and without pesticide protection at ICRISAT Center. These lines maintained their superiority over both the control varieties, C 11 and BDN 1, for grain yield and *Helicoverpa* tolerance (Table 16).

In addition, we tested again for yield and *Helicoverpa* tolerance 23 lines found promising in 1986. Of these, seven had less than 40% *Helicoverpa* damage compared with 96% in C 11 and 67% in ICPL 332. The *Helicoverpa* attack was so severe that the control cultivar, C 11, produced only 10 kg ha^{-1} of grain. Three of these lines yielded higher than the *Helicoverpa*-tolerant control, ICPL 332. They have larger seed than ICPL 332.

Inheritance Studies

The excessive vegetative growth of traditional pigeonpea cultivars is not amenable to efficient crop-management practices, such as foliar insecticide application and mechanized field operations. The use of dwarfing genes to develop short-statured genotypes is necessary to manage major and widespread pests of pigeonpea. ICRISAT is maintaining six dwarfing sources (ICRISAT Annual Report 1978-79, pp. 91-92). We completed inheritance studies of three medium-duration dwarfs D6, PDI, and PBNA. Genetic studies in six crosses, involving dwarf and tall phenotypes, revealed that dwarfism in each source was conditioned by a single recessive factor. D6 and PDI had similar alleles (t_3t_3), whereas PBNA had different alleles (t_3^h t_3^h) for dwarfness, which was recessive to D6/PD 1 allele, thus constituting a multiple-allelic series. We are developing high-yielding, large-podded, large-seeded dwarf lines in all the three phenological groups, suitable for both vegetable and dry seed purposes (Fig. 10).

Table 16. Mean performance of medium-duration *Helicoverpa*-tolerant lines under sprayed and nonsprayed conditions, ICRISAT Center, rainy season 1987.

Entry	MPAY Trial[2] (sprayed) yield (t ha^{-1})	Intercropping trial (sprayed)				PIRY Trial[1]		
		Sole-crop yield (t ha^{-1})	Borer-damaged pods (%)	Intercrop yield (t ha^{-1})	Borer-damaged pods (%)	Sprayed yield (t ha^{-1})	Nonsprayed yield (t ha^{-1})	Borer-damaged pods (%)
ICPL 87088	1.95	0.85	44	0.75	43	1.71	0.47	58
ICPL 87089	1.73	0.82	41	0.84	46	2.04	0.46	67
Controls								
C 11	1.43	0.09	95	0.17	68	1.88	-[3]	99
BDN 1	0.33	0.14	81	0.19	78	1.54	-	94
SE	±0.28	-	-	-	-	±0.27	±0.10	±8
Mean	L21	.	-	-	.	1.91	-	71
(Entries)	(16)	-	-	-	-	(12)	(12)	-
CV (%)	46	-	-	-	-	28	64	22

1. PIRY Trial = Pigeonpea Insect Resistant lines Yield Trial.
2. MPAY Trial = Medium-duration Pigeonpea Adaptation Yield Trial.
3. Yields less than 100 kg ha^{-1}.

Figure 10. Recently developed dwarf pigeonpea plant type, with prolific branching and pod-bearing trait, ICRISAT Center, rainy season 1988.

Cooperative Activities

International Trials and Requests

We continued cooperative testing of new improved pigeonpea genotypes in Asia and Africa. ICP 9145, a wilt-resistant, white-seeded, long-duration line, was released for cultivation in Malawi. We sent photoperiod insensitive material for adaptive testing at higher latitudes (over 40°N and S) in USA, Canada, and New Zealand, and higher altitudes (around 2000 m above sea level) in the Himalayan regions in India. The results of cooperative international trials received over the past year are summarized in Table 17.

We received requests for information from Belize and Trinidad on milling of pigeonpea to make split pea or dhal to substitute 'Pisum split peas'. Seed material for operational-scale production and information on 'dhal mills' were supplied. We also met specific requests for seed material and information on perennial pigeonpea for food, fodder, and fuelwood in alley cropping and intercropping systems, and initiated cooperation with the International Livestock Centre for Africa (ILCA) on the utilization of pigeonpea in crop-livestock production systems.

On-farm Adaptation Trials for Short-duration Pigeonpea

Collaboration between ICRISAT's breeders, agronomists, and economists in conducting adaptation trials on farmers'fields in Maharash-

Table 17. Performance of some promising pigeonpea lines in international trials, 1986-88.

Country and location	Date sown	Entry	Time to maturity (days)	Yield (t ha^{-1})	Trial mean (number of entries)	SE	CV (%)
Burma							
Myingyan	9 Aug 1987	ICPL 83019	89	0.79	0.56(16)	±0.08	23
		ICPL 86012	101	0.78			
	9 Aug 1987	ICPL 211	132	0.35	0.24 (9)	±0.04	31
		ICPL 85063	132	0.30			
Ethiopia							
Babile	26 May 1987	ICPL 161	177	0.65	0.54 (6)	±0.07	25
		ICPL 146	177	0.57			
Fiji							
Lega Lega	1 Apr 1987	ICPL 269	95	1.15	0.81 (16)	±0.09	19
		ICPL 146	95	0.90			
Sigatoka	14 Apr 1987	ICPL 83021	107	3.19	1.78 (16)	±0.26	25
		ICPL 288	122	2,81			
Kenya							
Kiboko	Nov 1986[1]	ICPL 146	94	1.07	0.79 (7)	±0,12	21
		ICPL 87	96	0.98			
	14 Apr 1987	ICPL 151	105	0.63	0.55 (9)	±0.08	31
Malawi							
Bvumbwe	9 Dec 1987	ICPL 269	86	0.30	0.20 (4)	±0.03	23
		ICPL 146	113	0.30			
Chitala	6 Jan 1987	ICPL 146	-[2]	1.73	1.56 (6)	±0.13	11
		ICPL 87	-	1.63			
	11 Dec 1987	ICPL 146	100	2.60	1.60 (6)	±0.30	29
		ICPL 269	93	1.90			
Makoka	3 Dec 1987	ICPL 146	97	0.90	0.50 (6)	±0.10	31
		ICPL 269	101	0.80			

1. Precise date not available.
2. - = Data not reported.

Continued

Table 17. *Continued.*

Country and location	Date sown	Entry	Time to maturity (days)	Yield (t ha^{-1})	Trial mean (number of entries)	SE	CV (%)
Niger							
Niamey	8 Jul 1987	ICPL312	102	0.83	0.41 (13)	±0.10	49
		1CPL 84019	94	0.68			
Pakistan							
Dhadar	27 Jul 1987	ICPL4	-[2]	1.45	1.11 (20)	±0.17	30
		ICPL 84020	-	1.36			
The Philippines							
Los Banos	19 Feb 1988	ICPL 87	-	1.05	0.58 (14)	±0.08	22
		ICPL 86003	-	0.80			
Sri Lanka							
Girandurukotte	22 May 1987	ICPL 4	84	3.95	3.36(12)	+0.34	17
		ICPL 84019	71	3.70			
Maha Illupallama	9 May 1987	ICPL 312	90	3.22	2.17(16)	±0.19	15
		ICPL 151	97	2.66			
Pallekele	30 Oct 1987	ICPL 86005	88	1.73	1.22(13)	±0.22	31
		ICPL 86010	89	1.54			
Tanzania							
Gairo	28 Feb 1987	ICPL 83016	104	0.88	0.72 (6)	±0.07	18
		ICPL 151	109	0.87			
Morogoro	2 Apr 1987	ICPL 87	-	1.19	0.90 (6)	±0.18	34
		ICPL 161	-	1.18			
	20 Feb 1987	ICPL 140	108	1.67	1.29(10)	±0.15	20
		ICPL 84035	110	1.54			
Ukiriguru	14 Dec 1987	ICPL 146	-	1.32	0.94 (7)	±0.09	19
		ICPL 161	-	1.28			
Thailand							
Khon Kaen	31 Jul 1987	ICPL 86008	125	2.66	1.84 (5)	±0.12	13
		ICPL 86009	125	2.32			
	31 Jul 1987	ICPL 332	-	1.80	1.52 (5)	±0.11	15
		ICPL 84060	-	1.58			
Zimbabwe							
Marundera	12 Dec 1986	ICPL 87	98	2.90	2.60 (9)	±0.21	14
Matopos	1 Dec 1987	ICPL 288	98	1.83	1.29(16)	±0.16	25
		ICPL 83016	87	2.35			
	1 Dec 1987	ICPL 138	121	2.08	1.14(15)	±0.28	43
		ICP 8863	127	1.90			
	Dec 1987[1]	ICPL 84060	127	1.31	0.59(13)	±0.16	56
		ICPL 332	129	1.01			
Lucydale	3 Dec 1987	ICPL 86012	83	1.70	1.18(14)	±0.32	47
		ICPL 85021	87	1.57			
	Dec 1987[1]	ICPL 270	-	1.89	1.09(14)	±0.13	23
		ICP 8863	-	1.45			

1. Precise date not available.
2. - = Data not reported.

tra and Andhra Pradesh (ICRISAT Annual Report 1987, p. 218) continued during the 1987/88 postrainy season and the 1988 rainy season. Farmers' interest, and their demand for seed of the improved varieties, indicated that these new sole-cropping systems, utilizing mainly ICPLs 87 and 151, were being accepted despite the problems posed by *Helicoverpa.*

Pigeonpea breeders cooperated with HAU scientists to lay out 16 on-farm trials in six districts of Haryana state, India. ICPLs 151 and 84023 were compared with the local control, Manak.

Publications

Institute Publications

Information Bulletin

Chauhan, Y.S., Nene, Y.L., Johansen, C., Haware, M.P., Saxena, N.P., Sardar Singh, Sharma, S.B., Sahrawat, K.L., Burford, J.R., Rupela, O.P., Kumar Rao, J.V.D.K., and Sithanantham, S. 1988. Effects of soil solarization on pigeonpea and chickpea. (Summary in Fr.) Research Bulletin no. 11. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 20 pp. ISBN 92-9066-167-4. (RBE 011)

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. International Pigeonpea Newsletter nos. 7 and 8. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0255-786 X. (NPE)

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Dent, D.R., and Pawar, C.S. 1988. The influence of moonlight and weather on catches of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in light and pheromone traps. Bulletin of Entomological Research 78(3):365-377. (JA 674)

Nambiar, P.T.C., Rupela, O.P., and Kumar Rao, J.V.D.K. 1988. Nodulation and nitrogen fixation in groundnut (*Arachis hypogaea* L.), chickpea (*Cicer arietinum* L.) and pigeonpea(*Cajanus cajan* L. Millsp.). Pages 21-52 *in* Biological nitrogen fixation: recent developments (Subba Rao, N.S., ed.). New Delhi, India: Oxford and IBH Publishing Co. (JA 515)

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Reed, W., Cardona, C., Lateef, S.S., and Bishara, S.I. 1988. Screening and breeding for insect resistance in pea, lentil, faba bean and chickpea. Pages 107-116 *in* World crops: cool season food legumes: proceedings of the International Food Legume Research Conference on Pea, Lentil, Faba Bean and Chickpea, 6-11 Jul 1986, Spokane, Washington, USA(Summerfield, R.J., ed.). Dordrecht, Netherlands: Kluwer Academic Publishers. (CP 269)

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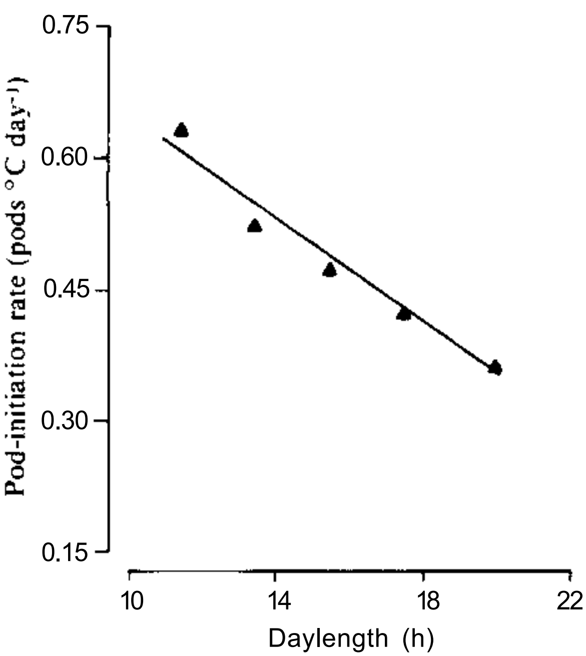
GROUNDNUT

The year 1988 has been a fruitful one for international collaboration in groundnut (*Arachis hypogaea* L.) research and training. Three workshops were held: in Malawi for the Southern African Development Coordination Conference (SADCC) region in March; in Niger for the West Africa region in September; and in Indonesia for the Asia region in November. This allowed ample interaction between groundnut scientists of ICRISAT, scientists of national agricultural research systems, and representatives of other regional and international organizations concerned with groundnut improvement. Information was exchanged and areas for collaborative research were defined. Activities that received strong support were the collection of data on occurrence and distribution of biotic and abiotic stresses and the mapping of these in relation to agroclimatic factors. These activities received further support through the workshop held at ICRISAT Center in December on "Agroclimatology of Asian Grain Legume Growing Areas" (see Technology Transfer section of this Annual Report).

On the research front, our virologists have brought high technology within reach of more laboratories by developing a technique that replaces the enzymes normally required for enzyme-linked immunosorbent assay (ELISA) with penicillinase. This reagent is more widely available, cheaper, and considerably safer to use than the conventional materials.

We anticipate that as groundnut production increases, there will be an increasing need to protect the stored produce from insects. The report that groundnut pods and seeds can be protected from key storage pests by application of a cheap nontoxic dust (attapulgite-based clay dust) could be an important development for the commercial future of the crop.



y = 0.934 (+ 0.050) - 0.029 (+ 0.003)x
(r = -0.98**; rse = 0.022)

Figure 1. Pod-initiation rate (pods °C day^{-1}) in groundnut genotype ICG 1697 (NC Ac 17090) as influenced by day length, ICRISAT Center, 1985-86.

Physical Stresses

Photoperiod Responses

In collaboration with the University of Bonn, we have determined the major mechanisms by which photoperiod influences yields. Firstly, while photoperiod does not influence the time to 50% flowering, it does influence the rate at which pods are initiated. Figure 1 shows data collected from three experiments in which the rate of pod initiation (adjusted for temperature differences) by the photoperiod-sensitive genotype ICG 1697 (NC Ac 17090) is plotted against photoperiod. A second response to photoperiod is a delay in the onset of rapid seed growth within pods. These two mechanisms combine to influence the harvest index (HI) of the crop.

In another experiment, we created a wide range of photoperiods with artificial lighting and examined the changes in HI of six genotypes (Fig. 2). Sensitivity varied considerably, both in the range of photoperiods over which change in HI occurs and the extent of that change.

We screened a range of advanced breeding lines currently under test within the All India Coordinated Research Project on Oilseeds (AICORPO) and ICRISAT International Trials series, together with released lines and parental germplasm, by subjecting them to normal daylengths and to an extended day length of 16 h.

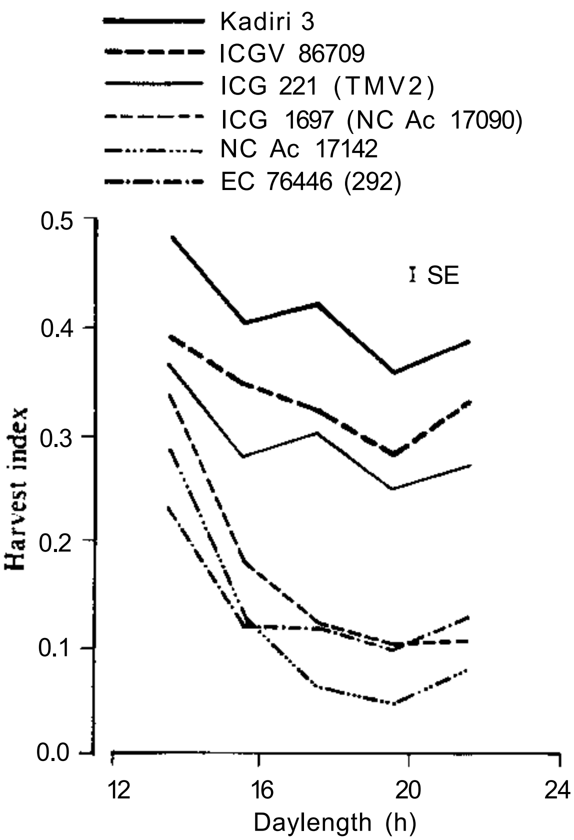


Figure 2. Effect of day length on harvest index in six photoperiod-sensitive and photoperiod-insensitive groundnut genotypes, ICRISAT Center, rainy season 1987.

Table 1. Photoperiod sensitivity in groundnut breeding selections and germplasm, ICRISAT Center, postrainy season 1987/88.

Source	Number of entries	
	Photoperiod insensitive	Photoperiod sensitive
Germplasm accessions	6	7
Material bred for:		
Confectionery uses	2	9
Foliar-diseases resistance	8	22
Pest resistance	2	7
Early maturity	13	1
Medium maturity	16	3

Genotypes were classified as being sensitive to daylength if the extended-day treatment changed the HI by >15%. Most lines emerging from breeding programs, aimed at overcoming biotic stresses, were photoperiod sensitive, while the early- and medium-duration, high-yielding lines were generally insensitive (Table 1). It is significant that material that has shown wide adaptation in India was mostly photoperiod insensitive, indicating that this attribute is important to adaptation.

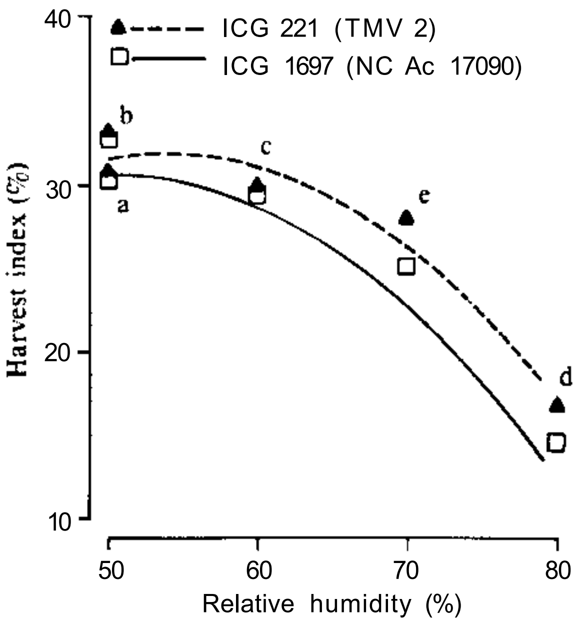
Drought

International Drought Nursery

We evaluated the performance of genotypes selected for drought tolerance at three locations in India, two in southeast Asia, and two in Africa. Some genotypes were superior for their total dry matter (TDM) productivity (17-19% averaged over all sites), but their pod yields were not always better, as the HI was not sustained. The variable HI is attributable to the many environmental factors that vary the balance between reproductive growth and vegetative growth. For example, reproductive growth and HI are influenced by the photoperiod sensitivity of the genotype (see Photoperiod Responses discussed earlier in this section).

Apart from photoperiod, we found that relative humidity (RH), during the growing season, also influenced HI. Analysis of environmental data from sites with similar photoperiods and temperatures showed that HI decreased as the mean RH increased. This effect of RH on HI was common across genotypes (Fig. 3).

a = ICRISAT Center postrainy season (33/18)
b = Anantapur (32/23)
c = Tirupati (33/25)
d = The Philippines (32/16)
e = Thailand (31/20)



y (□) = $-23.5 + 2.13x - 0.021x^2$ (r^2 = 0.98)
y (▲) = -32.5 + 2.38x - 0.022x2 (r^2 = 0.96)

Figure 3. Effect of relative humidity on harvest index of groundnut genotype ICG 221 (TMV2) and ICG 1697 (NC Ac 17090) grown in an international drought trial at five locations, 1986. (Values in parentheses, after location, are mean maximum and minimum temperatures (°C) during the growing season.)

Management of End-of-season Drought

When rain is evenly distributed throughout the growing season, long-duration genotypes will have better yields than short-duration genotypes. However, in seasons when the rains end early, the reverse is true. What should a farmer do to optimize production with minimal risk? One answer is to sow both types of cultivar. We carried out an experiment to test this hypothesis at ICRISAT Center and at Anantapur.

We grew one long-duration genotype and three short-duration genotypes either as sole crops, or as the intercrop of long- and short-duration genotypes in alternate rows. At ICRISAT, we continued uniform irrigation until 92 days after sowing (DAS), when the drought treatments commenced. We created eight levels of drought by varying the amount of water applied, using the line-source sprinkler technique. We conducted experiments with similar intercrop treatments at Anantapur in the 1985 and 1986 rainy seasons (July-December) under rainfed conditions, thus experiencing a mixture of droughts.

For the line-source experiment, we calculated water deficits relative to the potential evaporation using the formula:

$$\% \text{ water deficit} = \frac{(X_1-X_2)}{X_1} \times 100$$

where X_1 = Cumulative pan evaporation during the treatment period, and X_2 = Cumulative amount of water applied for the treatment period. ,

At ICRISAT, under fully irrigated conditions, the long-duration genotype (Kadiri 71-1) produced nearly double the TDM (13.8 ± 0.70 t ha^{-1}) achieved by the short-duration genotypes (5.2-6.7±0.70 t ha^{-1}). However, the relatively poor partitioning and low HI (21%) of the long-duration genotypes resulted in smaller advantages in pod yield relative to the more improved short-duration lines (HI >40%).

At intermediate-stress levels, TDM was greater (7.0 ± 0.39 t ha^{-1}) in all intercrop systems than in the sole crops (5.8-6.4 ± 0.39 t ha^{-1}). However, the pod yields of the short-duration genotypes grown as a sole crop were the same as those in the intercrop.

Under severe water deficits, the TDM of Kadiri 71-1 was only slightly more than that of the genotypes that matured earlier. The intercrops had a small advantage in TDM but produced lower pod yields than the sole crops of the early genotypes.

The land equivalent ratios (LERs) for TDM and pod yield (Fig. 4) across the full spectrum of water treatments show that generally intercropping produced higher yields than equal areas of sole crops of long- and short-duration genotypes.

Individual short-duration genotypes responded differently to the intercrop situation and drought. If this approach is to be taken further, specific combinations of genotypes should be tested. The Anantapur results supported the data collected from 1CRISAT Center.

Biotic Stresses

Foliar Fungal Diseases

Resistance Screening

Late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*). In the 1988 rainy season, we screened in the field at ICR1SAT Center 220 recently acquired germplasm lines for resistance to rust and late leaf spot. Of these, 12 showed useful levels of resistance to rust and 4 were resistant to late leaf spot (scores of 3-5 on the 1-9 scale, where 1 = No disease, and 9 = 50-100% of foliage destroyed). Three of the late leaf spot resistant lines were also resistant to rust.

We carried out further testing of lines previously identified as resistant to rust and/or late leaf spot in the 1988 rainy season in two separate

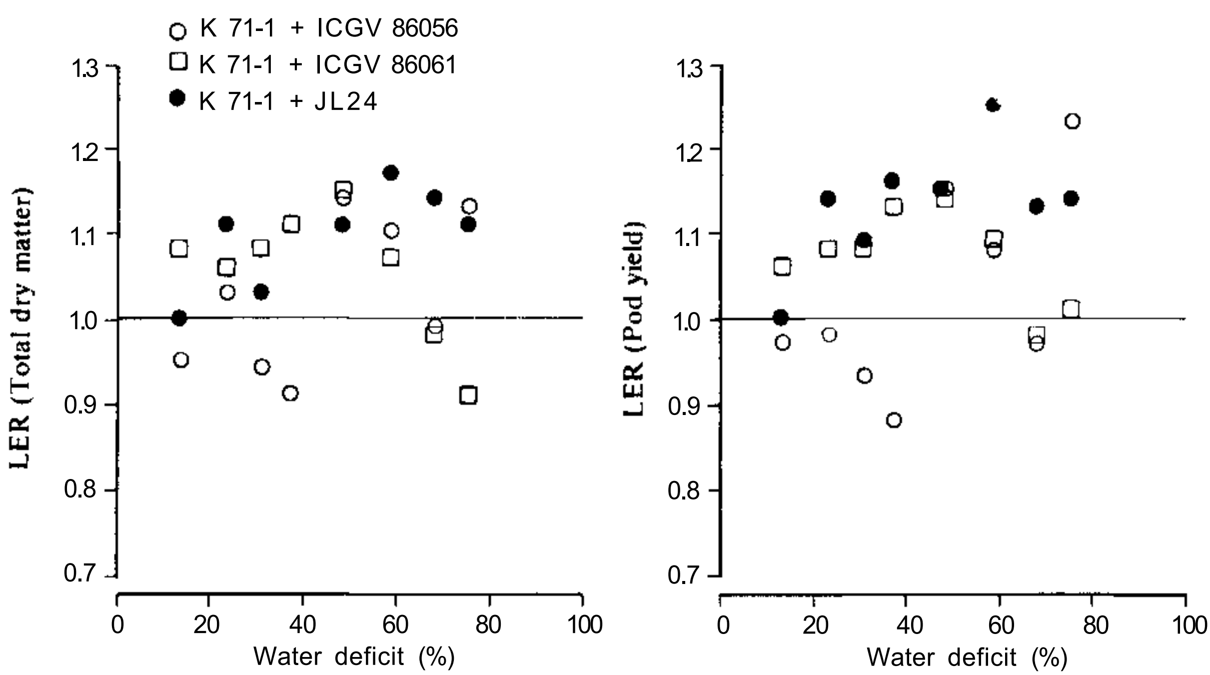


Figure 4. Land-equivalent ratios (LERs) of total dry matter (left) *and pod yield* (right) *for three long- and short-duration groundnut intercrop treatments at different water deficits, ICRISAT Center, post rainy season 1985/86.*

Table 2. Reaction of eight groundnut genotypes to early leaf spot (*Cercospora arachidicola*) disease at Pantnagar, rainy seasons 1987 and 1988.

Genotype		Disease score[1]		Percentage defoliation[2]	
ICG	Other identity	1987	1988	1987	1988
7862	PI 393527-B	4.3[3]	8.3[3]	50[3]	88[3]
9294	52-295	5.0	4.6	60	40
7885	PI 381622	5.7	4.3	48	10
586	EC 99215	6.0	7.3	55	83
-	2171-2-1	5.3	6.6	57	87
2368	NC Ac 2897	5.3	6.0	53	57
5270	EC 94159	5.7	8.6	30	80
6349	NC Ac 1121	5.7	8.0	23	70
Control					
221	TMV 2[4]	9.0	8.6	85	90
SE		±0.37	±0.41	±7.3	±7.4
CV (%)		9	11	20	21

1. Field-disease score on a 1 9 scale, where 1 = No disease, and 9 = 50-100% foliage damaged.
2. Percentage defoliation based on numbers of leaves lost from main stem.
3. Mean of three replications.
4. Early leaf spot susceptible cultivar.

trials. In one trial, rust was partially controlled with tridemorph (Calixin®) in the infector rows and test plots, while in the other trial, carbendazim (Bavistin®) partially controlled leaf spots. Three lines, NC Ac 17129, NC Ac 17130, and NC Ac 17142, were rated as susceptible to rust (scores of 8 on 1-9 scale), and NC Ac 17090, NC Ac 17130, and PI 390593 were rated as susceptible to late leaf spot (scores of 7 or more on a 1-9 scale).

Early leaf spot (*Cercospora arachidicola*). In the 1988 rainy season at ICRISAT Center, levels of early leaf spot were too low for effective field screening, but at Pantnagar, there were high levels of early leaf spot. We screened 98 lines at Pantnagar for their reaction to this disease. Of these, 28 scored 5 or less on the 1-9 scale, and had less than 50% defoliation. Eight lines had been screened at Pantnagar in 1987; there were some conflicting results (Table 2).

We also tested 13 interspecific hybrid derivatives and 7 wild *Arachis* species at Pantnagar. Of these, one interspecific hybrid derivative (259-2) scored 3 on the 1-9 scale, while *Arachis* sp 30126 scored 5. Derivative 259-2 retained all its leaves.

Resistance Breeding

Yield trials. During the 1987/88 postrainy season, we evaluated 171 foliar-diseases resistant varieties in three replicated trials at Bhavanisagar and ICRISAT Center to assess the adaptation of these lines under different photoperiod and temperature regimes, low disease pressure, and different soil types. The pod yields in these trials ranged from 5.77 ± 0.30 t ha^{-1} to 3.04 ± 0.20 t ha^{-1} on Alfisols and 6.71 ± 0.37 t ha^{-1} to 2.13 ± 0.28 t ha^{-1} on Vertisols. The yields of the foliar-diseases resistant control, ICGV 87157, and the recently released ICGS 11 (ICGV 87123) were surpassed by 113 varieties. One elite-trial entry, ICGV 87350, and two advanced-trial entries, ICGVs 87292 and 87248, outyielded the highest-yielding control at all three locations.

During the 1988 rainy season, we evaluated 44 alternately branching and 89 sequentially branching foliar-diseases resistant cultivars in five replicated trials at one to seven locations, depending on the stage of evaluation. In the alternately branching group trials, the pod yields ranged from 4.20 ± 0.18 t ha^{-1} to 0.30 ± 0.09 t ha^{-1}, and 35 varieties outyielded both the national

Table 3. Mean pod yields of selected elite foliar-diseases resistant, alternately branching groundnut varieties evaluated at seven locations in India, rainy season 1988.

	Location[1] and mean pod yield (t ha^{-1})							
Entry	1[1]	2	3	4	5	6	7	Mean
ICGV 87305	3.09(1)2	2.05(5)	1.97(1)	2.09(16)	2.16(9)	2.41(1)	1.84(20)	2.23
ICGV 87319	2.75(3)	2.05(6)	1.15(7)	2.73(4)	2.17(8)	2.19(3)	2.11(12)	2.16
ICGV 87302	2.45(7)	2.22(2)	0.84(16)	2.18(14)	3.11(1)	1.78(8)	2.42(7)	2.14
ICGV 87307	2.94(2)	2.38(1)	1.40(5)	2.27(12)	1.81(18)	2.26(2)	1.93(17)	2.14
ICGV 87298	2.70(4)	2.12(3)	1.52(3)	2.32(10)	2.17(7)	1.74(9)	1.58(24)	2.02
ICGV 87301	2.46(6)	2.09(4)	1.52(2)	2.15(15)	1.80(19)	1.89(5)	1.90(19)	1.97
ICGV 87290	1.76(20)	1.52(13)	1.09(8)	2.85(1)	2.41(4)	1.68(11)	2.41(9)	1.96
ICGV 87314	2.44(8)	1.92(7)	1.48(4)	1.91(20)	1.82(17)	2.06(4)	2.09(13)	1.96
ICGV 87306	2.33(9)	1.71(11)	0.95(13)	2.80(3)	2.04(15)	1.83(7)	1.90(18)	1.94
ICGV 87293	2.01(14)	1.72(9)	0.97(11)	2.03(17)	2.52(2)	1.70(10)	2.41(8)	1.91
Controls								
Kadiri 3	2.19(11)	1.16(22)	1.02(10)	2.24(13)	1.78(20)	1.46(17)	3.28(1)	1.88
ICGV 87157	1.68(22)	1.00(24)	0.95(12)	2.03(18)	1.18(25)	1.34(22)	2.28(10)	1.49
SE	±0.113	±0.076	±0.088	±0.162	±0.143	±0.272	±0.255	
Trial mean (25 entries)	2.14	1.60	0.99	2.23	2.03	1.67	2.18	
CV (%)	9	8	15	12	12	28	20	
Efficiency over RBD[3] (%)	100	105	103	100	100	100	109	

1. Location 1 = ICRISAT Center, Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, full insect-pest protection, in triple-lattice design, plot size 6 m^2, broadbed and furrows (BBF).
2 = ICRISAT Center, Alfisol, 20 kg P_2O_5 ha^{-1}, rainfed, no protection, in triple-lattice design, plot size 6 m^2 (BBF).
3 = ICRISAT Center, Vertisol, 20 kg P_2O_5 ha^{-1}, rainfed, no protection, in triple-lattice design, plot size 6 m^2 (BBF).
4 = Anantapur, Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
5 = Bhavanisagar, Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
6 = Dharwad, Vertisol, 60 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
7 = Hisar, Entisol, 60 kg P_2O_5 ha^{-1}, supplemental irrigation, no protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
2. Numbers in parentheses are the rankings.
3. RBD = Randomized-block design.

control, Kadiri 3, and the elite foliar-diseases resistant cultivar, ICGV 87157. A preliminary trial entry, ICGV 88271, recorded the highest pod yield of 4.20 ± 0.18 t ha^{-1} at ICRISAT Center.

In the sequentially branching group, the mean pod yields ranged from 3.51± 0.33 t ha^{-1} to 0.12 ± 0.88 t ha^{-1} with 40 entries outyielding the national control, JL 24, and 39 entries outyielding the elite resistant cultivar, ICGV 87157.

In the elite trial (alternately branching), eight entries gave higher average pod yields across seven locations than the best control cultivar. The best entry, ICGV 87305, gave an average pod yield of 2.23 t ha^{-1} (control Kadiri 3 gave 1.89 t ha^{-1}). ICGV 87305 had the highest yield at three locations (Table 3).

We found ICGVs 87305,87314,87319,87293, and 87302 to be moderately resistant to early and late leaf spots, iron chlorosis (caused by high pH and bicarbonates), and jassids (Table 4).

In the elite trial (sequentially branching), 10 selections had higher average pod yields across seven locations than the best control cultivar. The best entry, ICGV 87276, gave an average pod yield of 2.36 t ha^{-1} which compares well with the 1.79 t ha^{-1} produced by the best control, ICGV 87784 (Table 5).

Soilborne Fungal Diseases

The Aflatoxin Problem

In the 1988 rainy season field trials at ICRISAT Center and at cooperative research stations, the levels of seed infection by *Aspergillus flavus* were so low in susceptible control cultivars that no useful screening could be carried out. The low infection levels were attributed to the high and well-distributed rainfall and the absence of drought stress during pod maturation.

Table 4. Mean scores for some foliar-diseases resistant groundnut varieties against various stress factors, on a Vertisol[1], ICRISAT Center, rainy season 1988.

	Leaf spot[2]			
Variety	Early	Late	Iron chlorosis[3]	Jassids[4]
ICGV 87305	4.0	4.7	3.0	2.3
ICGV 87314	4.6	5.7	2.4	3.0
ICGV 87319	4.1	5.0	3.0	4.7
ICGV 87293	5.1	5.7	4.0	2.7
ICGV 87302	2.9	4.3	3.4	2.0
Controls				
Kadiri 3	9.0	9.0	4.4	5.3
ICGV 87157	8.2	7.3	8.4	6.3
SE	±0.3	±0.3	±0.5	±1.1
Trial mean (25 entries)	6.3	6.6	5.3	5.2
CV (%)	10	7	15	35
Efficiency over RBD[5] (%)	109	102	105	100

1. Triple lattice, plot size 6 m^2.
2. Scored on a 1-9 scale, where 1 = No disease, and 9 = 50-100% foliage damaged.
3. Scored on a 1-9 scale, where 1 = No chlorosis, and 9 = 100% yellowed foliage.
4. Scored on a 1-9 scale, where 1 = No damage, and 9 = 100% yellowed foliage.
5. RBD = Randomized-block design.

Table 5. Mean pod yields of selected elite foliar-diseases resistant, sequentially branching groundnut varieties evaluated at seven locations in India, rainy season 1988.

Entry	Location[1] and mean pod yield (t ha^{-1})							Mean
	1[1]	2	3	4	5	6	7	
ICGV 87276	2.84(2)[2]	1.49(3)	1.30(2)	2.61(3)	2.67(3)	2.24(8)	3.37(2)	2.36
ICGV 87287	2.85(1)	1.33(8)	0.97(11)	2.17(10)	2.87(1)	2.02(12)	3.25(3)	2.21
ICGV 87224	2.65(3)	1.41(5)	1.02(10)	2.18(9)	2.68(2)	2.24(6)	2.77(7)	2.14
ICGV 87350	2.63(4)	1.31(9)	1.14(7)	2.36(5)	2.45(7)	2.50(2)	2.38(10)	2.11
ICGV 87261	2.58(5)	1.56(2)	1.03(9)	1.97(14)	2.54(5)	1.89(16)	3.07(6)	2.09
ICGV 87282	2.06(11)	1.22(11)	1,04(8)	2.90(1).	1.85(21)	2.05(11)	3.51(1)	2.09
ICGV 87206	2.14(9)	1.18(13)	1.24(4)	2.25(6)	1.99(13)	1.90(15)	3.13(4)	1.98
ICGV 87288	2.42(6)	1.34(7)	1.38(1)	1.72(25)	2.27(9)	1.96(13)	2.13(14)	1.89
ICGV 87259	2.19(8)	1.17(15)	1.29(3)	2.41(4)	2.24(10)	1.80(19)	1.99(16)	1.87
ICGV 87280	1.49(21)	1.57(1)	1.20(6)	2.24(7)	2.62(4)	2.05(10)	1.88(19)	1.86
Controls								
ICGV 87784	2.30(7)	1.07(17)	0.93(13)	1.76(24)	1.54(24)	1.84(18)	3.10(5)	1.79
JL 24	1.91(15)	1.18(12)	0.64(20)	2.64(2)	1.85(22)	1.59(20)	2.71(9)	1.79
ICGV 87157	1.92(14)	1.02(18)	0.69(18)	1.80(23)	1.79(23)	1.30(23)	2.18(13)	1.53
SE	±0.111	±0.069	±0.083	±0.175	±0.177	±0.151	±0.326	
Trial mean (25 entries)	1.96	1.15	0.88	2.09	2.13	1.93	2.36	
CV (%)	10	10	16	15	15	14	24	
Efficiency over RBD[3] (%)	100	113	103	100	115	114	109	

1. For locations, see Footnote 1 of Table 3.
2. Numbers in parentheses refer to rankings.
3. RBD = Randomized-block design.

Breeding for *A. flavus* resistance. In 14 lines, we recorded natural seed infection with *A. flavus* at levels equivalent to or lower than the resistant control cultivar, J 11. In 17 breeding lines, in vitro seed colonization by *A. flavus* (IVSCAF) resistance was equal to or better than J 11, but ICGVs 86169,87089,87099, and 87117 exceeded J 11 in resistance to both natural seed infection by *A. flavus* and IVSCAF. At Bhavanisagar, 2 breeding lines outyielded J 11, while at Hisar, 10 breeding lines outyielded the control.

During the 1987/88 postrainy season, in irrigated Alfisol and Vertisol fields at ICRISAT Center, we evaluated the yield of 42 breeding lines that had shown resistance to aflatoxin infection in previous tests. Two breeding lines in the Alfisol field and one in the Vertisol field outyielded the control, J 11.

Stem and Pod Rots

During the 1987/88 postrainy season at ICRISAT Center, we screened 164 genotypes, including breeding lines and derivatives of interspecific crosses, in Vertisol fields for the incidence of stem and pod rots caused by *Sclerotium rolfsii.* In the preliminary screening trial, the stem rot incidence ranged from 1.8% to 45.9±6.6%, and pod rot from 1.0% to 64.0±11.3%. The mean disease incidence levels in the two control cultivars were, for Kadiri 3, 18± 1.20% stem rot and 55.2±2.67% pod rot, and for Gangapuri 20± 1.41% stem rot and 62.9±2.56% pod rot. We selected 14 genotypes with levels below 10% of both stem rot and pod rot for further screening.

During advanced screening (64 lines), the interspecific hybrid derivatives and breeding lines that had low levels (<10%) of stem rot and pod rot incidence in 1986/87 postrainy season trials (ICRISAT Annual Report 1987, p. 234) again showed low levels of disease.

Virus Diseases

Bud Necrosis Disease (BND)

We modified the procedure to purify tomato spotted wilt virus (TSWV), the causal agent of BND (ICRISAT Annual Report 1987, p. 234), by introducing gradient centrifugation in vertical rotors to yield larger quantities of intact virus particles than was previously possible. Reciprocal ELISA tests, conducted with antisera for several TSWV isolates, indicated that the Indian TSWV isolate is serologically distinct from those collected elsewhere in Asia and in the USA. The dot immunoblot assay using naphthol phosphate as a substrate for alkaline phosphatase conjugated antibodies, followed by staining with fast red, has been standardized to permit TSWV detection from 10 µL of groundnut leaf extract. It is potentially sensitive enough to detect TSWV in individual vectors (thrips).

Peanut Clump Virus (PCV)

Purification and serology. We developed a modified procedure to purify the Indian PCV (I-PCV) multiplied in common bean (*Phaseolus vulgaris,* cv Topcrop). It involves extraction in a phosphate buffer, treatment with chloroform, precipitation of the virus using polyethyleneglycol, and the separation of virus particles in quasiequilibrium zonal density gradients in sucrose solutions, and equilibrium zonal density gradients in cesium chloride solutions. This procedure yielded over 5.0 mg of virus from 100 g of tissue. We succeeded in detecting four I-PCV and one West African isolate of PCV by using ^{32}P labelled c DNA prepared for the Hyderabad isolate. This confirmed that c DNA probes are capable of distinguishing between PCV isolates.

Transmission. We found I-PCV (Hyderabad isolate) to be seed transmitted in the early-infected groundnut genotype, EC 76446(292), to the extent of 8.5%, and when the genotype was late infected, to the extent of 1.8%. In early-infected M 13 groundnut cultivar, seed transmission was 6.0% and in late-infected M 13, 4.5%. Two isolates of I-PCV were transmitted in finger millet *(EJeucine coracana)* seed.

Peanut Mottle Virus (PMV)

Resistance screening. In the 1987/88 postrainy and 1988 rainy seasons, we screened 377 germplasm lines for resistance to PMV. Of the 15 lines that showed less than 5% yield loss in the 1987 rainy season tests (ICRISAT Annual Report 1987, p. 235), 4 continued to show less than 5% yield loss.

Peanut Stripe Virus (PStV)

Surveys of groundnut fields in India, carried out in conjunction with the National Bureau of Plant Genetic Resources (NBPGR), revealed PStV in only one location (in Tamil Nadu). We cooperated with scientists of the Australian Centre for International Agricultural Research (ACIAR), and those of Moros Research Institute for Food Crops (MORIF) and Malang Research Institute for Food Crops (MAR1F) in Indonesia to screen 2059 genotypes at Muneng, East Java, and 1962 lines at Moros in South Sulawesi. At both sites, PStV incidence exceeded 90% in susceptible control cultivars. The majority of genotypes were susceptible to PStV. However, 29 lines, of which 23 were derivatives of interspecific crosses, were not infected or showed a low incidence of the disease.

We tested several wild *Arachis* species for resistance to PStV in the NBPGR quarantine facilities. Two accessions were not infected with the virus.

Seeds of genotypes that are resistant to the seed transmission of PMV at ICRISAT Center were also resistant to the seed transmission of PStV in the People's Republic of China. Some had less than 1.0% seed transmission when local cultivars showed more than 5.0% seed transmission with PStV.

Peanut Veinal Chlorosis Disease (PVCD)

This disease, which is characterized by stunting, veinal chlorosis, and the outward curling of leaflets, has been observed in several parts of peninsular India since 1977. As the disease incidence has increased considerably in recent years, we undertook the identification of the causal agent. We found a rhabdo virus (Fig. 5) to be associated with PVCD, the first record of this kind of virus being detected in groundnut grown in the field.

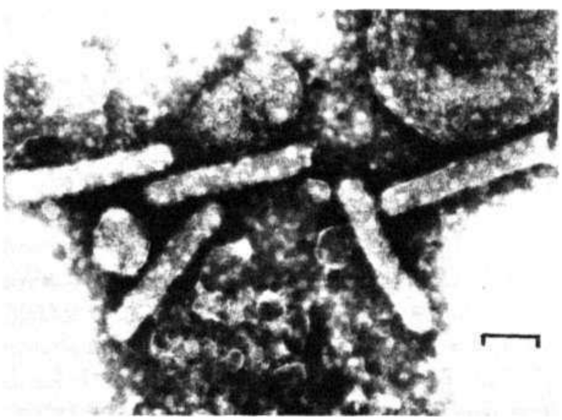


Figure 5. An electron micrograph of a rhabdo virus of groundnut (bar represents 200 nm), ICRISAT Center, 1988.

Modifications to ELISA

Alkaline phosphatase and horseradish peroxidase are commonly used in ELISA, but these enzymes are costly and hazardous. We have substituted penicillinase, utilizing the sodium or potassium salts of penicillin as a substrate. Penicillin is readily available in developing countries at a substantially lower cost than the substrates of alkaline phosphatase and horseradish peroxidase. The penicillinase-based ELISA that we developed has already replaced conventional ELISA in several laboratories in developed and developing countries.

Nematode Problems

Response to a Questionnaire on Nematode-caused Diseases of Groundnut

We sent copies of a questionnaire covering many aspects of research on nematode problems of chickpea, pigeonpea, groundnut, sorghum, and pearl millet to selected nematologists and plant protection workers concerned with these crops. Responses received from nematologists in 13 countries, including those in seven states of India, are presented in Table 6.

Surveys

Our surveys of the groundnut-producing regions in Nepal revealed that groundnut plants in farmers'fields at Nepalgunj and Nawalpur were free from the root-knot disease caused by *Meloidogyne* spp. We observed root-lesion disease in the sandy soils of the Sarlahi district.

In India, populations of *Helicotylenchus* sp were associated with groundnut in the Krishna, Kurnool, and Mahbubnagar districts of Andhra Pradesh, the Bangalore district of Karnataka, the Puri district of Orissa, the Dhule and Satara districts of Maharashtra, and the Chengalput district of Tamil Nadu. Populations of *Rotylenchulus reniformis* were in samples from the Kurnool district of Andhra Pradesh, the Raichur and Bangalore districts of Karnataka, the Satara and Dhule districts of Maharashtra, and the Ahmedabad district of Gujarat. There was no

Table 6. Important nematode pests of groundnut in 13 countries.

Country/States	Most important	Very important	Important
Australia	*Pratylenchus* sp	*Meloidogyne* sp	
Brazil	*Pratylenchus brachyurus*	*Macroposthonia ornata*	*Meloidogyne arenaria*
Egypt	*Meloidogyne javanica*	*Meloidogyne incognita*	*Meloidogyne arenaria*
India	*Meloidogyne* spp	*Pratylenchus* spp	*Tylenchorhynchus* spp
Andhra Pradesh	*Meloidogyne* sp	*Pratylenchus* sp	*Hoplolaimus* sp
Gujarat	*Meloidogyne arenaria*	*Tylenchorhynchus* sp	*Pratylenchus* sp
Haryana	*Meloidogyne* sp		
Karnataka	*Meloidogyne* sp	*Pratylenchus* sp	*Tylenchorhynchus* sp
Maharashtra	*Mela idogyne arenaria*		
Punjab	*Meloidogyne* sp	*Trichodorus* sp	*Xiphinema* sp
Rajasthan	*Meloidogyne arenaria*		
Jamaica	*Meloidogyne* sp	*Xiphinema* sp	*Pratylenchus* sp
Malawi	*Meloidogyne arenaria*		
Mexico	*Meloidogyne arenaria*		
Nepal	*Meloidogyne* sp		
Sudan	*Aphelenchoides* sp	*Ditylenchus* sp	*Paratrophurus* sp
Thailand	*Pratylenchus brachyurus*	*Macroposthonia ornata*	*Helicotylenchus* sp
USA	*Meloidogyne arenaria*	*Pratylenchus brachyurus*	
Zambia	*Meloidogyne* sp		
Zimbabwe	*Pratylenchus* sp	*Meloidogyne* sp	

Meloidogyne spp in these samples. We observed a low population of *M. javanica* in groundnut roots collected from Pallipalem in the Krishna district of Andhra Pradesh.

In Niger, we recorded plant-parasitic nematodes belonging to more than 10 genera in soil samples collected from 20 locations between Niamey and Maradi. These are *Ditylenchus* sp, *Hoplolaimus pararobustus, Pratylenchus* sp, *Scutellonema clathricaudatum, Trichodorus* sp, *Helicotylenchus* sp, *Macroposthonia curvata, Siddiqia* sp, *Telotylenchus indicus, Xiphinema attorodorum,* and *X. italiae.* We also recorded *Scutellonema clathricaudatum, Xiphinema* spp, and *Siddiqia* sp in root samples. A survey of groundnut fields at Sadore revealed the presence of *S. clathricaudatum, X. attorodorum,* and *T. indicus* in all fields. Population of these nematodes were three times [>200 nematodes (5 g roots)$^{-1}$] higher in root samples collected from patches showing poor plant growth than in roots collected from apparently healthy plants. Pods were generally free from lesions. Crop growth was very variable. Plants were severely stunted, leaves were small and chlorotic, and roots were stubby and proliferated. In many cases root tips were swollen.

Insect Pests

Incidence at ICRISAT Center. The thrips population was at its peak in the latter part of January, resulting in 23% damaged leaflets by the 1st week of February. In March, an inconsequential 6% of the total leaflets showed jassid (*Empoasca kerri*) injury. The groundnut leaf miner (GLM) (*Aproaerima modicella*) population density never reached 1 larva plant^{1}. *Spodoptera* and *Helicoverpa* activity was also low during this season, causing 1 % or less defoliation in unprotected plots. However, in insecticide-sprayed fields, these insects caused slightly more defoliation (3%).

In the rainy season, the continuous wet weather appeared to prevent the establishment of potential pest populations. In August, there were about 2.5 GLM larvae $plant^{-1}$, but the population had dwindled to zero by October.

Surveys

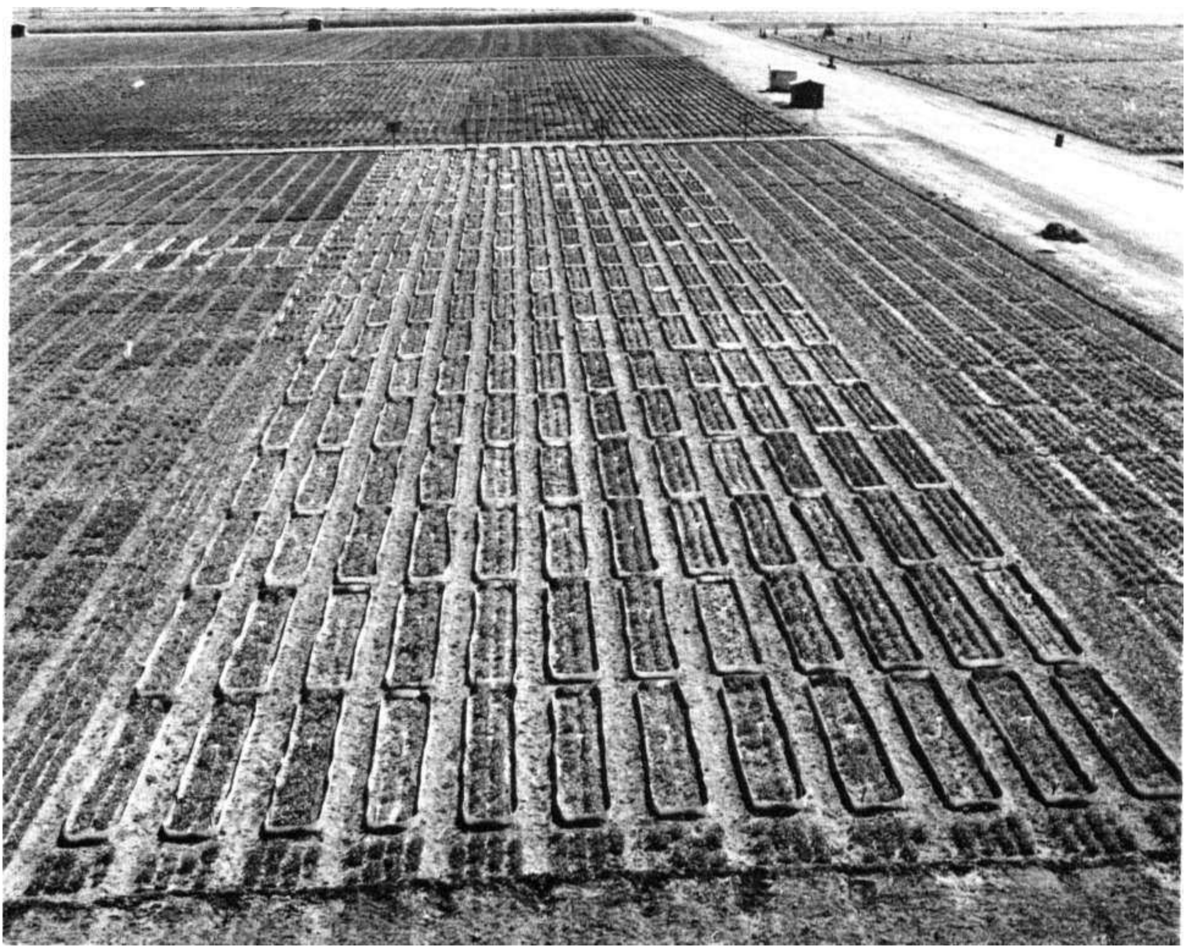
Insect pest surveys in Andhra Pradesh during the 1987/88 postrainy season indicated that 70% of farmers were applying insecticides to groundnut crops. Most of the farmers were applying them in inappropriate combinations when they were not even needed. GLM incidence was high in nonsprayed fields but reached damaging levels only in the Nalgonda and Khammam districts. In heavily sprayed fields, defoliators (*Spodoptera* and *Helicoverpa*) were more active than in nonsprayed fields, probably because of the negative effects of insecticides on the natural enemies of the defoliators.

Spodoptera litura

Defoliation studies using *S. litura* larvae in the previous five seasons (Fig. 6) indicated that:

- the vulnerability of groundnut crops to defo-

Figure 6. Enclosures placed to retain Spodoptera *larvae in an experiment determining the relationship between degree of defoliation and yield, ICRISAT Center, postrainy season 1986/87.*



liators decreases as the crop matures,
- the responses to defoliation in the rainy-season and postrainy-season crops are different and,
- in the rainy season, even 58% defoliation (caused by 5 larvae $plant^{-1}$) does not cause a significant reduction in pod yield.

During the 1988 rainy season, when 100% defoliation was induced by releasing 20 fourth instar larvae $plant^{-1}$ at peg formation [50 days after emergence (DAE)], there was a 39% yield reduction and a decrease in shelling percentage. When defoliation was 100% 70 DAE, there was no reduction in yield or shelling percentage.

Host-plant Resistance

We studied the mechanisms of aphid resistance in the genotype ICG 5240 (EC 36892), in collaboration with the Overseas Development Natural Resources Institute (ODNRI). We found no differences between ICG 5240 and other genotypes in initial landing preference of alates, but the population development was slower and the subsequent population declined faster on ICG 5240. There was a similar trend in behavioral studies in the screenhouse. In choice tests, a significant reorientation of the population in favor of the genotype ICG 221 (TMV 2) occurred over a 10-h period. The indications are that resistance in ICG 5240 is associated with the aphid's inability to penetrate or locate the phloem, or the lack of a feeding stimuli in or near the phloem. This suggests that ICG 5240 avoids groundnut rosette virus attack because the phloem is tapped less frequently by the vector than in other genotypes.

Natural Enemies

During the 1987/88 postrainy season, we found that 27% of the *Spodoptera* eggs were parasitized by *Trichogramma* and 15% larval mortality was caused by *Parwbaea orbata.* In the rainy season, larval parasitism was at a lower rate, but 2.5% was because of a newly observed *Ichneumon* parasite. Adult parasites emerged from 7-8-day-old pupae.

In the 1987 rainy season, we collected an aphid parasite *Aphidius* sp from the field and successfully multiplied it in the greenhouse. It kept aphids under control in greenhouse bays used for rearing caterpillars.

We identified a carabid predator of GLM larvae in the field as *Chlaenius* sp. This is the first report of carabid larvae eating GLM larvae.

Pheromone Trapping

Variability and ineffectiveness has been observed in locally manufactured pheromone traps. We tested the efficiency of four pheromone trap designs for monitoring *S. litura* during the 1987/88 postrainy season. The ICRISAT standard single-funnel trap (20-cm diameter) caught more moths than the small-sleeve (10-cm diameter) (local manufacture) and big-sleeve (20-cm diameter) traps. There was no improvement in the moth catch when the double funnel was used in the trap. The single-funnel trap caught four times more moths than the locally manufactured sleeve traps (Table 7).

Table 7. Efficacy of different trap designs in catching *Spodoptera litura* males at ICRISAT Center, February to March 1988.

Trap design	No. of moths caught per trap per week
Small sleeve (10-cm diameter)	84 (1.8)[1]
Big sleeve (20-cm diameter)	60 (1.6)
Double funnel (20-cm diameter)	352 (2.4)
Single funnel (20-cm diameter)	356 (2.5)
SE	±0.14
CV (%)	13

1. Numbers in parentheses are log-transformed values.

Storage Pests

We tested attapulgite-based clay dust (ABCD) from the Regional Research Laboratory, Hyderabad, for the control of three commonly occurring postharvest groundnut pests (Table 8). When we introduced the eggs of *Corcyra cephalonica* onto ABCD-treated groundnut seeds, (0.5% w/w), there was 100% egg mortality. There was a 93% reduction in the population of *Caryedon serratus* after one generation when groundnut pods treated with ABCD were infested with eggs. ABCD gave complete control of *Tribolium castaneum.*

Breeding for Insect-pest Resistance

Host-plant resistance. In the 1987/88 postrainy season, we evaluated 45 jassid-resistant varieties in replicated yield trials at three locations for adaptation to postrainy-season culture. ICGVs 86476 and 86454, in the sequentially branching group, outyielded control ICGS 11; and ICGVs 86352, 86377, and 86400, in the alternately branching group, outyielded control Kadiri 3, at ICRISAT Center on an Alfisol and a Vertisol.

We evaluated 64 elite insect-pest resistant groundnut varieties in two replicated multilocational yield trials in the 1988 rainy season (Table 9), Three varieties, ICGVs 86352, 86402, and 86351, outyielded the national control, Kadiri 3, and a minikit variety, ICGS 5, on an Alfisol at ICRISAT Center and Anantapur. Thirty-two varieties, including those listed in Table 9, showed the same level of resistance as the resistant control ICG 2271. ICGVs 86351, 86352, 86400, and 86402 had also significantly outyielded Kadiri 3 in the 1986 rainy season at ICRISAT Center (ICRISAT Annual Report 1986, p. 233). ICGVs 86352, 86377, and 86400 showed adaptation to rainy- and postrainy-season cultures.

Plant Improvement

We have reoriented our crossing program to generate material with multiple resistances, reducing our efforts on single-stress factor resistance breeding.

In the 1987/88 postrainy season, we made 201 crosses (26 470 pollinations). These included 122 crosses made in the field, which had an average success rate of 54%, and 79 crosses made in the greenhouse, which had an average success rate of 70%. We completed 121 crosses in the field with an average success rate of 90% in the 1988 rainy season.

We grew 360 F_1 populations during both seasons, and after confirming their hybridity, we allocated these to various breeding projects. There were, on average, 12% selfed plants.

Table 8. Effect of attapulgite-based clay dust (ABCD) on the population development of three postharvest groundnut pests, *Corcyra cephalonica, Caryedon cerratus,* and *Tribolium castaneum,* ICRISAT Center, 1988.

Days after release	Treatment of seed	Larval + pupal + adult population		
		C. cephalonica	*C. cerratus*	*T. castaneum*
40	Nontreated	10.0± 1.0	11.4±0.9	4.5±0.8
	Treated	0.2± 0.1	4.1 ±0.6	0.1±0.1
80	Nontreated	116.0±21.1	45.4±2.6	6.3±1.9
	Treated	0.0	8.8±0.8	0.0
120	Nontreated	-[1]	90.3±5.7	12.7±4.3
	Treated		6.5±3.5	

1. After 80 days, *Corcyra* larvae totally damaged the seeds.

Table 9. Mean pod yields of selected high-yielding jassid (*Empoasca kerri*) resistant/tolerant groundnut varieties in the Elite Insect Pests Resistance Varietal Trial (Alternately Branching), rainy season 1988.

	Location[1] and mean pod yield (t ha^{-1})							
Entry	1[1]	2	3	4	5	6	Mean	
1CGV 86402	2.82(3)[3]	1.47(3)	0.97(7)	3.51(1)	1.34(20)	3.46(7)	2.26	4.0
ICGV 86352	2.75(5)	1.62(1)	0.64(21)	3.12(2)	1.58(12)	3.56(5)	2.21	5.4
ICGV 86351	3.05(1)	1.52(2)	0.82(16)	3.09(3)	1.39(19)	3.39(9)	2.21	4.7
ICGV 86472	2.32(10)	1.20(8)	1.03(4)	2.48(9)	2.09(1)	3.78(2)	2.15	4.7
ICGV 86486	2.31(11)	1.41(5)	0.90(11)	2.41(11)	1.70(8)	3.01(14)	1.96	4.7
ICGV 86400	2.69(6)	1.14(10)	1.06(5)	2.35(13)	1.41(17)	3.07(12)	1.95	3.4
ICGV 86393	2.91(2)	0.82(23)	0.91(10)	2.61(7)	1.86(3)	2.43(20)	1.92	4.0
ICGV 86527	2.40(9)	1.44(4)	1.15(1)	2.76(5)	1.59(9)	2.13(24)	1.91	5.0
Controls								
Kadiri 3	1.86(21)	1.02(13)	0.84(14)	2.02(22)	1.70(7)	3.43(8)	1.81	6.0
ICGS5	2.05(18)	0.99(17)	0.72(18)	2.32(16)	1.84(4)	4.29(5)	2.04	7.3
ICG 2271	2.14(14)	1.41(6)	0.68(19)	1.94(25)	1.25(22)	3.18(11)	1.77	4.7
SE	±0.150	±0.060	±0.060	±0.140	±0.130	±0.350		±0.4
Trial mean (25 entries)	2.27	1.11	0.84	2.44	1.53	2.97		5.1
CV (%)	11	10	12	10	15	20	13	
Efficiency over RBD[4] (%)	113	102	105	100	141	117	101	

1. Location
   1 = ICRISAT Center, Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, full protection, in triple-lattice design, plot size 13.5 m^2, broad bed and furrow (BBF).
   2 = ICRISAT Center, Alfisol, 20 kg P_2O_5 ha^{-1}, rainfed, no protection, in triple-lattice design, plot size 13.5 m^2 (BBF).
   3 = ICRISAT Center, Vertisol, 20 kg P_2O_5 ha^{-1}, rainfed, no protection, in triple-lattice design, plot size 13.5 m^2 (BBF).
   4 = Anantapur, Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 6 m^2 (on flat bed).
   5 = Dharwad, Vertisol, 60 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 6 m^2 (on flat bed).
   6 = Hisar, Entisol, 60 kg P_2O_5 ha^{-1}, irrigation, research protection, in triple-lattice design, plot size 6 m^2 (on flat bed).
2. Jassid damage scored on a 1-9 scale under natural insect pest infestation, where 1 = No jassid damage, 9 = 90-100% jassid injury (leaf yellowing) at ICRISAT Center, Vertisol location only.
3. Numbers in parentheses are rankings.
4. RBD = Randomized-block design.

Breeding for Adaptation to Specific Environments and Requirements

In collaboration with our agroclimatologists, we began the exercise of zonalization of groundnut-growing environments. This will help us determine the complex of key stress factors operating in regions that need our help to breed lines with multiple resistance.

Early-maturing Group

We grew 689 F_2-F_{10} populations in the 1987/88 postrainy season and made 1144 selections, and grew 1144 F_2-F_{10} populations in the 1988 rainy season and made 1002 selections, based on pod number, pod maturity, pod shape and size, and seed maturity in early harvests. We selected 17 new lines in the 1988 rainy season for replicated yield trials.

Yield trials. We evaluated 233 varieties in six replicated multilocational trials for their pod-yield potential in early harvests during the 1987/88 postrainy season. Eighteen varieties produced higher pod yields than the highest-yielding control variety in different trials. In the elite trial, variety ICGV 87060 produced the highest pod yield at both harvest dates on Alfisol fields at ICRISAT Center, 2.08 ± 0.09 t ha^{-1} in the 98 DAS [1240 day degrees cumulative thermal time (CTT)] and 3.33 ± 0.16 t ha^{-1} in the 113 DAS (1475 CTT) harvests. On Vertisol fields at ICRISAT Center, the mean pod yield in three trials for a similar crop duration was 6-33% more than those on Alfisol fields. The highest pod yield of 4.05 ± 0.21 t ha^{-1} was recorded by ICCV 87005.

During the 1988 rainy season, we evaluated 197 varieties in four replicated trials at ICRISAT Center and other locations in India. Four varieties outyielded the highest-yielding control varieties in preliminary trials at ICRISAT Center. When compared with the highest-yielding control variety, eight varieties in the elite trial outyielded the control in early harvests at one or more locations (Table 10). Under high-input conditions on an Alfisol at ICRISAT Center (location 1), ICGV 87882 gave the highest pod yield of 1.68±0.08 t ha^{-1} in 78 DAS (1240 CTT), and it had a shelling percentage of 64% and a 100-seed mass of 26 g. ICGV 87919 gave the highest pod yield of 2.35±0.12 t ha^{-1} in 93 DAS (1475 CTT), but its shelling percentage was 62% and 100-seed mass was 33 g. ICGV 87910, which ranked second in the 93-DAS harvest (2.16± 0.12 t ha^{-1}), had 75% shelling percentage and a 100-seed mass of 32 g. ICGV 87047, which had performed well during the 1987/88 postrainy season, also performed well during the 1988 rainy season.

Medium- and Late-maturing Group

We grew 345 populations (F_2-F_{10}) from 137 crosses in the 1987/88 postrainy season and retained 324 populations and made 12 single plant and 388 bulk selections. Of these, 105 were rated visually as good or very good under postrainy-season conditions. We selected 55 advanced generation populations for evaluation in replicated yield trials.

In the 1988 rainy season, we grew 425 populations (F_2-F_{11}) of 216 crosses. We made 454 selections, 17 single-plant and 437 bulk, in the 416 retained populations. We rated 34 of these selections visually as good for pod yield. Because of heavy defoliation by foliar diseases and early cessation of rains, most of the early-generation, segregating populations were advanced to the next generation by single-pod descent bulk.

Yield trials. In the 1987/88 postrainy season, we evaluated 201 varieties in six replicated yield trials conducted at one to three locations, depending on the stage of evaluation. Of these, 183 varieties produced higher pod yields than the national control varieties (J 11 for the sequentially branching group, and Kadiri 3 for the alternately branching group). Alternately branching varieties as a group had higher mean pod yield than the sequentially branching varieties.

Table 10. Mean pod yields of sortie groundnut varieties in the Elite Early Groundnut Varietal Trial, rainy season 1988.

	Location[1] and mean pod yield (t ha^{-1})							
Entry	1[1] (78 DAS)[2]	1 (93 DAS)	2 (90 DAS)	3 (90 DAS)	4 (86 DAS)	5 (92 DAS)	6 (85 DAS)	Mean
ICGV 87882	1.68(1)[3]	2.15(3)	1.56(5)	1.06(1)	1.60(33)	1.91(5)	2.35(7)	1.76
ICGV 87885	1.23(29)	2.02(6)	1.48(9)	0.87(5)	2.29(1)	1.74(13)	2.36(4)	1.71
ICGV 87047	1.59(3)	1.88(14)	1.46(10)	0.97(2)	1.99(6)	1.89(7)	2.19(12)	1.71
ICGV 87919	1.37(13)	2.35(1)	1.66(3)	0.88(4)	1.66(29)	1.91(6)	1.70(37)	1.65
ICGV 87922	1.60(2)	2.07(4)	1.86(1)	0.81(7)	1.64(31)	1.44(39)	1.88(27)	1.61
ICGV 87910	1.30(19)	2.16(2)	1.40(14)	0.67(24)	1.56(37)	1.95(2)	2.14(15)	1.60
ICGV 87876	1.18(34)	1.51(36)	1.12(38)	0.67(23)	1.98(8)	2.25(1)	2.18(13)	1.56
ICGV 86154	1.23(28)	1.99(8)	1.80(2)	0.62(29)	1.81(20)	1.50(33)	1.59(42)	1.51
Controls								
Chico	1.12(40)	1.23(48)	1.37(15)	0.18(49)	1.94(10)	0.97(49)	1.79(32)	1.23
JL 24	1.19(33)	1.74(17)	1.34(18)	0.90(3)	1.74(26)	1.73(15)	2.22(11)	1.55
TMV 2	0.99(45)	1.51(37)	0.83(46)	0.53(40)	1.81(22)	1.69(18)	1.77(33)	1.31
SE	±0.082	±0.121	±0.076	±0.075	±0.139	±0.166	±0.128	
Trial mean (49 entries)	1.25	1.68	1.25	0.65	1.72	1.59	1.93	
CV (%)	11	12	10	20	14	18	11	
Efficiency over RBD[4] (%)	108	106	101	110	119	136	101	

1. For locations, see Footnote 1 of Table 3, except for plot sizes which are 6.75 m^2 at location I and 6 m^2 at all other locations.
2. DAS = Days after sowing; during 1988 rainy season, at location 1, 78 DAS and 93 DAS were equal to 1240 and 1475 Cumulative Thermal Time (CTT). 1240 CTT gets accumulated at ICRISAT Center in rainy season on an average in 75 DAS and 1475 CTT in 90 DAS (based on 14-year weather data and assuming 15 June as the sowing date).
3. Numbers in parentheses are rankings.
4. RBD = Randomized-block design.

In the sequentially branching group trials, the mean pod yield ranged from 5.57±0.31 t ha^{-1} to 1.68±0.13 t ha^{-1}. Of the 111 varieties in these trials, 75 had higher pod yields than the national control cultivar, J 11. ICGV 86953, which was in the preliminary trial (on an Alfisol at ICRISAT Center), produced the highest pod yield. Pod yields of some of the varieties evaluated in the elite trial are presented in Table 11.

In the alternately branching group trials, 54 of the 77 cultivars gave higher pod yields than the national control cultivar, Kadiri 3. The mean pod yield in these trials ranged from 5.62±0.24 t ha^{-1} to 1.96±0.17 t ha^{-1}. ICGV 86924, on an Alfisol at ICRISAT Center, had the highest pod yield. Table 12 presents the pod yields of some of the cultivars evaluated in the elite trial.

In the 1988 rainy season, 102 out of 245 breeding lines in eight replicated multilocational trials at ICRISAT Center and other locations in India outyielded the national control cultivars, JL 24 for the sequentially branching group, and Kadiri 3 for the alternately branching group, at one or more locations. Varieties with alternately branching habit as a group gave a mean pod yield of 1.8 t ha^{-1} compared with 1.6 t ha^{-1} for the sequentially branching habit group.

in the sequentially branching group trials, the

Table 11. Mean pod yields of some varieties in the Elite Medium- and Late-Maturing Groundnut Varietal Trial (Sequentially Branching), postrainy season 1987/88.

	Mean pod yields (t ha^{-1})			
	ICRISAT Center		Bhavanisagar	
Entry	Alfisol[1]	Vertisol[1]	Alfisol[2]	Mean
ICGV 86346	4.46(1)[3]	4.43(3)	3.00(3)	3.96
ICGV 86269	4.36(5)	4.40(4)	2.67(12)	3.81
ICGV 86188	3.50(41)	5.19(1)	2.35(30)	3.68
ICGV 86864	4.23(6)	4.33(6)	2.46(20)	3.67
ICGV 86310	4.16(10)	3.87(23)	2.90(9)	3.64
ICGV 86282	4.42(3)	4.19(13)	2.27(35)	3.63
ICGV 86199	4.19(8)	4.21(11)	2.47(17)	3.62
ICGV 86326	4.46(2)	4.28(8)	2.13(43)	3.62
ICGV 86251	4.40(4)	3.99(20)	2.45(22)	3.61
ICGV 86330	4.16(9)	4.23(10)	2.39(26)	3.59
ICGV 86303	4.12(12)	3.68(31)	2.95(5)	3.58
ICGV 86200	3.99(20)	4.26(9)	2.36(28)	3.54
ICGV 86243	3.92(23)	4.39(5)	2.28(31)	3.53
ICGV 86249	4.00(18)	4.55(2)	2.02(45)	3.52
ICGV 86314	3.95(21)	4.32(7)	2.27(34)	3.51
Controls				
ICGS 11	3.39(44)	4.15(14)	3.06(2)	3.53
ICGS44	3.40(43)	3.80(27)	2.95(6)	3.38
J 11	3.21(46)	3.23(44)	1.68(49)	2.70
SE	±0.173	±0.194	±0.134	
Trial mean (49 entries)	3.79	3.83	2.44	
CV (%)	8	9	10	
Efficiency over RBD[4] (%)	100	127	104	

1. 60 kg P_2O_5 ha^{-1}, full irrigation, full insect-pests protection, in triple-lattice design, plot size 13.5 m^2 (broadbed and furrow).
2. 60 kg P_2O_5 ha^{-1}, full irrigation, research protection, in triple-lattice design, plot size 4.8 m^2 (flat bed).
3. Numbers in parentheses are rankings.
4. RBD = Randomized-block design.

pod yields ranged from 3.99±0.22 t ha^{-1} to 0.22± 0.10 t ha^{-1}. Variety ICGV 88330, which was in the preliminary yield trial at ICRISAT Center under high-input conditions on an Alfisol, produced the highest pod yield. Pod yield of some of the varieties in the elite trial are presented in Table 13.

In the alternately branching group trials, pod yields ranged from 3.74±0.19 t ha^{-1} to 0.33±0.09 t ha^{-1}. Variety ICGV 88307, included in the preliminary varietal trial under high-input conditions on Alfisol fields at ICRISAT Center, gave the highest pod yield. Pod yields of some of the varieties in the elite trial are presented in Table 14.

Confectionery Group

We grew 670 populations (F_2-F_6) in the 1987/88 postrainy and 1988 rainy seasons. We made 530

Table 12. Mean pod yields of some varieties in the Elite Medium- and Late-Maturing Groundnut Varietal Trial (Alternately Branching), postrainy season 1987/88.

	Mean pod yields (t ha^{-1})			
	ICRISAT Center		Bhavanisagar	
Entry	Alfisol[1]	Vertisol[1]	Alfisol[2]	Mean
ICGV 86347	4.70(3)3	4.87(5)	3.23(7)	4.27
ICGV 86185	5.17(1)	5.20(1)	2.14(35)	4.17
ICGV 86259	4.58(4)	4.56(9)	3.24(6)	4.13
ICGV 86231	5.05(2)	4.91(4)	2.35(32)	4.10
ICGV 86191	4.40(6)	4.30(18)	3.57(1)	4.09
ICGV 86229	4.08(19)	4.52(11)	3.25(5)	3.95
ICGV 86869	3.93(25)	4.46(13)	3.42(2)	3.94
ICGV 86868	4.39(7)	5.04(2)	2.36(31)	3.93
ICGV 86194	4.20(13)	4.67(7)	2.75(19)	3.87
ICGV 86873	4.20(14)	4.34(16)	3.05(9)	3.86
Controls				
ICGS 5	3.99(21)	4.28(20)	2.54(26)	3.60
ICGS 65	4.13(16)	3.88(29)	2.40(30)	3.47
C 198	3.57(33)	4.45(14)	2.28(34)	3.43
Kadiri 3	3.68(31)	4.32(17)	1.96(36)	3.32
SE	±0.237	±0.225	±0.168	
Trial mean (36 entries)	4.09	4.29	2.78	
CV (%)	10	9	11	
Efficiency over RBD[4] (%)	107	119	100	

1. See Footnote 1 of Table 11.
2. See Footnote 2 of Table 11.
3. Numbers in parentheses refer to rankings.
4. RBD = Randomized-block design.

bulk selections based on pod yield, pod and seed shape, pod and seed size, and seed color.

In the 1988 rainy season elite trial, ICGVs 86566 and 86584 significantly outyielded the highest-yielding control, Chandra, a released Indian confectionery cultivar, at ICRISAT Center and at Dharwad. ICGVs 86564 and 86571, again outyielded Chandra at ICRISAT Center. ICGVs 86564 and 86571 had a 100-seed mass of 74 g across locations in the 1988 rainy-season evaluation.

A high oleic/linoleic acid ratio confers long shelf life to confectionery products. Trade sources in the UK have indicated a minimum level of 1.6 for this ratio. ICGVs 86560, 86564, and 86584 have proved satisfactory (>1.75) in this respect during several seasons at many places in India.

Confectionery lines should have a higher ratio of those amino acids giving a typical roasting flavor (e.g., aspartic acid, glutamic acid, histidine, and phenylalanine) than those giving a typical (off) flavor (e.g., threonine, lysine, tyrosine, and arginine). This is an important quality index. Tests of ICRISAT confectionery lines show that this ratio is in the range of 1:1.5-1.7 in

Table 13. Mean pod yields of some varieties in the Elite Medium- and Late-Maturing Groundnut Varietal Trial (Sequentially Branching), rainy season 1988.

Entry	Location[1] and mean pod yield (t ha^{-1})							Mean
	1[1]	2	3	4	5	6	7	
ICGV 86008	3.50(1)[2]	0.94(24)	1.07(25)	2.70(7)	2.00(8)	2.62(2)	3.92(4)	2.39
ICGV 86885	2.81(13)	1.50(5)	1.26(7)	2.89(3)	1.82(18)	2.39(5)	3.79(6)	2.35
ICGV 87935	3.45(2)	1.28(8)	1.32(5)	2.27(24)	1.84(16)	2.68(1)	2.75(28)	2.23
ICGV 86865	2.86(9)	0.87(27)	1.18(13)	3.01(1)	1.40(33)	2.19(9)	3.96(2)	2.21
ICGV 86350	3.34(3)	1.74(1)	1.21(12)	1.64(36)	2.08(3)	2.10(14)	3.24(17)	2.19
ICGV 86884	2.72(14)	1.09(16)	1.38(4)	2.88(4)	1.97(9)	1.81(24)	3.39(12)	2.18
ICGV 86876	2.90(7)	1.51(4)	0.79(31)	2.38(16)	2.30(1)	2.40(4)	2.84(26)	2.16
ICGV 86140	2.65(18)	1.17(14)	1.25(8)	2.39(13)	1.97(10)	2.11(13)	3.57(9)	2.16
ICGV 87125	2.70(16)	1.00(20)	1.24(9)	2.23(26)	1.65(29)	2.09(15)	3.93(3)	2.12
ICGV 86314	2.89(8)	1.24(11)	1.24(10)	2.39(14)	1.70(25)	1.96(19)	3.38(13)	2.11
ICGV 86233	2.57(23)	0.85(29)	1.17(16)	2.94(2)	1.19(35)	2.03(17)	3.98(1)	2.10
ICGV 86148	2.91(6)	1.24(10)	1.42(3)	2.18(28)	2.28(2)	1.58(33)	2.90(24)	2.07
ICGV 86320	2.46(29)	1.18(13)	1.12(18)	2.31(20)	2.04(6)	1.81(23)	3.44(11)	2.05
ICGV 86888	2.71(15)	1.45(6)	1.58(1)	2.37(17)	1.95(12)	1.88(20)	2.36(34)	2.04
ICGV 86294	2.69(17)	1.11(15)	1.22(11)	2.75(5)	1.29(34)	1.52(35)	3.67(8)	2.03
Controls								
ICGS 11	2.34(31)	0.87(28)	1.14(17)	2.64(9)	1.65(28)	1.61(32)	3.20(19)	1.92
JL24	1.87(34)	1.00(21)	0.79(32)	2.51(12)	1.75(20)	2.23(6)	2.56(32)	1.82
J 11	1.65(35)	0.54(36)	0.43(36)	2.34(18)	1.15(36)	2.13(10)	3.13(20)	1.62
SE	±0.163	±0.095	±0.108	±0.128	±0.180	±0.174	±0.313	
Trial mean (36 entries)	2.66	1.07	1.09	2.37	1.78	1.97	3.15	
CV (%)	11	15	17	9	18	15	17	
Efficiency over RBD[3] (%)	100	102	104	101	103	107	103	

1. For locations, see Footnote 1 of Table 3. except for plot sizes which were 13.5 m^2 at locations 1 to 3 and 6 m^2 at other locations.
2. Numbers in parentheses are rankings.
2. RBD = Randomized-block design.

favor of the desired amino acids.

We also evaluated 61 newly developed varieties and 27 introduced lines from North Carolina State University, Raleigh, USA, in replicated yield trials at ICRISAT Center during the 1988 rainy season. Thirty-two varieties outyielded the controls, M 13, Chandra, and ICGS 11 (Table 15). Several varieties recorded an oleic/linoleic acid ratio of 1.6 or more.

ICGV 88442 (NC 6 x early bunch) and ICGV 88433 (NC Ac 18445) had significantly higher pod yields than those of controls, but their 100-seed mass was much lower than those of controls. ICGV 88424 (NC Ac 18420), ICGV 88429 (NC Ac 18437), and ICGV 88438 (GP NC 343 x NC Ac 17367) had a higher 100-seed mass (70 g) than that of controls, but their pod yields were not significantly higher.

Table 14. Mean pod yields of some varieties in the Elite Medium- and Late-Maturing Groundnut Varietal Trial (Alternately Branching), rainy season 1988.

Entry	Location[1] and mean pod yield (t ha^{-1})							Mean
	1[1]	2	3	4	5	6	7	
ICGV 86300	2.72(1)[2]	1.79(1)	0.98(4)	2.12(12)	2.16(1)	2.55(1)	2.57(9)	2.13
ICGV 87135	2.56(4)	1.61(4)	1.07(3)	2.32(9)	2.13(2)	2.49(2)	2.63(8)	2.12
ICGV 86879	2.63(3)	1.27(9)	1.16(1)	2.62(3)	1.57(9)	2.36(3)	3.15(1)	2.11
ICGV 86894	2.16(11)	1.31(7)	1.09(2)	2.65(2)	1.64(7)	1.94(8)	2.98(3)	1.97
ICGV 86878	2.70(2)	1.61(3)	0.50(13)	2.56(4)	1.53(12)	1.81(11)	2.70(7)	1.92
ICGV 86897	2.41(6)	1.21(11)	0.44(14)	2.71(1)	1.54(11)	2.01(7)	2.92(4)	1.89
ICGV 86201	2.54(5)	1.34(5)	0.57(12)	2.10(13)	1.47(13)	2.24(4)	2.89(5)	1.88
Controls								
ICGS 5	2.15(12)	1.20(12)	0.93(5)	2.38(8)	1.64(6)	1.88(9)	2.51(10)	1.81
Kadiri 3	1.90(16)	1.18(14)	0.90(6)	2.46(6)	1.55(10)	1.41(15)	3.11(2)	1.79
C 198	2.08(13)	1.08(15)	0.33(16)	2.20(10)	1.32(16)	0.90(16)	2.12(14)	1.43
SE	±0.129	±0.046	±0.087	±0.090	±0.134	±0.163	±0.336	
Trial mean (16 entries)	2.32	1.34	0.74	2.32	1.66	1.91	2.54	
CV (%)	10	6	20	7	14	15	23	
Efficiency over RBD[3] (%)	100	100	100	133	100	100	132	

1. For locations, see Footnote 1 of Table 3.
2. Numbers in parentheses are rankings.
3. RBD = Randomized-block design.

Tolerance of Multiple Stresses

We have identified five varieties possessing some resistance to early and late leaf spots, iron chlorosis induced by high pH and bicarbonates, and jassids (see Foliar Fungal Diseases discussed earlier in this section). Three other foliar-diseases resistant varieties, ICGVs 86703, 86706, and 86615 showed either no or only low levels of seed transmission of PMV. ICGVs 87184, 86598, 87354, and 87259 showed lower than average levels of bud necrosis disease in the field.

Nutritional and Food Quality Studies

We analyzed four seasons' data on 100-seed mass, oil content, and protein content recorded on a set of 64 groundnut varieties. Both, variety and seasonal effects and variety x seasonal interaction effects were highly significant. The association of 100-seed mass with oil and protein contents was nonsignificant. They themselves were, however, negatively associated with each other (r = -0.61**). We also studied the effect of within-variety seed size variation on oil content in a subset of 33 groundnut varieties over three seasons, where all seven classes of seed size were available. Correlation studies confirmed that oil content in the same variety increased as the seed size increased (r = 0.976**) and that such variation in oil content was up to 6%. Eight groundnut varieties (ICGVs 87124,87125,87126,87134, 86564, 86529, 87871, and 87873) had shown a

Table 15. Performance of some confectionery groundnut varieties in a preliminary yield trial, ICRISAT Center, rainy season 1988[1].

Entry	Pod yield ($t\ ha^{-1}$)	Shelling (%)[2]	100-seed mass (g)[3]	Oil (%)[4]	Protein (%Y	Oleic/linoleic acid ratio[4]
ICGV 88386	3.57	67	71	51.1	24.4	2.0
ICGV 88382	3.52	64	79	51.5	24.0	1.9
ICGV 88403	3.49	66	76	50.8	23.1	1.9
ICGV 88376	3.37	68	80	51.4	24.3	2.0
ICGV 88367	3.32	67	74	50.8	23.7	1.7
ICGV 88391	3.30	70	71	48.8	25.3	1.2
ICGV 88385	3.25	64	84	47.5	25.3	1.6
ICGV 88415	3.22	66	80	46.2	24.0	1.6
ICGV 88408	3.17	68	87	52.8	22.3	1.8
ICGV 88358	3.15	70	71	49.1	23.7	1.7
Controls						
M 13	2.40	69	54			
Chandra	2.30	64	60			
ICGS 11	2.16	72	42			
SE	±0.230					
Trial mean (64 entries)	3.00					
CV (%)	13					
Efficiency over RBD[5] (%)	101					

1. Alfisol, 60 kg $P_2O_5\ ha^{-1}$, full irrigation, full protection, in triple-lattice design, plot size 6 m^2 (broadbed and furrow).
2. Recorded from bulk sample of 500 g pods.
3. Recorded from bulk sample of randomly selected sound, mature seeds.
4. Recorded from bulk sample of the 1987/88 postrainy-season crop.
5. RBD = Randomized-block design.

mean oil content of 50% in rainy as well as postrainy seasons as against 45% in JL 24.

Utilizing Wild *Arachis* Species

We screened stable *A. hypogaea*-like derivatives against severe late leaf spot infestation. *A. hypogaea x A. cardenasii,* 259-2, was the most resistant of all groundnuts grown at ICRISAT Center. It was also the most resistant of the material tested for early leaf spot resistance at Pantnagar (see Foliar Fungal Diseases discussed earlier in this section). We also selected 261 plants with a score of 4 or 5 for future studies.

From 1987, we have given increased priority to the transfer of early leaf spot and groundnut rosette virus (GRV) resistance to *A. hypogaea. Arachis* sp 30003, *Arachis* sp 30085, and *A. chacoensehavt* resistance to early leaf spot; *Arachis* sp 30003 and *Arachis* sp 30017 to GRV. These accessions are also resistant to groundnut rosette assistor virus (GRAV). *A. chacoense, Arachis* sp 30017, and *Arachis* sp 30085 are in section *Arachis,* and are cross compatible with *A. hypogaea,* but *Arachis* sp 30003 is in section *Erectoides,* and cannot be crossed easily with *A. hypogaea.*

The triploid hybrids produced last year, involving *Arachissp* 30085, *Arachis* sp 30017, and *A. chacoense,* have been backcrossed to *A. hypogaea.* We produced a fertile hexaploid from hybrids involving *Arachis* sp 30085 and back-crossed to *A. hypogaea.* We selfed the pentaploid progeny (BC_1) to produce many fertile and productive progenies.

To overcome barriers to hybridization, we attempted to identify a bridging species among the annual species of section *Arachis.* We tried *A. batizocoi, A. duranensis,* and *A. spegazinii* However, we again observed postzygotic barriers in these crosses, but not as complete as with *A. hypogaea. A. duranensis* x *Arachis* sp 30003 crosses produced 8.1% globular to cotyledonary embryos, *A.batizocoi* x *Arachis* sp 30003 crosses produced 5.2% embryos, and *A. duranensis* x autotetraploid *Arachissp* 30003 produced 16.9% ovules with embryos. We cultured ovules on filter-paper bridges. The embryos were dissected and transferred to semisolid media. A few seedlings have been established, and morphological studies indicate that they are hybrids; this will be verified cytologically when they flower.

Tissue Culture

In attempts to improve techniques for regeneration of plants from callus tissue, good results have been obtained using *A. villosulicarpa.* Plants regenerated from leaf disc-derived callus have been transplanted to the field, and have produced seeds. The regeneration potential of the cultivated groundnut is not as good as that of wild species, but altering the conditions of culture and modifying the vitamin concentrations in the media have improved the success rate.

Anther Culture

Studies of the *A. hypogaea* flower buds have shown that bud size is a reliable indication of the stage of development of microspores, but the size is specific to plants of the same age and genotype, grown under the same conditions. It has thus been possible to select buds in which more than 90% of anthers contain microspores, which are at the uninucleate stage. Cold pre-treatment of selected anthers produced multinucleate structures, and 61% of cultured anthers produced calluses. Cytological and morphological studies showed that most of the calluses had the same chromosome number, 2n = 40, as the original tetraploid plants, but some cells had the diploid number of chromosomes.

Cooperative Activities

Cooperation with AICORPO and Other Programs in India

Yield Trials

Of the 118 varieties currently under test in AICORPO trials, ICRISAT contributed 66; 47 varieties (60%) in the rainy season (kharif) and 19 (47%) in the postrainy season (rabi/summer).

Varieties in the final stage of evaluation, as per the revised zoning system, are ICGS 44-1 in zones IV and V, ICG(FDRS) 43 in zone V in the National Elite Trial (Spanish Bunch), ICGS 65 in zone IV, and ICGS 76 in zone V in the National Elite Trial (Virginia Bunch) in the rainy season. In the postrainy season, ICGSs 87 and 105 in zones I and II, and ICGSs 84,87,103,105, and 109 in zone III are in the final stage of evaluation in the National Elite Trial (Spanish Bunch).

The consistent performances of ICGS 37 (ICGV 87187) and ICGS 6 (ICGV 87122) in trials by agricultural universities may result in their release in Madhya Pradesh (ICGS 37) and Maharashtra (ICGS 6).

Release and Seed Supply of ICRISAT Material

Early this year, the Central Sub-Committee on Release of Varieties of the Government of India formally notified for release, variety ICGS 44

(ICGV 87128) for postrainy season cultivation in Gujarat state. This variety has become popular in all groundnut-growing areas of India as it does equally well in the rainy season.

We also supplied 517 advanced populations or varieties to scientists at 34 locations in India. We made 10 crosses involving bud necrosis disease-tolerant parents for use in the breeding program of the University of Agricultural Sciences, Raichur. ICRISAT-developed materials are being used increasingly in various breeding programs in India.

International Trials and Observation Nurseries

Five new international trials (Fourth Series) will become available to our cooperators in 1989 (Table 16). For drought-tolerant and confectionery material, we will continue with the old set of trials (Third Series) for one more year.

We continued to supply sets of international trials of the Third Series in 1988, bringing the totalfor 1987 and 1988 to 31 of the International Early Groundnut Varietal Trial, 23 of the International Medium and Late Groundnut Varietal Trial, 16 of the International Confectionary Groundnut Varietal Trial, 10 of the International Pest-resistant Groundnut Varietal Trial, 14 of the International Foliar Diseases Resistant Groundnut Varietal Trial, and 6 of the International Drought Nursery. In 1988, we sent 37 sets to 13 countries. New recipients included Guatemala, Sierra Leone, and Swaziland. We have so far received data from 22 trials sent out in 1987.

Some results reported by our cooperators are as follows.

Early-maturing Groundnut Varietal Trial

In Benin, ICGVs 86092 and 86015 significantly outyielded the local variety at Niouli. These early-maturing lines produced 1.48±0.16 t ha^{-1} and 1.27±0.16 t ha^{-1} of pods while the local variety produced only 0.82±0.16 t ha^{-1}.

Four early-maturing varieties, ICGV 86074 [ICGS(E) 61], ICGV 86056 [ICGS(E) 22], ICGV 86087 [ICGS(E) 120], and ICGV 86017 [ICGS(E) 123] were reported to tolerate shade at the University of Philippines, Los Banos. ICGV 86074 with 0.8 t ha^{-1} pod yield was reported to be stable across three levels of shading.

At Bryan, Texas, USA, the early-maturing variety ICGV 86015, which produced 2.6 t ha^{-1} of pods by 121 DAS and was the best among the early-maturing breeding and germplasm lines.

Table 16. The Fourth Series of International Groundnut Varietal Trials available from ICRISAT Center for cooperators.

Trial name	No. of entries
International Early-maturing Groundnut Varietal Trial (IEGVT 4)	24(+1)[1]
International Medium- and Late-maturing Groundnut Varietal Trial (Sequentially Branching) [IMLGVT(SB) 4]	23(+2)
International Medium- and Late-maturing Groundnut Varietal Trial (Alternately Branching) [IMLGVT(AB) 4]	14(+2)
International Foliar Diseases Resistance Groundnut Varietal Trial (IFDRGVT 4)	24(+l)
International Insect Pests Resistance Groundnut Varietal Trial (IIPRGVT 4)	15(+1)

1. Numbers in parentheses are total local controls.

In an advanced yield trial, at Khon Kaen University (KKU), Thailand, ICGV 86046 gave 26% higher yield than the local cultivar, Tainan 9. It matured at the same time as cv Chico and was 20 days earlier than cv Tainan 9.

Medium- and Late-maturing Groundnut Varietal Trial

Burma, Malawi, Nepal, the Philippines, Somalia, and Sri Lanka reported results from the first season of evaluation.

In Burma, ICGV 87126 produced the highest pod yield of 1.46±0.15 t ha^{-1}, a 36% increase over that of the local variety Kyaung Gon. It also had a higher 100-seed mass (43 g) than the local variety (34 g).

Variety ICGV 87141 yielded as well as the local variety Banki 4 in Nepal, but matured 9 days earlier. In the Philippines, it produced a higher pod yield (1.12 ± 0.06 t ha^{-1}) than the control variety UPL Pn 4 (0.91 ± 0.06 t ha^{-1}), and also had a higher 100-seed mass.

In Malawi, the local variety (Mawanga) and ICGV 87148 had similar pod yields but the latter matured 2 weeks earlier than Mawanga.

In Burundi, ICGV 86010 produced a pod yield of 4.36 ± 0.47 t ha^{-1} compared with 2.40 ± 0.47 t ha^{-1} of G 18 and 1.57 ± 0.47 t ha^{-1} of A 65, both local varieties. Fourteen varieties have been retained for further evaluation.

Insect-pests Resistance Groundnut Varietal Trial

In Vietnam, two varieties, ICGVs 86011 and 87153, produced 40% higher pod yield than the local control, Tram Xuyen, and showed resistance to foliage pests.

Confectionery Groundnut Varietal Trial

In the 2nd year of evaluation, ICGV 86564 maintained its superior pod yield in Nepal. It had a 100-seed mass of 84 g compared with 40 g of the local control.

In Burundi, three groundnut varieties, ICGVs 86577, 86028, and 86564, recorded higher pod yields (2.45-3.16 t ha^{-1}) and higher 100-seed masses (57-90 g) than the control variety, G 18, which produced 1.79 ± 0.34 t ha^{-1} pod yield and had a 100-seed mass of 40 g.

Foliar Diseases Resistance Trial

In Burma, ICGV 87179 gave the highest pod yield of 1.7 t ha^{-1} compared with 0.14 ±0.12 t ha^{-1} of the local variety, Japan Kalay.

In Indonesia, ICGV 87158 gave 28% higher pod yields than the local control, Kelinci.

In Thailand, in an 'intermediate yield trial', conducted by our cooperator at KKU during 1986/87, two foliar-diseases resistant selections, ICGVs 86600 and 87987, continued to do better than the local control, Tainan 9.

Drought Resistance Varietal Trial

In the International Drought Resistance Varietal Trial conducted at KKU, Thailand, during 1987/88, ICGV 86708 [ICG(FDRS) 60] with a pod yield of 2.5 t ha^{-1} outyielded the best control, Moket (1.9±0.22 t ha^{-1} of pods), under nonirrigated conditions.

Adoption of ICRISAT Material

Two ICRISAT groundnut varieties, ICGSs 44 and 37, are in the process of registration by the National Seed Registration Department of Pakistan.

The National Oilseeds Development Programme (NODP) in Nepal has identified ICGS 36 as the most promising variety from ICRISAT. A proposal for its release in the country is being submitted by the NODP.

After four seasons of regional evaluation, Project FAO- CIAM (UTF/ GAB/005), Ministry of Agriculture, Gabon, has selected three ICRISAT varieties ICGV 86014 [ICGS(E) 52], ICGV 86015 [ICGS(E) 56], and ICGV 86092 [ICGS(E) 128], with control, JL 24, for national evaluation.

Regional Groundnut Improvement Program for Southern Africa

The SADCC/ICRISAT Regional Groundnut Improvement Program is based at the Chitedze Research Station, near Lilongwe, Malawi. Our principal endeavor is to provide the national groundnut research teams of the SADCC countries with a continuous supply of high-quality material for evaluation and utilization in their groundnut improvement programs. Our work is thus primarily concerned with the effective broadening of the genetic resources of the region, and our priorities are vested in breeding and selecting for increased yields and better quality, particularly early-maturing varieties, with disease resistance.

Fungal Diseases

Early Leaf Spot (*Cercospora arachidicola*)

Early leaf spot is the most important groundnut disease in the region. Epidemics are consistently severe at Chitedze, and afford suitable conditions to assess tolerance or resistance.

Screening for resistance. We screened 35 lines reported to have resistance to early leaf spot at ICRISAT Center in a field trial, together with the highly susceptible Malimba, and a Valencia selection with tolerance of early leaf spot through good leaf retention, ICGMS 55. Six lines had low levels of resistance but none was better than ICGMS 55.

Of the 105 lines carried over from our 'bulk' testing in the 1986/87 season, we retained ICGs 50, 84, and 11282. We screened 12 selections derived from interspecific hybrids, retaining 5 for further evaluation.

Field assessment of early leaf spot. In the 1987/88 season, we used the susceptible Spanish variety Malimba in a 2^5 factorial experiment to assess the effects of single applications of chlorothalonil on the incidence of early leaf spot and on yield. Fungicides were applied at 32, 46, 60, 74, or 88 DAS. There were highly significant yield reponses to single applications made on the first four dates. The best response (274 kg ha^{-1}) was from a spray at 46 DAS. The application at 88 DAS did not increase yield.

We used several different methods to estimate early leaf spot severity and compared the relative efficiency of each by measuring the correlation between field score and yield. Disease was assessed 32, 42, 53, 69, 82, and 97 DAS. The methods compared were:

1. the ICRISAT 1-9 scale,
2. the Cole 0-6 scale,
3. actual defoliation count,
4. estimated leaf area damaged, using standard area diagrams,
5. the Cole 0-6 scale transformed into leaf-area damaged,
6. the ICRISAT 1-9 scale arbitrarily transformed into leaf-area damaged (where 1 = 0%; 2 = 2.5%; 3 = 5%; 4 = 10%; 5 = 20%; 6 = 32.5%; 7 = 50%; 8 = 70%; and 9 = 90% leaf-area damaged),
7. estimates of remaining green leaf (RGL), derived from method 6 above, and actual defoliation count,
8. estimates of RGL (using method 5 above) and actual defoliation count,
9. estimates of RGL calculated from leaf-area damaged (using method 4 above) and actual defoliation count.

Disease indices at 82 DAS were most closely related to yield. The estimate of RGL using an arbitrarily transformed ICRISAT 1 -9 scale (method 7 above) appeared to be the most closely associated.

Wild *Arachis* species screening. We screened 27 *Arachis* species accessions. Six gave good seedling establishment and of these, *Arachis* sp 30126 and *Arachis* sp JKP 9990 showed promising reactions to early leaf spot. The many small necrotic lesions that developed on the leaves were apparently sterile.

Virus Diseases

GRV Disease

Screening for resistance. We tested 12 700 F_3 plants derived from crosses between resistant and susceptible lines. In spite of rigorous field screening of the F_2 generation in 1986/87 and greenhouse screening of the survivors during 1987, we continued to record a scattering of susceptible individuals plants.

Two GRV-resistant varieties from West Africa, KH 149A and 69-101, were subjected to stringent greenhouse-inoculation tests. We detected and discarded a low proportion of susceptible plants. Progenies from apparently resistant survivors will be used in GRV-resistant crosses in 1989.

We continued with attempts to purify the West African resistant selection KH 241 D. In 1986, we tested seedlings for resistance to GRV by aphid inoculation. Plants that developed symptoms were discarded, and the survivors top-grafted with scions of the highly susceptible cultivar, Spancross, to test for covert infection of GRV. None of the top grafts developed symptoms of rosette. We grew the plants to maturity and included the seeds in the 1986/87 field-screening nursery. Only 3 plants of the 81 exposed became infected with GRV. We harvested 26 seeds from the apparently healthy plants and these were sown in the greenhouse. We inoculated the seedlings with GRV. Six developed early and severe symptoms of rosette, and four more developed symptoms after a delay of several weeks.

GRAV. All the GRV-resistant varieties we tested at Chitedze (RG 1, RMP 40, RMP 91, RRI/6, and RRI/24) were susceptible to GRAV. To estimate the possible loss in yield caused by GRAV, we raised 200 seedlings of RG 1 in the greenhouse and inoculated 100 with GRAV, and then transplanted all into the field. We took shoots from each plant 70 days after transplanting, and sent these to the Scottish Crop Research Institute (SCRI) where serological (ELISA) tests for the presence of GRAV or PMV were made. All 100 inoculated plants contained GRAV, but so did 54% of the noninoculated controls.

We also collected shoots of 20 RG 1 plants at random from a plot some distance from the experiment. Of these, 14 contained GRAV suggesting a rapid natural spread of GRAV and a resultant high incidence.

We found PMV in 48% of the plants tested. The complications resulting from random infections of control plants with GRAV and of infections of PMV across treatments precluded any possible estimates of the effect of GRAV on yield.

PMV

The high incidence of PMV in the above GRAV crop-loss experiment prompted a check on the GRV/GRAV culture. Serological tests showed that it was not contaminated with PMV, and that the field incidence (50%) was the result of natural spread, either from infected seed or by aphid transmission. We measured the seed infection in RG 1 in two experiments.

From the 1987/88 crop of RG 1, we sowed a random sample of 1000 seeds in pots in the greenhouse. Twenty-eight seedlings showed mild virus-like symptoms, and 14 indexed positive in sap inoculation tests to common bean (*Phaseolus vulgaris,* cv Black Turtle Soup), We took a further 115 symptomless plants at random and similarly indexed them. We found seven positive for PMV. SCRI tested an additional 86 seeds serologically but found no infection.

We sowed 450 seeds from PMV-infected RG 1 plants in the greenhouse and indexed the seedlings to common bean plants by sap inoculation. PMV was detected in seven (1.6%) of them.

These results suggest that PMV is seed borne in RG 1, and that aphid transmission is effective enough to cause high incidence in the field.

Groundnut Streak Necrosis Disease (GSND)

We compared yields of healthy and GSND-infected plants of ICGM 197 and the Mozambican variety, Bebiano Encarnado. ICGM 197 is sensitive to GSND and reacts severely to infection, whereas the reaction is mild in Bebiano Encarnado. GSND caused a seed yield loss of 58% in ICGM 197 and 44% in Bebiano Encarnado, indicating some resistance to GSND in the latter.

We also monitored the incidence of GSND in relation to the time of sowing. At Chitedze, we recorded an incidence of 0.2% in plots sown in early December; 0.7% in those sown in mid-December; 2.5% in late-December sowings; and 4.4% in early-January sowings. This pattern is similar to that encountered with GRV.

We also monitored populations of the vector of GSND, *Aphis gossypii,* in Moericke (yellow water) traps during the season. There was a close correlation between the peak migration period in mid-February and the comparatively high incidence of GSND in the latest-sown plants.

Plant Improvement

Hybridization

We made 130 crosses in the field. Crosses for the Regional Program included 21 for adaptability, 19 for leaf retention, 10 for high yield and quality, and 23 for GRV resistance, using KH 241 D, a newly purified, early-maturing source of resistance. We also made 20 crosses for the Zimbabwe national program for GRV and early leaf spot resistance, 10 crosses for ICRISAT Sahelian Center for GRV resistance, 21 crosses for the Malawi national program for high yield and quality, and 6 crosses for the Mozambique national program for adaptability and leaf retention.

We made 17972 pollinations, which resulted in 3854 hybrid pods representing a 21% success rate.

Breeding for Disease Resistance

Breeding material. We received 52 interspecific derivatives from ICRIS AT Center to screen in observation plots. These included 40 *A.chacoense* derivatives. We retained some for further evaluation and made 15 selections.

We sowed 63 F_2 populations from crosses made for leaf retention. Few plants showed superior leaf retention, but we selected 1 836 single plants for evaluation in progeny rows. Most of those selected for leaf retention had a poor yield.

From 23 F_6-F_9 populations, which included disease-resistant material, we retained 9 and made 11 bulk selections.

We sowed 40 selections made locally from interspecific derivatives and retained 22 from which we made 23 selections. Of these, 12 will be included in preliminary yield trials.

Breeding for High Yield and Quality

Breeding material. We sowed 10 F_1 populations from crosses made between genotypes having high-yield potential and genotypes with bold seed, to confirm their hybridity and to advance them to the next generation.

From 24 F_2 populations we made 461 pedigree selections, and from 232 F_3-F_7 populations we retained 152 and made 190 bulk and 90 pedigree selections. We selected 8 F_5, 6 F_6, and 6 F_7 selections for inclusion in yield trials. Four selections from the crosses Egret x Ah 114, 1CGS 6 x Makulu Red, and ICGS 15 x ICGS 20 had good yield potential. Other promising selections were from the crosses F 334 A-B-14 x Makulu Red, NC Ac 171352 x Makulu Red, ICGS 6 x Makulu Red, ICGS 49 x Makulu Red, and SP1 x Ah 114.

Germplasm evaluation. From the International Confectionery Groundnut Variety Trial, two entries, ICGVs 86555 and 86584, outyielded local controls and had superior shelling percentage, but all entries had small seeds. ICGVs 86555 and 86584 have been included in advanced variety trials.

Breeding for High Yield and Adaptability

We sowed 20 F_1 populations from crosses involving genotypes showing wide adaptability in the SADCC region and having superior leaf retention to confirm their hybridity and to advance them to the next generation.

Yield Trials

Regional Program preliminary yield trials. We evaluated 75 sequentially branching and 97 alternately branching breeding lines in five yield trials. Two selections from the cross J 11 x TG 3 x NC Ac 17090 and one selection from NC Ac 274 x Chico performed well.

ICRISAT Center preliminary yield trials. We evaluated 118 medium and late, foliar-diseases resistant and multiple-stress resistant breeding lines in three trials at the Chitedze Research Station. We selected four entries for further evaluation.

ICRISAT Center international yield trials. We evaluated 127 early-maturing, confectionery, foliar-diseases resistant, medium and late, and pest-resistant breeding lines in five trials at the Chitedze Research Station.

We selected one foliar-diseases resistant line, two confectionery lines, and one pest-resistant line for inclusion in advanced yield trials. The early-maturing groundnut variety trial yielded useful results and will be repeated at two sowing dates in 1988/89.

Regional Program advanced yield trials. We evaluated 37 sequentially branching and 37 alternately branching breeding lines in two trials at the Chitedze Research Station.

Many sequentially branching entries outyielded the local control, Malimba, and several showed promise for yield potential and large seed size (Table 17). We selected nine entries for inclusion in regional yield trials including selections from J 11 x TG3 x NC Ac 17090, Robut 33-1 x NC Ac 17506, Gaug 1 x SM 5, and JL 24 x RG 1.

Many alternately branching lines were superior to the local control, but none was superior to Mani Pintar or Makulu Red. ICGV SM 83708 (ICGMS 42) remains a difficult standard to better (Table 17). We selected eight entries for inclusion in the regional yield trials. Among these were selections from (Robut 33-1 x NC Ac 282) x (USA 20 x TMV 10), Makulu Red * NC Ac 343, and introductions from Zambia.

SADCC Regional Yield Trials. The Virginia cultivar trial was grown at 8 locations in five countries, the Spanish cultivar trial at 11 locations in six countries, and the Valencia cultivar trial at 9 locations in six countries.

Of the Virginia cultivars, ICGV-SM 83708 (ICGMS 42) again ranked highly at most locations and was superior to local varieties at most sites. Many other entries were consistently highly ranked, notably ICGV-SMs 85726,85727,86715, 86717 (all interspecific hybrid derivatives), and ICGV-SM 86725 [(Robut 33-1 x NC Ac 2821) x (USA 20 x TMV 10)]. Fifteen entries have been selected for further evaluation.

Several entries in the Spanish trials performed consistently but others performed erratically. Entries with high rankings included ICGV-SM 85038 [(PI 261911 x PI 262092) x Egret], ICGV-SM 85048, ICGV- SM 86066, ICGV-SM 86068 [(Goldin 1 x Faizpur 1-5) x (Manfredi x M 13)], ICGV-SM 85045 (JH 171 x Robut 33-1), and ICGV-SM 86062 (J 11 x HG 1). Thirteen entries have been selected for further evaluation.

At most Valencia trial locations, test entries were significantly superior to control varieties. ICGMs 189, 284, 285, and 286 performed consistently well.

We supplied sets of seeds from the regional trial for the 1988/89 season to Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe. We supplied also selected early-maturing and drought-resistant lines to Botswana, Lesotho, Zambia, and Zimbabwe. We responded to requests from Rwanda, Burundi, Zaire, and Mauritius for selected germplasm.

Table 17. Performance of some groundnut breeding lines in advanced yield trials, Chitedze, Malawi, 1987/88.

Entry	Pedigree	Time to maturity (days)	Seed yield (t ha⁻¹)	Shelling (%)	100-seed mass (g)	Seed color	Mean early leaf spot score[1]
Alternately branching[2]							
ICGV-SM 86708	[(Robut 33-1) x NC Ac 2821] x (USA 20 x TMV 10)]	113	1.70	70	61	Tan	5
ICGV-SM 83708	(USA 20 x TMV 10)	126	1:69	75	56	Red	4
ICGV-SM 86705	(Robut 33-1 x 944)	111	1.68	68	43	Tan	5
ICGV-SM 86761	ICGM 929 (introd. ex Zambia)	126	1.68	74	47	Red	4
Local control							
Mawanga		126	1,33	68	48	Variegated	5
SE			±0.09				
Trial mean (42 entries)			1.36				
CV (%)			12				
Sequentially branching[2]							
ICGV-SM 86053	ICGM 291 (ICG 8528)	120	2.13	71	43	Tan	4
ICGV-SM 86021	[(USA 20 x TMV 10) x (Robut 33-1-10-3)]	120	2.06	74	50	Tan	4
ICGV-SM 87003	(J 11 x TG 3 x NC Ac 17090)	106	1.94	76	29	Tan	6
ICGV-SM 86014	(Robut 33-1 x NC Ac 17506)	118	1.89	71	37	Tan	5
ICGV-SM 85011	(Gaug 1 x SM 5)	107	1.80	76	25	Tan	6
Local control							
Malimba		107	1.43	74	27	Tan	5
SE			±0.10				
Trial mean (42 entries)			1.52				
CV (%)			!2				

1. Scored at 73 days after sowing on a 1-9 scale, where 1 - No disease, and 9 = 50-100% of foliage damaged.
2. 6 x 7 lattice, plot size 14.4 m^2.

Regional Groundnut Improvement Program for West Africa

The ICRISAT Regional Groundnut Improvement Program for West Africa is based at the ICRISAT Sahelian Center (ISC), Sadore, near Niamey, Niger. Our key areas of research are drought, leaf spots, rust, GRV, peanut clump, aflatoxin contamination, varietal adaptability, cropping systems, plant nutrition, and crop-growth variability. Our activities were concentrated at three locations in Niger: Sadore (13° 18'N; 568 mm mean annual rainfall), the Institut national de la recherche agronomique du Niger (INRAN) station at Bengou (11°59'N; 839 mm mean annual rainfall), and the INRAN station at Maradi (13°28'N; 642 mm mean annual rainfall).

Drought

We ran a drought simulation trial at Sadore during the 1987/88 dry season in which four groundnut genotypes were irrigated every 1, 2, or 3 weeks, each irrigation giving either 20 mm or 40 mm of water. In the first trial, run from September-December 1987, we found no difference between genotypes, and we, therefore, concluded that it is not feasible to screen for drought tolerance during that time of the year at ISC.

We carried out a similar trial, but with eight genotypes, in February-June 1988, during much hotter weather. Plots irrigated every 3 weeks effectively gave no pods; their data were excluded from the analysis. ICGS 11 (ICGV 87123) and cv 55-437 gave the highest pod yields over all other irrigation treatments, but had low haulm yields. There were no significant interactions between genotype and irrigation treatment for pod or haulm yield. It seems that under drought-stress conditions at ISC, the plants may be able to produce reasonable haulm yields or reasonable pod yields, but not both.

We made weekly determinations of soil moisture with neutron probes, and took daily measurements of crop canopy air temperature difference (CCATD) with infrared thermometers on all plots in the trial. We found no differences in soil moisture between genotypes, but there were considerable differences between genotypes in CCATD. There was a strong negative correlation between midseason CCATD and pod yield under intermediate drought-stress conditions (20 mm water each week), whereas there was no such correlation when 40 mm were applied each week or when only 20 mm were applied every 2 weeks. It would appear that, under intermediate drought-stress conditions, the genotypes that maintain a cooler canopy are able to produce higher pod yields. We consider that measurements of CCATD, when the rainfed crop is showing drought stress, could give us a useful indication of potential drought tolerance.

We also grew the ICRISAT Center Advanced Drought Resistant Groundnut Cultivar Trial at Sadore during the 1988 rainy season. Although this trial did not suffer any significant drought stress, ICGV 86973 gave a mean pod yield of 3.0 t ha^{-1} and ICGV 86630 gave a yield of 2.7 t ha^{-1}, significantly outyielding the local control cultivars TS 32-1 (1.98±0.16 t ha^{-1}) and 55-437 (1.80± 0.16 t ha^{-1}).

Plant Nutrition

Phosphorus

We compared rock phosphate from three sources: Parc-W rock phosphate (PRP), Tahoua rock phosphate (TRP), and partially acidulated rock phosphate (PARP), with single superphosphate (SSP) and triple superphosphate (TSP) at three levels (0, 20 and 40 kg ha^{-1} P_2O_5) on two groundnut genotypes, 55-437 and ICGS(E) 30, at Tara and Sadore, and 28-206 and ICGS(E) 30, at Bengou. At Sadore, we applied the treatments with or without carbofuran. As in 1987, increasing the rate of TRP or PRP phosphorus from 0 kg ha^{-1} to 40 kg P_2O_5 ha^{-1} did not increase pod or haulm yields. However, pod yield increased at Tara when we applied SSP, TSP, or PARP (Fig. 7). Haulm yield also increased in a similar way with the application of SSP, TSP, or PARP at Tara. We observed a similar trend at Sadore. At Bengou, there was no response to phosphorus application.

At Sadore, pod yields from carbofuran treated plots were higher (2.29 ± 0.04 t ha^{-1}) than from nontreated plots (1.47 ± 0.04 t ha^{-1}); haulm yields were also higher (2.53 t ha^{-1} in treated plots and 1.47 ± 0.06 t ha^{-1} in nontreated plots).

Cropping Systems

Intercropping Millet and Groundnut

We initiated intercropping studies to assess the tolerance of groundnut to interplant competition at Bengou and Sadore. We grew three genotypes (cv 55-437, TS 32-1, and ICGS(E) 11) at Sadore, and three [28-206, 47-16, and ICGS(E) 11] at Bengou, both as a sole crop and intercropped with millet cultivar CIVT grown at 1 m x 1 m, 1

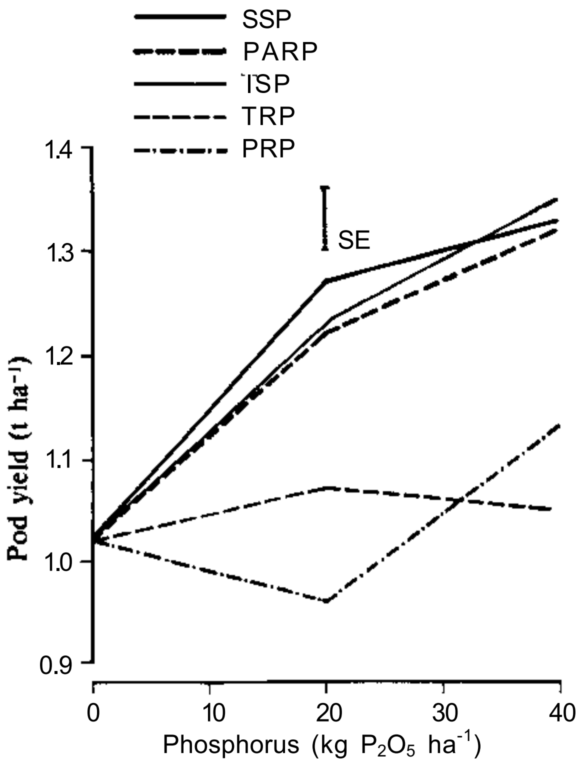


Figure 7. Effect of various sources of P and rates of application on pod yields of groundnut genotypes 55-437 and ICGS(E) 30 at Tara, Niger, rainy season 1988.

m x 2 m and 1m x 3m spacing. Groundnut was grown at 50 cm x 10 cm as a sole crop or between the millet rows when intercropped.

At Sadore, bivariate analysis of the groundnut/millet trial gave an average positive correlation between the yields of millet grain and groundnut pods, i.e., for higher groundnut pod yield, a higher millet grain yield is needed to achieve the same value (Fig. 8). Pod and haulm yields increased as the millet seed yield decreased with increasing spacing of millet. None of the intercrops outyielded sole millet or sole groundnut. There was no significant difference in the mean pod yields of the three groundnut cultivars under intercropping. TS 32-1 produced significantly more haulm (*P* <0.05) than cv 55—437 and genotype 1CGS(E) 11.

Biotic Stresses

Late and Early Leaf Spots

Development of infections. We studied the development of leaf spots on a susceptible cultivar 55-437, at Sadore, Bengou, and Maradi during the 1988 rainy season. At 40, 55, 70, 85, and 100 DAS, we collected 10 plants at random from each location and estimated the percentage of leaf area destroyed. We calculated the area under disease progress curve (AUDPC) for each location. Late leaf spot appeared very early in the season and progressed rapidly because of frequent and well-distributed rainfall, especially at Bengou, causing extensive damage to the foliage (Fig. 9). The AUDPC was high at all locations; Sadore (A = 2100), Bengou (A = 3907), and Maradi (A = 2168). We observed early leaf spot at all locations but it was not severe.

Yield losses. Five local genotypes and ICGS 11 (ICGV 87123) (Table 18) sprayed with either water (500 L ha^{-1}) or chlorothalonil solution (1.6 kg in 800 L water ha^{-1}) treatments at 30,45, 60, 75, and 90 DAS. Late leaf spot occurred in epiphytotic proportions at all locations. The proportions of the leaf area affected were high in the water-spray treatment at all locations. There were marked differences in pod yields between water-sprayed and fungicide-sprayed plots at all locations, especially at Sadore and Bengou. The percentage loss in pod yield attributable to leaf spots was very high at Sadore (mean 32%), Bengou (mean 38%), and Maradi (mean 20%). 28-206 gave the highest pod yields at Sadore, ICGV 87123 at Bengou, and 796 at Maradi, in both spray treatments (Table 18).

Screening for resistance to late leaf spot. We screened 217 breeding lines in replicated field trials for resistance to late leaf spot under natural epiphytotics at Bengou and identified several promising lines. The genotypes ICGVs 87185, 87156, 87183, 87160, 87172, and 87157 from the ICRISAT Center International Foliar Disease Resistance Nursery significantly outyielded local susceptible cultivars.

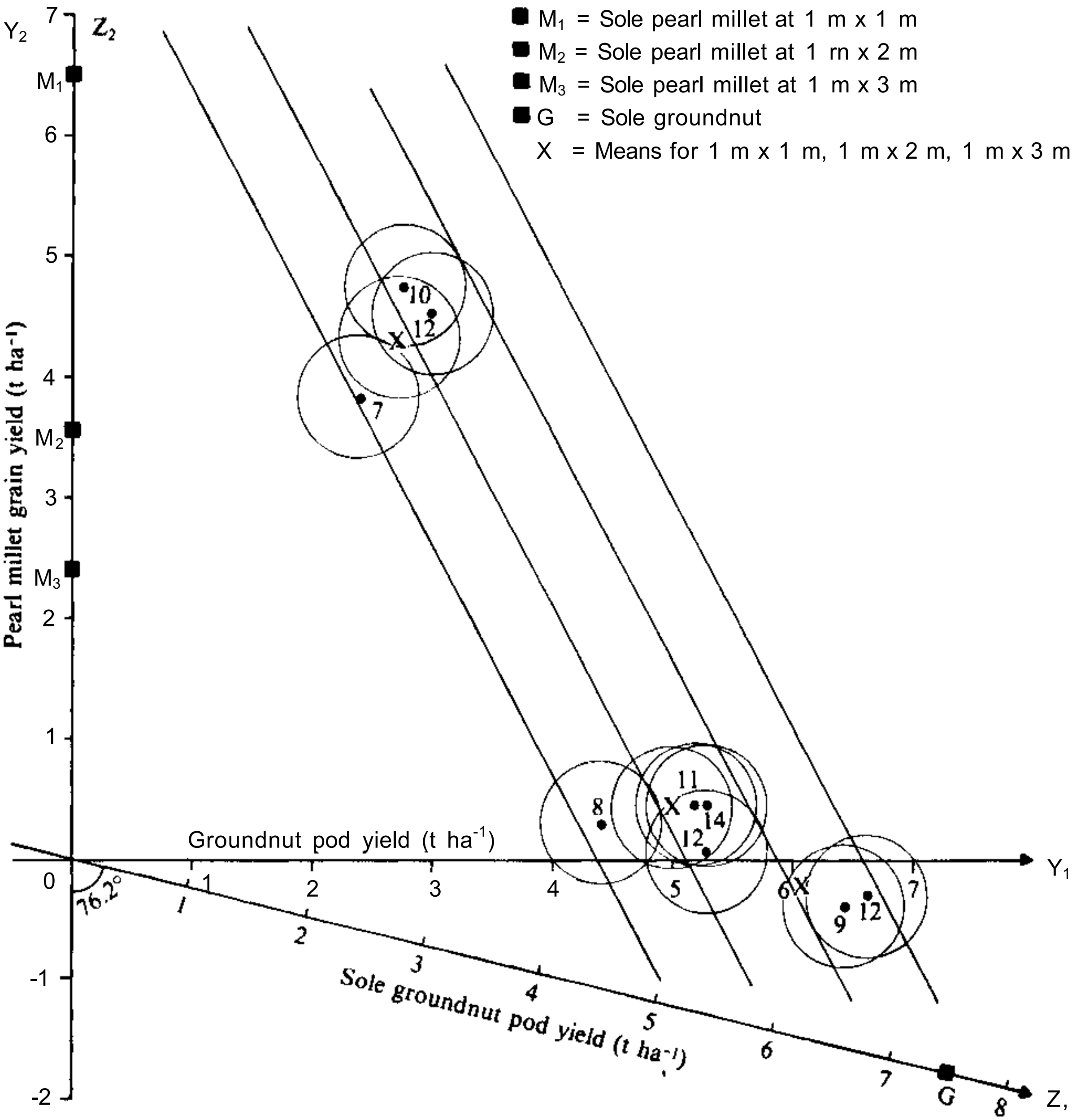


Figure 8. Bivariate graph showing the effects of millet / groundnut intercropping on transformed millet grain and groundnut pod yields at Sadore, Niger, rainy season 1988. Circles represent standard errors.

GRV Disease

The 1988 epidemic of predominantly green GRV was severe in all major groundnut-growing areas of the Department of Maradi, Niger, leading to almost total destruction of groundnut crops in many farmers'fields. This is the second consecutive GRV-epidemic year in this area, and may seriously effect the level of future groundnut cultivation.

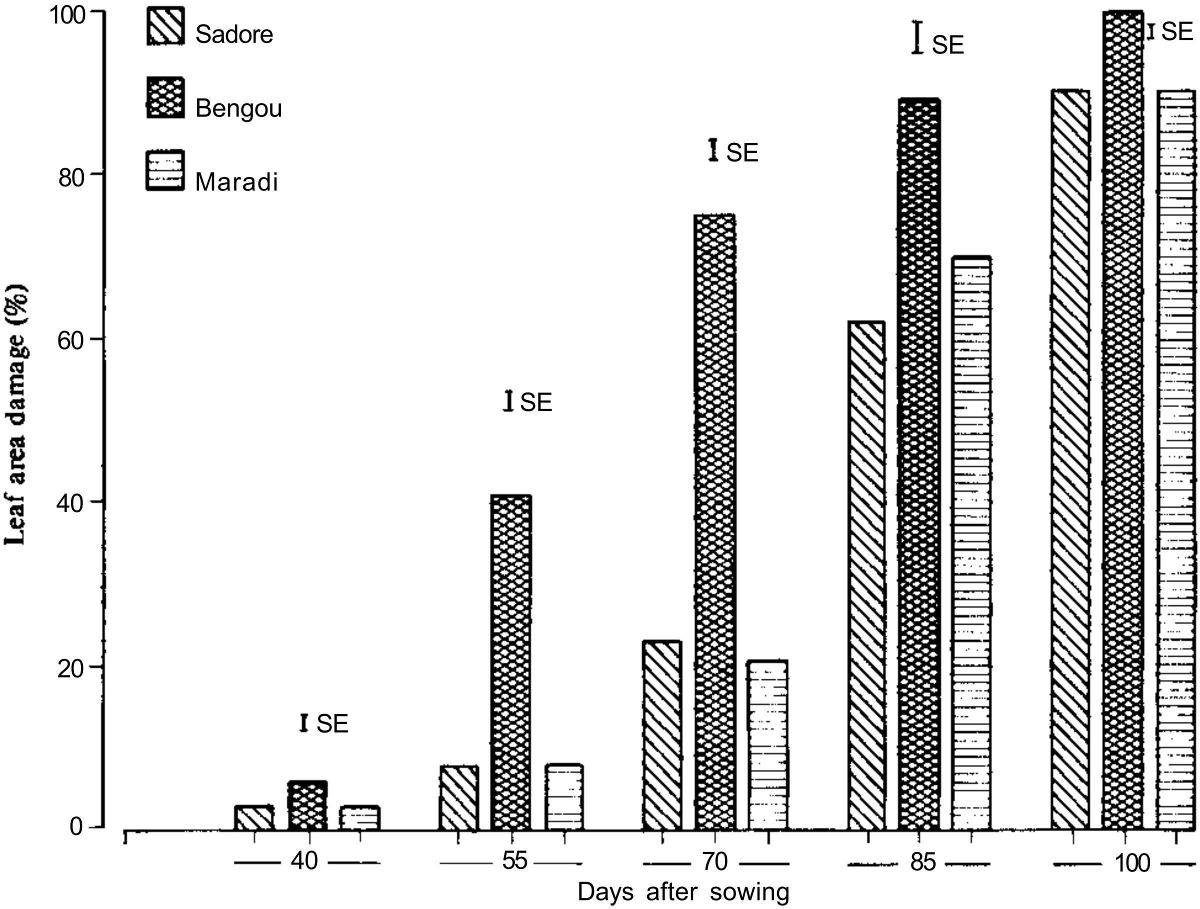


Figure 9. Development of late leaf spots (Phaeoisariopsis personata) *on a susceptible groundnut cultivar, 55-437, at three locations in Niger, rainy season 1988.*

Screening for resistance. We evaluated GRV-resistant varieties KH 241 D and KH 149 A, short-cycle Spanish types, from Burkina Faso, and RG 1, a medium-cycle Virginia type from Malawi for GRV resistance in Maradi. Disease incidence in a GRV-susceptible cultivar 55-437 was around 75%. The cultivars KH 241 D and KH 149 A also showed high GRV incidence (around 50%) but there was no evidence of the disease in RG 1.

We also evaluated two high-yielding GRV-resistant cultivars (M 25.68 and M 554.76) recently released for cultivation in Nigeria and five advanced-generation breeding lines (M 516.791, M 578.79, MDR-8-19, M 576.80 1, and M 576.79) from Samaru, Nigeria, in a field-screening trial in Bagauda, Kano, Nigeria. The GRV-resistant material had a low (<1%) infestation when compared with that in the susceptible controls (50-60%). These are progenies of crosses between GRV-resistant (RMP 91) and GRV-susceptible parents, and are long-cycle (130 days) Virginia bunch types.

The Aflatoxin Problem

Aflatoxin contamination. We grew seeds of eight genotypes with resistance to IVSCAF with two susceptible genotypes at Bengou (rainfed),

Table 18. Effect of fungicide spray on leaf-spot severity and pod yields of six groundnut cultivars at three locations in Niger, rainy season 1988[1].

	Sadore				Bengou				Maradi			
	Leaf-area damage (%)[2]		Pod yield ($t\ ha^{-1}$)		Leaf-area damage (%)		Pod yield ($t\ ha^{-1}$)		Leaf-area damage (%)		Pod yield ($t\ ha^{-1}$)	
Entry	WS[3]	FS[3]	WS	FS	WS	FS	WS	FS	WS	FS	WS	FS
55-437	100	10	2.65	3.51	100	12	1.98	3.61	98	11	0.97	1.16
TS 32-1	98	9	2.43	3.92	100	10	2.57	3.88	95	9	1.06	1.34
796	96	10	2.59	4.01	100	9	1.48	3.45	95	9	1.39	1.90
ICGS 11 (ICGV 87123)	89	8	2.25	3.59	98	11	3.52	5.59	91	9	0.94	1.15
28-206	81	8	3.02	4.03	90	11	2.48	3.53	85	14	0.76	0.90
47-16	88	8	2.59	3.78	95	13	2.21	3.03	88	7	0.79	0.94
SE[4]	±1.5		±0.19		±1.5		±0.22		±1.8		±0.55	
Mean	92	9	2.59	3.81	97	11	2.37	3.85	92	10	0.99	1.23
SE[4]	±1.0		±0.07		±0.7		±0.09		±0.7		±0.12	
CV (%)	6		12		5		14		7		11	

1. Split-plot design with spray treatments as main plots, and cultivars as subplots with four replications; main plot size 60 m^2 and subplot size 10 m^2.
2. Percentage leaf-area damage estimated at maturity. Mean of five plants per replication.
3. Water spray (WS) and fungicide spray (PS) at 15-day intervals. Five sprays had been given.
4. Standard errors of the percentage leaf-area damage data are not applicable to values of 100%.

Maradi (rainfed), and Sadore (rainfed and irrigated) during the 1987 rainy season (ICRISAT Annual Report 1987, p. 261), and collected 10 groundnut seed samples from local markets in Niamey. We analyzed these for aflatoxin content at Texas A & M University, in cooperation with the Peanut Collaborative Research Support Program (CRSP). All samples from Bengou, Sadore, and local markets were free from anatoxins. However, the samples from Maradi were highly contaminated (primarily aflatoxin B_1) (425 $\mu g\ kg^{-1}$ to 22 364 $\mu g\ kg^{-1}$). The groundnut crop in Maradi suffered from severe drought stress during pod maturity and a high percentage of seeds were moldy at harvest. Seed of cv 55-437 and cv J 11 contained small amounts of aflatoxins.

Agronomic evaluation of *A. flavus* resistant genotypes. We measured the pod yields of several IVSCAF-resistant groundnut genotypes at Sadore. ICGVs 87088, 87118, 87078, 87104, 86168, and 87087 significantly outyielded the local control cultivars.

Crop-growth Variability

Variation in crop growth (Fig. 10) is one of the major limiting factors for groundnut production in the Sahel.

Plant Parasitic Nematodes

Distribution of nematodes in soil profiles. We investigated the occurrence and distribution of plant-parasitic nematodes at various soil depths. Plant-parasitic nematodes were more abundant in soils at depths of 11 cm to 23 cm [231 nema-

Figure 10. Groundnut field showing crop variability, Sadore, Niger, rainy season 1988.

todes (100 cm^3 soil)$^{-1}$] than at 0 cm to 11 cm [91 nematodes (100 cm^3 soil)$^{-1}$], 23 cm to 34 cm [63 nematodes (100 cm^3 soil)$^{-1}$], and 34 cm to 46 cm [34 nematodes (100 cm^3 soil)$^{-1}$] depths.

Survey of nematodes. We collected soil and root samples from various fields at Sadore showing severe variation in crop growth and extracted the nematodes (see Nematode Problems discussed earlier in this section).

Analysis of soil and root samples of other crops such as pearl millet, cowpea, and bambara groundnut at Sadore showed that these soils also contained high populations of *Scutellonema clathricaudatum, Telotylenchus indicus,* and *Xiphenema attorodorum.* The population density of these species was much higher in roots than in the soil.

Management of Crop-growth Variability

Effect of carbofuran and farmyard manure (FYM). We investigated the effect of treating the soil with 3, 6, 9, 12, and 15 kg a.i. ha^{-1} of carbofuran on crop-growth variability at Sadore. Nematode populations in the soil and roots were greatly reduced at all doses. Plant height and yields of pods and haulms were highest and the variation in crop growth was least with 9 kg a.i. ha^{-1}. Variation in crop growth was greatly reduced and plants were vigorous, whereas, in control plots, plants were severely stunted and chlorotic. Higher doses (12 and 15 kg a.i. ha^{-1}) were detrimental to plant growth and yield.

We also found that soil treatment with a mixture of carbofuran (10 kg a.i. ha^{-1}) and FYM (10 t ha^{-1}) was effective in reducing the variation in crop growth (rainfed and with irrigation) and increasing the yield (Table 19, Fig. 10). Soil treatment with carbofuran alone or in combination with FYM, greatly reduced populations of plant-parasitic nematodes in soil (Table 19). Nematode populations in roots were also reduced in carbofuran-treated plots.

We sowed cv 55-437 in the 1988 off-season in the plots at Sadore that had been treated with carbofuran and/or FYM during the 1987 rainy season. Plants were vigorous and healthy in carbofuran and FYM-treated plots and gave the highest pod yields.

Effects of pesticides on crop growth variability. We evaluated four pesticides, dibromochloropropane (DBCP), aldicarb, carbofuran, and isazophos (rates and results in Table 20) as soil treatments for reducing the variability in crop growth at Sadore. DBCP was most effective in reducing the variation in crop growth and increasing the yield (Table 20). Plants in nontreated plots were severely stunted and chlorotic with severely necrosed root systems. The populations of plant-parasitic nematodes in soil and roots were greatly reduced in all pesticide-treated plots.

We sowed cv 55-437 in the 1988 dry season in plots at Sadore that had been treated with aldicarb, DBCP, carbofuran, or dazomet during the 1987 rainy season. There was a marked residual effect, plants being more vigorous in the treated plots than in control areas where the yields were low (0.37 t ha^{-1} of pods, 1.06 t ha^{-1} of haulm). The pod yields (t ha^{-1}) in plots with pesticide residues were: DBCP 0.83, dazomet 0.71, carbofuran 0.65, and aldicarb 0.61. Haulm yields were in the range of 1.57-2.31 t ha^{-1}.

Effect of foliar application of oxamyl. Oxamyl, a systemic nematicide, was sprayed on plots at two concentrations, 5 L and 10 L in 500 L of water ha^{-1}, 20, 35, and 50 DAS. Control plots were sprayed with water (500 L ha^{-1}). Plant height was significantly greater in oxamyl-treated plots (33±1 cm), especially at the higher rate, than in the nontreated control plots (15±1 cm). Pod yield was significantly higher in oxamyl-treated plots (1.31 ±0.07t ha^{-1}) than in the control plots (0.40±0.07 t ha^{-1}). Haulm yields were also

Table 19. Effect of carbofuran and farmyard manure on populations of plant-parasitic nematodes in soil, plant height, and pod yield of groundnut (cv 55-437) under irrigated and rainfed conditions at Sadore, Niger, rainy season 1988[1].

	Nematodes in 100 cm^3 of soil[2]		Plant height[3] (cm)		Pod yield (t ha^{-1})	
Treatment[4]	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Carbofuran + farmyard manure	25 (4.8)5	40 (6.3)	59	62	3.51	4.88
Carbofuran	38 (5.8)	58 (7.6)	41	44	2.13	3.67
Farmyard manure	135 (11.1)	93 (9,6)	20	48	0.94	3.46
Control	160(12.5)	130(11.3)	14	22	0.73	2.61
SE	(±1.1)	(±0.5)	±4	±2	±0.21	±0.17
CV (%)	(26)	(12)	23	11	23	9

1. Latin square design with four replications; plot size 18.45 m^2.
2. *Scutellonema clathrkaudatum, Telotylenchus indicus,* and *Xiphinema attorodorum.*
3. Mean of 10 plants per replication.
4. Carbofuran (10 kg a.i. ha^{-1}) and farmyard manure (10 t ha^{-1}) were applied to the field plots just before sowing.
5. Square-root transformed data are shown in parentheses.

Table 20. Effect of four pesticides on populations of plant-parasitic nematodes in soil, plant height and pod yield of groundnut (cv 55-437) under irrigated and rainfed conditions at Sadore, Niger, rainy season 1988[1].

	Nematodes in 100 cm^3 of soil[2]		Plant height[3] (cm)		Pod yield (t ha^{-1})	
Treatment[4]	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Dibromochloropropane	0	95 (9.7)[5]	70	34	5.16	3.50
Aldicarb	90 (9.3)	63 (7.8)	53	37	4.12	3.42
Carbofuran	58 (6.7)	53 (7.2)	48	36	4.31	3.38
Isazophos	55 (7.0)	53 (6.9)	36	32	3.60	2.98
Control	220 (14.7)	135(11.6)	22	20	2.01	2.27
SE	(±1.0)	(±0.7)	±4	±3	±0.30	±0.18
CV (%)	(25)	(16)	18	17	16	12

1. Randomized-block design with four replications; plot size 6.15 m^2 under irrigation and 10.25 m^2 under rainfed condition.
2. *Scutellonema clathricaudatum, Telotylenchus indicus,* and *Xiphinema attorodorum.*
3. Mean of 10 plants per replication.
4. Dibromochloropropane (20 L in 85 L of water ha^{-1}), aldicarb (4 kg a.i. ha^{-1}), carbofuran (6 kg a.i. ha^{-1}), and isazophos (6 kg a.i. ha^{-1}) were applied to the field plots on the day of sowing.
5. Square-root transformed data are shown in parentheses.

markedly higher in oxamyl-treated plots (1.68 ± 0.10 t ha^{-1}) than in the control plots (0.49 ±0.10 t ha^{-1}).

Insect Pests

During the 1988 growing season, we conducted two millipede- and termite-control trials at Bengou. We designed the first to evaluate carbofuran incorporated at 5 kg and 10 kg a.i. ha^{-1} and chlorpyrifos incorporated at 10 kg ha^{-1}.

These extremely high rates failed to give any significant differences in pest populations or in yields.

In the second trial, we monitored populations of various groundnut pests throughout the growing season. The seasonal mean density of millipede density was 19.9 m^{-2} with a maximum of 30.0 m^{-2} on 14 July. This compares with a seasonal mean of 27.0 m^{-2} in 1987 with a maximum of 56.0 nr^2 found on 28 August. Termite scarification was less common in 1988 than in 1987. Other pest populations remained below damaging levels throughout the growing season.

Plant Improvement

Cultivar Trials

Advanced Groundnut Cultivar Trial. We grew this trial at three sites during the 1988 rainy season; at the INRAN station at Bengou, the INRAN station at Maradi, and two trials at ISC Sadore, with and without preplanting application of carbofuran at 10 kg a.i. ha^{-1}. The Indian cultivar JL 24 gave the highest pod yield at Bengou and Maradi (Table 21). ICGV 87141 had the highest pod yields in both trials at Sadore and had a very high shelling percentage and large seeds. There was a severe outbreak of GRV at Maradi, which severely reduced pod yields particularly of the later-maturing genotypes (e.g., 28-206) and almost destroyed ICGV 86529, which emerged late because of seed dormancy. ICGV-SM 83005, from the SADCC/ICRISAT Groundnut Improvement Program in Malawi, again yielded well at Bengou and Sadore.

Intermediate Groundnut Cultivar Trial. We grew this trial during the 1988 rainy season at the

Table 21. Performance of the Advanced Groundnut Cultivar Trial, Sadore, Niger, rainy season 1987[1].

	Yields (t ha^{-1})										
	INRAN, Bengou		INRAN, Maradi		ISC, Sadore (without carbofuran)		ISC, Sadore' (with carbofuran)				
Entry	Haulm yield	Pod yield	Haulm yield	Pod yield	Haulm yield	Pod yield	Haulm yield	Pod yield	Time to maturity (days)	Shelling %	100-seed mass(g)
ICGS 11 (ICGV 87123)	2.60	2.29	2.91	1.16	1.32	1.87	1.50	3.12	112	67	52
ICGV 87132	2.84	2.33	2.30	0.87	1.20	1.67	1.36	2.92	112	66	56
ICGV 87141	3.08	2.26	3.31	0.92	1.43	2.21	1.90	3.58	112	74	68
ICGV 87144	3.25	2.01	3.29	0.93	1.47	1.83	1.51	3.01	112	69	62
ICGV 86047	3.42	1.64	2.85	1.10	1.64	1.61	2.37	2.25	92	66	49
ICGV 86063	3.68	1.94	3.01	1.19	1.36	1.41	1.97	2.28	94	68	38
ICGV 86529	2.34	1.93	1.95	0.12	1.46	1.98	1.91	2.87	112	66	65
ICGV 86024	3.57	2.05	2.23	0.98	1.24	1.65	2.16	3.11	112	64	59
ICGV-SM 83005	2.95	2.30	3.20	0.60	1.41	1.86	2.24	3.42	112	70	63
ICGMS 38	3.79	2.00	3.45	0.77	1.67	1.75	2.08	3.11	112	65	63
Controls											
J 11	4.35	2.05	3.59	0.94	1.83	1.74	2.72	2.39	93	64	40
JL 24	3.82	2.47	3.42	1.72	2.02	1.66	2.52	2.49	96	67	52
55-437	3.92	1.77	2.68	0.77	1.41	1.51	1.90	1.92	92	68	36
28-206	4.70	2.04	3.49	0.50	1.76	1.60	2.98	3.47	121	71	52
TS 32-1	4.00	2.14	3.15	0.95	1.98	1.90	2.12	2.77	95	67	48
W ß-9	3.05	1.90	3.17	1.32	1.42	1.77	2.25	2.75	93	67	41
SE	±0.21	±0.09	±0.21	±0.09	±0.12	±0.17	±0.18	±0.17	±1	±2	±2
Trial mean (16 entries)	3.46	2.07	3.00	0.93	1.54	1.75	2.09	2.84	105	67	53
CV (%)	14	10	16	23	18	22	21				

1. 4 x 4 lattice square with 5 replicates, plot size 8 m^2.

INRAN station at Bengou and two trials at ISC, Sadore, with and without a preplanting application of carbofuran at 10 kg a.i. ha^{-1}. ICGV-SM 83708, from the SADCC-Malawi program, and the confectionery variety, ICGV 86028, were noteworthy.

Preliminary Groundnut Cultivar Trial. We tested the performance of 201 lines selected in 1987 from a sample of the world germplasm screen. There were six control cultivars each repeated four times in a 15 x 15 lattice design with two replicates. We ran the trial at Sadore, and at the INRAN station at Bengou. At Sadore, ICG 2371 from Tanzania (3.55±0.27 t ha^{-1}), ICG 1011 from India (3.23±0.27 t ha^{-1}), and ICG 1586 from Mozambique (3.22±0.27 t ha^{-1}) significantly outyielded the best control TS 32-1 (2.58 ± 0.13 t ha^{-1}). At Bengou, none of the test lines gave significantly higher pod yields than the best control, again TS 32-1.

Groundnut Cultivar Trials from other ICRISAT Programs. The International Confectionery Groundnut Cultivar Trial from ICRISAT Center was grown at Bengou. The best three test varieties were: ICG V 86028 (2.44±0.18 t ha^{-1}), 1CGV 86024 (2.23±0.18 t ha^{-1}), and ICGV 86548 (2.22±0.18 t ha^{-1}).

In the Southern Africa Regional Spanish Cultivar Trial at Sadore, ICGV-SM 85038 gave a significantly higher pod yield (3.507 ±0.15 t ha^{-1}) than the best control, 55-437 (2.58 ± 0.15 t ha^{-1}), and significantly outyielded all other test lines. This line also gave the highest pod yield in the same trial at Chitedze, Malawi, in the 1986/87 season. In the same trial at Bengou, ICGV-SM 83005 gave the highest pod yield, repeating its performance there in the 1987 season. In the Southern Africa Regional Virginia Groundnut Cultivar Trial, ICGV-SM 83708 gave the highest pod yield. This line also performed well at Bengou in the 1987 rainy season and was one of the outstanding lines in the 1988 intermediate groundnut cultivar trial at Sadore and Bengou.

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RESOURCE MANAGEMENT

Contents

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RESOURCE MANAGEMENT

Interpreting the word in its widest sense, the "resources" of the semi-arid tropics (SAT) have been a major focus of ICRISAT's research since the Institute began and efforts to improve their management are now concentrated in the activities of the Resource Management Program. Formed in 1986, the Program operates both at Patancheru, India, and at Niamey, West Africa. This report integrates complementary activities of the two groups and presents them according to some of the Program's dominant research themes.

First, we observe, measure, and analyze the resources of the SAT: physical, biological, and institutional. A few examples from a range of diverse activities are grouped under the heading "Characterizing Resources". This activity is an essential basis to develop technology that will make new resources available to farmers or help them use existing resources more effectively. This year, the process is illustrated mainly by work on improving the physical properties and nutrient status of soil.

The testing of new technology on an operational scale is represented by a report on a pearl millet/cowpea intercropping system, first demonstrated at the ICRISAT Sahelian Center (ISC) as operational scale research (OPSCAR) and now being adopted by several national research services in the West African region.

The Program regards "modeling" as an essential step towards making sound generalizations about the environment or about the management of environmental resources, given sets of observations that are inevitably very limited both in space and time. Illustrations this year for pearl millet and sorghum presage our plans to extend existing models of crop growth to make them deal more realistically with the behavior of root systems and with the uptake of nutrients.

Finally, we have brought together under the heading "Assessing Sustainability", lines of work that describe part of our effort to increase, stabilize, and diversify crop production without degrading the environment. The topics chosen to illustrate this point are far from exclusive: the whole Program has and must always retain a strong sustainability bias because the concept is central to all attempts to manage environmental resources wisely in the interests of the farmers of today and of their children, some of whom will be farming well into the 21st century.

Characterizing Resources

Production Systems

Crop Enterprises in West Africa's SAT

A 380-page report, presenting baseline information on the major crop enterprises in three agroclimatic zones of Burkina Faso, was completed in 1988. The three regions represent broad portions of West Africa's SAT. The report contains information on costs and returns by crop enterprise, on the gender of the decision maker, on the location of the plot in relation to toposequence and domicile, on the timing of operations, on cultural practices, and on soil fertility management. Separate budgets are presented for traction and manual plots within the same crop and zone. Some of the major findings follow.

Crop diversification. Crop diversification was least in the Sahel and was positively associated with production potential across the zones. Similar to India's SAT, a harsh environment severely limits the number and types of crops that can be grown economically. Because drought is the major source of risk for all rainfed crops in the Sahel, crop diversification to reduce the chance of crop failure is less effective in the Sahel than in the higher-rainfall Sudanian and Guinean zones.

Toposequence. Plateaus are extensively cultivated only in the northern Guinean zone where the production potential is good and where rainfall is sufficient to exploit shallow soils. In both the Sahel and Sudanian Savanna zones, farmers avoid plateau areas that account for less than 3% of the total cultivated area.

Sowing dates. For most crops, the date of first sowing extends over several weeks. For sorghum and pearl millet, sowing takes over 40 days in the Sahel and 80 days in the northern Guinean Savanna. These long periods reflect the large areas sown, the time-consuming nature of hand-sowing methods, and the irregular distribution of early-season rainfall.

Animal traction and sowing date interactions. Soil preparation by animal traction is associated with delayed sowing, which can significantly reduce the yield potential of photoperiod-sensitive varieties. For all zones and for most crops, soil is prepared after the mean sowing date. This anomalous result is because traction is most often used to remove weeds before sowing on plots that are sown late. For pearl millet and sorghum combined, the average date on which soil is prepared with traction is nearly 18 days after the mean sowing date of manual plots in the Sahel, 5 days later in the Sudanian zone, and more than 22 days later in the northern Guinean zone.

Women's role in crop management. Although in parts of Africa women manage the bulk of crop production, this is not true in the study regions. Only in the Sudan Savanna does the share of women's plots in total cultivated area exceed 10%. However, in several speciality crops grown as cash crops or as plants producing sauce for domestic consumption, management by women is dominant. In both the Sahel and the Sudan Savanna, for example, more than 50% of the area sown to groundnut, earthpea, and okra is managed by women. The cereal fonio in the Sahel and eggplant in the Sudan Savanna are also primarily cultivated by women.

Labor use. Household members comprise the majority of farm labor in all zones. The use of nonhousehold labor is highest in the northern Guinean zone where it represents 24% of total labor. Similar amounts of labor were used to grow legume intercrops with major cereals and to produce sole-cropped cereals.

Soil fertility management. For most crops, farmers practice a rotation strategy in manuring plots. Manure was applied during consecutive years on less than 20% of total cultivated area in the three regions. Generally, less than half of the sorghum and pearl millet area received manure in any given year except for white sorghum in the Sudanian zone. Grain legumes such as groundnut and earthpea were seldom manured and attempts to maintain soil fertility focused on fallowing. Except in the Sahel, substantially more organic matter is applied where traction tillage is used. This reflects the combined effects of access to manure for households that possess traction animals and the lower cost of transporting manure with draft power. The frequency of fallowing is consistently less on plots that use traction than on those cultivated manually. Longer periods of continuous cultivation on plots with animal traction require larger soil amendments to arrest the decline in soil fertility.

Profitability of different crop enterprises. Exceedingly high returns were evident for a limited number of speciality crops. Constraints to their expansion cannot be deduced solely from the analysis of enterprise budgets. It is believed, however, that limiting factors for specific crops include appropriate land types (rice and maize), limited household and market demand (fonio, sweet potatoes, yam, okra, and red sorghum) and household objectives of achieving or approaching domestic food self sufficiency (cotton).

Climate

Frequency of Dry Spells in West Africa

Two major symposia in 1973 and 1987 on the problems of drought in West Africa highlighted the need for analysis of historical weather data to provide the length of dry spells, their frequencies and probabilities.

We analyzed long-term records of daily rainfall for 150 stations in Burkina Faso, Mali, Niger, and Senegal for length and frequency of dry spells. The analysis is intended to aid crop planning in West Africa, so we defined onset of rains for each year as the sowing date and examined the number of days until rainfall exceeded a threshold value (length of dry spell) and the frequencies of these dry spells.

Table 1 gives an example for Niamey, Niger, of the length of dry spells at 90, 50, and 10% probability levels for three rainfall thresholds. For example, at 50 days after sowing (DAS) for the 10-mm rainfall threshold, 50% of the dry spells at Niamey will end after 3.9 days while 90% of the dry spells will end after 10.3 days. Dry spells between 30 DAS and 70 DAS are shorter than at other times. This is most evident at the 90% probability level. In terms of crop phenology, dry spells between emergence and panicle initiation (up to 20 DAS) last longer than those between panicle initiation and flowering (20-60 DAS). The length of dry spells increases with time after 90 DAS.

To present the general pattern of the dry spell frequencies in West Africa, we computed the average frequency of dry spells of <5 days, 10-15 days, and >20 days with a rainfall threshold of 10 mm. A map of the average frequency of dry spells of 10-15 days during the growing season (Fig. 1) shows a pronounced north-south gradient. The relationship between mean annual rainfall and the average frequency for dry spell ranges shows distinct patterns (Fig. 2). Frequencies of the lowest dry-spell range of <5 days

Table 1. Length of dry spell (days) for indicated rainfall thresholds (1 mm, 10 mm, and 25 mm) at three probability levels (%) for Niamey, Niger.

Days after sowing (DAS)	Mean rainfall[1] (mm)	1 mm			10 mm			25 mm		
		90%	50%	10%	90%	50%	10%	90%	50%	10%
10	37.9	4.8	1.4	0.2	18.5	5.6	0.8	30.3	11.5	2.8
20	35.3	7.4	2.2	0.3	18.5	7.0	1.7	31.3	13.5	4.3
30	36.3	5.9	1.8	0.3	15.0	5.7	1.4	27.8	12.0	3.8
40	46.2	5.0	1.5	0.2	11.1	4.2	1.0	24.7	9.4	2.3
50	48.7	5.1	1.5	0.2	10.3	3.9	1.0	25.6	9.7	2.4
60	48.7	5.6	1.7	0.3	10.3	3.1	0.5	25.9	9.8	2.4
70	63.1	5.1	1.5	0.2	10.5	1.8	0.2	25.2	7.6	1.1
80	51.3	13.6	2.3	0.1	16.2	2.7	0.1	32.2	12.2	3.0
90	39.3	13.0	2.2	0.1	24.8	7.5	1.1	39.5	18.6	6.9
100	33.3	19.1	3.2	0.1	31.3	9.4	1.4	39.5	19.9	8.2
110	22.0	20.6	3.5	0.2	33.9	12.9	3.1	40.8	21.6	9.6
120	12.9	30.1	9.1	1.4	38.6	18.2	6.7	39.5	25.1	15.0
130	8.6	32.6	12.4	3.0	39.6	22.5	11.2	40.7	27.7	17.8
140	2.8	41.1	20.8	8.5	41.6	27.4	18.6	41.6	27.4	18.6

1. Rainfall was totalled for consecutive 10-day periods from the predicted date of sowing for each year and averaged over all the years.

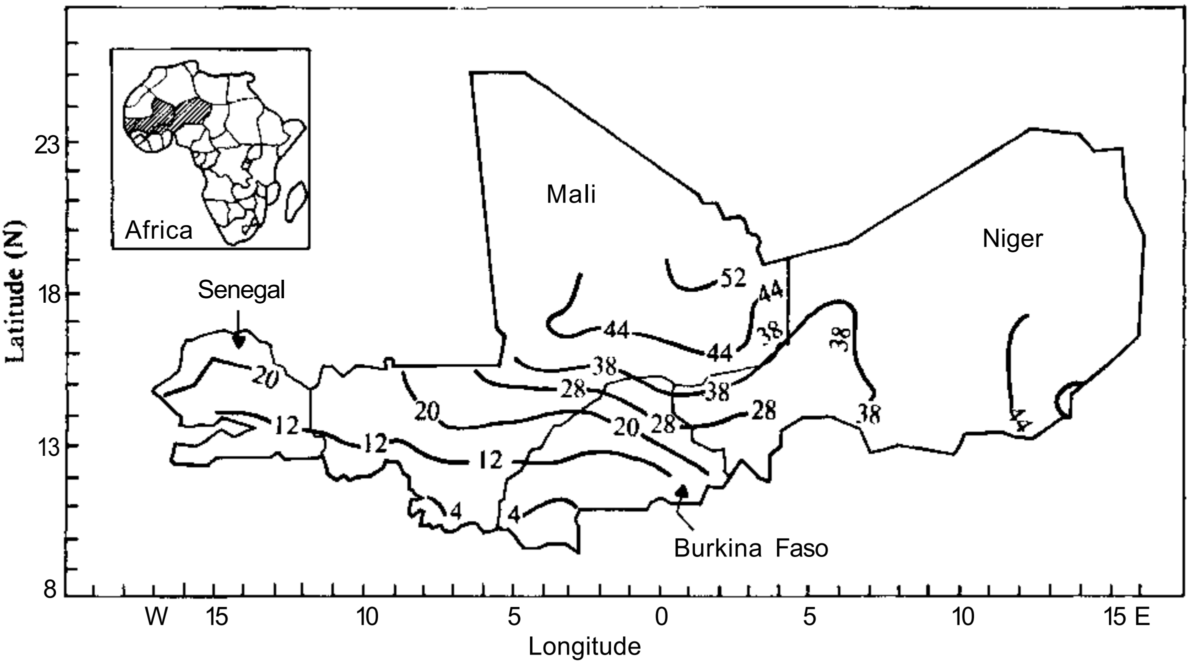

Figure 1. A verage frequency (%) of 10-15-day dry spells during (he growing season in selected countries of West Africa.

increase asymptotically with increasing annual rainfall (Fig. 2a). For the intermediate range of 10-15 days, frequencies are low (3-12%) and change little as annual rainfall increases (Fig. 2b). With dry spells exceeding 20 days (Fig. 2c), frequencies decrease sharply with increasing mean annual rainfall. The relationships in Figure 2 are well defined by the fitted equations and permit the prediction of the frequency of spells from annual rainfall totals. The relationships will be valid only in locations with a rainfall-distribution pattern similar to that of Niamey.

Storm Characteristics and the Spatial Variability of Rainfall

The spatial variability of rainfall using a systematic network of rain gauges at ISC has been reported (ICRISAT Annual Report 1987, p. 287). In view of the variability in the isohyetal patterns for individual rainstorms, we analyzed the influence of storm characteristics (volume, duration, intensity, direction, and the time of the year) on the spatial variability of rain. We computed correlation coefficients relating 17 rain gauges located over ISC with the rain gauge situated at the meteorological observatory in the center of the station. We compared effects of different storm characteristics to the decay of the correlation coefficient with distance.

Storm volume showed a large influence on the correlation decay with distance (Fig. 3). The reduction in the correlation coefficients with rain gauges located farther away from the meteorological observatory was least for the smallest storm volumes (<10 mm). Storm duration, storm intensity, and time of the year had little effect on the correlation decay and virtually all correlation coefficients were greater than 0.9.

In general, correlations in the west-east and southwest-northeast directions were higher than those in the north-south and northwest-southeast directions. This suggests that a higher sampling density should be maintained in the north-south and northwest-southeast directions to reduce the

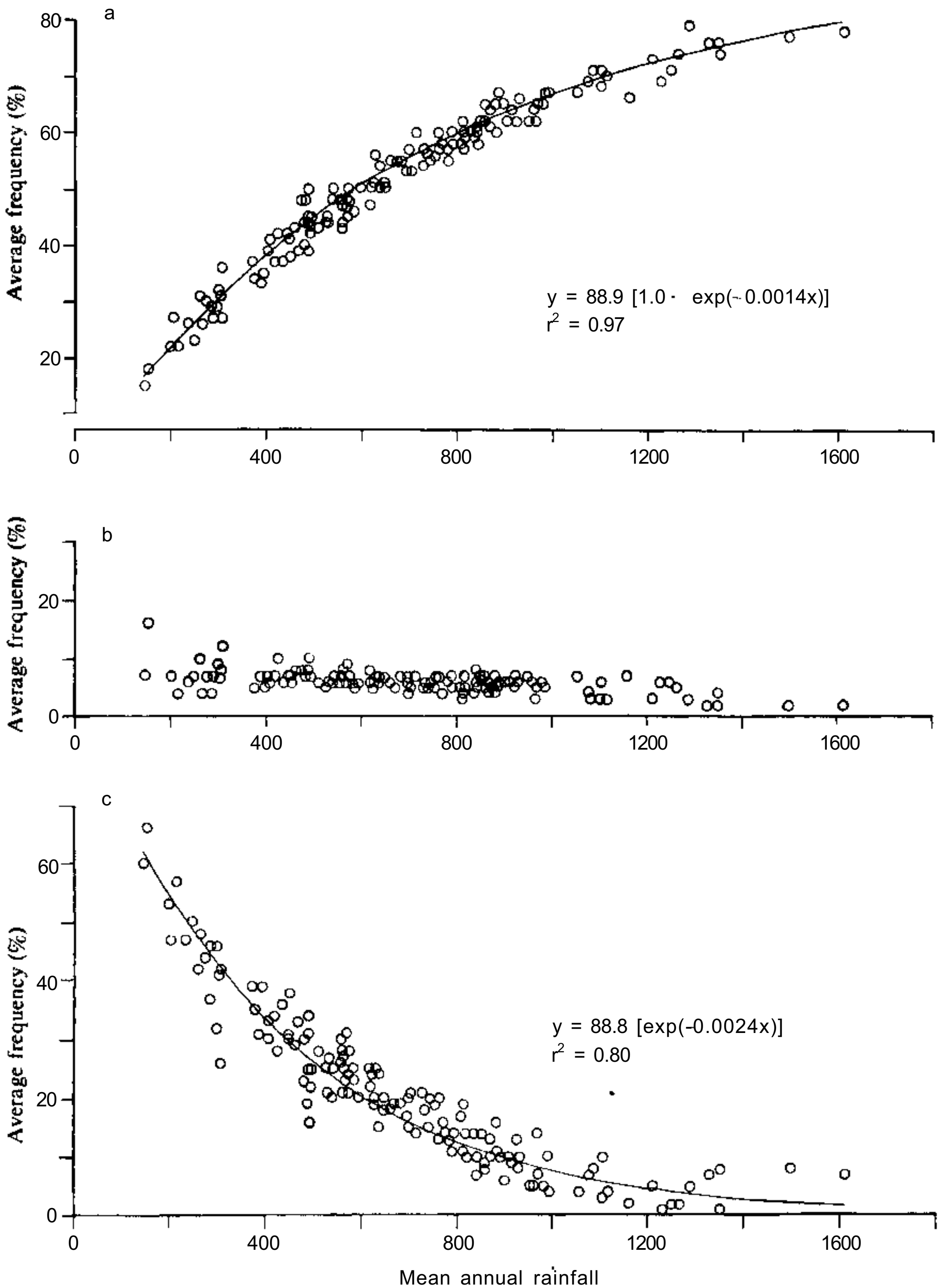

Figure 2. Relationship between mean annual rainfall and the average frequency for dry spell ranges of (a) <5 days, (b) 10-15 days, and (c) >20 days for locations in West Africa.

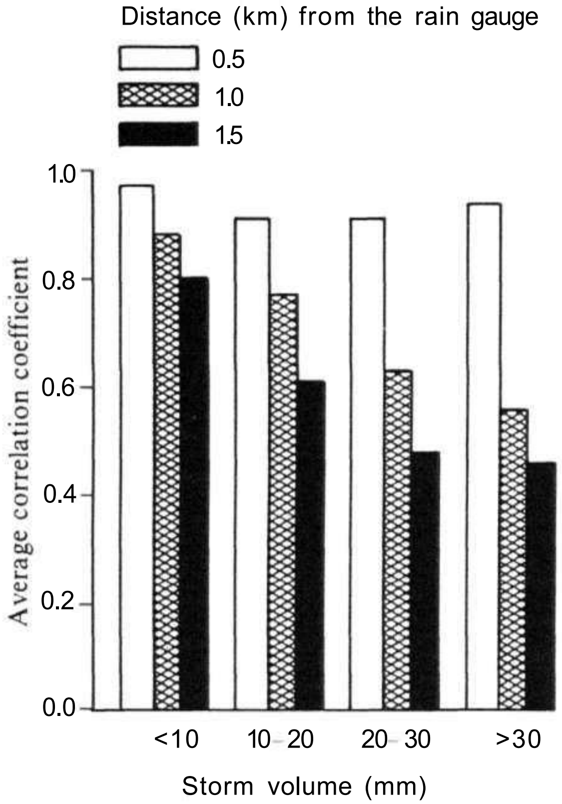

Figure 3. Effect of storm volume on the variation of the correlation coefficients of rain gauges located at different distances with the rain gauge located at the meteorological observatory, ISC, Sadore, Niger.

measurement error in isohyetal storm patterns.

We computed the spatial relative variability (V) for each storm as, V = 100 (S/M), where M is the network mean rainfall and S is the average deviation from the mean. The relationship between spatial relative variability and network average rainfall (Fig. 4) shows that with larger storm volumes, the network lowered the spatial relative variability to about 10%.

Spatial patterns of rainfall in semi-arid areas are not easily defined. There was no discernible pattern among the rain gauges for different storms. To obtain an accurate spatial average of rainfall on large experimental stations in the SAT, it is necessary to install gauges to supplement information from the meteorological station.

Soil

Phosphorus (P) in Vertisols

Crops on Indian Vertisols commonly respond less to fertilizer-P than those on Alfisols. This difference has been attributed to a large amount of added P being fixed by Vertisols, which makes it unavailable to plants. However, we showed earlier at ICRISAT, (ICRISAT Annual Report 1984, p. 257) that the P fixation by a Vertisol was not much greater than that by an adjacent Alfisol. To further investigate the availability of P to plants in these two benchmark soils, we measured adsorption and desorption using ^{32}P to discriminate between the P already in the soil and that added. The research was carried out in collaboration with the University of Reading, UK.

We measured the amounts of exchangeable, nonexchangeable, and total adsorbed P simul-

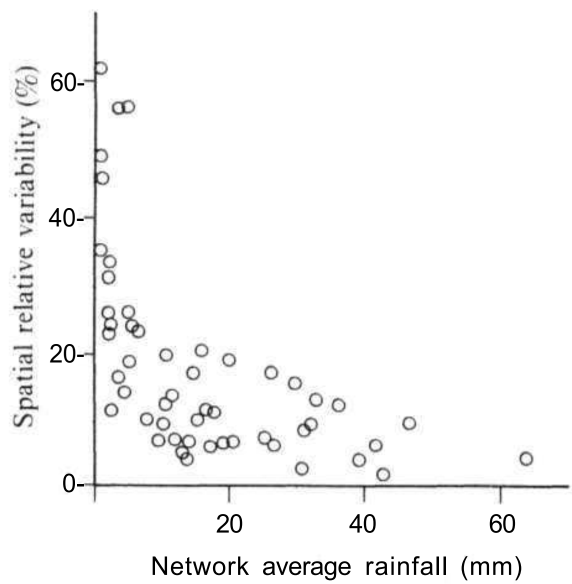

Figure 4. Relationship between spatial variability and network average rainfall at ISC, Sadore, rainy seasons 1986 and 1987.

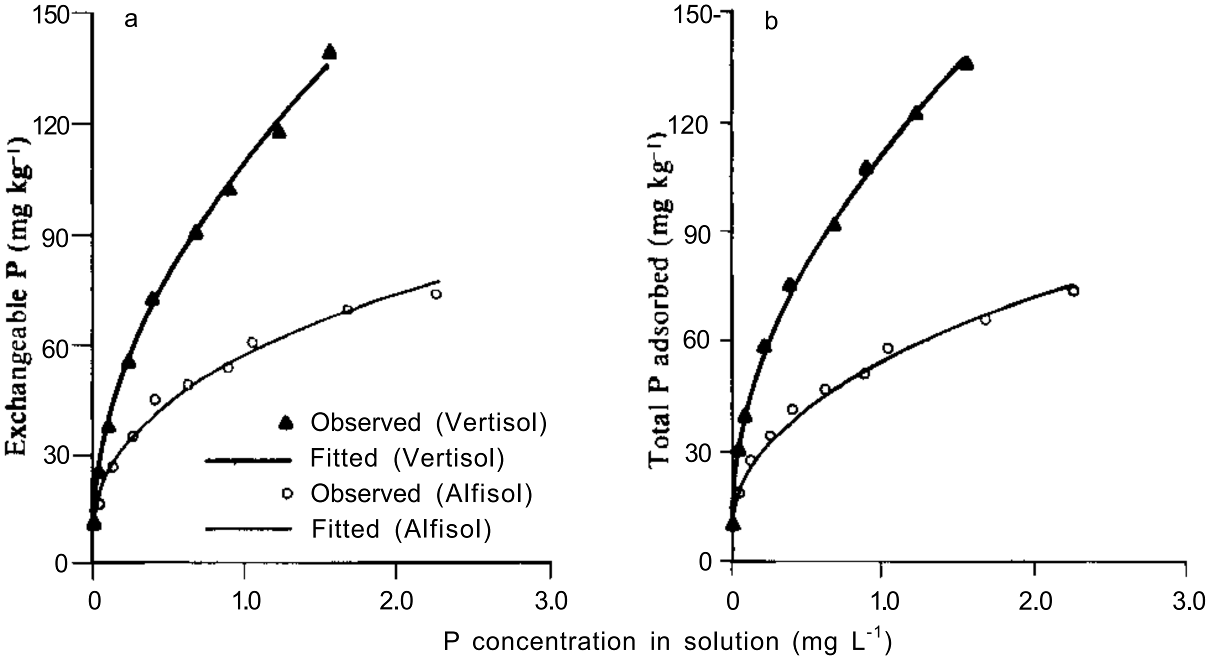

Figure 5. Relationship between (a) *exchangeable P and solution P concentration, for a Vertisol and an Alfisol, and* (b) *total adsorbed P and solution P concentration after adsorption, for a Vertisol and an Alfisol. The lines are fitted to the Freundlich isotherm.*

taneously in each soil by equilibrating the soil samples after adding 11 rates of P (as KH_2PO_4, ranging from 0 to 170 mg P kg^{-1} soil) in 0.01 M $CaCl_2$. We then desorbed the phosphate with 0.01 M $CaCl_2$ and repeated the process for a second desorption.

For each soil, the relationships between phosphate in solution (C) and (1) exchangeable phosphate (P_e) and (2) total adsorbed phosphate (Pt), were described by the Freundlich isotherm:

$$P = aC^{(b/a)}$$

where, a is the amount of adsorbed P and b is the buffer capacity. We used iterative method to compute the parameters a_e and b_e for exchangeable phosphate, and a_t and b_t for total adsorbed phosphate.

On the completion of the first desorption, the exchangeable and total adsorbed phosphate P_e' and P_t', were fitted to analogous isotherms with the parameters a_e', b_e', a_t', and b_t'. In this case a_t' and b_t' refer to the added phosphate that remained on the soil after the adsorption/desorption procedure. In the same way, the exchangeable and total adsorbed phosphate after the second desorption were fitted to isotherms with the parameters a_e'', b_e'', a_t'', and b_t''.

For the Alfisol, added P was distributed only between that in solution and exchangeable P (added P that was not taken up nonexchangeably) up to levels of 120 mg added P kg^{-1} soil. Similarly, for the Vertisol, little P was taken up nonexchangeably, up to levels of 170 mg P kg^{-1} soil. For both soils, the data fitted the Freundlich isotherm well (Fig. 5).

Comparison of the fitted parameters (Table 2) showed that there was no significant difference between a_e and a_t, or between b_e and b_t so that the fitted isotherms for total adsorbed and exchangeable P were identical, confirming that all the adsorbed P remained exchangeable both in the Vertisol and in the Alfisol. The parameters

a_e and b_e were larger for the Vertisol than for the Alfisol. Exchangeable and total adsorbed P were calculated for three values of C (Table 3), with a wide range of concentrations. At all concentrations, the Vertisol adsorbed more P than the Alfisol.

Table 2. Fitted parameters for Freundlich isotherms describing relationships of exchangeable P and total adsorbed P with solution P concentration (mg L^{-1}) after adsorption for an Alfisol from Patancheru and a Vertisol from Kasireddipalli, Andhra Pradesh, 1986.

Exchangeable P (mg kg^{-1})	a_e	SE	b_c	SE	r^2
Alfisol	56.4	±0.89	21.2	±1.06	0.99
Vertisol	108.3	±1.03	54.3	±1.53	0.99
Total adsorbed P (mg kg^{-1})	a_t	SE	b_t	SE	r^2
Alfisol	54.7	±0.62	20.6	±0.75	0.99
Vertisol	110.2	±1.09	52.51	±1.53	0.99

Table 3. Computed amounts of exchangeable and total adsorbed P at different solution P concentrations, after adsorption of phosphate for an Alfisol from Patancheru and a Vertisol from Kasireddipalli, Andhra Pradesh, 1986.

	Solution P concentration (mg L^{-1})		
	0.05	0.2	1.0
Exchangeable P (mg kg^{-1})			
Alfisol	18.3	30.8	56.4
Vertisol	24.1	48.3	108.3
Total adsorbed P (mg kg^{-1})			
Alfisol	17.7	29.8	54.7
Vertisol	26.4	51.2	110.2

Similarly, for each soil, the relationships of exchangeable P and total adsorbed P with solution phosphate concentration after the first and second desorptions were described very well by the Freundlich isotherm (Table 4). After the first desorption, a_e' and b_e' were similar to a_t' and b_t'.

Table 4. Fitted parameters for Freundlich isotherms describing the relationships of (1) exchangeable P and (2) total adsorbed P with solution phosphate concentration in an Alfisol from ICRISAT Center and a Vertisol from Kasireddipalli, Andhra Pradesh, after first and second desorptions, 1986.

First desorption					
Exchangeable P (mg kg^{-1})	a_e	SE	b_c	SE	r^2
ICRISAT Center Alfisol	74.8	±1.4	34.6	±1.7	0.99
Kasireddipalli Vertisol	143.0	±1.8	78.7	±2.5	0.99
Total adsorbed P		SE	bt	SE	r^2
ICRISAT Center Alfisol	71.5	±2.4	28.4	±2.5	0.98
Kasireddipalli Vertisol	143.5	±1.6	64.9	±1.9	0.99
Second desorption					
Exchangeable P (mg kg^{-1})	a_e	SE	b_e	SE	r^2
ICRISAT Center Alfisol	104.2	±3.4	52.2	±3.6	0.99
Kasireddipalli Vertisol	201.4	±3.9	114.8	±4.6	0.99
Total adsorbed P (mg kg^{-1})	a_t	SE	b_t	SE	r^2
ICRISAT Center Alfisol	86.8	±3.0	37.1	±2.9	0.99
Kasireddipalli Vertisol	174.7	±3.0	80.8	±3.2	0.99

However, after the second desorption a_e" and b_e" were significantly larger than a_t" and b_t", so that exchangeable P exceeded total P. It is likely that the labeled P was becoming equilibrated with a pool of soil P larger than the ^{31}P taken up on adsorption. There was little difference between the Alfisol and the Vertisol in the ratio a_e"/a_t" and b_e"/b_t" (Alfisol—1.20 for a_e"/a_t" and 1.40 for b_e"/b_t"; Vertisol—1.15 for a_e"/a_t" and 1.42 for b_e"/b_t"), which describe the proportions of exchangeable to total adsorbed P.

These measurements have shown that Vertisols do adsorb more P than Alfisols. The greater sorption, however, is not sufficient to explain the lack of response of crops to applications of P fertilizer on Vertisols. Further, the ^{32}P data show that virtually all of the sorbed P can be desorbed so almost no fertilizer P is irreversibly fixed by the soil. These results support field work on the P response of sorghum in Vertisols, showing that P is more freely available than is indicated by the chemical soil test.

Soil Classification by Farmers

We intensively examined indigenous systems of soil classification in three ICRISAT study villages of peninsular India (ICRISAT Annual Report 1982, p. 315). The indigenous classifications were drawn up solely from interviews with farmers and were based on their perceptions of edaphic characteristics in fields where input and production data had been collected since 1975.

Major differences in farmers' systems of soil classification were evident between villages with red and black soils (Fig. 6). In Aurepalle, which represents the Alfisol region, soil categories were very distinct and were organized nonhierarchically on multiple characteristics. In the two villages representative of Vertisol regions, the farmers' classification was based on the deviation from an 'ideal'soil type. Thus, farmers in the Vertisol areas viewed their soils as less distinct than farmers in the Alfisol region. These fundamental differences are reflected in variations in crop and soil management practices between fields within the village. This source of management variation can be summarized as an adjustment to central principles in the Vertisol tracts and as the targeting of cropping systems and groups of practices to the diverse soil types in the red-soil regions.

We drew up soil samples for each soil type listed in Figure 6 for laboratory analysis. We determined electrical conductivity (EC), pH, available water, cation exchange capacity (CEC), organic carbon (C), available P, and exchangeable cations (Ca, Mg, K, and Na).

The laboratory analyses generally supported the farmers' way of thinking about their soils. In the red-soil village, all analyzed chemical and physical properties, with the exception of available P, were significantly different ($P<0.05$) for the five major soil groups in the top panel of Figure 6 (Table 5). In the black-soil villages, differences in chemical and physical characteristics of major soil groups within a village were not as marked. In Shirapur (Fig. 6), the major soil groups differed significantly in available water and exchangeable cations (Ca, Mg, K, and Na). With the exception of exchangeable Ca, the problem soils (Morrum, Chicken, and Malachi) ranked lowest for every trait. In Kanzara CEC, organic C, available P, and exchangeable K distinguished the main soil groups ($P<0.05$).

We also compared this classification system by farmers to the descriptive soil taxonomy used in the ICRISAT Village Level Studies (VLS) since 1975. Soil depth and color figure prominently in the VLS soil classes, which are similar to those used to elaborate the 1968 Soil Map of India. In comparing the farmers' assessment to this more formal system of classifying soils, cross classification was generally inconsistent, i.e., fields within a major farmers' soil group were frequently placed in several of the VLS soil groups. Land perceived by farmers as having problem soils was often not identified as such by the VLS soil descriptors.

Summing up, the indigenous systems appear to provide an informative and compact base for indexing variation in land quality. Farmers' soil classification would also appear to have the potential to hasten the process of technology generation and transfer. Additional research is

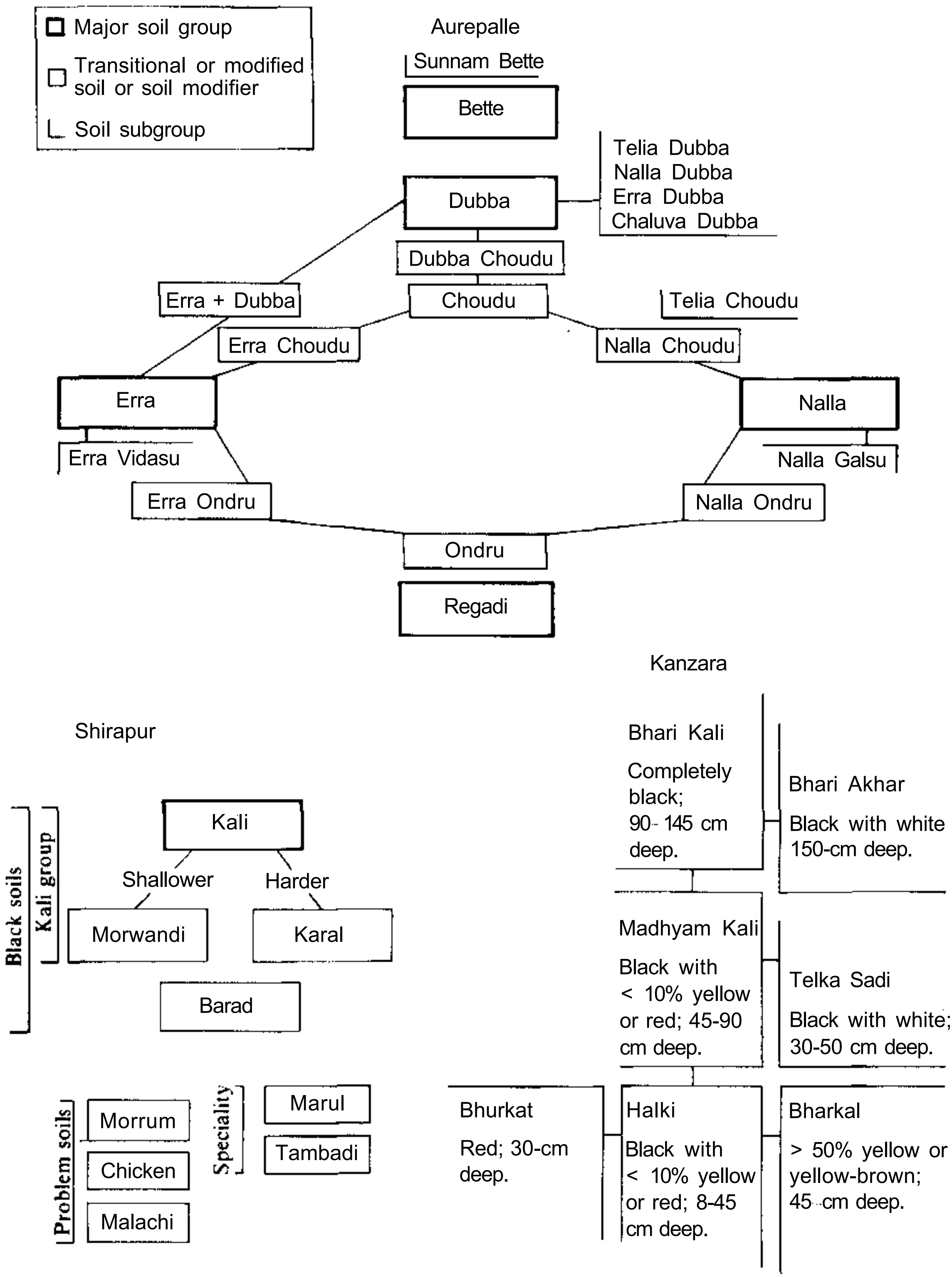

Figure 6. Soil classification by farmers in three villages of Peninsular India.

Table 5. Mean soil test values for farmer soil groups, Aurepalle, Andhra Pradesh, April and May 1986.

Soil group	PH	EC (10^{-3}ds m^{-1})	Available water [g (100 g soil)$^{-1}$]	Organic C(%)	Available P (mg kg^{-1})	CEC	Ca	Mg	K	Na
						(Cmol kg^{-1})				
Bette	8.5	123	5.9	0.40	3.6	15.0	15.8	1.79	0.75	0.22
SE	±0.1	±10	±0.3	±0.5	±0.001	±1.1	±0.004	±0.13	±0.17	±0.08
Dubba	8.1	78	2.7	0.20	3.1	6.1	5.7	0.79	0.25	0.12
SE	±0,1	±7	±0.2	±0.03	±0.5	±1.0	±1.3	±0.19	±0.03	±0.02
Erra	7.7	75	3.8	0.25	1.9	8.5	5.4	0.96	0.32	0.14
SE	±0.2	±8	±0.6	±0.02	±0.4	±1.1	±1.2	±0.10	±0.03	±0.02
Nalla	8.5[1]	92	4.0	0.15	2.9	8.6	11.3	0.99	0.32	0.08
Regadi	8.9	243	9.6	0.32	3.2	29.6	25.8	5.52	0.66	2.24
SE	±0.1	±27	±0.5	±0.2	±1.0	±1.7	±1.5	±0.44	±0.04	±0.67
Village mean	8.20	117.4	5.2	0.26	2.74	12.87	11.03	1.98	0.40	0.60

1. One sample.

needed on the extent to which a farmers' system of classification from a representative village can be extrapolated to a larger area.

Industry

Coarse Cereal Research in the Private Sector

In 1987, we conducted a survey that combined mailed questionnaires and personal interviews to ascertain the amount of research by private companies on sorghum and pearl millet in India. The principal objective of this collaborative study (with Rutgers University, New Jersey, USA), was to identify factors that contributed to modest but vigorous private research on breeding these crops. Questionnaires were sent to 51 seed companies that had received breeders'seed, nurseries, or genetic material of sorghum and pearl millet from ICRISAT. Twenty-three companies returned usable questionnaires; eighteen of those firms were also interviewed.

Our sample is not representative of the Indian seed industry as a whole. The sample is biased toward the largest and most Research and Development (R&D)-intensive segment of the seed industry. Scientists of the seed technology section of the Indian Agricultural Research Institute (IARI) and officials of two seed industry associations, assured us that all the companies that have research programs in the major field crops were included in the list of respondents.

On average, the firms have been in the seed business for 11 years. The oldest was founded 28 years ago. Nine of the companies have entered the seed industry since 1980.

Seventeen of the 23 firms conduct research. The smaller a company, the less likely it is to invest in R&D. Research activity does not vary continuously with the size of the firm; size must exceed a threshold before a firm undertakes research. On average, firms spent 4% of seed sales on research. This figure compares well with the seed industry in USA, which spends about 3% of seed sales on R&D. Most of the firms are involved in R&D for pearl millet, sorghum, sunflower, and cotton. Pearl millet, sunflower, and sorghum receive the most R&D expenditure.

Research expenditure in 1986/87 was about Rs 3.5 million for sorghum and Rs 3.7 million for pearl millet. Those figures are of similar magnitude to the public-sector investment in the All India Coordinated Sorghum Improvement Project (AICSIP) and the All India Coordinated Pearl Millet Improvement Project (AICPM1P) in 1985. Information on seed sales and on distributors' margins show that consumers and producers benefit the most from private sector hybrids and that the profits of private companies are not exorbitant.

The dependence of private breeding programs on the public sector and on ICRISAT is indicated in Table 6 which shows private sector use of public sector products ranging from germplasm to hybrids. Private companies specialize in applied breeding research. Their recent success with these crops, as demonstrated by the position of private hybrids in the All India trials and the popularity of these seeds with farmers, suggests that the public sector could shift their R&D emphasis to more basic breeding like population improvement or to biotechnology. Public sector R&D will be most effective in this role if it collaborates closely with the private sector. For example, public sector research is extremely important for the continued development of private research in India because only a few companies are working on new male-sterile lines.

The recent entry of larger food, chemical, and consumer product firms into the seed industry suggests that the seed industry will have more capital for growth and stability in the future. This implies that private companies can undertake more responsibility for seed production and that the government seed corporations can reduce their production of hybrid seed without harming farmers.

The complementary nature of the public- and private-sector roles in crop improvement and seed production does not mean that the government should stop financing research to develop new hybrids. The production of some hybrids by the public sector is probably the best way to ensure competition in the seed industry.

Table 6. Sources of genetic material for breeding programs of private seed companies in India, 1987.

	Pearl millet	Sorghum
No. of companies using breeding material from		
ICRISAT	16	6
AICSIP/AICMIP	6	3
Universities	6	3
Foreign companies	0	2
Other Indian companies	4	2
Own collections	7	5
No. of companies receiving different types of material from ICRISAT		
GRU material	8	6
Nurseries	7	4
Breeder seed	19	10
No. of companies producing		
ICRISAT hybrids	11	3
Private hybrids	5	4

Improving Technology

Soil Management

Soil Tillage

At ISC, we started a soil and crop management experiment in 1986 to evaluate tillage practices and crop rotation in a no-fallow cultivation system. Tillage methods consisted of plowing to a depth of 10-15 cm, ridging without prior tillage (75 cm between ridges, ridge height 15 cm), and a treatment without primary tillage referred to as zero-tillage. Postharvest tillage was included as a treatment because timeliness is often a problem

Table 7. Grain yields of pearl millet cv CIVT, and cowpea cv Suvita 2, in response to tillage, timing of tillage, and rotation, ISC, rainy season 1986-88.

	Grain yield (t ha^{-1})[1]							
	Continuous pearl millet			Rotated pearl millet		Cowpea		
Treatment	1986	1987	1988	1987	1988	1986	1987	1988
Presowing tillage								
Plowing	0.91	0.57	0.69	0.73	0.83	1.28	0.41	0.52
Ridging	0.91	0.46	0.87	0.75	0.76	1.10	0.32	0.46
Postharvest tillage								
Plowing	-[2]	0.63	0.38	0.80	0.62	-	0.34	0.41
Ridging	-	0.44	0.36	0.66	0.71	-	0.30	0.49
Zero-tillage	0.76	0.43	0.78	0.48	0.91	1.06	0.32	0.53
SE	±0.06	±0.03	±0.06	±0.03	±0.06	±0.07	±0.03	±0.06
Mean	0.86	0.51	0.62	0.68	0.77	1.15	0.34	0.48
CV (%)	28	22	36	22	36	18	23	37

1. Randomized-block design with 8 replications; plot size 60 m^2.
2. - = Not available.

at sowing time, when draft animals are usually weak at the end of the dry season, and because the practice may conserve soil moisture. Tillage was carried out either before sowing, after rain had moistened the soil to a depth of 15 cm, or as soon as possible after harvest.

We compared continuous pearl millet (cv CIVT) with a pearl millet-cowpea (cv Suvita 2) rotation. Pearl millet and cowpea were sown in rows 75-cm apart at 1.2 hills m^{-2} for pearl millet and 3.2 hills m^{-2} for cowpea. A blanket application of 13 kg P ha^{-1} was given each year before sowing. All crop residue was removed each year. The experimental field had been under bush fallow for 5 years. The average pretreatment organic matter level was 0.35%, Bray P_1 4.7 mg kg^{-1} and soil pH (H_2O) was 5.9. The soil had a sand fraction exceeding 90% and the field was susceptible to wind erosion.

Total seasonal rainfall was 657 mm in 1986, 450 mm in 1987, and 693 mm in 1988, i.e., the years were neither extremely dry nor were they wet. However, conditions for the establishment of pearl millet were markedly different each year. In 1986, there was a dry spell of 17 DAS followed by a number of inconsequential rains that were accompanied by strong sandblown winds. In 1987, no such sandstorms occurred, but rains were 5 weeks late. In 1988, severe sandblasting occurred during pearl millet emergence.

Presowing tillage generally improved the survival of pearl millet, resulting in higher grain yields than in the zero-tillage treatment (Table 7). In 1987, postharvest tillage was done late on a rapidly drying soil. This resulted in a poorly structured surface soil, particularly after ridging, which was shallower than plowing. Subsequent sandblasting in 1988 considerably reduced grain yields of the continuous pearl millet plots compared with the rotated pearl millet. Apart from the rotation effect, which might have caused this yield difference, the soil at the time of postharvest tillage was slightly wetter in the previous cowpea plots resulting in a more stable soil surface.

Crop rotation increased pearl millet grain yields consistently over the years by 0.16 t ha^{-1} on average. Cowpea responded well to presowing tillage in all years except in 1988. Generally, stover and hay yields responded better to tillage, as grain yields were reduced by insects and birds. Pearl millet grain yields became increasingly affected by raghuva headworm (*Heliocheilus albipunctella*). The percentage of headworm-infested pockets increased from 38% in 1986, to 79% in 1987, and to 92% in 1988. Postharvest tillage in the year 1987 reduced the raghuva infestation in the 1988 pearl millet crop to 85% compared to 97% for the presowing tillage (SE = ± 1). Zero-tillage plot infestation was 96%.

Soil moisture was monitored throughout the trial. Ridging enhanced early-season soil moisture accumulation. On 15 July 1986, total soil moisture in the 0.3-2.6 m profile was 199 mm for ridged plots, 173 mm for plowed plots, and 168 mm for the plots without primary tillage (SE = ± 10). On 7 July 1988, ridged plots had accumulated 165 mm, plowed plots 134 mm, and untilled plots 142 mm (SE = ± 7). This was probably caused by runoff from the ridge into the furrow and the subsequent deeper infiltration.

One advantage of postharvest tillage is that it kills weeds and thereby reduces transpiration. Maximum soil moisture gains at sowing time were modest, averaging only 18 mm. However, the extra soil moisture stored in the profile could be advantageous in dry years.

Soil pH, organic matter, and Bray were measured after harvest in 1986 and 1987. Neither tillage nor crop rotation significantly changed the values of these properties. By the end of 1987, average organic matter levels had dropped slightly from 0.35 to 0.33%. Continuous pearl millet plots had 0.34% compared to 0.32% organic matter for the rotated crops (SE = ± 0.01).

Management of Vertisol Cracks

The development of cracks due to shrinkage upon drying is a major structural feature of Vertisols (Fig. 7). The frequency, size, and rate of development of surface cracks influence infiltration, aeration, and plant growth. Widely spaced, large and deep cracks could increase infiltration, but aeration and seedling emergence may be improved by small, frequent cracks. This study, conducted in miniplots on a Vertisol at ICRISAT Center, aimed to show if crack size and distribution could be raised by soil compaction and by shading.

Figure 7. Gross cracks are a dominant structural feature in dry Vertisols.

Soil was compacted by repeated rolling of a pneumatic wheel on wet soil and shaded by covering the soil with a sheet of milky white polythene. The depth of major cracks (>5 mm width) was measured by probing with a 2-mm diameter wire. Photographs of the cracking patterns were analyzed by an Area Meter (Delta-T Devices Ltd., Cambridge, England) to determine the area of cracks at the soil surface and the size of intercrack structural units (ISUs).

The depth of cracks increased from 2.0 ± 0.1 cm to 5.1 ± 0.3 cm and the area of ISUs increased from 23.3 ± 1.5 cm^2 to 199.4 ± 25.0 cm^2 due to soil compaction. Thus, soil compaction resulted in bigger ISUs separated by deeper and wider cracks. Similarly, shading resulted in bigger ISUs, and deeper and wider cracks. The area of ISUs under shade was 140.1 ± 9.6 cm^2 compared with 37.0 ± 2.9 cm^2 in the unshaded plots. The crack depth increased from 1.8 ± 0.1 cm to 3.1 ± 0.1 cm due to shading.

This study has shown that the distribution of cracks with a width of >5 mm can be managed by both compaction and shading. It will now be possible to study the effects of management of crack distribution on infiltration, soil aeration, and crop establishment.

Surface Sand Content and Runoff on an Alfisol

Alfisols often have a strong tendency to form a surface seal following the impact of raindrops. This seal, coupled with an inherently small water-holding capacity, promotes runoff and erosion. When dry, this type of soil often becomes hard and mechanically impedes seedling emergence.

At ICRISAT Center, we began an experiment in 1987 to find out whether mixing coarse sand in the surface of such a soil would reduce sealing and crusting. The top 10 cm of soil was texturally a sandy loam: coarse sand (2-0.2 mm), 43.3%; fine sand (0.2-0.02 mm), 30%; silt (0.02-0.002 mm), 6.6%; and clay (<0.002 mm), 20.1%. We mixed fixed amounts of clean river sand (92.4% coarse sand) with surface soil in a cement mixer to obtain average compositions, of 50.4%, 62.7% and 80.0% coarse sand (or 76.4%, 85.4%, 94.2% coarse plus fine sand). The mixtures are referred to as 75%, 85%, and 95% sand. The top 10 cm of soil was then replaced by the mixtures in 1.5-m square plots, confined and divided into two subplots (0.75 m x 1.5 m) by a metal sheet wall inserted 10 cm into the ground.

We measured runoff and soil loss on 36 subplots of each mixture between 9 August and 11 November 1987 (rainfall 478 mm) and 10 subplots of each mixture between 22 April and 30 September 1988 (rainfall 960 mm). Runoff as a percentage of rainfall was 47.2% for the 75% sand mixture, 40.2% for the 85% sand mixture, and 5.3% for the 95% sand mixture in 1987, and 41.6% for the 75%, 38.1% for the 85%, and 11.9% for the 95% sand mixtures in 1988. The percentage of rainfall registered as runoff for light and heavy storms (arbitrarily separated at 20- and 50 mm) is shown in Table 8. Heavier storms produce relatively more runoff but a sand content of 95% on the surface evidently reduces runoff by maintaining infiltration. The effect of coarse sand was less in heavier storms in 1988. Future work will show whether this reduction was due

Table 8. Surface runoff (mm) and standard error in parentheses (by storm size classes) for three sand mixtures on an Alfisol, ICRISAT Center, rainy seasons 1987 and 1988.

	1987			1988		
Storm size	<20 mm	20-50 mm	>50 mm	<20 mm	20-50 mm	>50 mm
Cumulative rainfall (mm)	153	240	85[1]	296	463	201
Sand mixtures (%)						
75	34.9	125.2	32.8	67.9	238.6	92.5
	(±1.4)	(±3.6)	-	(±0.8)	(±2.7)	(±1.3)
85	22.1	109.0	30.1	59.7	214.9	91.0
	(±1.2)	(±17.1)	-	(±1.1)	(±2.8)	(±2.2)
95	6.2	15.7	3.3	13.2	61.9	40.0
	(±0.7)	(±3.0)	-	(±0.5)	(±2.7)	(±5.7)

1. There was only one rainstorm of >85 mm.

to surface sealing despite the high sand content, or to the saturation of the profile. Records from individual storms suggest that as little as 5 mm of rain can produce runoff if rainfall on the previous day exceeds 40 mm.

The soil loss figures are a guide to soil movement by splash detachment. The cumulative soil losses were 4.6 t ha^{-1} for 75% sand, 3.8 t ha^{-1} for 85% sand, and 0.6 t ha^{-1} for 95% sand in 1987. The mean soil loss rates covered the relatively narrow range of 21.8-24.0 kg of soil loss mm^{-1} of runoff, showing that splash detachment and transport processes were unaffected by sand content. The soil losses during 1988 were 6.4 t ha^{-1}, 6.0 t ha^{-1}, and 1.5 t ha^{-1} for the three mixtures resulting from 13.5-16.3 kg of soil loss mm^{-1} of runoff. The loss rates per unit of runoff were lower in 1988 because the soil surface resisted splash detachment as the easily erodable material was washed away.

We measured crust strength on dry soil during April-May 1988 using a recording cone and a pocket penetrometer. Mean strength indices (to 60 mm) decreased with increasing proportion of coarse sand. A reduction in crusting and hard setting can therefore be ascribed to a reduction in the proportion of fine material available to act as a bonding agent. Our results show that adding coarse sand to surface soil can improve water infiltration and reduce soil strength and further work is underway to develop a better understanding of the mechanisms involved.

Agronomy

Pearl Millet/Groundnut Intercrop

At ISC in 1987 and 1988, we evaluated early-maturing (90-100 days) groundnut cultivars from ICRISAT Center as intercrops with pearl millet. Our preliminary trials at Sadore in 1985 and 1986 showed that cultivars ICGSEs 13, 19, 20, and 21 performed well as sole crops compared to the control 55-437.

The density of pearl millet (CIVT) was 1.0 hill m^{-2} in sole-cropped plots and 0.7 hills m^{-2} in intercropped plots. Sole-cropped groundnut was sown 20-cm apart in 40-cm wide rows. In the intercrop, two rows of groundnut were sown at 40-cm spacing between the pearl millet rows spaced 1-m apart. In 1987, pearl millet was sown on 10 July and groundnut on 15 July. Pearl millet was harvested on 19 October and groundnut 7 days later. In 1988, pearl millet was sown on 14 June and groundnut on 25 June. Pearl millet was harvested on 26 September and groundnut on 11 October. We broadcast 13 kg ha^{-1} of P before sowing and applied 400 kg ha^{-1} of gypsum to the groundnut at the pegging stage.

Both crops yielded much less in 1987 than in 1988 (Tables 9 and 10) because the growing season in 1987 was shorter and drier than in 1988. In both years, ICGSEs 21 and 13 were the best groundnut cultivars and were as good or better than the control 55-437 in both intercrop and sole crops. Grain and hay yield of these two cultivars were significantly higher in 1988 than those of 55-437. Land equivalent ratios of ICGSE21 were>l for grain and forage production in both the bad year (1987) and the good year (1988). This cultivar seems to be the best for intercropping at Sadore.

Cowpea Genotypes for Intercropping with Pearl Millet

Cowpea is an important food legume in the semi-arid regions of West Africa and is grown at low densities in association with pearl millet and sorghum, which are the most important cereals there. Farmers do not use plant protection and apply very little or no fertilizer. As a result, cowpea yields are extremely low. The local varieties are largely photosensitive and they frequently mature after the end of the rainy season. In years of erratic rainfall, these varieties produce very little grain. The IITA/ICRISAT program at ISC emphasizes the development of cultivars suited to the millet-based cropping systems and on improving local varieties which are generally adapted to low-input and low-density conditions.

Trials at ISC since 1984 have examined the performance of contrasting cowpea cultivars as

Table 9. Grain yields (t ha^{-1}) of pearl millet (cv CIVT) and groundnut cultivars in sole- or intercrops at Sadore, Niger, rainy seasons 1987 and 1988[1].

	Pearl millet		Intercrop groundnut		Sole groundnut		LER[2]	
Crop/cultivar	1987	1988	1987	1988	1987	1988	1987	1988
Pearl millet	0.93	1.71						
Groundnut								
55-437	0.44	0.90	0.30	0.61	0.34	1.14	1.35	1.07
ICGS(E)21	0.47	0.93	0.26	0.93	0.41	1.09	1.13	1.39
ICGS(E) 13	0.37	0.86	0.23	0.84	0.43	1.31	0.93	1.14
ICGS(E) 20	0.38	0.92	0.21	0.47	0.45	1.16	0.88	0.95
ICGS(E) 19	0.43	1.13	0.15	0.67	0.42	1.23	0.82	1.20
SE	±0.09	±0.18	±0.04	±0.12	±0.07	±0.24		
CV (%)	38	33	36	35	34	41		

1. Randomized-block design with 4 replications; plot size 36 m^2.
2. LER = combined land equivalent ratio, calculated using means.

sole crops and intercropped with pearl millet. Lack of evidence for genotype x cropping system interactions suggests that selection and testing cowpea cultivars and progeny evaluation can be done in either sole- or intercropping systems.

The indeterminate, spreading cultivars that matured medium to late, yielded more grain and fodder than erect determinate cultivars that matured early (Table 11). Early-maturing cultivars were less competitive with pearl millet

Table 10. Straw yield (t ha^{-1}) of pearl millet (cvCIVT) and hay yield (t ha^{-1}) of groundnut cultivars in sole- or intercrop at Sadore, Niger, rainy seasons 1987 and 1988[1].

	Pearl millet		Intercrop groundnut		Sole groundnut		LER[2]	
Crop/cultivar	1987	1988	1987	1988	1987	1988	1987	1988
Pearl millet	2.57	3.21						
Groundnut								
55-437	1.23	1.52	0.39	0.64	0.44	1.17	1.37	1.02
ICGS(E) 21	1.53	1.56	0.32	0.96	0.48	0.98	1.27	1.47
1CGS(E) 13	0.95	2.10	0.37	0.94	0.67	1.35	0.92	1.35
ICGS(E) 20	1.30	1.65	0.27	0.57	0.57	1.19	0.98	0.99
ICGS(E) 19	1.33	1.92	0.25	0.73	0.59	1.28	0.94	1.17
SE	±0.33	±0.28	±0.05	±0.11	±0.06	±0.19		
CV (%)	44	28	29	29	23	32		

1. Randomized-block design with 4 replications; plot size 36 m^2.
2. LER = combined land equivalent ratio, calculated using means.

Table 11. Effect of cowpea plant type on yield (t ha^{-1}) of cowpea/pearl millet intercrop, ISC, rainy seasons 1985, 1986, and 1988.

		1985			1986			1988		
		Cowpea		Pearl millet	Cowpea		Pearl millet	Cowpea		Pearl millet
Cultivar	Plant type[1]	Grain	Fodder	grain	Grain	Fodder	grain	Grain	Fodder	grain
IT82E 60	1	0.10	0.32	2.04	0.09	0.11	1.30	0.10	0.21	1.01
1T82D716	1	0.12	0.40	2.17	0.10	0.18	1.14	0.19	0.41	0.99
TVX 3236	2	0.40	0.83	1.79	0.20	0.23	1.10	0.22	0.54	0.72
SUVITA 2	2	0.62	1.34	1.55	0.43	0.50	1.13	0.26	0.61	0.77
TN88-63	3	0.42	1.06	1.60	0.18	0.46	1.23	0.30	0.58	0.54
58-57	3	0.60	1.30	1.56	0.38	0.77	1.17	0.41	0.91	0.77
Sole pearl millet				2.24			1.30			1.20
SE		±0.08	+0.08	±0.12	±0.06	±0.06	±0.21	±0.03	±0.05	±0.04
CV (%)		25	28	16	35	33	20	34	30	29

1. = Extra-early erect (60-65 days).
2 = Early, spreading (70 days).
3 = Medium maturity, prostrate (80 days).

than medium- to late-maturing cultivars. This offers an opportunity to modify cropping patterns without radically changing the traditional system.

We also examined the influence of cowpea genotype and date of sowing on yield of both pearl millet and cowpea when intercropped. Date of sowing cowpea in relation to pearl millet and the cowpea genotype had a significant influence on the performance of the crops (Table 12). When cowpea sowing was delayed until 3 weeks after pearl millet, there was a sharp decline in yields of both cowpea grain and fodder. The decline was more severe in early-maturing cultivars. In years when rainfall stops in mid-September as was the case in 1985, the late-maturing cowpea produced no grain. The influence on pearl millet yield was in the reverse order. With early intercropping of cowpea, pearl millet yields were affected and the decline in yield also depended on the genotypes. The late-maturing local varieties caused the largest negative effects.

In the short-season environment of the Sahel, growing two crops together will require compatible cultivars that are resistant to drought. From the results of the past 4 years, it is evident that a suitable cowpea cultivar for intercropping with pearl millet will be a compromise between grain and fodder types. Such a cultivar should be weakly competitive with the cereal, early maturing to escape end-of-season drought, and should produce both grain and fodder.

Weed Control

The objective of weed research at ICRISAT is to develop effective and economically viable weed-management systems for the major crops of the SAT. The average small farmer of the SAT is unable to rely solely on herbicides to solve his weed problems because of limited resources. In addition, the weed flora and agricultural environment of the SAT are complex. Therefore, research should consider combinations of tradi-

Table 12. Effect of cowpea genotype and sowing time of cowpea on yield (t ha^{-1}) of cowpea/pearl millet intercrop, ISC, Niger, rainy seasons 1985-1988.

Sowing time of cowpea	Early-maturing cowpea[1]			Late-maturing cowpea[2]		
	Cowpea		Pearl millet grain	Cowpea		Pearl millet grain
	Grain	Fodder		Grain	Fodder	
1985						
Simultaneous	0.49	0.93	1.04	No grain harvest	2.27	0.34
1 week after pearl millet	0.24	0.75	1.21		1.97	0.63
3 weeks after pearl millet	0.08	0.27	1.31		0.59	1.31
SE	±0.01	±0.08	±0.05		±0.08	±0.05
CV (%)	19	20	19		20	19
1986						
Simultaneous	0.19	0.38	0.57	0.04	1.28	0.68
1 week after pearl millet	0.12	0.40	0.74	0.03	1.31	0.68
3 weeks after pearl millet	0.10	0.16	0.81	0.01	0.45	0.84
SE	±0.01	±0.02	±0.02	±0.01	±0.02	±0.02
CV (%)	32	20	23	32	20	23
1988						
1 week after pearl millet	0.21	0.67	0.78	0.17	1.16	0.68
3 weeks after pearl millet	0.06	0.34	0.80	0.05	0.50	0.90
SE	±0.01	±0.01	±0.01	±0.01	±0.01	±0.01
CV (%)	31	22	26	31	22	26

1. TVX 3236.
2. Local Sad ore'.

tional methods and herbicides to shift the crop-weed balance in favor of the crops.

A series of field trials were conducted: (1) to examine the extent of crop losses due to weed competition; (2) to determine crop tolerance and effectiveness of some selected herbicides and their combinations, and (3) to evaluate the efficacy of herbicides in combination with hand weedings. Herbicides evaluated included atrazine, propazine, ametryn, prometryn, terbutryn, alachlor, metolachlor, pendimethalin, and fluchloralin.

For sorghum, no toxic symptoms were observed with metolachlor up to 1.0 kg ha^{-1}. This dose resulted in good weed control and a healthy crop with excellent plant vigor. Crop emergence and establishment were satisfactory when atrazine was applied at 0.50 kg ha^{-1}, but weed control was not satisfactory. With 0.75 kg ha^{-1}, the emergence was good but initial symptoms of leaf scorching were noticed and plants remained stunted for about 3 weeks. In this condition, sorghum would be particularly vulnerable to shoot fly.

For pearl millet, propazine was found to be the safest herbicide up to 1.0 kg ha^{-1}. Prometryn can be used safely up to 0.75 kg ha^{-1} and arazine up to 0.50 kg ha^{-1}. For terbutryn, the margin of tolerance and susceptibility appears to be very narrow.

On groundnut, pigeonpea, and chickpea, metolachlor (1.0 kg ha^{-1}) and pendimethalin (1.5 kg ha^{-1}) controlled weeds better than all other herbicides without any adverse effects on the crop. In addition, a combination of metolachlor + pendimethahn (1.0 kg ha^{-1} each) resulted in good control in fields having mixed weed-flora.

The combination of preemergent herbicides with one weeding and hoeing at around 25-30 days after crop emergence (DAE) resulted in the complete control of persistent weeds and fewer weeds than with higher concentrations of herbicides alone. Yields were found to be similar to weed-free conditions in all the trials.

Intercropping can reduce weeds, but the system by itself does not completely eliminate them. Weed control was therefore studied on a sorghum/ pigeonpea intercropping system (Table 13). Preemergent application of metolachlor (0.75 kg ha^{-1}) followed by a single interrow cultivation and hand weeding within the row resulted in complete control of weeds. The performance of fluchloralin was not satisfactory at 0.5 kg ha^{-1} and was toxic to sorghum at 1.0 kg ha^{-1}.

Results obtained from the studies conducted for 2 years clearly indicated the superiority of metolachlor over atrazine in sorghum. However, seed treatment with oxabetrinil (Concep-II®) at 1-2 g kg^{-1} of seed is required to protect sorghum from metolachlor injury. Both metolachlor and pendimethalin were found to be very effective and safe for the control of weeds in pulse crops. Since metolachlor is not readily available in India and pendimethahn introduced recently, the latter can be used successfully to mitigate weed problems. We are planning experiments to identify a readily available herbicide with an efficacy comparable to metolachlor to avoid the use of atrazine in sorghum.

Rice-based Cropping Systems

In collaboration with the Directorate of Rice

Table 13. Weed management in sorghum (CSH 6) and pigeonpea (ICP-6) intercropping on Vertisols, ICRISAT Center, rainy season 1987.

		Yield (t ha^{-1})	
Treatment	Rate (kg a.i. ha^{-1})	Sorghum	Pigeonpea
Fluchloralin	0.5	3.95	0.64
Fluchloralin + IC[1]	0.5	4.25	0.78
Fluchloralin	1.0	3.77	0.73
Fluchloralin + IC	1.0	4.15	1.04
Metolachlor	0.75	4.50	0.90
Metolachlor + IC	0.75	4.59	1.00
Metolachlor	1.5	4.21	0.91
Metolachlor + IC	1.5	4.40	1.02
Weedy control	-[2]	2.87	0.43
Weedfree	-	4.28	0.80
SE	-	±0.12	±0.05

1. IC = Intercultivation
2. - = Not applicable.

Research [Indian Council of Agricultural Research (1CAR)], Rajendranagar, we conducted experiments at ICRISAT Center to increase the cropping intensity in rice-based systems. We used newly developed rice cultivars, which mature in 75-110 days and have potential yields of 2.0-4.0 t ha^{-1}. Systems with increased and stable production are sought by intercropping and sequence cropping. We conducted field trials: (1) to evaluate the feasibility of growing sole crops of standard and early-maturing cereals or legumes on residual moisture and examine the benefit of supplementary irrigation in rice fallows and (2) to identify the best cultivars of groundnut, pigeonpea, chickpea, and sorghum for intercropping with rice.

During the rainy season, we grew two rice varieties, IET 8890 of 110 days to maturity and IET 9576 of 100 days to maturity in flooded conditions. We sowed sequential crops of two cultivars each of groundnut, chickpea, pigeonpea, and sorghum during the postrainy season with two moisture regimes: (1) crops grown on residual soil moisture and (2) with irrigation of about 40 mm.

Results from experiments in 1986 and 1987 indicated that the differences in the maturity dates of rice cultivars had no effect on the yield of postrainy-season crops. This was because water seepage from adjacent plots delayed land preparation to the same extent with both cultivars. One irrigation application resulted in substantial increases in yields of sorghum, pigeonpea, and groundnut, but not chickpea (Table 14). Sorghum yielded better than the other crops and SPH 221 was significantly more productive than ICSV 1 (CSV 11). There were no significant differences between the cultivars of other crops.

Our findings suggest that short-duration cultivars of pigeonpea, groundnut, and chickpea in rice fallows do not produce economic yields. Possible reasons for the poor performance could be short daylengths during the postrainy season. A separate trial with longer-duration cultivars indicated that higher biomass accumulation was possible but grain yield increase was only marginal without supplementary irrigation. Poor aeration and high compaction of the puddled soil probably restricted root penetration and would explain why the roots did not extract moisture stored in the profile at deeper layers. In contrast, the sorghum cultivars were well adapted to both aerial and edaphic environments.

Fertilizer Management

Nitrogen (N). In Niger, it is generally recommended that N should be applied to sorghum in two equal doses for efficient uptake. The first dose is applied 2 weeks after sowing and the second 6 weeks after sowing when crop growth becomes rapid and N demand is high.

In an experiment in southern Niger, we determined the efficiency of N uptake by sorghum and N loss for each fertilizer application. There were two treatments: in one, the first dose was labeled with ^{15}N, and in the other the second dose was labeled. Since both treatments received the same amount of N, yield was not affected differentially by either application.

Although total ^{15}N recovery from the plants and soil was the same for both treatments (66-68%), significantly more N was taken up by sorghum from the second dose. The distribution of ^{15}N within the plant and soil was different for the two treatments at harvest (Table 15). For the second dose, one-third of the applied N was found in the plant, mostly in the grain.

For both treatments, most of the ^{15}N was found in the 0-15 cm layer (Fig. 8). However, in deeper layers, more ^{15}N was recovered from that applied 2 weeks after sowing. It appears that the N applied when the plant is small is poorly absorbed, and can be carried downwards by infiltrating water. When N is applied at 6 weeks after sowing, the sorghum roots are better developed and uptake is more efficient. To assure good plant response and grain yield, it may be necessary to split the application of fertilizer N.

On-farm fertilizer evaluations. Farmer-managed trials in Gobery were established in 1986 to test promising fertilizer systems and their interaction with farm-management practices. Twenty farm-

Table 14. Mean grain/pod yields (kg ha^{-1}) of crops grown after rice cultivars, IET 9576 and IET 8890, at ICRISAT Center, postrainy seasons 1986 and 1987.

		IET 9576		IET 8890	
Year/Crop	Variety	Rainfed	Supplementary irrigation	Rainfed	Supplementary irrigation
1986					
Sorghum	ICSV 1 (CSV 11)	1.45	2.60	0.94	2.33
	SPH 221	1.19	2.08	1.10	2.02
SE		±0.16			
Chickpea	ICCC 37	0.42	0.46	0.58	0.28
	ICCC 42	0.32	0.42	0.41	0.30
SE		±0.09			
Pigeonpea	ICPL 270	0.55	0.80	0.56	0.66
	ICPL 161	0.49	0.64	0.54	0.63
SE		±0.03			
Groundnut	ICGSE21	0.22	1.31	0.05	1.68
	ICGS 11	0.32	1.12	0.04	1.58
SE		±0.04			
1987					
Sorghum	ICSV 1 (CSV 11)	0.87	2.55	0.96	2.71
	SPH 221	1.42	3.39	1.30	3.30
SE		±0.15			
Chickpea	ICCC 37	0.24	0.30	0.29	0.10
	ICCC 42	0.37	0.33	0.40	0.11
SE		±0.10			
Pigeonpea	ICPL 270	0.35	0.54	0.31	0.86
	ICPL 161	0.43	0.68	0.51	0.97
SE		±0.07			
Groundnut	ICGS E 21	0.03	0.75	0.01	0.81
	ICGS 11	0.02	0.38	0.01	0.52
SE		±0.07			

Table 15. ^{15}N recovery in sorghum plant and the soil at two different times of N application, Gaya, Niger, rainy season 1986.

Time of N application	Grain	Stover	Total plant	Total soil	Total recovery
			(%)		
First split	8.4	15.5	25.8	40.3	66.0
Second split	19.2	13.6	33.1	34.9	68.1
SE	±1.8	±2.9	±3.9	±1.9	±5.3

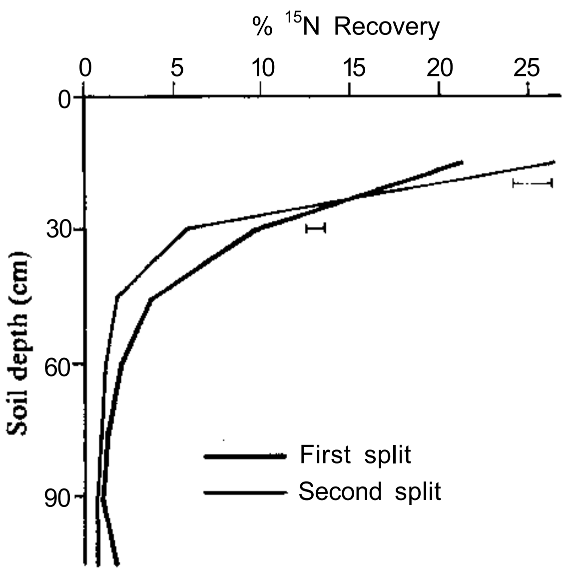

Figure 8. ^{15}N recovery in the soil profile at different soil depths for different times of N application at Gaya, Niger, rainy season 1986.

ers were involved and each managed four of the following treatments:

1. traditional method with no fertilizer application;
2. 13 kg P ha^{-1} as single superphosphate (SSP) and 30 kg N ha^{-1} both broadcast and incorporated (SSP 13 BI + N30 BI);
3. 13 kg P ha^{-1} as SSP and 30 kg N ha^{-1} both hill placed (HP) (SSP 13 HP + N30 HP);
4. 13 kg P ha^{-1} as SSP broadcast and incorporated (SSP 13 BI);
5. 13 kg P ha^{-1} as Parc-W partially acidulated rock phosphate (PARP) at 50% and 30 kg N ha^{-1} both broadcast and incorporated (PARP 13 BI + N30 BI).

In 1987, plots were split, half receiving fertilizers and half left with residual nutrients.

Pearl millet yield was increased about 2.5 times with the use of fertilizers under farmers' management (Table 16). In the 1988 season, pearl millet yields were reduced due to disease and sandblasting at emergence, which resulted in low stand density. Both total dry matter and stand density were significantly improved by the use of fertilizers. The significant effect of fertilizer use on plant density illustrates the strong effect that fertilizer can have on early crop development and survival.

Parc-W PARP performed as well as commercial SSP. There was no difference between broadcasting and hill placement of fertilizers and there was also a good residual effect from the fertilizer application in 1987.

At the beginning of the 1988 season, we weighed the crop residue remaining on each plot of the trial. Fertilizer application in 1986 and 1987 had a significant positive effect on the amount of crop residue remaining on the soil surface when the different fertilizers were applied in 1986 and 1987 (Table 16). The use of fertilizers allowed farmers to increase the supply of stover to the farm and still have enough remaining at the soil surface at sowing time to provide protection from soil erosion. This practice, if adopted, could be crucial in maintaining the sustainability of crop production in the Sahel.

Machinery

Donkey-drawn Tillage Implements

The daba (hand hoe) is the most common farm implement used by small farmers in the SAT regions of West Africa. Farmers in these areas

Table 16. Effect of different fertilizers and methods of application on pearl millet grain yield, total dry matter, density, and remaining stover, Gobery, Niger, 1986-88.

	Grain yield ($t\ ha^{-1}$)			Total dry matter ($t\ ha^{-1}$)			Crop density (hills m^{-2})			Remaining stover[1] ($t\ ha^{-1}$)
Treatment	1986	1987	1988	1986	1987	1988	1986	1987	1988	
Traditional	0.32	0.33	0.15	2.87	1.55	2.69	0.34	0.41	0.22	0.69
SSPI3[2] BI[2] + N3O[2] BI	0.86	0.82	0.37	5.85	4.17	3.79	0.46	0.61	0.41	1.68
SSPI3 BI + N30 BI residual	-[3]	0.48	0.17	-	2.13	2.89	-	0.55	0.28	0.86
SSPI3 HP[2] + N30 HP	0.76	0.93	0.56	4.44	4.07	4.45	0.51	0.64	0.54	1.67
SSPI3 HP+ N30 HP residual	-	0.55	0.23	-	2.93	2.91	-	0.56	0.34	0.99
SSP13 BI	0.73	0.64	0.34	4.74	3.24	3.37	0.47	0.60	0.42	1.30
SSP13 BI residual	-	0.52	0.19	-	2.36	2.53	-	0.54	0.31	1.08
PAPR13[2] BI + N30BI	0.86	0.87	0.50	4.33	3.76	3.56	0.59	0.65	0.57	1.84
PAPR13 BI + N30 BI residual	-	0.55	0.31	-	2.58	2.89	-	0.59	0.57	1.10
SE	±0.04	±0.06	±0.05	±0.27	±0.27	±0.25	±0.02	±0.05	±0.04	±0.13
CV (%)	27	36	64	27	37	30	18	33	44	43

1. Remaining stover in the field at the beginning of 1988 rainy season.
2. SSP13 - 13 kg P ha^{-1} as single superphosphate; BI = Broadcast and incorporated; N30 = 30 kg N ha^{-1}; HP = Hill placed; PAPR13 = 13 kg P ha^{-1} as Parc-W partially acidulated rock phosphate.
3. - = Not applicable, plots were split in 1987.

are aware of animal-drawn implements, but few can afford them.

Seeding and weeding are the two most important and labor-intensive farm operations, where precision and timeliness are critical. Because additional land is usually available, the area cropped depends on the ability of a farming family to perform these operations. Hence priority should be given to develop implements that allow families to farm larger areas and thus increase their ability to produce food. Improved implements must be simple in construction, easy to operate and repair and must have potential for acceptance and sustained use by farmers.

Most farming families own at least one donkey to pull a cart. During the seeding and weeding operations, the whole family concentrates on field work and the donkey may be idle. We therefore designed and fabricated, partly at ICRISAT Center and partly at Cinzana (Republic of Mali), low-cost cultivation implement that can be pulled by a donkey. The implement consists of a frame made of a wooden plank with two rigid beams. A set of three duckfoot sweeps or a ridger can be attached to the plank with the help of simple clamps. Adjustments can be made in sweep spacings to cover a strip up to 60-cm wide (Fig. 9).

A small wheel attached to the frame controls the depth of penetration of the implement and facilitates transport. The implement can be hitched to a donkey with the harness used for donkey carts. When tested in fields at Cinzana, the implement worked well for interrow cultivation with duckfoot sweeps. It can also be used for shallow tillage, or for making ridges before sowing. Field capacity is approximately 0.1 ha h^{-1}, allowing coverage of about 0.5 ha in a day. The draft requirement when operated at a depth of 5

Figure 9. A simple donkey-drawn tillage implement fabricated partly at Cinzana (Mali) and partly at ICRISAT Center.

cm in a sandy soil, was found to be less than 40 kg and the estimated cost is approximately 20000 CFA or US $65.00.

Groundnut Digger for Hard Soil

About 70% of the world's groundnuts are grown under rainfed conditions in the SAT. Timely harvest of groundnuts is essential for the maximum yield of good quality pods with high shelling percentage, oil content, and seed mass. Harvesting is difficult when soils become dry and hard. Lifting plants by hand is ineffective and existing implements, mainly blade types, fail to penetrate to a suitable depth. As a result, harvesting often has to wait for rain to soften the soil and the delay increases losses and lowers the quality of nuts due to pests and diseases.

To overcome this problem, we designed and developed at ICRISAT Center, a groundnut digger to harvest bunch-type groundnuts in hard soils. It consists of a horizontal digger-bottom with a vertical standard bar attachable to a tool bar or a drawpole. The digger-bottom has two shares inclined at 120° and fitted with chisel points for increased penetration into hard soil. A single digger-bottom attached to a tool bar can be pulled by a pair of oxen and two or more digger-bottoms can be pulled behind a tractor (Fig. 10). The digger-bottom covers a 60-cm strip or one row of the crop, has an average field capacity of about 0.04 ha h^{-1}, and requires a pull of about 100 kg when the soil is hard.

In a test on an Alfisol at ICRISAT Center, we attached two digger-bottoms (covering a 1-m wide strip) to a tractor-drawn tool bar. The soil was dry (moisture content approximately 4%) and hard (cone index = 18 MPa) but the new digger-bottom penetrated the hard soil and undercut the main roots of plants leaving them upright. We then lifted the plants manually. The harvesting losses were less than 6% (SE ± 0.7). In contrast, a blade-type digger failed to penetrate to the desired depth and left 15-25% of nuts in the soil.

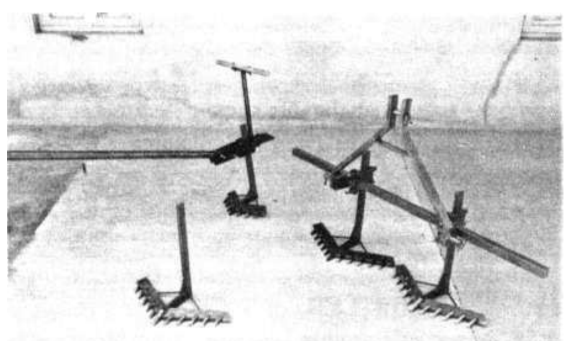

Figure 10. Groundnut diggers, to be used in hard soil conditions, designed and developed at ICRISAT Center.

Assessing Sustainability

Cropping Systems

Agroforestry

Agroforestry experiments with *Leucaena leucocephala* began at ICRISAT Center in 1984 in conjunction with a study funded by the Ford Foundation to examine the potential role of agroforestry in the SAT (ICRISAT Annual Report 1985, p. 303). The findings of the Ford Foundation study, as reported in the ICRISAT Annual Report 1986 (p. 306), highlighted two major constraints to the introduction of agroforestry and alley cropping in SAT India. First, trees compete strongly with crops, a fact that has subsequently been shown to be due to competition for water (ICRISAT Annual Report 1987, p. 332). Second, the close association of trees and crops does not have the positive interactions often observed in conventional intercropping. Indeed, many agroforestry combinations may be economically inferior to combinations of annual crops in the SAT, but unequivocal data to demonstrate this are lacking.

We now have sufficient information on alley-cropping systems based on leucaena to allow us to examine: (1) the evidence for positive interactions, especially in terms of productivity and microclimate amelioration, and (2) the economic comparison of alley cropping and annual cropping over a large range of fodder prices. The hypothesis that alley cropping is less productive than sole leucaena in terms of biomass was explored previously by measuring the total amount of solar radiation intercepted by leucaena hedgerows and three cropping systems on a Vertic Inceptisol (ICRISAT Annual Report 1987, p. 310). These calculations showed that when sole leucaena was managed optimally, the total land equivalent ratio (LER) of the alley crop reached 0.58. None of the sole leucaena treatments was managed optimally for biomass production because they were pruned in the rainy season even when there was no demand for fodder, but they provide a comparison of an alley-cropping system where prunings are used as green manure during the rainy season.

We started a multidisciplinary experiment in 1984 on shallow Alfisols to determine the advantage of incorporating prunings of leucaena (cv Cunningham) into annual cropping systems and the consequences on runoff and yield. We grew leucaena in paired rows at alley spacings of 3.0 and 5.4 m, and pruned hedges regularly. Annual crops were pearl millet/pigeonpea intercrop in 1984 and 1986, castor in 1985, and groundnut in 1987. We spaced sole leucaena at 1.2 m x 0.25 m, which was optimal for canopy development and dry matter production.

Incorporation of 3—10 t ha^{-1} of prunings per annum had a negligible effect on crop production, so results for both mulched and non-mulched treatments were combined (Table 17). This observation is consistent with the bulk of the evidence in SAT India. Dry matter production in 1984 and 1985 was poor in all three treatments, probably because of exceptionally low rainfall. With more rain during 1986 and 1987, the biomass production of all treatments during these years increased markedly. Over the 4 year period, sole leucaena still produced the greatest amount of biomass per unit field area, closely followed by the yields in alley cropping. The annual crop treatment produced 66% of the sole leucaena over the same period. The superiority of the sole leucaena stand over the alley crop was clearer during the off-season from January to early June, when the demand for fodder is greatest. Calculations of LER show no advantage at 5.4 m and a value of 1.18 at 3.0-m spacings. Such a value of LER is insufficient to compensate for the loss in economic return from grain yield at 3.0 m. This finding supports the hypothesis that alley cropping based on leucaena is not more productive than sole leucaena even when leucaena is not managed optimally. A similar conclusion was drawn from an alley cropping trial of leucaena/sorghum/pigeonpea on Vertic Inceptisols reported previously (ICRISAT Annual Report 1986, pp. 308-310), in which the highest LER was 1.14, using the best annual crop treatment as a base.

We carried out an economic comparison of

Table 17. Biomass production of leucaena and alley crops on a shallow Alfisol, ICRISAT Center, 1984-88.

Treatment	1984	1985	1986	1987	1988[1]	Total	SE
Total biomass (t ha^{-1})							
Annual crop	3.82	1.27	7.18	1.60	.2	13.87	±0.15
Sole leucaena	-	5.04	11.02	11.34	6.17	33.57	±0.37
Alley crops (3.0m)	2.66	3.28	11.35	9.10	5.13	31.52	±0.19
Alley crops (5.4m)	3.17	2.18	10.25	6.66	4.19	26.45	±0.29
SE	±0.12	±0.20	±0.62	±0.51	±0.40		
Off-season biomass (t ha^{-1})							
Sole leucaena	-	0.40	3.30	4.85	6.13	14.68	±0.27
Alley crops (3.0m)	-	0.22	2.77	3.94	5.13	12.06	±0.15
Alley crops (5.4m)	-	0.09	2.02	3.01	4.21	9.33	±0.13
SE		±0.03	±0.19	±0.29	±0.28		
Annual rainfall (mm)	655	557	713	879	115		
Annual crops[3]	PM/PP	C	PM/PP	G	-		

1. Off-season values: January to June.
2. - = Not available.
3. PM = Pearl Millet; PP = Pigeonpea; C = Castor; G = Groundnut.

the most remunerative alley- and annual crops over a wide range of prices for leucaena dry fodder for both the Alfisol and Vertic Inceptisol trials (Fig. 11). The best alley crop treatments were the widest spacings in both trials, 5.4 m for the Alfisol and 5.55 m for the Vertic Inceptisol. Both trials revealed that the economic superiority of alley cropping was small and was confined to the price range of Rs 0.8-1.6 kg^{-1}. Below this price range, the annual crop gave the best economic returns, and sole leucaena dominated above Rs 1.6 kg^{-1}. The poor comparative performance of alley cropping on the Alfisol was partly due to the lack of response to mulching, but even if response to both mulching and fertilizer were significant, applying more fertilizer to annual crops will always be economically preferable to sacrificing land to leucaena hedgerows.

Runoff and soil loss. On Alfisols in the SAT, substantial runoff often causes erosion. Even under improved annual cropping systems at ICRISAT Center, 20-28% of the seasonal rainfall was lost as runoff in the period 1975-85. Of most concern is that a significant portion of this seasonal runoff occurred when soil profiles were not fully charged.

Runoff was monitored for 3 years (1985-87) and erosion for 2 years (1986-87) in the multidisciplinary experiment described earlier. The main objective was to determine the extent to which leucaena and its prunings could control runoff and soil loss on Alfisols. Unfortunately the amount of runoff in 1985, 1986, and 1987 was only 10% of the long-term average (1975-84), but the effect of the treatments could still be seen.

Leucaena plants were very effective in controlling seasonal runoff and erosion (Table 18). The sole leucaena treatment reduced runoff by 79% and soil loss by 78% compared with the annual crop. Significant reductions were also obtained

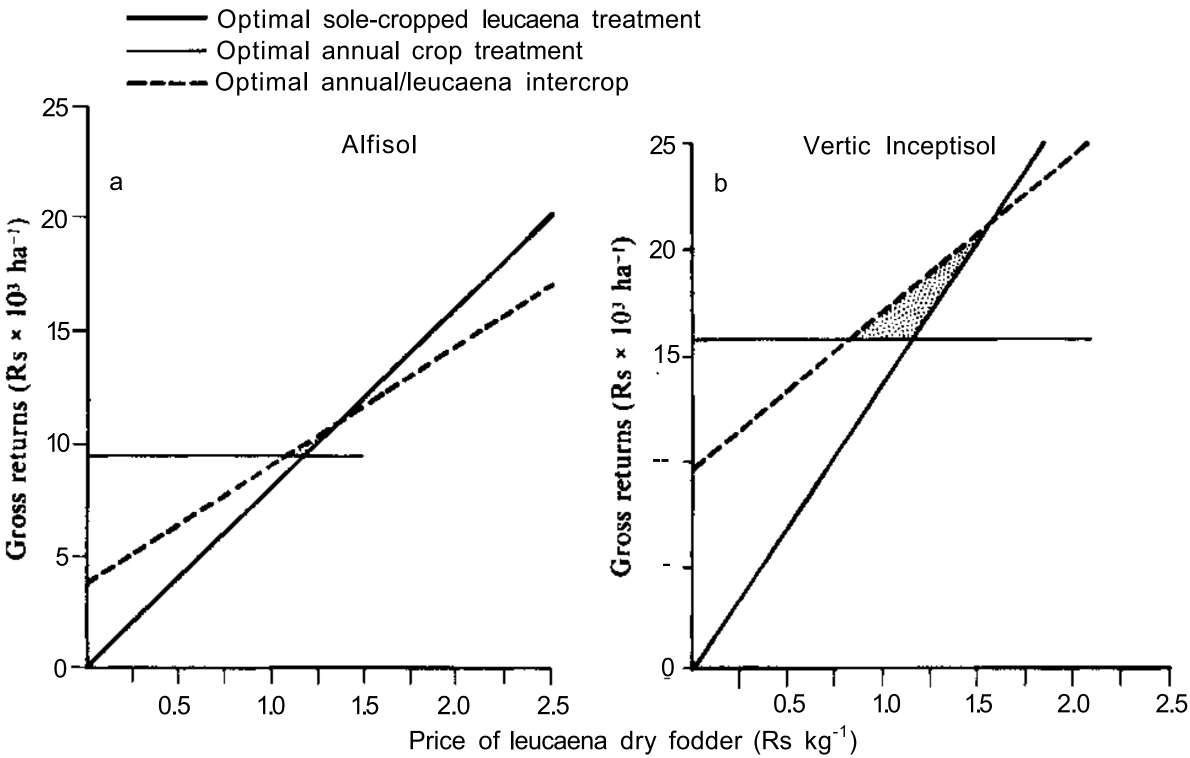

Figure 11. Comparison of the most economic leucaena agroforestry system with the most economic intercropping system on (a) *an Alfisol and* (b) *a Vertic Inceptisol, at ICRISAT Center, 1985-1988.*

with intercrops of leucaena and annual crops. All four treatments with mulches resulted in the smallest amounts of seasonal runoff and erosion, but the general trend between treatments remained similar to those that were nonmulched.

The relationships between daily rainfall and runoff for nonmulched treatments showed trends similar to the annual results. Daily runoff and erosion generally decreased as the proportion of leucaena increased.

The runoff for various treatments during two storms is shown in Figure 12. Runoff and erosion were reduced with all the leucaena treatments. Athough these were the biggest storms in the 3 years (1985-87), they are small compared to large storms of an average year.

Microclimatic modification in alley-cropping system. Previous studies have demonstrated the severe competition for moisture between leucaena hedgerows and crops in our joint experiment with the Central Research Institute for Dryland Agriculture (CRIDA) (ICRISAT Annual Report 1987, p. 333). In contrast, many workers have suggested that one of the benefits of agroforestry is the beneficial modification of microclimates. Earlier studies at ICRISAT on microclimatic modification in conventional intercropping systems have indicated positive interactions (ICRISAT Annual Report 1986, pp. 302-303). A study was conducted in 1986 and 1987 with the University of Nottingham, UK to quantify changes of microclimate in leucaena alley cropping systems. A major emphasis was to develop appropriate analysis methods that relate microclimatic variables to growth and development of associated annual crops.

In the rainy season, we grew pearl millet cv BK

Table 18. Effect of different agroforestry treatments on annual runoff and soil loss on shallow Alfisols, ICRISAT Center, 1987.

Treatment	Runoff[1] (mm)	Soil loss[1] (t ha^{-1})
Nonmulched		
Groundnut	43.6	0.45
Groundnut/leucaena intercrop (5m apart)	30.4	0.33
Groundnut/leucaena intercrop (3m apart)	19.9	0.22
Leucaena	9.1	0.10
SE	±4.1	±0.04
Mulched		
Groundnut	5.5	0.22
Groundnut/leucaena intercrop (5m apart)	3.0	0.10
Groundnut/ leucaena intercrop (3m apart)	1.4	0.06
Leucaena	0.3	0.02
SE	±0.3	±0.02

1. Based mostly on observed and a few calculated values. Some of the values were calculated using a regression equation based on the observed values of other events. Values are much smaller than normal because it was a dry year.

560 as an alley crop between hedges of 1-year-old leucaena spaced at 3.4 m, which were cut to 0.7 m prior to sowing the pearl millet and at 30 DAS. We monitored wind speed, saturation deficit, leaf temperature, soil temperature, and light interception in sole pearl millet and the alley crop at the height of pearl millet.

To relate the response of the crop developmental processes of leaf production and phenology to temperature, we used the concept of thermal time. When we calculated thermal time for each 10-day period, there were no differences in the totals between the sole and alley crops. This is not surprising as mean temperature during the rainy season varies from 24 to 27°C which is ideal for the growth and development of pearl millet.

Saturation deficit is a difficult quantity to relate to plant growth and development and in our analysis, we consider its effect on growth of the crop using an index, Z:

$$Z = I - [(D - a)/b]$$

where D is the mean saturation deficit in kPa during daytime and a = 1 and b = 5 are empirical constants. There were no significant differences in the values of Z between sole pearl millet (0.89 ± 0.08) and the alley crops (0.93 ± 0.04). Mean daytime saturation deficit varied from 0.73 to 1.34 kPa during the period of comparison which was confined to a range favorable for plant growth.

During the first 35 days, the wind speed above the alley-crop pearl millet was reduced by 50-60% of the value for sole pearl millet because the leucaena hedgerows were higher than the crop, but when the pearl millet started to elongate and exceed the height of the hedgerow, there was no difference in wind speed. This suggests that the main benefit of the windbreak in such a system would be during the early seedling period when wind speeds are greatest (2-4 m s^{-1}).

Thus, in contrast with the evidence on conventional intercropping, microclimate amelioration for alley cropping is small and relatively insignificant in the environment studied here. The main reason is that the temperature, saturation deficit, and wind speed are already favorable for crop growth during the rainy season and when microclimate modification might be most effective, i.e., in summer, it is too dry for sowing understory crops.

Our discouraging experience with leucaena-based alley cropping is consistent with the bulk of the evidence in SAT India. The physical and economic environments in SAT India differ greatly with the conditions that favor alley cropping in Africa and in parts of Asia other than India. The most important factors are the lack of substantial positive interactions such as mulching and crop growth, small environmental improvement, and severe competition for moisture between leucaena and annual crops. Leucaena-

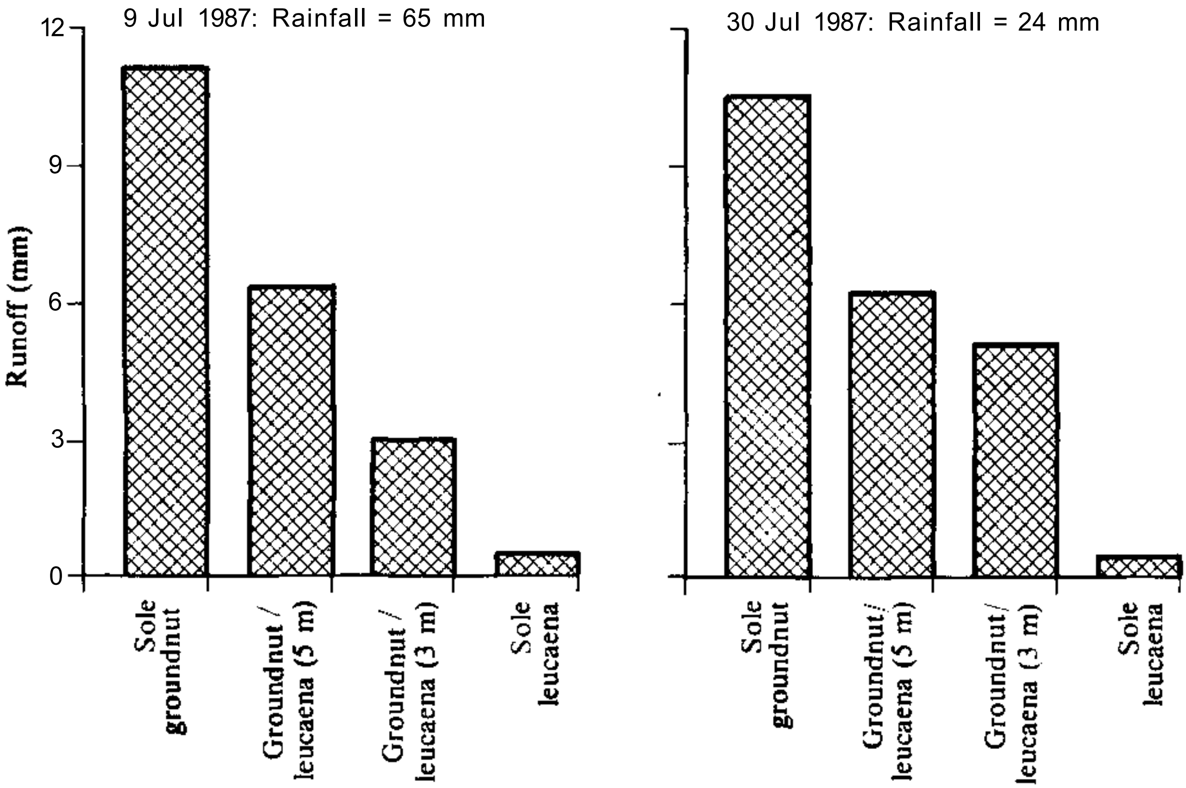

Figure 12. Runoff from different agroforestry treatments during two large storms, ICRISAT Center, rainy season 1987.

based alley cropping is successful where lack of rainfall is not a major constraint to crop yield, where inorganic fertilizer is inappropriate, unavailable, or too expensive, and where competition with annual crops is not appreciable. Our attention in agroforestry has therefore turned to a nonaggressive species—perennial pigeonpea—which has many of the beneficial characteristics well-known in conventional intercropping systems.

Collaboration with CRIDA. We conducted a joint experiment with CRIDA at Hayatnagar farm to determine the mechanisms responsible for the apparent absence of competition between two nitrogen-fixing trees, *Faidherbia albida* and *Albizia lebbek,* and dryland crops. The beneficial role of *E albida* in the Sahel is well established but its potential in SAT India is largely untapped. A preliminary trial at CRIDA has confirmed that it has two major advantages over the predominant native tree species in the Deccan region, *Acacia nilotica.* First, it has no apparent adverse effects on understory crops like sorghum and castor, which are important crops of the region. Second, its growth rate exceeds that of all the useful native tree species. *Albizia lebbek* is native to India and also has no adverse effects on dryland crops but its growth rate is slower than *F. albida.*

We planted the trees at 4 x 4 m spacings in 1985 on a shallow gravelly Alfisol and planted sorghum and castor in July without inorganic fertilizers, following farmers' practice in the region. With this low-input management, the crops utilize only a small proportion of the rainfall. Much of the water is lost directly from the soil by evaporation and water stored in the soil is not fully exploited by poorly developed root systems. The hypothesis is that deep-rooting tree species like *F. albida* and *A. lebbek* could increase the utilization of rainfall and stored soil moisture in such sowing arrangements where the leaf area index seldom exceeds 1. We used fisheye photography to quantify shading by the tree canopies (Fig. 13) and employed a heat-pulse technique to measure the hourly transpiration rate of both the tree species during the rainy and postrainy seasons.

Initial analysis showed that the fractional area of shade beneath the tree canopies was less than 15% so that the growth of understory crops would be little affected. In the rainy season, *F. albida* transpired 17.5 L d^{-1} per tree equivalent to 1.1 mm d^{-1} (for the total ground area), while *A. lebbek* used 13 L d^{-1} per tree or 0.8 mm d^{-1}. The estimated transpiration of sorghum ranged from 2.5 to 3 mm d^{-1} or 63-75% of the potential evapotranspiration. These calculations show that those two tree species and crops are compatible in

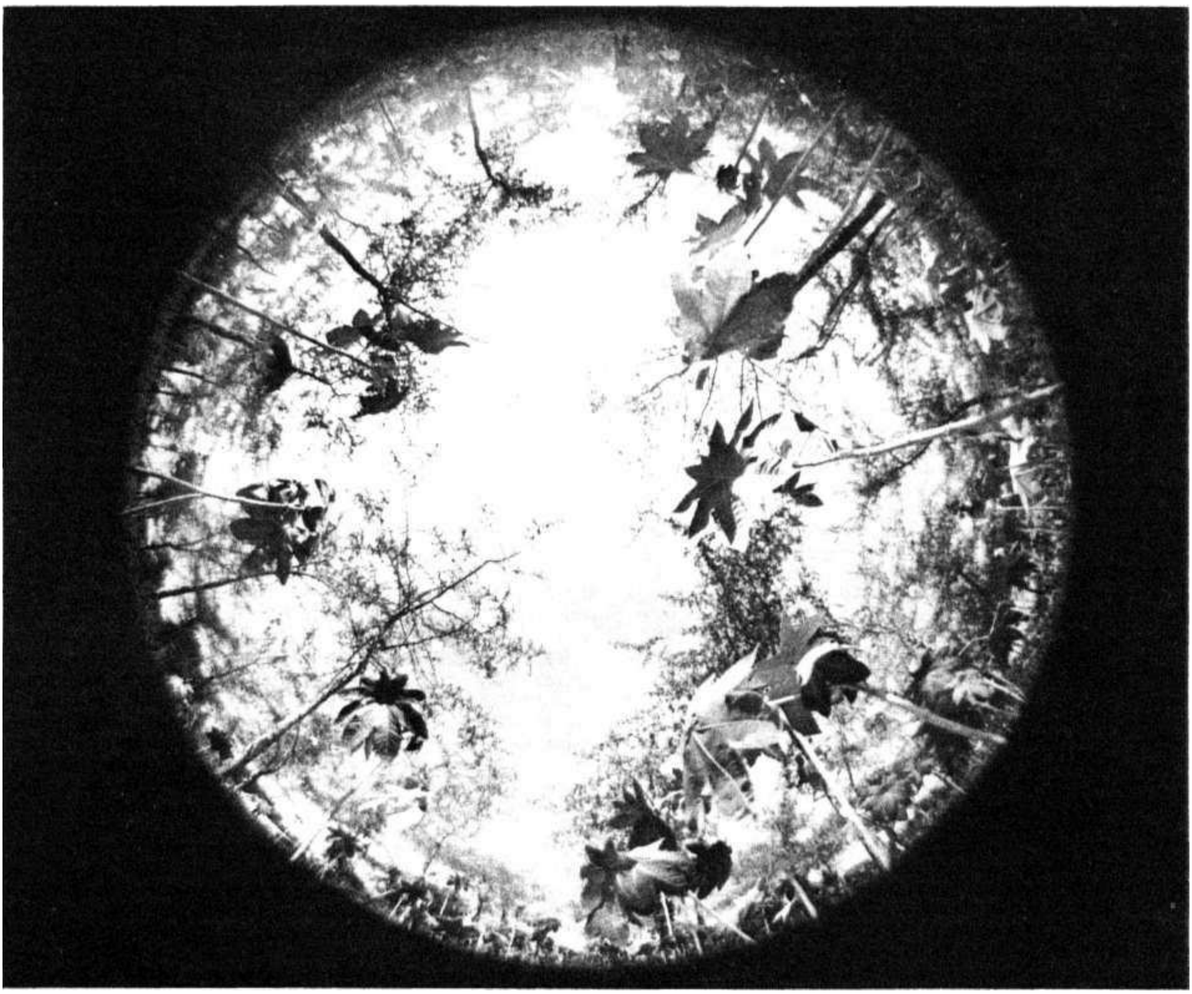

Figure 13. Fisheye photograph used to estimate canopy cover in an agroforestry system with castor bean (foreground) as an understory crop in a Faidherbia albida *plantation at Hayatnagar Farm, Andhra Pradesh, October 1988.*

their utilization of rainfall. The transpiration rate of *F. albida* appeared to be proportional to the incident radiation whereas the rate for *A. lebbek* was restricted during midday (from 1000 to 1600) (Fig. 14). This difference in the pattern of transpiration may explain the superiority of *F. albida* over *A. lebbek* in biomass production.

Competition between neem windbreaks and pearl millet at ISC. Neem (*Azadirachta indica*) is a well-adapted exotic tree species in the Sahel, which has been widely sown in forestry projects for avenue shade, and as shelter in towns and on cropped lands. Major, successful windbreak sowings of neem may be found in central Niger (Majjia Valley) and northern Nigeria (Sokoto state). As a result of these projects, enthusiasm for the use of this species in windbreaks is growing.

Neem windbreaks are being proposed for areas with environments very different from the places where they have benefitted crops. In the Majjia Valley, for example, the water table is only 7-10 m deep, whereas at ISC it is 40-m deep. It is likely that in areas with deep water tables and low rainfall, tree roots would have to extend into the cropped fields to obtain sufficient water. In this case, neem trees could be competing with crops grown between them. Such negative effects could obviate any shelter benefit that the trees

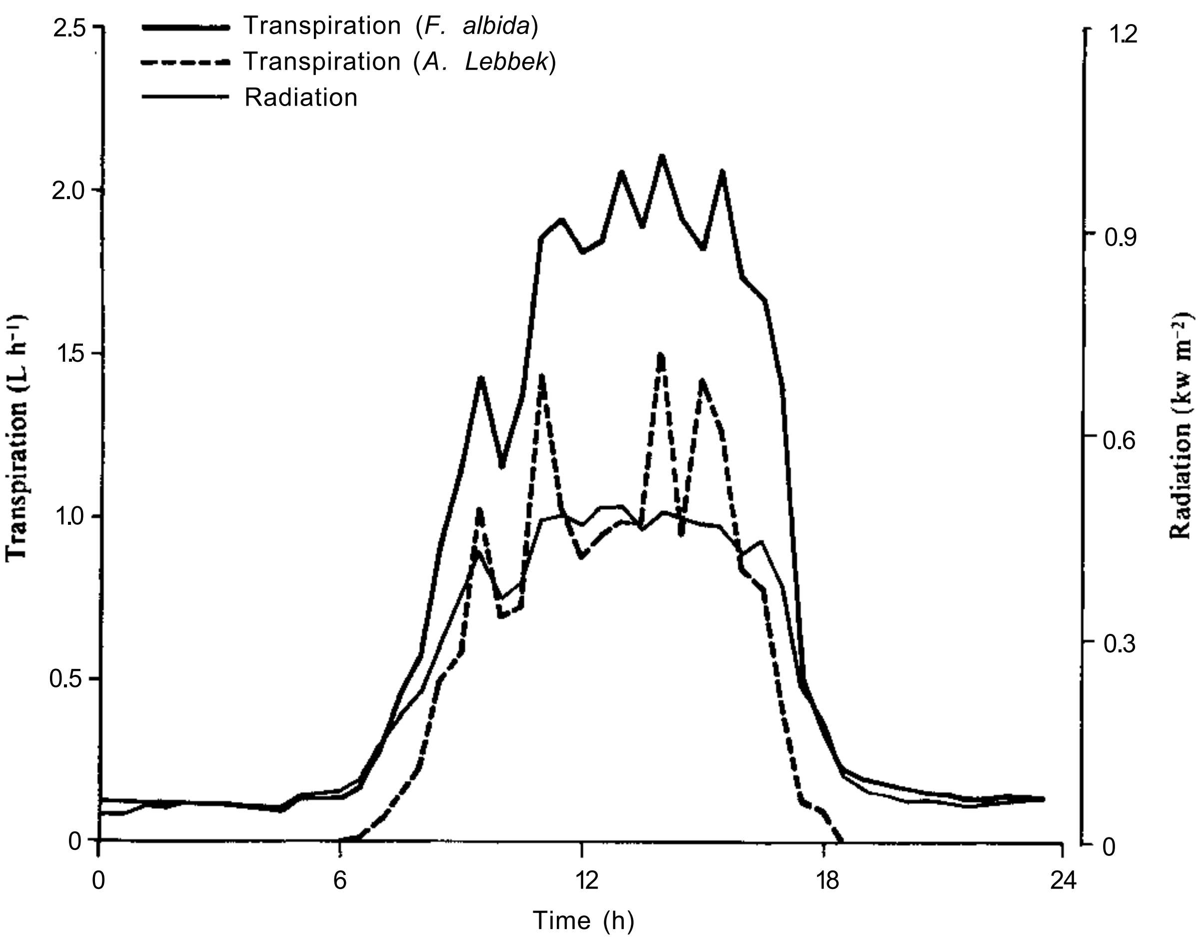

Figure 14. An example of the diurnal trends and solar radiation in the transpiration rate of Faidherbia albida *and* Albizia lebbek *in September 1987, Hayatnagar Farm, Andhra Pradesh.*

provide.

In 1987, on the ISC station, we began to study these effects utilizing 5-year-old, 5-m tall windbreaks that were sown in north-south lines 100-150 m apart, perpendicular to the damaging winds of the rainy-season storms. We compared pearl millet yields in the rainy seasons of 1987 (lower than average rainfall, late onset of rains) and 1988 (above average and favorably distributed rainfall) with an irrigated pearl millet crop grown in the off-season, 1987-88.

The irrigated trial examined the effect of drought on the development of 42 pearl millet cultivars. Drought stress was imposed by withholding irrigation after 50% flowering. At the time of harvest, we sampled plants from both irrigated and stressed plots in the study, moving away from the windbreak in 3-m increments. Grain and biomass were markedly reduced within 15 m of the trees in the stressed plots (Fig. 15). For fully irrigated plots, competition was noticeable only within about 8 m of the windbreaks. Trends of yield in the poor rainfall year (1987) closely followed those of the stressed plots in Figure 15, while trends in the good rainfall year (1988) followed the irrigated plots.

In areas with deep water tables, neem is slower-growing but more competitive than on land with shallow water tables. There is some competition even when it is 5 years old, and even in relatively good rainfall years. It is likely that the major source of competition is for soil water. We are continuing studies to develop water and energy balance models for neem at ISC, and to develop silvicultural methods to reduce the competitive effects of neem on pearl millet.

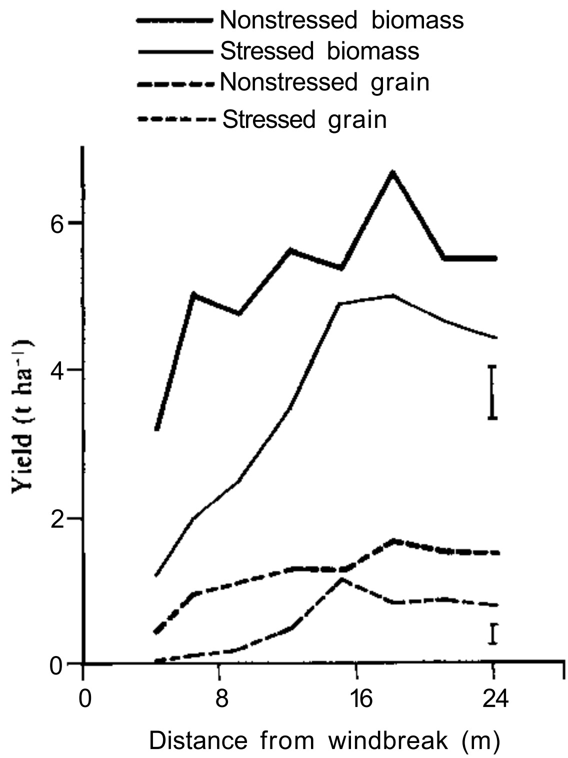

Figure 15. Effect of distance and drought on competition between neem windbreaks and pearl millet grown in Sadore, postrainy season 1987/88.

Risk and Groundnut Genotypes

In 1984 (ICRISAT Annual Report 1984, pp. 197-202), groundnut physiologists presented the results of a large experiment designed to measure genotype response to drought. In the 1982/83 postrainy season, we subjected 25 lines to 12 patterns of drought with eight intensities within each pattern. Thus the experiment provided information on yield response to drought for 96 states of nature in 25 genotypes. We combined that information with meteorological records from three groundnut-growing locations—Hyderabad and Anantapur (Andhra Pradesh), and Anand (Gujarat). Information on the location-specific incidence of drought and genotype responses provided raw material for a PhD student to analyze the risk of growing different groundnut genotypes in the different locations.

We modeled yield response to available water so that simulated yield distributions could be generated for each genotype in each location. We examined four locations. In the experimental location, the states of nature were not adjusted by the historical meteorological data, i.e., each of the 96 experimental outcomes was given equal weight. In the other three locations, we derived the frequency of drought stress from meteorplogical records, using 83 years of data for Hyderabad, 73 years of data for Anantapur, and 31 years of data for Anand.

We compared methods incorporating economic concepts of risk: mean-variance analysis, ordinary and generalized stochastic dominance, mean-Gini and mean-extended Gini criteria, and the exponential utility, empirical moment generating function.

Efficient genotypes—those that maximize yield for a given level of risk or minimize risk for a given level of yield—are listed in Table 19 for the experiment and for Hyderabad, Anantapur, and Anand according to the different risk assessment criteria. Surprisingly, some well-established genotypes were not selected as efficient in any of the locations. Higher-yielding genotypes were preferred over the moderately risk averse range, but they were not dominant over the full range of risk aversion.

Selected genotypes varied substantially with location. Genotype number 4 was usually selected in the experimental location, number 8 was prominent in the Hyderabad and Anand locations, and number 17 in Anantapur. Genotypic choice was not sensitive to changes in risk

Table 19. Efficient groundnut genotypes by risk assessment criteria[1] in different locations in India.

Criterion	Experimental location	Hyderabad	Anantapur	Gujarat
Mean variance	4, 18,9, 16	8, 4, 5, 7	17, 6, 5, 16	8, 17, 4, 5, 7
Stochastic dominance				
Second degree	4, 18, 6, 11, 5, 9	8,4, 17,6,5	17,6,8,3,5,4, 14	8, 17,4, 6, 14, 18, 5
Third degree	4, 18, 6, 11, 5, 9	8,4, 17,6, 5	17,6, 5,9	8, 17,4,6, 14, 18, 5
Mean Gini	4	8,4	17,6, 5	8
Stochastic dominance with respect to a function				
$r^2 < 0$	4	8	17	8
$0 < r < 0.00005$	4	8	17	8
$0.00005 < r < 0.00015$	4	8,4	17, 6	8
$0.00015 < r < 0.00037$	4	4	6	8, 17
$0.00037 < r < 0.00198$	4, 18	4,6	6,5	17,4,6,5
$0.00198 < r < 0.005$	4, 18, 5, 9	6,5	5,9	4,5
Expected Utility Moment Generating Function (EUMGF)				
r = 0	4, 18, 14, 17,6	8,4, 17,6,20	17, 6, 8, 3, 5	8, 17,4, 20, 6
r = 0.00005	4, 18, 14, 17, 6	8,4, 17,6,20	17, 6, 5, 8, 3	8, 17, 4, 20, 6
r = 0.00015	4, 18, 14, 17, 6	8,4, 17, 6, 20	6, 17, 5, 3,4	8, 17, 4, 6, 20
r = 0.00037	4, 18, 14, 6, 17	4, 17, 8, 6, 20	6, 5, 17, 4, 3	17, 4, 6, 8, 20
r = 0.00198	18,9,4, 14, 17	6,5,4, 18, 17	5, 9, 6, 18, 15	5, 6, 18, 4, 14
r = 0.005	9, 5, 18, 11, 16	5, 6, 8, 20, 17	9, 5, 6, 18, 16	4, 5, 6, 3, 18

1. Numbers refer to genotypes. Within a row, efficient genotypes are ranked by their mean yields, except for EUMGF criteria, which are ranked by certainty equivalents.
2. Absolute risk aversion coefficient. High values indicate greater risk aversion.

assessment criteria within regions. Given the consistency of results within each location and the sensitivity of the results across locations, the direction for future research lies not with the refinement of selection criteria, but with the improved modeling of yield response to water and of the incidence of drought stress.

Land and Water Management

Vetiver Grass for Soil and Water Conservation

Vegetative barriers are useful for soil and water conservation and may have advantages over earth structures. Vegetative barriers normally take the form of hedges, planted at intervals across slopes to reduce runoff velocity and soil erosion, and to increase infiltration and sediment deposition within fields. Ideally, species to be used as vegetative barriers for arable farming in dry environments should have the following features:

- Ability to survive moisture and nutrient stress.
- Capability to withstand frequent grazing even in dry months and to re-establish top growth quickly after rain.
- Minimum loss of crop yield implying that the barrier should:
  1. not proliferate as a weed;
  2. not compete for moisture, nutrients, and light;
  3. require only a narrow width to be effective;
  4. not be a host for pests and diseases.
- Form an erect, stiff, and uniformly dense hedge so as to offer high resistance to overland flow.
- Have roots which bind soil to prevent rilling and scouring near the barrier.
- Preferably supply products of economic value to farmers.

The use of vetiver grass (*Vetiveria zizanioides*) as a vegetative barrier in cultivated fields has been promoted by the World Bank but information on its performance in dry environments is scanty. In July 1987, we planted Vetiver hedges to observe performance under two different conditions:

1. On an Alfisol morrum exposed in a gravel pit (30% slope) representing marginal soil conditions.
2. On a level Alfisol field (< 1 % slope) representing more normal soil conditions.

We established the hedges by planting clumps consisting of five root divisions (slips) in small furrows in moist soil. Fertilizer (diammonium phosphate) was applied at 1.5 kg 100 m^{-1} of the hedge. Two patterns of clump spacing within the hedge were compared: single-row hedge, distance between clumps 0.1 m, and double-row hedge with staggered clumps, distance between clumps 0.2 m and between rows 0.1 m.

Observations led to the following conclusions:

1. Establishment of clumps was satisfactory at 75% on the murrum and 96% on the level field. However, gap filling during the first 2 years is essential for the formation of a satisfactory hedge and to strengthen the barrier at any weak points that could allow scouring.
2. The width of a 1 -year-old hedge was 15-25 cm for the single row and 25-35 cm for the double-row planting system. The single-row hedge takes less area out of production and quickly forms a uniform barrier, whereas the double-row grows as individual tussocks. Gaps between tussocks could form scour points. The single-row hedge is therefore preferable provided its effectiveness is not impaired by reduced width.
3. The grass is capable of surviving through the dry summer months. With the onset of rains, green and vigorous shoots usually sprout quickly from many of the seemingly dead clumps.
4. After satisfactory establishment, the grass is able to withstand pruning at a height of 15 cm at weekly intervals during the dry months. Thus the barrier is not likely to be destroyed by frequent grazing, if pruning is a reasonable simulation of grazing (Fig. 16).
5. Two-to-three prunings during the cropping period appear to be essential for minimizing

Figure 16. Pruning of Vetiver grass to simulate effects of grazing on establishment.

competition with crops for light, moisture, and nutrients.

Further information is needed on the effect of Vetiver barriers on runoff, erosion, soil moisture, and pests. We also need to compare performance of this grass with other species.

Optimal Land Management Practices for Alfisols

Several systems of land management were tested at ICRISAT Center from 1981 to 1987 in an attempt to develop a land- and water-management system for medium-to-shallow Alfisols to increase and stabilize agricultural production. The main objective was to increase infiltration and to decrease erosion by controlling runoff. Two groups of experiments are reported here: land surface configuration and crop residue management.

Land surface configurations. We continued to compare the flat-on-grade cultivation with raised configurations (e.g., broadbed and furrow, narrow ridge and furrow) as first described in the ICRISAT Annual Report 1985 (p. 277). Recent work on Alfisols with slopes of less than 1.5% has confirmed that runoff and erosion are less and crop yields more on flat land than on land with raised beds or ridges. These are prone to breaching during storms and are inconvenient for the spacing of some crop combinations. On the other hand, penetrometer measurements clearly showed that soil in raised beds or ridges stays looser than on flat land and this difference could increase the yield of a crop such as groundnut. However, the outcome is ambiguous and mechanisms need to be explored.

Where irrigation is necessary, the narrow ridge and furrow configuration is the most efficient system for applying water to an Alfisol and the flat system is the least efficient. In the direction of cultivation, the most appropriate slope for soil and water conservation and for the application of irrigation water is 0.2-0.4%. On slopes exceeding 0.6%, erosion can be excessive and the application of irrigation water inefficient.

For Alfisols with slopes exceeding 1.5%, a contour bund system with gated outlet effectively reduces runoff and erosion and increases crop yields. Crop yields in this system were consistently heavier than in conventional contour bunds, broadbed and furrows, or traditional flat beds with field bunds.

Crop residue management. On Alfisols, incorporation of nondecomposed dry crop residue was not beneficial. Incorporation of dry sorghum straw (5 t ha^{-1}) induced N deficiencies, and crop yields were severely reduced.

Surface mulches of groundnut shells that were incorporated in subsequent years improved rainfall infiltration, reduced soil erosion and increased crop yields. On average, over 6 years, a mulch rate of 10 t ha^{-1} reduced seasonal runoff by 69%, reduced erosion by 82%, increased sorghum yield by 23%, and increased pigeonpea yield by 31%.

Although yield increased consistently, the use of such large quantities of mulch is not practical on large areas of land. Groundnut shells are not normally used for any other purpose and significant water conservation could be achieved on limited areas.

Testing and Assessing Technology

Operational Scale Research

Rainfall in the Sahel is low, variable, and undependable whereas potential rates of evaporation are very rapid throughout the year. Sandy soils with little organic matter, a small water-holding capacity, and poor N and P status, cover 46% of the region. The problems of poor soils and a harsh environment, combined with generally poor socioeconomic conditions at farm level, contribute to low agricultural productivity.

Increased production and productivity can be obtained by better management: improved varieties, cropping systems that optimize the use of limited resources, limited fertilizer inputs to alleviate soil-nutrient deficiencies, techniques to reduce the damaging effects of sandstorms and drought spells, and improved methods to optimize labor requirements for various operations.

Scientists in the ISC Resource Management and Crop Improvement Programs, along with researchers in the national programs identified components of research that showed promising results (see ICRISAT Annual Report 1986, pp. 310-311). They are summarized below:

- Application of limited quantities of P (13 kg ha^{-1}), which was earlier found to be economical (ICRISAT Annual Report 1985, p. 305), and doubled pearl millet yields.
- An improved variety of pearl millet, ICMV 5 (ITMV 8001), recommended for release to farmers in Niger, gave increased and stable yields in multilocational tests.
- 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 resulted in better establishment and later survival of pearl millet (ICRISAT Annual Report 1985, p. 268).
- Use of animal traction for ridging and weeding resulted in a significant reduction of labor needs (ICRISAT Annual Report 1985, p. 273).

These components were systematically combined over the period 1986-88 to find out which combinations were advantageous. Crop rotations were included to assess the residual effects of a legume on pearl millet sown the following year. There were 13 treatments (Table 20), for which the agronomic details and the experimental design were given in the ICRISAT Annual Report 1986 (p. 311).

Table 20. Treatment combinations in Operational Scale Research (OPSCAR)[1] at ISC, Sadore, Niger, rainy seasons 1986-88.

Treatment combinations[2]	Sole/intercrop		
	1986	1987	1988
Continuous cropping			
Traditional	PM/C[3]	PM/C	PM/C
Improved			
Manual	PM/C	PM/C	PM/C
Manual	PM	PM	PM
Animal	PM/C	PM/C	PM/C
Animal	PM	PM	PM
Rotation cropping			
Improved			
Manual	PM/C	C	PM/C
Manual	C	PM/C	C
Manual	PM	C	PM
Manual	C	PM	C
Animal	PM/C	C	PM/C
Animal	C	PM/C	C
Animal	PM	C	PM
Animal	C	PM	C

1. Randomized-block design with 8 replications; plot size 500 m^2.
2. Explanation of treatments: Traditional: Local cultivars, no fertilizer, no animal traction.
   Improved : Improved cultivars with fertilizer (13 kg P ha^{-1}).
   Manual : Manual labor for sowing and weeding.
   Animal : Animal traction for ridging and weeding.
3. PM = Pearl millet; C = Cowpea; PM/C = Pearl millet/ cowpea intercrop.

In the 1st year (1986), rainfall was 657 mm, 17% above the long-term average of 560 mm. The rainy season started in late May and continued to the end of September. Since rotation and continuous cropping treatments for some combinations were similar, yield data for such combinations were pooled. There was a significant effect of ridging (with animal traction) on grain and stover yields in pearl millet in both sole and intercrops. Ridging had no significant effect on the yields of intercropped cowpea grain and hay but resulted in a significant increase of sole-cropped cowpea yield (Tables 21 and 22).

In 1987, rainfall was 450 mm, 20% below the average. The late onset of rain delayed sowing until 15 July, but the rain continued up to early October. Insect attacks reduced pearl millet grain yields which were lower than those in 1986, except from the traditional treatment. Pearl millet under improved management treatments (fertilizer or ridging), was severely attacked by Raghuva and *Rhinyptia infuscata* at the end of the season. In the traditional treatment, delayed maturity of pearl millet cultivar Sadore Local resulted in lower infestation. Cowpea suffered from drought stress at the flowering stage (end of August). Nevertheless, yields of grain and vegetative parts were significantly higher than those in the traditional practices.

In 1988, rainfall was 700 mm, 23% above the average. The rainy season started in mid-June and no drought spells occurred until the end of September. Since the operational scale research was in the 3rd year, we were able to compare the continuous system with the legume/ cereal rotated system. Traditional treatments produced almost the same quantity of grain as in previous years, but vegetative production was much higher than in 1987 (Tables 21 and 22).

There was a dramatic advantage of the rotation system vis-a-vis the continuous system. Pearl millet in 1988, after cowpea in 1987, yielded three times more grain than the continuous traditional system and almost twice as much as the continuous improved system. Production of stover was also almost doubled. There was no residual effect of intercropped cowpea on the grain yields of either sole pearl millet or sole cowpea sown the following year.

Sowing on ridges, which gave significantly higher pearl millet grain yields in 1987, did not affect grain production in 1988, but did increase stover production. In 1986 and 1988, adequate soil moisture was present at the flowering stage in cowpea and soil cultivation resulted in better grain production than in nonridged plots. In all years, cowpea hay production was promoted by soil cultivation before sowing in sole cowpea

Table 21. Grain yields (t ha^{-1}), recorded in different treatments in operational scale research (OPSCAR), ISC, Sadore, Niger, rainy seasons 1986-88.

	Pearl millet			Intercropped cowpea[2]	Sole cowpea		
Treatment[1]	1986	1987	1988	1986	1986	1987	1988
Continuous							
Traditional	0.30	0.30	0.27	0.12	-[3]	-	-
SE	±0.03						
Improved							
Manual	0.64	0.40	0.48	0.10	-	-	-
Manual	0.68	0.38	0.50	-	-	-	-
Animal	0.86	0.37	0.56	0.11	-	-	-
Animal	0.92	0.51	0.70	-	-	-	-
Rotation							
Improved							
Manual	0.64	-	0.93	0.10	-	0.25	-
Manual	-	0.55	-	-	0.66	-	0.43
Manual	0.68	-	0.94	-	-	0.41	-
Manual	-	0.51	-	-	0.66	-	0.48
Animal	0.86	-	1.12	0.11	-	0.40	-
Animal	-	0.68	-	-	0.80	-	0.66
Animal	0.92	-	0.96	-	-	0.50	-
Animal	-	0.58	-	-	0.80	-	0.77
SE	±0.02	±0.07	±0.08	±0.01	±0.02	±0.05	±0.05
CV (%)	31	41	31	45	24	35	23

1. For explanation of treatments and design, see Table 20.
2. Cowpea grain yields were lower than 0.1 t ha^{-1} in 1987 and 1988.
3. - = Not applicable.

plots. Fertilizer application (13 kg ha^{-1}) of P uniformly increased pearl millet yields. Pearl millet grain production was not affected by the intercropped cowpea sown at a density of 0.5 hills m^{-2}.

For yield increases, there is good evidence of the advantage of a system combining limited application of P (13 kg ha^{-1}), improved varieties of pearl millet and cowpea, cereal legume rotation and the use of animal traction. However, the economics of the system still have to be analyzed. We have started similar OPSCAR studies with INRAN in Birni N'Konni (Niger) (ICRISAT Annual Report 1987, p. 324) and IER in Cinzana (Mali).

Adoption

High-yielding Cereal Cultivars

In the early and mid-1960s, fertilizer-responsive, photoperiod-insensitive, high-yielding cultivars of maize, pearl millet, rice, sorghum, and wheat

Table 22. Yields for vegetative parts (t ha^{-1}) recorded in different treatments in operational scale research (OPSCAR), ISC, Sadore, Niger, rainy seasons 1986, 1987, and 1988.

	Pearl millet stover			Intercropped cowpea hay			Sole cowpea hay		
Treatment[1]	1986	1987	1988	1986	1987	1988	1986	1987	1988
Continuous									
Traditional	1.15	0.52	1.41	0.52	0.19	0.33	-[2]	-	-
SE	±0.11			±0.06					
Improved									
Manual	2.06	1.04	1.59	1.21	0.27	0.48	-	-	-
Manual	2.01	0.86	1.48	-	-	-	-	-	-
Animal	2.77	0.93	1.78	0.92	0.32	0.46	-	-	-
Animal	3.18	1.33	2.91	-	-	-	-	-	-
Rotation									
Improved									
Manual	2.06	-	2.75	1.21	-	0.36	-	0.32	-
Manual	-	1.47	-	-	0.19	-	0.48	-	0.71
Manual	2.01	-	3.28	-	-	-	-	0.38	-
Manual	-	1.27	-	-	-	-	0.48	-	0.69
Animal	2.77	-	3.97	0.92	-	0.46	-	0.47	-
Animal	-	1.97	-	-	0.23	-	0.58	-	1.22
Animal	3.18	-	3.84	-	-	-	-	0.46	-
Animal	-	1.71	-	-	-	-	0.58	-	1.23
SE	±0.03	±0.18	±0.32	±0.04	±0.04	±0.08	±0.08	±0.07	±0.17
CV (%)	32	40	35	29	50	51	43	32	49

1. For explanation of treatments and design, see Table 20.
2. - = Not applicable.

were released in India. In many regions, these high-yielding varieties and hybrids were rapidly adopted by farmers, but in other areas, farmers still favored local landraces.

A systematic inquiry was made by a PhD scholar into the reasons for this interregional variation in cereal adoption. Data from 1956 to 1984 were assembled for 236 districts in nine Indian states. For each of the five cereals, the 60 districts with the largest crop production were selected for analysis. Ceiling or plateau levels of adoption were estimated for each district by fitting a logistic function to the time-series data.

For most of the districts, adoption of a particular cereal displayed the typical s-shaped diffusion pattern illustrated in Figure 17, but the estimated ceiling levels often did not approach 100%. Wheat was the exception: full adoption had occurred in the majority of major wheat-producing districts. For the other cereals, sharp disparities in regional adoption patterns were evident. Sorghum hybrids were popular in central Maharashtra, but they had made little headway in areas of postrainy-season production in western Maharashtra and Karnataka (Fig. 18, left). Likewise, pearl millet hybrids pre-

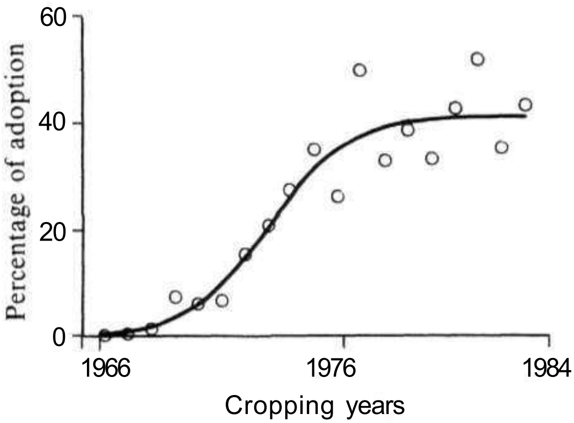

Figure 17. A logistic or S-shaped adoption pattern (fitted curve) for hybrid sorghum in Chitadurga, a district in peninsular India.

vailed in major growing districts in Gujarat, Tamil Nadu, and Haryana but in other districts, particularly in Rajasthan, diffusion had not taken off or had peaked at levels significantly less than 100% (Fig. 18, right).

Analysis of factors explaining the variation in adoption ceilings across major cereal-producing regions confirmed that agroclimatic and soil differences were substantially more important than infrastructural and institutional differences for all the five cereals. For sorghum, regional adoption was significantly ($P<0.05$) and positively associated with irrigation, June rainfall, fertilizer sales, and fractional area sown to sorghum in the rainy season. Adoption was significantly and adversely affected by more variable total

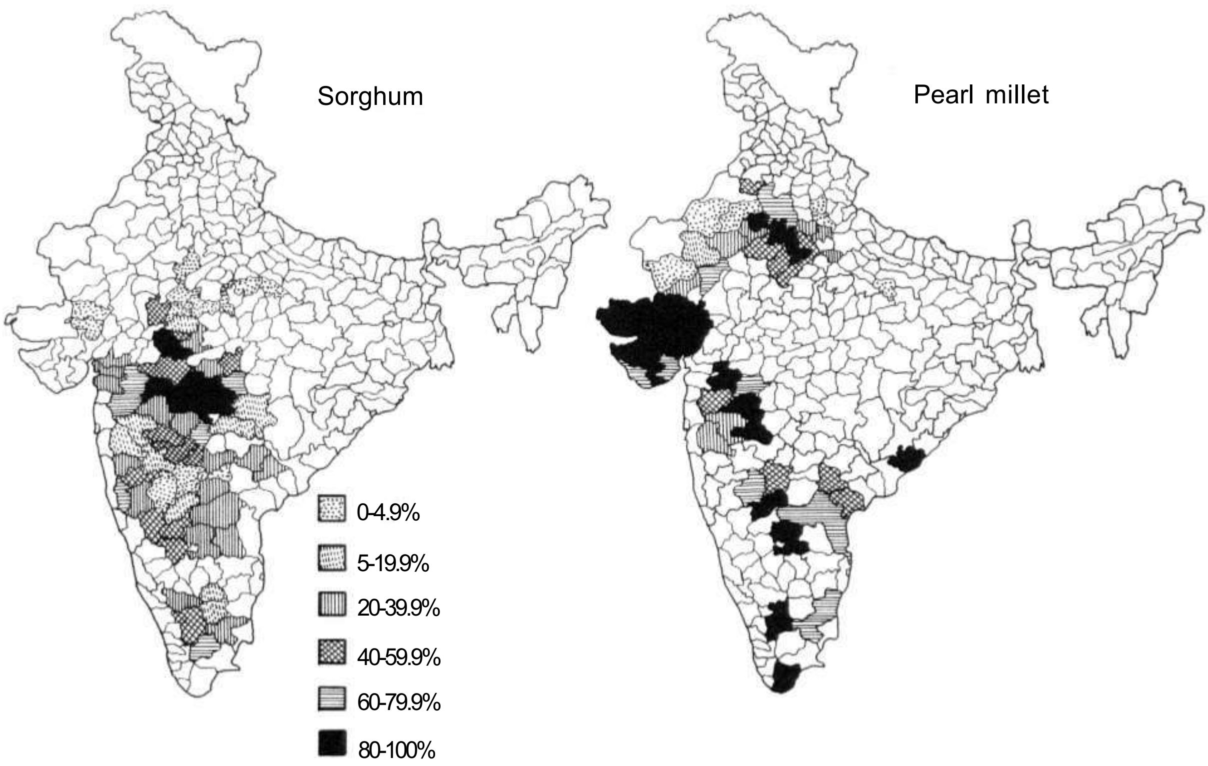

Figure 18. Estimated ceiling levels of adoption of sorghum and pearl millet in the major producing districts of India.

rainfall, more variable September rainfall, higher man/land ratios, and higher total rainfall, particularly on deeper black soils where drainage can be a problem. The effect of higher man/ land ratios probably reflects greater urban demand for milk, and consequently fodder, for which the modern grain cultivars are often perceived by farmers as inferior to local types.

Turning to pearl millet, adoption was significantly and positively correlated with June rainfall and with regional production potential reflected in yield in the 1950s and early 1960s before hybrids were introduced. If all other relevant factors remained unaltered, the ceiling level of adoption was significantly reduced in districts with more variable June, July, and August rainfall, with alluvial soils and high rainfall, and with sandy soils and low rainfall.

These findings suggest that investing more resources in infrastructural improvement such as extension, roads, or markets will not have a marked effect in raising adoption ceilings. Faster adoption in those laggard districts needs qualitatively different genotypes and more decentralized plant breeding, focusing on specific yield reducers and end-use preferences in well-defined climatic and edaphic regions.

Modeling

Pearl Millet Model

A pearl millet simulation model has been described earlier in the ICRISAT Annual Report 1987 (pp. 330-332). We have now used this model to assess sowing dates and to simulate grain yield during the rainy seasons for one representative pearl-millet growing area of India (Jodhpur, Rajasthan 26 °N, 73 °E) using daily climatic data from 1930-1987. Rainfall during the growing season ranged from 71 to 710 mm, and so, crop growth under rainfed conditions must have fluctuated widely from year to year.

To start a cropping season, we chose the first sowing date after 1 June, when at least 30 mm rain had fallen within three consecutive days. The probability of sowing was then 28% by 1 July, and 62% by 15 July. Simulated sowing dates matched the actual sowing dates well (Fig. 19) in Jodhpur, between 1971 and 1985. Actual sowing dates and yields of pearl millet (cv BJ 104) grown at the C.R. Farm, Jodhpur, were taken from the annual reports of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) for the period 1971-85. A mixture of 20 kg N ha^{-1} and 40 kg P ha^{-1} was drilled at sowing and the 20 kg N ha^{-1} was top dressed a month after sowing. The crop was infected by ergot disease in 1976. We estimated from long-term climatic analysis that crops should have been resown in 6 of the 58 years because there was no rain for more than 20 days after the first sowing, the criterion for failure of crop establishment.

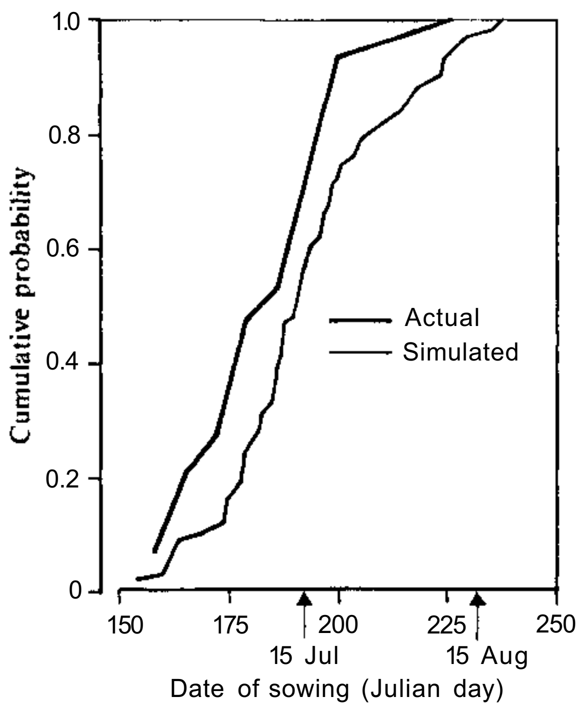

Figure 19. A comparison of the actual and simulated probabilities of sowing pearl millet (on a particular day) between 1 Jun and 31 Aug at Jodhpur, Rajasthan, India. Actual data were for 1971 -85 and simulations were for 1930-87.

Yields of the cultivar BJ 104 were simulated, assuming an optimum plant stand, adequate nutrients, and plant protection. Simulated yields using climatic data from 1971 to 1985 (data base for actual yields) showed similar probabilities to that of 1930-87. The simulated yield (1930-87) ranged from nil to 3.2 t ha^{-1}, matching the range of actual yields observed at Jodhpur from 1971 to 1985 (Fig. 20). However, in 80% of the years, simulated yields were greater than actual yields and several aspects of the model may be responsible for this discrepancy. For example, the assumption of an optimum plant stand and the assumption that the harvest index is 45%, which may be correct only in years when rainfall is well distributed. The model needs to be changed to account for the effects of early-season stress on plant establishment, and of terminal stress on harvest index. Nevertheless, it is likely that much of the discrepancy between the actual and simulated yields are a consequence of biotic and nutrient stresses implying that it should be possible to increase yields by better management. For example, resowing in some of the years as assumed in the simulation study, critical timing of N application in relation to rainfall distribution, and adequate pest/disease control could have improved yields.

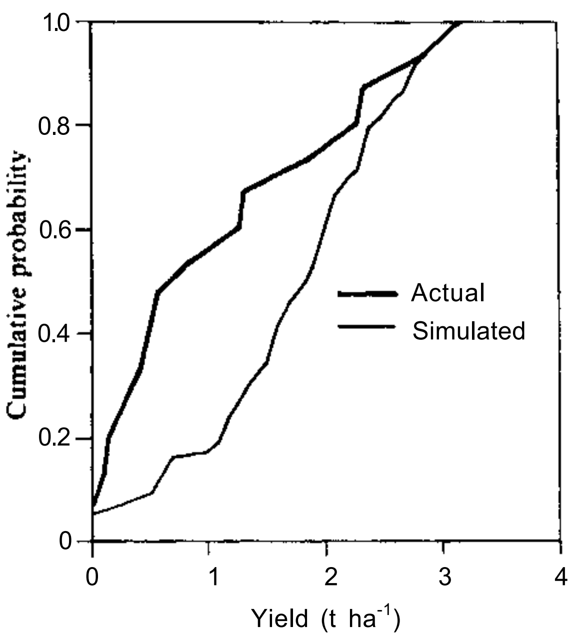

Figure 20. Probability of less than a specific yield of pearl millet in the rainy season at Jodhpur, Rajasthan, India. Actual data were for 1971-85 and simulations were for 1930-87.

Water and Nitrogen Responses

Pearl Millet

A growth model for pearl millet was used to consider the effect of drought at different phenological stages (ICRISAT Annual Report 1987, pp. 330-332). More information is needed to include N in the model, in addition to water. To study the response of pearl millet (cv BJ 104) to amounts of N and to drought treatments imposed at different phenological stages, we conducted two experiments on an Alfisol during the dry seasons of 1985 and 1986. The drought treatments were:

MI = adequate water supply throughout the season,

M2 = drought during growth stage 2 (GS2), i.e., from panicle initiation to anthesis,

M3 = drought during growth stage 3 (GS3), i.e., from anthesis to physiological maturity.

In both years, seed was sown in the 1st week of February. Fertilizer (21 kg P ha^{-1} in the form of single superphosphate, and N in the form of urea) was applied at sowing in both years. Subplots in each drought treatment received four levels of N in 1985 and six in 1986.

Irrigation was applied when accumulated open-pan evaporation exceeded 80 mm. In 1985, total evaporation during the growing season from the crop and soil was 410 mm in MI, 308 mm in M2, and 312 mm in M3. Corresponding values in 1986 were 512 mm in MI, 409 mm in M2, and 304 mm in M3.

Table 23 shows grain yield and total dry matter (TDM) for both years. The pattern of response of pearl millet to water and N was somewhat similar in both years. Drought stress in GS2 affected grain yield and TDM, but the

Table 23. Response to drought and N of grain yield and total dry matter (main culms + tillers) (t ha^{-1}) of a pearl millet cultivar (BJ 104) on an Alfisol, ICRISAT Center, postrainy seasons 1985 and 1986.

Nitrogen ($kg\ ha^{-1}$)	Drought treatments					
	M1	M2	M3	M1	M2	M3
	Grain yield			Total dry matter		
			1985			
0	1.43	1.90	1.47	3.77	3.75	3.23
40	2.14	2.42	1.46	4.71	5.13	3.72
80	2.31	2.32	1.44	5.65	4.81	4.04
120	2.60	2.32	1.55	6.20	5.20	4.47
SE_1[1]		±0.16			±0.29	
SE_2[2]		±0.11			±0.23	
			1986			
0	1.32	1.28	0.60	3.03	2.56	2.16
25	1.74	1.63	0.83	4.35	3.44	2.41
50	2.04	1.65	0.86	4.78	3.48	2.69
75	2.36	1.67	1.00	5.78	3.70	3.12
100	2.26	2.19	0.85	5.58	4.58	2.69
125	2.43	2.02	0.81	5.67	4.62	3.01
SE_1[1]		±0.14			±0.30	
SE_2[2]		±0.10			±0.23	

1. SE_1 = SE for comparing drought treatment at the same or at different levels of N.
2. SE_2 = SE for comparing N levels at the same drought treatment.

effect of drought was more pronounced for TDM. In the M2 treatment, there was no response to N beyond 40 kg ha^{-1} in 1985, and 100 kg ha^{-1} in 1986.

Drought stress in GS3 reduced grain yield at all N levels in both years, more so in 1986. The yield reduction was mainly because of a smaller contribution by tillers. Another reason was that drought stress in GS3 reduced the grain-filling period by about 1 week in both years and at all N levels. Though grain yield did not increase with N in M3, the TDM did. Thus in both years, drought reduced the harvest index when applied in GS3 but increased it when applied in GS2 (Fig. 21).

The smaller grain yield and TDM in the 1986 M3 treatment compared to the 1985 treatment suggests that the drought may have been more intense in 1986. Another general observation is that both grain yields and TDM were smaller in summer-season crops than in rainy-season crops. Though N, radiation, and water supply were not limiting in the M1 treatment, higher saturation deficits and air temperatures inevitably increase the demand for water and this may restrict crop growth and development.

Sorghum

Root biomass and N fertilizer. The root system of a crop is important not only in its function,

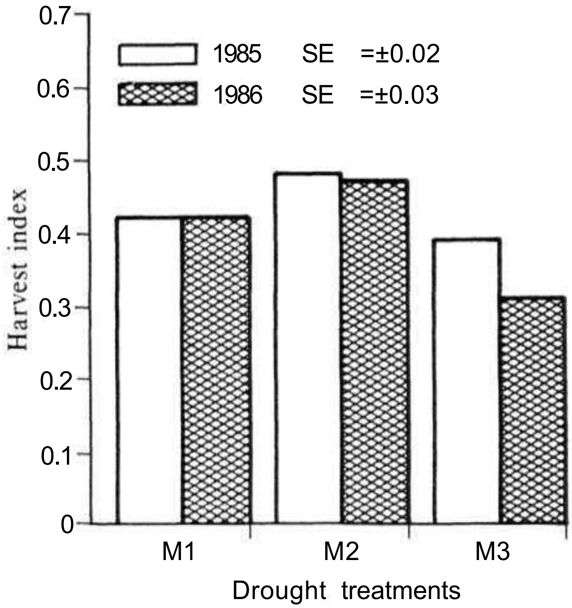

Figure 21. Harvest index (grain yield/total dry matter) of pearl millet (BJ 104) in three drought treatments (M1 = adequate water supply, M2 - stress in GS2, M3 = stress in GS3) averaged over different N levels. The crops were grown on an Alfisol at ICRISAT Center, post rainy seasons 1985 and 1986.

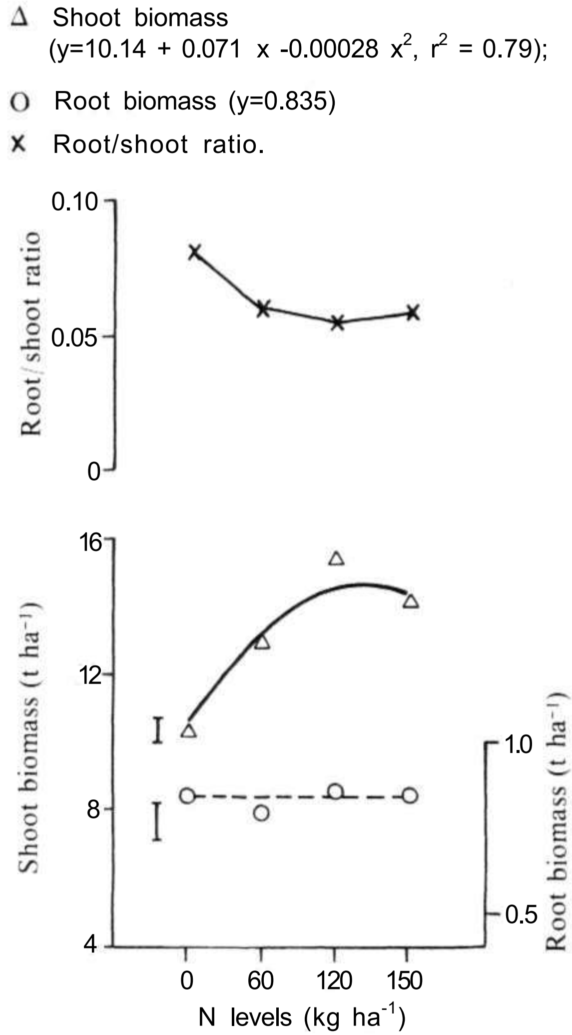

Figure 22. Root biomass, shoot biomass, and root/shoot ratio of sorghum CSH 11 at harvest, grown on an Alfisol, ICRISAT Center, rainy season 1988. Panicle is included in shoot biomass, each N level includes three P levels (0, 13, and 26 kg ha^{-1}), harvested area is 0.4 m^2.

but also in terms of biomass accumulation. Dry matter accumulates in the roots at the expense of the shoot, but decomposition of roots provides nutrients to the soil and also reduces loss by immobilizing soil nutrients. Accurate observation of the way in which root biomass can be altered by fertilizers will provide information to make crop growth models more realistic and to help soil management.

We grew sorghum [ICSH 153 (CSH 11)] in the rainy season at ICR1SAT Center on an Alfisol with three levels of P fertilizer (0, 13, and 26 kg ha^{-1}), and four levels of N fertilizer (0, 60, 120, and 150 kg ha^{-1}). We sampled shoots (including panicles) and roots to a depth of 0.9 m from a 0.4 m^2 area at harvest to determine biomass.

Neither root nor shoot biomass was significantly affected by P levels. Application of N fertilizer did not change root biomass significantly, but a significant increase in shoot biomass was observed (Fig. 22). This result indicates that in soils where P and water are not limiting, changes in the root-shoot ratio depend only on changes in shoot biomass. An optimum level of N fertilizer would produce a large amount of shoot biomass, with minimum diversion of carbon to the root system. The input of root organic carbon into the soil is not reduced, so soil fertility is maintained.

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TECHNOLOGY TRANSFER

Human Resource Development

During 1988, 224 research scientists and technical staff from 51 countries participated in 4628 weeks of individualized training programs at 1CRISAT Center (Tables 1 and 2). Our training officers and research scientists guided these participants in individualized Postdoctoral Fellowships, In-Service Fellowships, Research Scholarships (MSc and PhD), and In-Service Trainee and Apprentice programs, which were coordinated by the Training Advisory Committee. The participants were nominated by national Ministries of Agriculture, universities, or semi-arid

Table 1. Participants in long-term training program, ICRISAT Center, 1988.

Category	Number	Weeks	Countries
Postdoctoral Fellows	3+15[1]	710	12
In-service Fellows	27+5	187	16
Research Scholars	9+14	794	12
In-service Trainees	126+11	2779	39
Apprentices	7+7	158	7
Total present	172+52	4628	51[2]

1. Number continuing into 1989.
2. Different countries.

Table 2. Participants by region, country, and category in training, ICRISAT Center, 1988.

Region/country	IS[1]	ISF[1]	RSC[1]	PDF[1]	App[1]	Total
Western Africa						
Benin	1					1
Burkina Faso	6					6
Cameroon	1					1
Chad	3					3
C6te dTvoire	2					2
Ghana	4			0+1[2]		4+1
Guinea	3					3
Mali	6					6
Mauritania	2					2
Niger	9					9
Nigeria	4					4
Senegal	5					5
The Gambia	2					2
Eastern Africa						
Burundi	2					2

Continued

Table 2. *continued.*

Region/country	IS[1]	ISF[1]	RSC	PDF[1]	App[1]	Total
Ethiopia	11	2+1	0+1			13+2
Kenya	2		2			4
Somalia	3+1	1	0+2	0+1		4+4
Sudan	2+1	1				3+1
Uganda					0+1	0+1
Southern Africa						
Angola	1					1
Botswana	1					1
Malawi	3+1					3+1
Mozambique	4					4
Tanzania	3	1	0+1			4+1
Zambia	6+1					6+1
Asia						
Afghanistan	0+2					0+2
Bangladesh	2	1				3
India	2	3+2	3+5	4+2	0+1	12+10
Indonesia	3	4				7
Malaysia		1				1
Nepal	2	2			4	
Pakistan	2+2	1				3+2
People's Republic of China	4	2	0+1			6+1
Republic of Korea		1				1
Sri Lanka	3+1	4		1		7+2
Thailand	6	2				8
The Philippines	4+1	2				6+1
Vietnam	7		0+1			7+1
Yemen Arab Republic	2					2
Latin America and the Caribbean						
Argentina				0+1		0+1
El Salvador	1					1
Mexico	3	1				4
Trinidad				0+1		0+1
Others						
Australia				1	1	2
Belgium			1			1
Federal Republic of Germany			2+1	0+1	3	5+2
France				0+1		0+1
Japan			1	0+1	0+3	1+4
The Netherlands					2+1	2+1
UK			1		2	3
USA			0+1	0+2	1	1+3
Total	126+11	27+5	9+14	3+15	7+7	172+52

1. IS = In-service Trainees, ISF = In-service Fellows, RSC = Research Scholars, PDF = Postdoctoral Fellows, App = Apprentices.
2. Number continuing into 1989.

tropics (SAT) research and development programs.

International, regional, and national training activities involved more than 216 SAT national scientists, technicians, and students from 32 countries (Tables 3 and 4). We conducted training courses at ICRISAT Center and at national research centers, dealing with research skill development, research station management, thesis research, field study, field day, and traveling seminars.

In-service Training Programs at ICRISAT Center

The 12th intensive 8-week course in scientific English comprehension and skill development was attended by 47 research scientists and technicians from 16 countries: Burkina Faso, Burundi, Chad, C6te d'Ivoire, Guinea, Italy, Mali, Mauritania, Mexico, Mozambique, Niger, People's Republic of China, Senegal, Sudan, Thailand, and Vietnam.

Postdoctoral fellow in pathology working on phytophthora blight of pigeonpea.

Table 3. International, regional, and national special training activities, 1988.

Activity (sponsors/ leadership)	Location	Participants	Country and participants
1 Feb to 4 Mar. Training in millet pathology for West African technicians (1CRISAT, ISC)	India	10	Benin, Burkina Faso, Cameroon, Ghana, Mali, Niger(2), Nigeria, Senegal(2).
7 Mar to 17 Apr. Land and water management for Vertisols (ILCA, ICRISAT)	India	6	Ethiopia.
1 Jul to 30 Sep. Evaluation of grain and food quality of cereals (ICRISAT)	India	7	Burundi, Ghana(2), Niger, Nigeria, Tanzania, Zambia.
11-26 Jul. Detection of groudnut viruses, with special emphasis on peanut stripe virus (FAO, ICRISAT, CRIFC, IDRC)	Indonesia	12	India, Indonesia(2), Republic of Korea, Malaysia, Nepal, Pakistan, People's Republic of China, Sri Lanka, Thailand, the Philippines(2).
1-14 Aug. Evaluation of grain and food quality of legumes (FAO, ICRISAT, ADB)	India	8	Bangladesh, Indonesia, Nepal, Pakistan, Sri Lanka, Thailand, the Philippines, Vietnam.
7 Aug to 8 Oct. Special training in agroclimatology (ICRISAT)	India	3	Zambia.
3-16 Oct. Integrated control of grain legume pests in Asia (FAO, ICRISAT, ADB)	India	10	Bangladesh, India(2), Indonesia, Nepal, Pakistan, Sri Lanka, Thailand, the Philippines, Vietnam.
1 Feb to 5 Mar. Station development and management training (SADCC/ICRISAT, ICRISAT)	Zimbabwe	14	Botswana(3), Lesotho(3), Malawi(2), Swaziland(2), Zambia(2), Zimbabwe(2).
12-19 Oct. Training workshop on sorghum and millet modeling (IBSNAT, IFDC, ICRISAT)	India	20	Australia, Ethiopia, India(12), Somalia, Thailand, USA(4).
5 17 Dec. Training workshop on agroclimatology of Asian grain legume growing areas (ICRISAT, AGLN, FAO, IBSNAT)	India	35	Bangladesh(3), India(6), Indonesia(3), Italy, Malaysia, Nepal(4), Pakistan(3), People's Republic of China(2), Sri Lanka(2), Thailand(3), the Philippines(4), USA(3).

The 75 rainy-season participants represented 30 countries. The cereals improvement, legumes improvement, crop production, and resource management groups (Table 5) received training in plant breeding, pathology, physiology, entomology, field and laboratory research methods, data analysis, production agronomy, resource management, and research management (Tables 6 and 7). Data continue to demonstrate that differences in an individual's managerial decisions and agronomic skills result in greater differences in findings among similar demonstrations and experiments than a variety or treatment. The participants successfully completed their 6-

month study and summarized their experimental findings, organized reports, and presented seminars.

Other programs included an agroclimatic analysis of 15 Zambian stations conducted by three technicians during a 6-week training program. A special program to study the climatic data from Marin, Mexico, was completed during a Mexican trainee's 6-month program. Six Ethiopian scientists and technicians participated in a 6-

Table 4. In-country training activities, 1988.

Location	Activity (sponsors/ leadership)	Participants	Countries or representatives
Nepal	20-30 Mar. Training course on chickpea, pigeonpea, and lentil (NARSC, NGL1P/ ICRISAT, AGLN, ICARDA)	18	Subject matter specialists from District Offices or Farming Systems Research Development Divisions in Nepal.
India	9-10 May. Training workshop on groundnut production technology (LEGOFTEN/ ICRISAT)	34	State department agricultural scientists (10 states).
India	11-13 May. Training workshop on pigeonpea and chickpea production technology) (LEGOFTEN/ICRISAT)	39	State department agricultural scientists (10 states).

Table 5. In-service rainy-season participants in 1988.

Study group	Country participants	Total number of participants
Cereals Improvement	Burkina Faso, El Salvador, Ethiopia(2), Guinea, Kenya, Mali(2), Mauritania, Mexico, Mozambique, Niger, Nigeria, People's Republic of China(2), Senegal(2), Tanzania, the Gambia, Vietnam(2).	21
Legumes Improvement	Guinea, Kenya, Niger, People's Republic of China(2), Senegal, Thailand, Vietnam(2).	9
Crop Production	Burkina Faso, Burundi, Chad(2), Cote d'Ivoire, Ghana, Malawi(2), Mali(2), Mauritania, Mozambique, Somalia(3),,Sudan(2), Tanzania, Thailand, the Philippines, Yemen Arab Republic(2), Zambia(2).	24
Resource Management	Angola, Botswana, Burkina Faso(2), Chad, Guinea, Indonesia, Malawi, Mali, Mexico(2), Mozarnbique(2), Niger(2), Nigeria, Thailand(2), the Gambia, the Philippines, Vietnam.	21
Postrainy-season Legumes Improvement	Afghanistan(2), Malawi, Pakistan(2), Sri Lanka, Sudan, the Philippines, Zambia.	9

In-service resource management trainee studying cropping systems.

Table 6. Experiments, trials, and demonstrations planned and conducted by rainy-season in-service trainees, ICRISAT Center, 1988.

Experiment or trial involving	Crop				Inter-cropping	Total
	Sorghum	Pearl millet	Groudnut	Pigeonpea		
Varieties	12	4	14	3		33
Hybrids	6					6
Fertilizers	12	10	4	2		28
Weed control	1	1				2
Plant density	13	3	5	1		22
Sowing dates	2		2			4
Rhizobium use			1			1
Pathology	6	2	3			11
Entomology	4					4
Intercropping					31	31
International trials	8	12	5	2		27
Demonstrations	1	1	1		3	6
Crossing blocks	20	12	5			37
Total	85	45	40	8	34	212

Table 7. Practical in-service training activities guided by program scientists, ICRISAT Center, Jun-Oct 1988.

Discipline	Participants and length of study			
	I week	2 weeks	3 weeks	6 weeks
Cereals Program				
Breeding		18		
Entomology	1	4	10	
Genetic resources	13			
Pathology	10	5		
Physiology	14			
Legumes Program				
Pathology	8	10		1
Physiology	3	1		
Breeding	2		6	
Entomology	14			
Genetic resources	8			
Virology	2			
Resource Management				
Economics	14			
Soil fertility	13			1
Land and water management	21			1
Cropping systems	26			
Farm power and equipment	1			
Agroclimatology	12		1	
Soil physics and conservation	9			
General				
Research station management	12			1
Biochemistry	4	3		
Microcomputer uses	13	2		
Experimental designs	15	2		
On-farm research methods	2			
Training methods	1			
Plant quarantine	2			
Plant protection	15			

week course on management of Vertisols organized by the Resource Management Program. An Ethiopian technician was trained for 6 months in laboratory techniques for soil analysis.

The postrainy-season group consisting of nine participants from seven countries studied legumes improvement skills (Table 8). Their training was based on the use of supplemental irrigation in managerial and agronomic considerations.

In-Service Regional and National Activities

Participants of the training program in sorghum improvement and production completed 3-month courses at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) with the Mesoamerican Sorghum Program. They were

In-service resource management trainee studying cropping systems.

Table 6. Experiments, trials, and demonstrations planned and conducted by rainy-season in-service trainees, ICRISAT Center, 1988.

Experiment or trial involving	Crop: Sorghum	Crop: Pearl millet	Crop: Groudnut	Crop: Pigeonpea	Inter-cropping	Total
Varieties	12	4	14	3		33
Hybrids	6					6
Fertilizers	12	10	4	2		28
Weed control	1	1				2
Plant density	13	3	5	1		22
Sowing dates	2		2			4
Rhizobium use			1			1
Pathology	6	2	3			11
Entomology	4					4
Intercropping					31	31
International trials	8	12	5	2		27
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Pathology	10	5		
Physiology	14			
Legumes Program				
Pathology	8	10		1
Physiology	3	1		
Breeding	2		6	
Entomology	14			
Genetic resources	8			
Virology	2			
Resource Management				
Economics	14			
Soil fertility	13			1
Land and water management	21			1
Cropping systems	26			
Farm power and equipment	1			
Agroclimatology	12		1	
Soil physics and conservation	9			
General				
Research station management	12			1
Biochemistry	4	3		
Microcomputer uses	13	2		
Experimental designs	15	2		
On-farm research methods	2			
Training methods	1			
Plant quarantine	2			
Plant protection	15			

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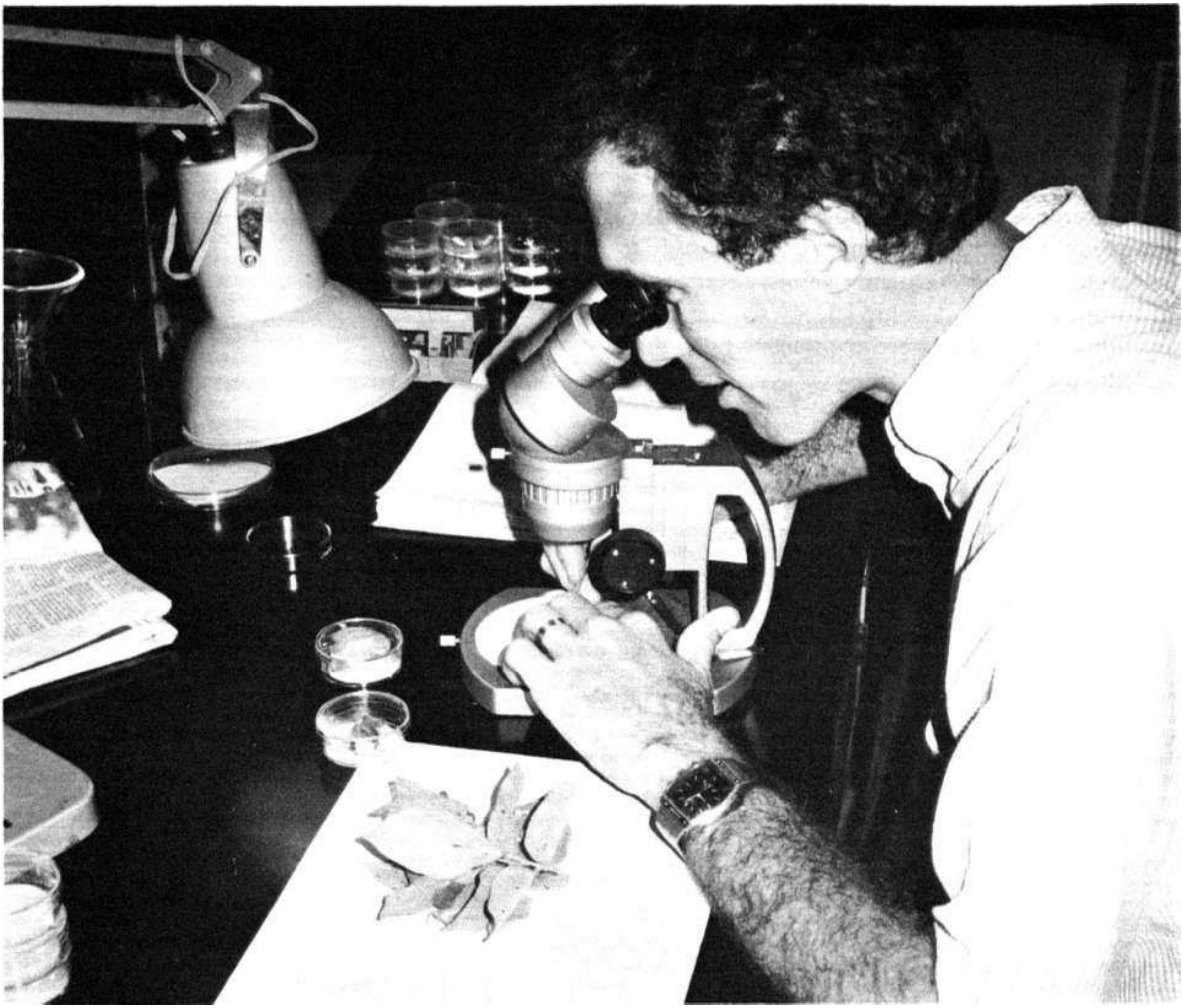


PhD entomology research scholar studying groundnut leaf miner and its parasites.

completed a 2.5-year thesis research and identified transferable salinity tolerance in pigeonpea and some of its wild relatives.

A Kenyan MSc student from the University of Nairobi completed an 18-month study on the inheritance of dwarfism in pigeonpea. Another Kenyan student's MSc thesis research was on the effect of environmental factors on growth, pod set, and yield of short-duration pigeonpea.

A Japanese student from the Tokyo University of Agriculture and Technology studied for 10 months the response of pigeonpea to mycorrhizal inoculation in relation to soil phosphorus and moisture stress.

A PhD student from the Max-Planck Institute completed field studies for a PhD degree on the potential chemical basis of resistance/susceptibility to *Helicoverpa* in pigeonpea and chickpea.

A Belgian PhD student from the University of California studied for 7 months the current production systems and determinates of technical change in the semi-arid tropics of West Africa.

Resource Management Program

A British PhD student from the University of Nottingham completed a 2-year thesis on competition between a row crop and Leucaena in an alley cropping system.

A PhD student from the University of Groningen, the Netherlands, spent an additional 6 months collecting field data on rainfall insurance.

Genetic Resources Unit

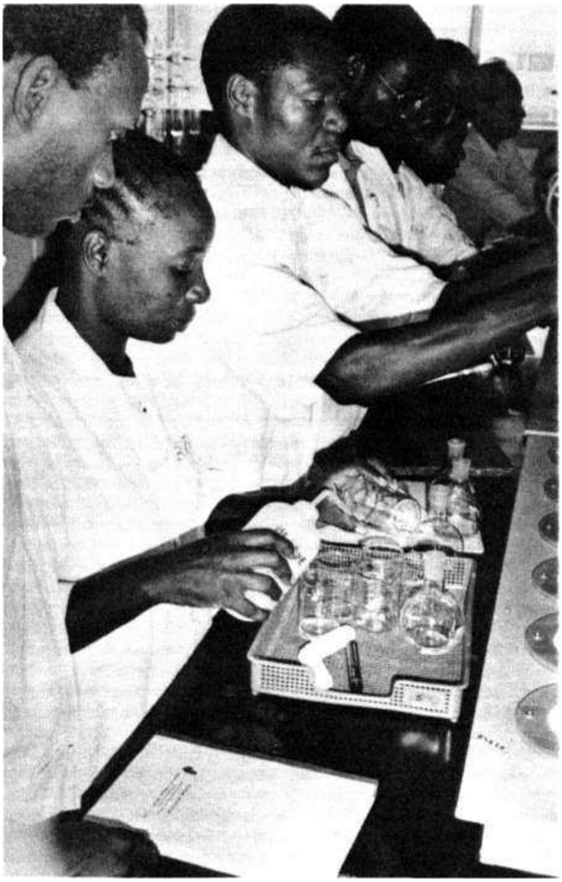
An Indian Institute of Technology student's 6-month MTech thesis research was on genetic resource management techniques in relation to pearl millet improvement.

Research Scholar Regional and National Activities

Mali

ICRISAT-Mali scientists supervised the field projects of two Katibougou Agricultural College students who studied the productivity of pearl millet/sorghum and sorghum/groundnut intercropping systems.

A technician from ICRISAT Center demonstrating downy mildew inoculation techniques to his counterparts from West Africa during the 5-week training course in pearl millet pathology held 1 Feb to 4 Mar at ICRISAT Center.



Food quality in-service trainees preparing foods.

Niger

A PhD student from the Federal Republic of Germany completed a 3.5-year thesis research program in soil chemistry with the staff of the ICRISAT Sahelian Center (ISC) and University of Hohenheim. MSc students from the University of Wageningen completed research (6 months each) on the effect of soil tillage on the reduction of bulk density, soil structural stability, and on pearl millet growth, and on soil and crop management (weeding) effects on weed growth and pearl millet yields. Nigerian technicians in agriculture completed a 4-month degree project on the evaluation of germination of forage grasses and legumes, and on the interaction of crop residues and soil fertility.

Two students from the University of Niamey completed a 3-month research project on calcium nutrition in groundnut and varietal evaluations of groundnut, while a PhD student studied phosphorus and micronutrient nutrition in groundnut for one cropping season. Our pathologists guided a 3-month study project done by two Chadian students, on the reaction of the *Pennisetum violaceum* to *Striga hermonthica* in pots and the relationship between infestation level of *Striga hermonthica* in pots and in the field.

A Nigerian from the Institut pratique de developpement rural (IPDR), Kolo, completed a 4-month study for a thesis project on stand establishment of pearl millet in farmers' fields. A Nigerian MSc student of the University of Rennes completed a 3-month field study on varietal differences in development and dry matter partitioning in pearl millet. A Burkina Faso student had a 3-week special training in the biology of *Heliocherlus (Raghuva) albipuntella.*

Zimbabwe

SADCC/ICRISAT staff accommodated 10 final-year BSc agricultural degree students from the University of Zimbabwe, in a 3-month on-station study program. Two persons completed study projects in each study area: cereal agronomy, pearl millet breeding, sorghum breeding, cereal entomology, and cereal pathology, with special emphasis on methods of literature review, research methods, report writing, and seminar presentation. Twelve students initiated similar study programs late in the year.

A Botswana student from Texas A&M University initiated PhD thesis research on aphid resistance. One University of Zimbabwe PhD student continued his thesis research on losses due to stem borer in sorghum. A Federal Republic of Germany PhD student from the University of Hohenheim continued economic studies on the potentials of and constraints in small grain production, consumption, and marketing in smallholder farming systems of Zimbabwe.

A British student of the University of London continued research on the biology and epidemiology of ergot on sorghum.

Apprentice Activities

An Australian student from the University of New England had a 3-month work-study program in economics. An undergraduate from UK initiated a study program on the interaction of nitrogen and water in relation to the growth of postrainy-season sorghum. A Dutch intern worked for 6 months on ways to estimate yield of sorghum in response to weather and soil fertility using modeling techniques. A self-supported Federal Republic of Germany undergraduate completed a 4-month cytogenetics study on regeneration of pigeonpea and its wild relatives from callus and explant tissues. An undergraduate from the Netherlands undertook a 3-month study in chickpea breeding techniques. Two apprentices from the Federal Republic of Germany worked with pearl millet breeding projects related to identification of drought-resistance characteristics in selections from drought-prone areas. Three Japanese apprentices studied legumes in response to phosphorus uptake from soils.

Networks

Networks at ICRISAT Center

Over the years ICRISAT has formed strong links with scientists in the National Agricultural Research Systems (NARSs) through its many international nurseries, workshops, training activities, and literature distribution. These links have provided a means of moving material and technologies developed at ICRISAT to NARS scientists, and of facilitating feedback from these scientists to ICRISAT. These same links have been used to promote the interchange of information and ideas among the NARS and ICRISAT scientists. Convinced of the value of these links, ICRISAT has increasingly become involved in formalizing its network activities. The goal of the networks is to maximize the effectiveness of the existing NARS research capabilities in helping to solve the problems of the semi-arid tropics (SAT) farmer. Examples are the eastern and the southern African sorghum and millet improvement networks (ICRISAT Annual Report 1986, pp. 61-63); the West African sorghum research network (ICRISAT Annual Reports 1986, pp. 60-61, and 1987, p. 71), and the Asian grain legumes network (ICRISAT Annual Report 1986, pp. 204-205). Each network is based on an ICRISAT mandate crop, and focuses on problems shared by the network members. The activities of each network are facilitated by a coordinator or a coordination unit, guided by a steering committee comprising NARS representatives. This section reports network activities and services that are helping ICRISAT to fulfill its technology transfer mandate.

Asian Grain Legumes Network (AGLN)

The Asian Grain Legumes Network (AGLN) was established by ICRISAT in 1986 to facilitate the effective utilization of ICRISAT's research products by national agricultural research systems in South Asia (Bangladesh, Burma, India, Nepal, and Sri Lanka) and Southeast Asia (Indonesia, People's Republic of China, Thailand, and the Philippines). Such research products consisted of plant material, research methods, and results available from the groundnut, chickpea, and pigeonpea programs at ICRISAT Center. By the end of 1988, we had identified over 300 legume scientists who expressed their interest in becoming AGLN cooperators. The AGLN has helped organize and financially support several activities to bring cooperators into contact with the appropriate ICRISAT scientists and with each other for the exchange of information and material, for planning collaborative research, and for training.

Memoranda of Understanding

Memoranda of Understanding (MOUs) between ICRISAT and individual governments in the region are being used to ease the movement of material and exchange of scientists for collaborative research activities. Thus in April, the Vice Chairman of the Chinese Academy of Agricultural Sciences in Beijing came to ICRISAT Center with a delegation to sign an MOU with the Director General of ICRISAT. In November, ICRISAT's Acting Director General signed an update of the MOU with Bangladesh in Dhaka and another with the Secretary General of the Ministry of Agriculture in Jakarta, Indonesia in December. ICRISAT now has an MOU with each of its 10 AGLN-member countries. We made further contacts and exchanges with other Asian countries including Afghanistan, Malaysia, and Vietnam.

Work Plans

Work plans giving details of AGLN's planned activities in each country were agreed upon in periodic meetings between representatives of national agricultural research systems and AGLN/ICRISAT. These plans were attached to the MOUs. Review and planning meetings were held in Burma, Nepal, and Sri Lanka. These meetings reviewed past AGLN activities and developed a revised work plan for each country. The AGLN was also associated with the pigeonpea review and planning meetings sponsored by the Australian Centre for International Agricultural Research (ACIAR) in Thailand and with similar meetings for groundnut and pigeonpea in Indonesia.

Activities

National scientists traveled with ICRISAT scientists in several countries to identify problems, monitor trials, and develop collaborative activities. For example, we arranged a tour for pigeonpea and groundnut scientists in Sri Lanka. Input was provided by ICRISAT staff for pest management of large-scale pigeonpea trials in Thailand. In Thailand and Indonesia, follow-up consultations were held with participants of the 1987 ACIAR/AGLN Workshop on Management of Legume Pests (ICRISAT Annual Report 1987, p. 219).

The AGLN organized an in-country training course on chickpea, pigeonpea, and lentil in Nepal. The 18 participants included production agronomists, subject-matter specialists, scientists, and farming systems site coordinators from Nepal. Instructors included scientists from National Grain Legume Improvement Programme (NGLIP), International Center for Agricultural Research in Dry Areas (ICARDA), and ICRISAT. Lectures, demonstrations, and field visits covered agronomy, breeding, physiology, and pest and disease management. The AGLN also helped organize several courses concerning pigeonpea by ICRISAT staff. These courses were funded by the FAO.

Legumes On-Farm Testing and Nursery (LEGOFTEN) Unit

Groundnut

The LEGOFTEN Unit continued to cooperate with agricultural scientists in several Indian states to compare the states' currently recommended cultural practices for groundnut with ICRISAT-recommended practices.

In the 1987/88 postrainy season, groundnut yield trials were carried out in the states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Orissa, and Tamil Nadu. Of 20 trials, six failed because of water shortage (2), poor germination (2), bud necrosis disease (1), or salinity

(1). The advantages from use of the ICRISAT technology were evident (Table 1). Increased yields outweighed the slightly increased production costs.

In the 1988 rainy season, 35 trials were laid out in nine states, and at least one trial in each state was monitored jointly by LEGOFTEN and scientists from that state. Yield data from the 14 trials so monitored are presented in Table 2.

Chickpea and Pigeonpea

Following the success of this Unit in demonstrating improved groundnut technologies in 1987, the Government of India requested that its activities be extended to chickpea and pigeonpea. The Indian Union Ministry of Agriculture, the Planning Commission of India, and the State Departments of Agriculture, held a meeting with ICRISAT scientists during 25-26 April at ICRISAT Center, to plan strategies to increase chickpea and pigeonpea production in India.

Subsequently, an intensive training workshop was held during 11-13 May at ICRISAT Center for the staff of various Departments of Agriculture who would implement demonstrations in the rainy season. About 35 participants representing 10 Indian states were trained. On-farm trials were planned using ICRISAT pigeonpea

Table 1. Average pod yield[1], shelling percentage, seed mass, oil content, haulm mass, and cost of cultivation of groundnut crops grown according to ICRISAT and state practices under irrigated conditions, postrainy season 1987/88.

	Cultivation practice			
	ICRISAT		State	
Parameters	ICRISAT cultivars	State cultivars	ICRISAT cultivars	State cultivars
Dry pod mass (t ha^{-1})	3.82	2.66	2.95	2.25
(range)	(2.28-5.55)	(0.69-3.73)	(1.60-4.31)	(0.56-3.65)
Shelling percentage	75	73	71	72
(range)	(69-82)	(63-80)	(65-78)	(64-76)
100 seed mass (g)	517	399	444	364
(range)	(461-603)	(349-520)	(313-558)	(300-443)
Oil content (%)	47.1	46.7	46.6	46.4
(range)	(44.4-50.6)	(44.0-48.8)	(42.8-52.2)	(42.4-49.0)
Haulm mass (t ha^{-1})	4.13	3.66	3.87	3.93
(range)	(2.62-6.00)	(1.73-4.98)	(2.64-5.36)	(1.70-6.10)
Cost of cultivation (1000 Rs ha^{-1})[2]	9.3	9.1	8.3	8.0
(range)	(7.0-13.4)	(7.0-12.4)	(5.9-11.7)	(5.1-10.7)

1. Plot size = 0.2 ha.
2. US $ 1 = Rs 15.

variety Pragati (ICPL 87) for southern India and ICPL 151 for the northern states. Forty-four pigeonpea trials were planned in 11 Indian states (Table 3). Of these, 12 trials (at least one in each state) were identified for joint monitoring by ICRISAT and the State Departments of Agriculture. The trials are being harvested and data compilation is in progress.

Table 2. Mean dry pod yields of groundnut crops grown according to ICRISAT and state practices at 14 locations with supplementary irrigation, rainy season 1988.[1]

	Dry pod yield (t ha^{-1})			
	Cultivation practice			
	ICRISAT		State	
State and location	ICRISAT cultivars	State cultivars	ICRISAT cultivars	State cultivars
Andhra Pradesh				
Tangadencha	1.97	1.17	1.65	0.74
Yemmigannur	0.92	0.30	0.89	0.45
Karnataka				
Guladhalli	1.05	0.62	1.34	0.52
Turkondona	1.67	0.88	1.77	0.83
R.K. Shala	3.43	1.61	1.86	1.35
Tamil Nadu[2]				
Musaravakkam	2.38	2.02	2.36	1.91
Neyveli	2.55	2.32	2.00	1.86
Maharashtra[2]				
Latur	0.61	0.15	0.24	0.23
Amraoti	1.83	1.48	1.58	1.17
Orissa				
Sukinda	2.37	1.54	2.23	1.37
Madhya Pradesh				
Bhikengaon	2.32	2.30	1.45	1.40
Dhar	2.32	2.03	2.08	1.86
Uttar Pradesh				
Hardoi	1.80	1.50	1.10	1.00
Gujarat[2]				
Junagadh	2.54	2.13	1.93	1.71
Mean	1.96	1.39	1.58	1.12

1. Plot size = 0.2 ha.
2. Under supervision of the State Department of Agriculture.

Table 3. Locations chosen by State Departments of Agriculture for high yield demonstrations of pigeonpea, rainy season 1988.

State	Locations	Option[1]
Gujarat	Bharauch, Mangol, Hathrol, Mandvi[2]	I
Karnataka	Devihosur, Gulbarga, Chandpur, Radewadgi, Gangavati[2], Guladhalli	I
Maharashtra	Akola, Amraoti, Aurangabad, Latur[2], Yeotmal	I
Madhya Pradesh	Narsinghpur[2], Raisen, Betul, Bhikengaon, Chhindwara, Hoshangabad	I
Tamil Nadu	Danishpet[2], Attiyanthal	II
Orissa	Phulbani, Daspalla, Banki, Sukinda[2]	III
Haryana	Rai[2] (Sonipat), Gopalpur(Rohtak)	III
Andhra Pradesh	Chelgal, Kothapally, Tangadencha[2], Garikapadu, Yemmigannur, Amravati	III
Uttar Pradesh	Koarsi Farm[2] (Aligarh), Varanasi, Etawah, Kotwa (Azamgarh)	III and I
Punjab	Nurpurdona[2], Bara	III
Rajasthan	Bundi, Ajmer[2], Bharatpur, Alwar	III

1. Options:
   - Option I: ICRISAT variety (demonstrations) 0.4 ha
   - Option II: ICRISAT variety with ICRISAT package 0.2 ha and ICRISAT variety with state package 0.2 ha
   - Option III: ICRISAT variety with ICRISAT package 0.2 ha and state variety with state package 0.2 ha
2. ICRISAT/ Department of Agriculture collaborative trial.

Regional Legumes Network Coordinators' Meeting

The Regional Legumes Network Coordinators' Meeting was held at ICRISAT Center during 15-17 December. The Asian Grain Legumes Network (AGLN) country coordinations from eight countries met with ICRISAT scientists and representatives from eight regional and international organizations interested in legumes research. The participants reviewed the progress of the AGLN since its establishment in 1986, reexamined each country's problems and research priorities for groundnut, chickpea, and pigeonpea, evaluated existing research priorities, resources, and work plans, and recommended the future course of the AGLN in the light of the information gathered. These recommendations suggested that;

- AGLN remain a high priority activity for ICRISAT,
- a steering committee be formulated,
- in-country training be encouraged at all levels,
- SATCRIS be prompted among members,
- AGNL activities should include other legume crops with special emphasis on collaboration with other research organizations working on legumes in the region, and
- funding to support network activities be sought as a matter of priority.

The general understanding emphasized was that all ICRISAT legume scientists are equal partners in the AGLN with national scientist cooperators and that the AGLN Coordination Unit, provided by ICRISAT, was to make sure that the needs of all the network cooperators were met by facilitating contact among all network scientists.

Fifth Regional Workshop of the Comision Latinoamericano de Investigadores en Sorgo (CLAIS)

This workshop, held 7-11 Dec 1987, in Tegucigalpa, Honduras, was organized in collaboration with INTSORMIL and was combined with INTSORMIL's regional workshop. It was attended by sorghum research workers from nine national programs in the region, INTSORMIL, and by representatives of companies producing and/or selling sorghum seed in the region. The meeting focused on *maicillos criollos,* the local photoperiod-sensitive sorghums, grown by small farmers in Central America and the Caribbean. The program included both formal presentations and field visits. The proceedings of this workshop will comprise available information on these sorghums. In addition, the content and distribution of the 1988 regional sorghum trials were planned at this meeting.

Sixth Regional Workshop of CLAIS

This workshop was held in San Salvador, El Salvador, 6-9 December. Sorghum research workers from seven national programs in the region, INTSORMIL, Centro Agronomico Tropical de Investigation y Ensenanza (CATIE), and representatives of companies producing and/or selling sorghum seed in the region attended. The meeting focused on sorghum seed production and distribution in the region. Both formal paper presentations and field visits were included in the program. In addition, the content and distribution of the 1989 regional sorghum trials were planned.

West African Sorghum Improvement Program (WASIP) Network

Third West African Regional Sorghum Workshop

This workshop was held at Maroua, Cameroon, 20-23 September, followed by a steering committee meeting on 24 September. The objectives were: (1) to discuss the results of sorghum research carried out in 1986 and 1987 in the national programs with special emphasis on regional trials; (2) to finalize entries for various regional trials and nurseries for 1989 and 1990; and (3) to elect new members of the steering committee.

The workshop was attended by 52 participants from 14 national programs and representatives from Semi-Arid Food Grain Research and Development (SAFGRAD), Institut de recherches agronomiques tropicales et des cultures vivrieres (IRAT)/Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), and ICRISAT Center. Thirty-three technical papers were presented, and a field trip made to the Guiering Research Station and to on-farm trials. The new Steering Committee members were elected.

Results of regional trials were discussed and entries finalized for the 1989 and 1990 regional trials. It was agreed that variety trials would be organized by WASIP-Mali and hybrid trials by WASIP-Nigeria.

East African Regional Sorghum and Millet (EARSAM) Network

Sixth Regional Workshop

This workshop was held 20-27 July, in Mogadishu, Somalia, and was attended by scientists from Burundi (1), Ethiopia (3), Kenya (5), Rwanda (2), Somalia (25), Sudan (5), Tanzania (1), and Uganda (2), and from ICRISAT (7), International Development Research Centre (IDRC) (2), Global 2000 (3), and Texas A&M University (1). The main objective of the workshop was to enable the sorghum and millet researchers of the region to participate in peer review of their programs and continue to effectively share research findings and germplasm. The following recommendations and actions were taken.

- A new steering committee was elected.
- The seventh regional workshop scheduled for 1990 will be held in Kenya.
- A regional short course on crop protection will be conducted in 1989.
- A regional EARSAM sorghum and millet yield trial will be organized in 1989.
- In addition to the six on-going collaborative research projects, eight additional new projects will be initiated on grain mold, covered smut, anthracnose, leaf blight, finger millet, pearl millet, and grain processing and utilization.

Conferences/ Workshops/ Meetings

International Workshop

Workshop on Sorghum and Pearl Millet Modeling

ICRISAT, in cooperation with International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and International Fertilizer Development Center (IFDC), hosted a training workshop on sorghum and pearl millet modeling during 12-19 October. The aim was to train agricultural researchers on principles and operational aspects of crop modeling and to obtain feedback about potential use and limitations of models currently available. It was attended by about 50 participants from Ethiopia, India, Somalia, Thailand, Togo, and USA.

The workshop identified future areas of research, which included understanding of root growth, ammonia volatilization losses, and research on stresses. The participants felt that the models described in this workshop can be of great assistance in selecting appropriate cultivars, in determining optimum sowing dates, plant populations, fertilizer practices, and in the adoption of improved water management.

Regional Workshops

West African Regional Pearl Millet Improvement Workshop

The annual Regional Pearl Millet Improvement Workshop was held in cooperation with IAR of the Ahmadu Bello University in Zaria, Nigeria, 15-18 August. This workshop brought together 44 pearl millet scientists from 13 West African countries, the Institut du Sahel (INSAH) of the Comite permanent inter-etats de lutte contre la secheresse dans le Sahel (CILSS), and ICRISAT. Twenty-four technical papers were presented during 2.5 days, followed by visits to IAR research station and laboratories. The major recommendation of this workshop was to create a 'West African Pearl Millet Research Network' to strengthen research at the national institutes in the region. ICRISAT was given the task of initiating this research network with the involvement of SAFGRAD, INSAH, and organizations such as the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL). Other recommendations stressed the importance of interdisciplinary research and the need to enlarge germplasm conservation efforts in the region. Responses of the participants indicated that the workshop was extremely useful, particularly in the opportunity it provided for interaction between scientists from national programs, INSAH, and ICRISAT.

West African Regional Workshop on Drought Screening Methods for Pearl Millet

A training workshop on drought response screening methods for pearl millet was held from 2 to 5 May at the ISC. The objective was to familiarize West Africa's pearl millet breeders and agronomists/physiologists with drought screening methods developed by ICRISAT, and to transfer information, through collaborative research, to institutes working or proposing to initiate research on drought. Twenty-three participants from eight national programs, ORSTOM, and INTSORMIL attended this workshop.

The workshop program was a balance between formal presentations and field visits. Invited speakers made nine presentations, covering physiological mechanisms involved in drought response, screening for seedling and terminal drought resistance, and the use of a simple water balance model to interpret multilocational trials in droughted environments. Detailed explanations were given of the analysis of data for different screening methods. Computer programs for analysis of data from screening nurseries and water balance calculations were provided to interested participants. The program included two half-day field trips to the ISC research fields where participants saw operating field screens for crop establishment and terminal drought. The participants indicated that the workshop was extremely useful, that the screening methods demonstrated could be implemented by them in their programs, and that the workshop offered an opportunity for useful interaction between all participating scientists.

Fifth Regional Workshop of the Southern Africa Sorghum and Millet Program

This workshop was held in Maseru, Lesotho, 20-23 September. There were 35 participants from the nine SADCC countries, together with 11 from the regional program, and one representative each from the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), International Livestock Centre for Africa (ILCA), Volcani Center (Israel), ICRISAT Center, United States Agency for International Development (USAID), and Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ). Crop utilization, economics, and research station development were discussed as new topics, in addition to the usual topics of breeding, agronomy, and plant protection. An improvement over past years was an increase of entries contributed by the national programs into the various regional trials and nurseries. The keen interest in forage and dual-purpose sorghums was evident during the meeting.

SADCC/ICRISAT Regional Cereal Workshop

The Annual Regional Cereal Workshop was held in Maseru, Lesotho, from 21 to 23 September. The workshop brought together national scientists from nine SADCC countries, four invited scientists, and representatives from United States Agency for International Development (USAID), Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), and ICRISAT Center. Participants presented and discussed the work on millets and forages in their countries and the activities of the regional pearl millet, finger millet, and forage breeding programs for the 1987/88 rainy season.

There was a definite increase in interest in expanding the forage research project, as indicated by the increase in the number of requests for forage trials. As a consequence, the Regional Millet Program will put more emphasis on this aspect of its research.

Workshop on Agroclimatology of Asian Grain Legume Growing Areas

A Workshop on Agroclimatology of Asian Grain Legume Growing Areas, held at ICRISAT Center during 5-17 December, was attended by legume scientists and agroclimatologists from nine Asian countries. This included scientists associated with the FAO Agroecological Zoning projects in four countries and a coordinator from Rome. A scientist from the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) provided input on the use of agroclimatology information in conjunction with growth models. Each participant brought production and climatology data from his/her own country and used this to develop maps showing present distribution of groundnut, pigeonpea, and chickpea, the extent of constraints to production such as diseases and pests and the potential areas for production of the three crops as determined by the agroecological patterns in their country. Consultant geographers and cartographers from India and USA assisted in the design and drawing of the maps. The text and maps generated will provide readily understood information to help policymakers, research planners, and legume scientists develop their plans.

Third Regional Groundnut Workshop for Southern Africa

All the Southern African Development Coordination Conference (SADCC) countries with the exception of Angola were represented at the Third Regional Groundnut Workshop for Southern Africa held 13-18 March, at Lilongwe, Malawi. Attendance was highly satisfactory: out of a total of 26 national program scientists actively engaged in groundnut improvement in eight SADCC countries, 24 participated. Mauritian and Zairian groundnut scientists were also present.

Groundnut specialists from ICRISAT Center, India, and the ICRISAT Sahelian Center, Niger, also attended and contributed significantly both by their presentations and through informal discussions with SADCC scientists.

The recommendations arising from the meeting afford a valuable guideline for regional project activities.

First West African Regional Groundnut Meeting

The first ICRISAT West African Regional Groundnut Meeting was held 13-16 September, at Niamey, Niger. The meeting provided an opportunity for participating scientists to share experiences on the status of groundnut production and improvement in various countries in the region and define areas for collaborative research.

Benin, Burkina Faso, Cameroon, Chad, Gambia, Ghana, Guinea, Mali, Niger, Nigeria, Senegal, and Togo were represented. Also represented were Peanut Collaborative Research Support Program (Peanut CRSP), Institut de recherches pour les huiles et oleagineux (IRHO), Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM), the African Groundnut Council, Food and Agriculture Organization of the United Nations (FAO), Centre regional de formation et d'application en agrometeorologie et hydrologie operationnelle (AGRHYMET), the UK Overseas Development Administration (ODA), University of Niamey, ICRISAT Center, SADCC/ ICRISAT Regional Improvement Program, and ICRISAT Sahelian Center (ISC). The meeting was attended by 56 participants and 29 papers were presented. The participants visited field trials at Bengou and Sadore and were shown the new ICRISAT facilities at Sadore.

The meeting recommended that for the West Africa Region there should be:

- greater emphasis on disease and pest surveys and determination of associated crop losses;
- better coordination of research on groundnuts across the region;
- increased exchange of germplasm and breeding lines especially for material with resistance to biotic stresses and with short duration;
- a series of regional groundnut evaluation trials with financial and technical support;
- more attention given to postharvest technology and storage of groundnut;
- better supply of publications, and translation of articles from English to French and vice versa;
- production of a handbook on methods of scoring for resistance to rust and late leaf spots; and
- greater emphasis on training at the scientist level.

It was suggested that similar meetings should be held every 2 years with specialist meetings in the intervening years.

Regional Workshop on the Role of Small Watershed Hydrology in Rainfed Agriculture

A regional workshop on the Role of Small Watershed Hydrology in Rainfed Agriculture was held 22-24 November at ICRISAT Center. The objectives were to develop a better understanding of past work, identify research needs, and to establish linkages. The meeting was attended by 31 participants representing the Central Soil Conservation Research and Training Institute (CSCRTI), Central Research Institute for Dryland Agriculture (CRIDA), Indian Council of Agricultural Research (ICAR), Indian Institutes of Technology (IITs), and Asian Institute of Technology (AIT).

Delegates presented papers dealing with five topics: watershed water balance, watershed hydrology and productivity, instrumentation, land use and management, and modeling of watershed hydrology. Discussion groups emphasized the need for more intensive collection of hydrological data, and for rapid analysis and ready availability of these data; the development and adoption of simple, robust and easy-to-operate instruments; evaluation of new materials such as geocrete and natural fibers for runoff control structures; development of process-based models needing simple inputs; and studies to establish relations between watershed hydrology and land use and productivity.

National Workshops

In-country Workshop on Sorghum and Millet in Mali

The first in-country workshop on sorghum and millet was held at Bamako, Mali, 4-8 October, in collaboration with the Institut d'economie rurale, and Ciba-Geigy Research Foundation. It was attended by 75 participants representing different research and extension organizations. The workshop discussed problems and prospects related to research and development of these two crops in Mali. The participants developed a set of recommendations on future research priorities and themes for extension. The proceedings will be published in French by the Mali Program.

Workshop on Phosphorus in Indian Vertisols

A workshop was held at ICRISAT Center, 23-26 August, to discuss the behavior of phosphorus (P) in Vertisols. There were 36 participants, the majority from India and two from other countries (Mexico and England). The aim of the workshop was to compile past research results, identify gaps in knowledge, and determine the need for future research, both at ICRIS AT Center and in collaboration with national programs.

Information from a wide range of environments confirmed that responses to P were highly variable and inconsistent, reinforcing the urgent need for research on P in Vertisols under dryland agriculture. In future work, the need to stratify the environment was identified, both according to the soil and the moisture environment. A particular area of poor knowledge is the nutrition of crops grown in the postrainy season, when soil moisture supplies normally decrease with crop growth.

Two future needs were identified: first, an integrated (multidisciplinary) approach involving both crop P demand and soil P supply, while accounting for other climatic and soil factors; second, detailed strategic studies at central research centers, followed by multilocational testing of concepts on appropriate Vertisols. All participating organizations expressed interest in developing a collaborative project.

Joint ICRISAT/NBPGR (ICAR) Workshop on Collaborative Germplasm Exploration and Evaluation

A joint ICRISAT/NBPGR (ICAR) Workshop on Collaborative Germplasm Exploration and Evaluation in India was held at ICRISAT Center, 14-15 November. Priority areas for collection and evaluation of germplasm were identified. A united and concerted program of germplasm evaluation and use was highlighted in the recommendations of the workshop. The workshop was regarded as most successful. Proceedings are available from ICRISAT Center.

Groundnut Scientists' Meeting at Malang, Indonesia

In cooperation with the Indonesian Agency for Agricultural Research and Development (AARD), a Groundnut Scientists' Meeting was held at MARIF, Malang, Indonesia, 14-17 November. Representatives of research institutes concerned with groundnut in nine Asian countries (People's Republic of China, India, Indonesia, Malaysia, Nepal, the Philippines, South Korea, Thailand, and Vietnam) met with scientists from ICRISAT, Australian Center for International Agricultural Research (ACIAR), Peanut CRSP, FAO, Internation Development Research Centre (IDRC), Winrock International, United States Agency for International Development (USAID), ATA-272 (Netherlands Project), and South Asian Association for Regional Cooperation (SAARC), to discuss constraints on groundnut production and research being done to solve the various probelms. Priorities for research were agreed and recommendations made for continued research collaboration and increased inputs into training of scientists within the region.

International Field Day

International Sorghum Field Day at ICRISAT Center

An International Sorghum Field Day was held on 20-21 September. It was attended by 35 sorghum scientists from national programs. There were 24 scientists from India, 2 from the Philippines and 1 each from Burundi, Ethiopia, Guatemala, Kenya, Malaysia, Mali, Mexico, Rwanda, and Thailand. Participants took part in presentations and discussions on sorghum germplasm, physiology, pathology, entomology and breeding. On the 2nd day they visited experimental fields and the food quality research laboratory. The program ended with a discussion session in which participants asked ICRISAT to intensify research efforts on (1) grain-mold resistance, (2) conversion of germplasm lines to breeding lines, (3) diversification of breeding material in terms of maturity ranges and agronomic types, (4) drought resistance, and (5) *Striga* control.

Regional Tours

SADCC Regional Pearl Millet Research Monitoring Tour

The SADCC regional program organized a research monitoring tour from 24 February to 6 March in which nine scientists from the region and one from ICRISAT Center participated. The objective of the tour was to evaluate the pearl millet entries in the regional trials, and to provide an opportunity for scientists to visit the national programs of Zimbabwe and Zambia. The scientists visited regional and national trials at Matopos, Aisleby, Makoholi, the Research and Specialist Services Centers at Harare and Gwebi in Zimbabwe, and the Longe, Simulumbe, Kataba Namusekhande, Kaoma, and Lusitu stations in Zambia. The participants agreed that there was need for exchange of genetic materials between the regional and national programs, and appreciated the opportunity for both the regional and national program scientists to make selections of promising materials from the various breeding programs visited.

Cereal Forage Research Monitoring Tour

The SADCC Regional Program organized the Cereal Forage Research Monitoring Tour from 10 to 23 February, in which 15 scientists from the region and one ILCA representative participated. The team visited five countries: Zimbabwe, Botswana, Lesotho, Swaziland, and Mozambique, during which tour the participants reviewed future strategy on the improvement of forage sorghums and millets. The group recommended that forage research should be expanded, with emphasis on the breeding of superior varieties of sorghum, pearl millet, and bana grass (*Pennisetum glaucum x P. purpureum*). Forage agronomists and animal nutritionists from the region will collaborate in conducting forage trials and in developing agronomic packages. SADCC/ICRISAT and ILCA/PANESA will jointly assist the national programs in developing agronomic packages; the feeding trials will be conducted by the national programs.

National Field Days

Field Day for Seed Producers at ICRISAT Center

A Sorghum Field Day for seed producers in India was held on 22 September and was attended by representatives from 20 companies. They visited breeding trials, seed parents nurseries, populations, and source development nurseries. This was followed by a discussion session on problems of seed production, production areas, and sowing dates. The seed producers commented favorably on the variation and potential use of newly developed A-, B-, and R-lines. They also expressed their gratitude to ICRISAT for seeds of sorghum cultivars and breeding material freely supplied to them on request and for organizing the field day.

Field Visit in Guatemala

Eighteen Guatemalan extension workers, agronomists, and breeders attended a cooperative in-country seminar and field trip on 6 September near El Progreso Guastotoya in eastern Guatemala on the potential of millets as short-duration grain and forage crops in this dry region. In this area, it appears possible to obtain one good grain harvest from *Setaria* or *Pennisetum* millets by sowing after establishment of the rain in June and harvesting in the mid-season dry period called *canicula.* This could then be followed by a second crop (beans, sorghum) sown at the second peak of the rainfall in September. Such a system might be more stable than the maize/sorghum/bean single crop currently practiced. Further study is needed, especially on the suitability of millets for use in local foods.

Information Services

Information Services assists ICRISAT scientists in the transfer of technology by exercising its responsibility to edit and publish Institute-level publications and to maintain public awareness.

We provide the Secretariat for the Editorial Committee, which operates an internal peer review system for the Institute's scientists. This Committee ensures that ICRISAT scientists, in their communication with other scientists via journal articles, conference papers, and multiauthor book chapters, achieve a high acceptance-rate by publishers, and consequently obtain scientific and technical feedback from fellow scientists, most of whom work within invisible colleges related to ICRISAT's disciplines. In 1988, the Editorial Committee handled the review of 201 documents destined for publication in this open scientific literature system.

In Information Services' own publishing program, we continued to issue a range of publications communicating the results of ICRISAT's research aimed primarily at scientists and policymakers in developing countries, but also at donors, the international scientific community, and interested public. These publications comprise the annual report, research highlights, and quarterly and half-yearly newsletters, as well as issues within the following categories: Plant Material Descriptions, Books, Research Bulletins, Information Bulletins, Conference/Workshop Proceedings, Bibliographies, General Audience Publications, and Audiovisual Materials. A new category was created this year with the issue of Germplasm Catalogs concerning pigeonpea and chickpea. Both were published in two companion volumes—evaluation and analysis and passport information—and comprised full listings of ICRISAT's gene-bank holdings.

In 1988, we published 58 items within these categories. We responded to requests from librarians in SAT countries and from a range of clients who collaborate with the Institute in various ways by dispatching some 94% of priced publications (24 459) free of charge. Such gratis distribution helps those who assist ICRISAT in the fulfilment of its mandated mission by providing ready access to copies of the Institute's publications relevant to their work. Most of these Institute-level publications were produced in-house via the Division's own art, photography, and composing units and the printshop. This year our artists completed 1200 jobs directly and indirectly connected with this publishing work, our photographic staff handled 1700 assignments and processing jobs, our compositors created and processed 4537 m of galleys. Our French Unit translated abstracts and papers for inclusion in the Institute's publications and assisted in the Institute's communication with francophone collaborators and clients. Approximately 25% of ICRISAT's major publications now have foreign-language (French, Spanish, and/ or Portuguese) editions as well as English editions.

A member of staff, on sabbatical leave, underwent a short-course of instruction on the creation of tape-slide programs, and provided scientific liaison with the BBC Open University Production Centre, UK, in the coproduction of a video on African agriculture. The video is a case study in a planned series of TV programs on the environment aimed at Open University students, and involved location work on the ISC station at Sadore as well as in other parts of Niger and in Kenya. The objective of this training and participation in the coproduction was to provide the Information Services with a wider experience in audiovisual productions, and to obtain comparative data concerning the costs, techniques, and staff required to create a range of audiovisual media.

In support of the public-awareness program of the Consultative Group on International Agricultural Research (CGIAR), in 1988, we made the organizational arrangements for the Group's participation in the New Delhi World Book Fair, and manned a stall publicizing a wide range of CGIAR publications. We issued eight press releases on ICRISAT's research and activities and arranged several public relations events in which local media persons participated. Indian and foreign TV crews also filmed ICR1-SAT's research activities and results with assistance and coordination of the Information Services' staff.

Library and Documentation Services

Acquisitions

During 1988, we added 2424 documents to our collection (Table 1).

Table 1. Status of acquisitions, ICRISAT Library, 1988.

Documents	Additions during 1988	Total holdings as on 31 Dec
Books and reports	627	22 859
Bound volumes of periodicals	1127	14198
Annual reports	145	1681
Pamphlets	521	5 332
Microforms	4	824

Database Development

A major development in 1988 was the full-fledged implementation of the library's database on the Institute's VAX-11/780. The database is built with machine-readable data received every month from two international databases: Commonwealth Agricultural Bureaux International (CABI) and the FAO's International Information System for Agricultural Sciences (AGRIS). To these sources is added data pertaining to books and other documents procured by the library.

The conceptual design of the library's database ensures that it is possible to import data from two global databases and also that such data is integrated with local input. We developed a Database Production Manual to ensure consistency in data entry.

During the year, 6800 records were added to the database. A breakup of contributing sources to the database is given in Table 2.

Table 2. Sources contributing to the database during 1988.

Source	No. of records
CABI	2322
AGRIS	1269
Local input	1207
Data from the retrospective sorghum and millet bibliographies	1034
Retrospective library catalog data	967
Total	6799

We believe that the library's methodology for database creation and maintenance enables us to build a comprehensive bibliographic database covering information on the crops mandated to ICR1SAT and to associated topics.

Compact Disk-Read Only Memory (CD-ROM) Database

We acquired the Agricultural On-Line Access (AGRICOLA) database (1979-88) of the US National Agricultural Library (NAL) on CD-ROM during the year. AGRICOLA contains about 2.5 million references to information on books added to the NAL, United States Department of Agriculture (USDA) reports, and journal articles abstracted at the NAL. The addition of the CD-ROM database has greatly increased our capabilities to respond quickly to information searches.

Documentation Services

Semi-Arid Tropical Crops Information Service (SATCRIS)

SATCRIS, a project funded in part by IDRC in 1986 to succeed the Sorghum and Millets Information Center (SMIC), provides documentation and information retrieval services on the five crops mandated to ICRISAT and associated areas to users all over the SAT.

Selective Dissemination of Information (SDI)

The manual Selective Dissemination of Information (SDI), which was begun by SMIC, was replaced by an automated SDI service using the newly created database and the monthly inputs received from CABI and AGRIS. The service, begun in March, has 211 recipients from 33 countries mainly in Asia and Africa, as of December 1988. A country wise breakup of recipients of the SDI service is given in Table 3.

Table 3. Country wise breakup of recipients of the SDI service.

Country		No. of recipients
Africa		
Benin		1
Botswana		1
Burkina Faso		7
Cameroon		1
Cote d'Ivoire		1
Ethiopia		10
Kenya		5
Mali		2
Niger		9
Nigeria		2
Senegal		3
Somalia		8
Sudan		1
Zambia		4
Zimbabwe		2
Americas		
Mexico		3
Nicaragua		1
Peru		1
USA		4
Asia		
Bangladesh		1
India		121
ICRISAT	42	
Other Institutions	79	
Indonesia		2
Iraq		1
Japan		1
Pakistan		4
People's Republic of China		7
Syria		1
Vietnam		1
Yemen (PDR)		2
Europe		
Federal Republic of Germany		1
The Netherlands		1
UK		1
Yugoslavia		1
Total		211

Literature Search Services

During the year, we conducted 150 on-demand literature searches for users all over the SAT. This is more than twice the number of search requests responded to in 1987 and includes 24 on-line searches. The availability of search results is made known widely to enable other users to utilize search results. We received requests from 244 users for copies of search results that were made for others.

Search services reached users in 12 countries including eight in Africa. The countrywise distribution of search services is given in Table 4.

Specialist Abstracts Services

An agreement was signed with CABI to produce two new abstracts services jointly with ICRISAT, called Chickpea and Pigeonpea Prompts and Groundnut Prompts. These two services are in addition to the Sorghum and Millets Abstracts, also being produced by CABI as a joint publication with ICRISAT.

The three abstracts services are now being provided free of charge to 761 individuals or institutions in over 45 countries of the SAT.

Microfiche Collection Development at ISC

A total of 255 primary documents were put on microfiche and provided to the ICRISAT Sahelian Center (ISC) as part of the plan to develop a selected microfiche collection of primary literature at ISC. The collection will be used by the ISC to provide document delivery services to users in the region.

Table 4. Countrywise distribution of search services.

	Type of search			
Country of user	CD-ROM	Manual	On-line	Total
India				
ICRISAT	46	16	23	85
Others	19	19	-	38
Africa				
Burkina Faso	1	-	-	1
Ethiopia	3	2	-	5
Kenya	2	1	-	3
Mali	1	-	1	2
Niger	-	2	-	2
Sudan	-	3	-	3
Zambia	1	-	-	1
Zimbabwe	2	1	-	3
Other countries				
Sri Lanka	-	1	-	1
Sweden	-	1	-	1
Syria	4	-	-	4
Venezuela	1	-	-	1
Total	80	46	24	150

SATCRIS Workshops in Eastern Africa

Two staff members from SATCRIS traveled to three countries of eastern Africa in November to conduct workshops. The workshops aimed to improve the awareness of potential end users in different institutions in eastern Africa to the resources and services of SATCRIS, to identify gaps in accessibility to information on ICRISAT's five mandate crops, to build contacts with libraries and documentation centers in the region, and to identify sources of conventional and nonconventional literature.

Seventy-five participants from 17 institutions in Ethiopia, Kenya, and Somalia participated in these workshops.

Input to the AGRIS Database

Items of ICRISAT-generated conventional and nonconventional literature, totaling 120, were input to the AGRIS database.

Training

As envisaged in the SATCRIS project, the documentalist appointed at ISC under the SATCRIS project was trained at ICRISAT Center during February. The training emphasized SATCRIS methodologies and services, and documentation and information retrieval services useful to scientists in the region.

ICRISAT Sahelian Center

The ICRISAT Sahelian Center Library caters to the information needs of its scientists as well as of other scientists engaged in similar fields. Established in 1984, the library subscribes to 53 periodicals covering a wide range of topics and branches in the world of science, and has around 4350 specialized books, annual reports, progress reports, conference proceedings, and bound volumes of periodicals.

The Information Service has close contacts with the other information centers and libraries of this region and overseas, based on an exchange basis.

This service presently handles the SATCRIS in the subregion. This year, we provided logistic support to scientists during workshops and meetings held in Niamey and outside Niamey, by displaying books, distributing publications, and operating the audiovisual equipment.

We provided a strong logistic support to the British Broadcasting Corporation (BBC) team in July and September, during their work in Niger.

We provide a translation service for the scientists. We publish a biannual newsletter in French called "Nouvelles de l'ICRISAT" (At ICRISAT) and bring out a monthly internal information bulletin, INTRA-INFO, 13 issues of which have been published so far.

We translated a leaflet about SATCRIS into French and completed the translation of the Sorghum descriptors. The French version will be an IBPGR/ICRISAT co-publication. Other translations include: Pearl millet anatomy, Rust disease of groundnut, Groundnut descriptors, and Proceedings of the Sorghum and Millet Workshop held in Mali.

Publications

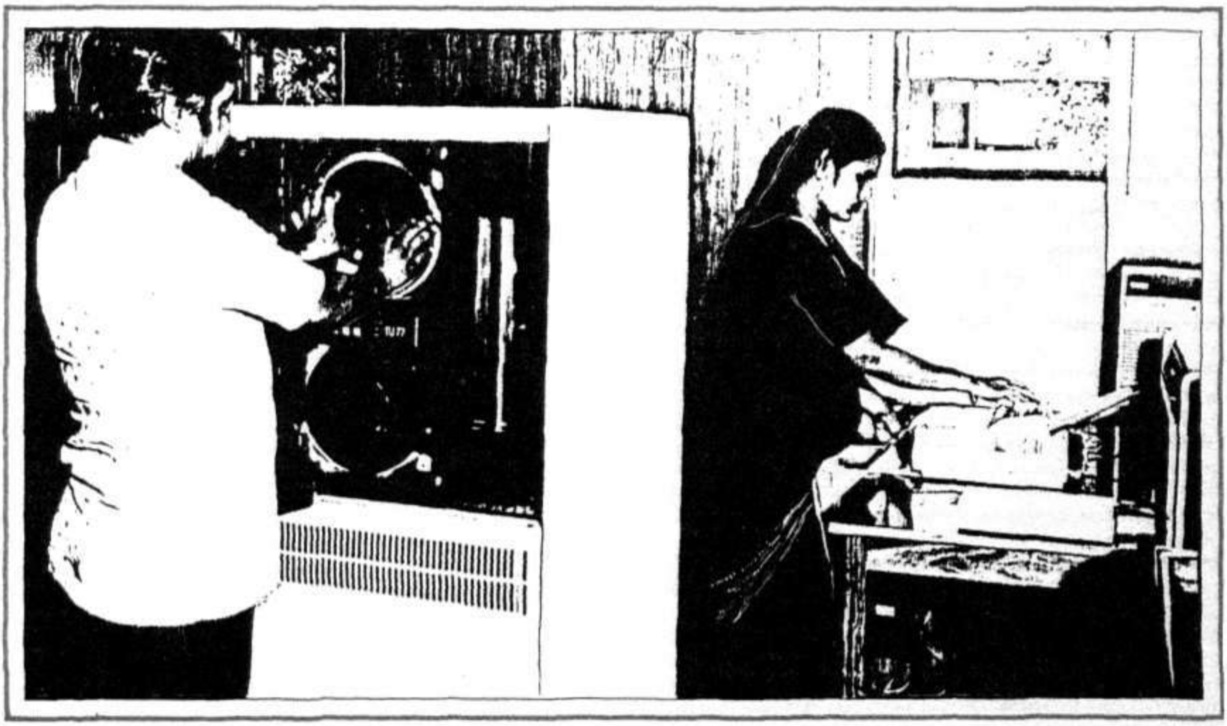
Institute Publications

Annual Progress Reports

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual report 1987. Patancheru, A.P. 502 324, India: ICRISAT. 418 pp. ISSN 0257-2478. (ARE 014)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Research highlights 1987. Patancheru, A.P. 502 324, India: ICRISAT. 52 pp. ISSN 0257-2532. (RHE 009)

RESEARCH SUPPORT ACTIVITIES



Contents

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

RESEARCH SUPPORT ACTIVITIES

Genetic Resources

Concerted efforts during the past 15 years have resulted in the collection, assembly, and conservation of a large number of germplasm accessions of the five ICRISAT mandate crops and six minor millets. However, the need to collect, especially from previously unexplored and remote areas, these mandate crops and their wild relatives is well recognized. Evaluation at ICRISAT Center and other locations is progressing, with the aim to identify useful traits that could be used to improve our mandate crops.

Germplasm Collection and Assembly

We added to our gene bank, 2096 accessions of mandate crops (Table 1) and 153 of minor millets, collected from southern and Central Africa, and from South Asia. These additions raised the total collection to 96 200. Material collected from outside India is in various stages of quarantine processing. In addition, 534 samples of sorghum, 1129 of pearl millet, 48 of chickpea, 222 of pigeonpea, and 568 of groundnut have either just been released from quarantine or are in various stages of release. Collection efforts in India, in collaboration with the National Bureau of Plant Genetic Resources (NBPGR), will continue according to joint plans finalized during November at a workshop on Collaborative Germplasm Exploration and Evaluation in India.

Germplasm Maintenance

We rejuvenated 15 661 cultivated and 463 wild relatives of our mandate crops, and 1546 minor millet accessions. We gave increased attention to seed viability monitoring and quality control. The viability of 2412 sorghum, 2054 pearl millet, 212 chickpea, and 1735 groundnut accessions was tested and we identified 203 sorghum, 251 pearl millet, 57 chickpea, and 146 groundnut accessions for rejuvenation. These were sown in either the rainy or postrainy season, 1988. Maximum care is being taken to keep the rejuvenated material close to its original genetic makeup. New equipment was acquired to dry seeds at low temperature and low humidity. We are also investigating observed cleavage damage in pea-shaped chickpeas caused by rapid seed drying.

Germplasm Evaluation

We sowed 13 347 accessions at ICRISAT Center for evaluation and characterization. These included 2154 sorghum, 2320 pearl millet, 945 chickpea, 924 pigeonpea, 5464 groundnut, and 1540 minor millet accessions. All the groundnut accessions sown were checked for infection by viruses. Evaluation in Africa progressed further (Table 2). We plan to give increased emphasis to collaborative germplasm evaluation work in eastern, southern, and West Africa to help identify material suited to crop improvement work in those areas.

Germplasm Enhancement

Converted sorghum lines from USA and ICRISAT are maintained as a'conversion collection', for use by sorghum beeders. Photoperiod sensitivity screening of pigeonpea is in progress. Attempts to utilize exotic germplasm in pearl millet and chickpea, and the sorghum introgression program also continued.

Documentation

We published the chickpea and pigeonpea germplasm catalogs. Catalogs for sorghum, pearl millet, and groundnut are being prepared. We supplied computer printouts of passport and/or evaluation data of the entire sorghum and groundnut collections to Texas A&M University, USA; ISC; and SADCC/ICRISAT Groundnut Improvement Program (Malawi). Passport data on new accessions and evaluation data from all recent seasons on all the crops have been entered into computer files.

Table 1. Additions to ICRISAT germplasm collection in 1988.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
Africa					
Burkina Faso	-	113	-	-	-
Burundi	2	-	-	-	-
Ethiopia	-	-	1	-	-
Mali	-	-	-	-	156
Morocco	-	-	187	-	-
Mozambique	6	-	-	-	2
Niger	-	-	-	-	1
Senegal	-	-	-	-	3
Somalia	294	-	-	-	-
Tanzania	257	299	-	-	7
Togo	-	29	-	-	-
Zimbabwe	11	-	-	-	31
Asia					
Bangladesh	-	-	1	-	-
India	176	270	6	1	1
Iran	-	-	119	-	-
Republic of Korea	-	-	-	-	18
Europe					
Spain	-	-	1	-	-
America					
Argentina	-	-	-	-	3
Bolivia	-	-	-	-	42
El Salvador	1	-	-	-	-
Jamaica	-	-	-	3	-
Guatemala	1	-	-	-	-
Peru	-	-	-	-	7
Haiti	1	-	-	-	-
Honduras	3	-	-	-	-
Nicaragua	1	-	-	-	-
USA	-	-	-	-	37
Venezuela	-	-	-	2	-
Oceania					
Australia	-	-	3	-	-
Total accessions	753	711	318	6	308

Table 2. Collaborators, locations, number of accessions, and type of material evaluated under joint evaluation programs, 1988.

Crop	Collaborator	Location	No. of accessions	Type of material
Sorghum	NBPGR, India	Issapur	2993	Selected germplasm
	AICSIP, India	Akola, Coimbatore, Indore, Rajendranagar, and Surat	1405	Rainy season basic collection
	Ministry of Agriculture, Somalia	Bonka, Baidoa	253	Somalian collection
			2000	Short-duration accessions
Pearl millet	NBPGR, India	Issapur	2000	Diverse germplasm
	NBPGR, India	Jodhpur	500	Rajasthan collection
	NBPGR, India	Jodhpur	81	Promising accessions for drought resistance
	AICPMIP, India	Pune	2000	Diverse germplasm
	SADCC/ICRISAT Zimbabwe	Bulawayo	1000	Germplasm from SADCC countries
Chickpea	NBPGR, India	Akola	1320	Short-duration accessions
	NBPGR, India	Gwalior	1320	Long-duration accessions
	NBPGR, India	Issapur	1320	Long-duration accessions
	PGRC/E, and ARC, Ethiopia[1]	Debre Zeit	1034	Selected accessions
Pigeonpea	NBPGR, India	Issapur	350	Short-duration accessions
	NBPGR, India	Akola	300	Medium- and long-duration accessions
Groundnut	NBPGR, India	Jodhpur	1500	Selected accessions
	NBPGR, India	Akola	1500	Selected accessions

1. PGRC/E = Plant Genetic Resources Center/Ethiopia, Addis Ababa.
ARC = Agricultural Research Center, Debre Zeit.

Germplasm Distribution

Table 3 shows the distribution of germplasm to various disciplines within ICRISAT during 1988. In addition, we sent 39 875 samples to scientists in India, and 22 825 samples to scientists in other countries (Table 4).

Collaboration with the Indian Council of Agricultural Research (ICAR)

The annual ICRISAT/NBPGR discussion was held in February in New Delhi and work plans for 1988/89 were finalized. During 1988, we characterized 13184 germplasm accessions in India (Table 2). Continued joint projects with NBPGR will provide information on the performance of germplasm in different regions of India. This will help in better utilizing the available diversity by crop improvement scientists.

Sorghum Germplasm

This year, we added 753 new accessions to our gene bank raising the total to 31 030. The new accessions came from 11 countries (Table 1).

In February, we organized a collection mission to northern Cameroon in collaboration with the Institut de la recherche agronomique (IRA), Ministere de l'Enseignement Superieuret de la recherche scientifique (MESRES), Republic of Cameroon (Fig. 1). We collected five major ecotypes, 'Safrari'—yellow pericarp grain, 'Madreji'— chalky white grain, 'Bourgouri'—colored grain, 'Adjagameri' or 'Dalassi'—white

Table 3. Seed samples supplied to ICRISAT Crop Programs in 1988.

	Cereals		Legumes			
Discipline	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
Agronomy	-	-	3 301	16	-	3317
Physiology	36	41	-	-	231	308
Pathology	5 524	247	388	51	728	6938
Entomology	282	2	1037	312	71	1704
Breeding	368	128	4187	181	40	4904
Biochemistry	91	1000	829	319	746	2 985
Cytogenetics	-	-	-	-	53	53
Training	16	2	9	-	-	27
Nematology	-	-	-	144	24	168
Others	1	-	-	-	18	19
Total	6318	1420	9751	1023	1911	20423

Table 4. Germplasm samples distributed by GRU, ICRISAT, 1988.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (1+2+3)	No. of countries
Sorghum	6318	21472	7 227	35017	28
Pearl millet	1420	8 734	2623	12 777	9
Chickpea	9 751	3595	1500	14 846	17
Pigeonpea	1023	1588	1531	4 142	21
Groundnut	1911	3909	6430	12250	24
Minor millets	-	577	3514	4091	10
Total in 1988	20423	39875	22825	83123	
Cumulative total to date	426992	211035	218 523	856 550	

Figure 1. Collecting 'muskwari' (transplanted) sorghums in northern Cameroon.

lustrous grain, and 'Soukatari'—red grain. The majority of these collections belong to races Durra, Durra-caudatum, or Caudatum and are agronomically elite, with large panicles and bold grain. A collection mission was organized in collaboration with NBPGR in the hilly areas of Adilabad district of Andhra Pradesh bordering Maharashtra, India, where we collected 97 samples. These include a *Sorghum halepense* and primitive cultivars belonging to subrace Roxburghii of race Guinea, and of race Durra.

We grew 534 samples from Cameroon (248), Kenya (136), Morocco (19), Somalia (26), and Sudan (105) in the post-entry quarantine isolation area (PEQIA) for inspection and release.

We collaborated with NBPGR and evaluated 2993 accessions at Issapur, New Delhi, India (Table 2). We identified 56 promising, mostly dual-purpose, grain and forage types. We also evaluated the 'kharif basic collection', at six locations in India (Akola, Coimbatore, Indore, Rajendranagar, Surat, and ICRISAT Center) in collaboration with the All India Coordinated Sorghum Improvement Project (AICSIP) and NBPGR. This basic collection consisted of 1405 accessions, selected from the world collection, stratified taxonomically and geographically, and based on their adaptation at ICRISAT Center in the rainy season. From these, we selected 36 accessions for further testing and utilization in the Indian breeding program to broaden the genetic base for rainy-season sorghums.

In collaboration with the Ministry of Agriculture, Government of Somalia, and with support from the International Development Research Centre (IDRC), the ICRISAT's Somalian sorghum collection was evaluated at the Bonka Agricultural Research Station, Baidoa, Somalia (Latitude 3°N) and at ICRISAT Center. Twenty-nine accessions were selected for utilization in the Somalian sorghum breeding program. In addition, we evaluated 2000 short-duration accessions at Baidoa and selected 69 (Fig. 2). This method of collaborative evaluation effort provided a unique field training opportunity and was highly appreciated.

In the rainy and postrainy seasons, we characterized 749 new accessions at ICRISAT Center. The 349 final converted lines of Zerazera landraces on different height and maturity backgrounds were sown and characterized at five locations in India (Akola, Coimbatore, Rajendranagar, Surat, and ICRISAT Center). From these, promising lines were selected for utilization by breeders from India and Ethiopia. We rejuvenated 6277 cultivated and 274 wild sorghum accessions during 1988. A postrainy-season basic collection, constituted at ICRISAT Center, was sent to Mohol, Parbhani (Maharashtra), Annigeri and Gulbarga (Karnataka), and Tandur and Rajendranagar (Andhra Pradesh) for evaluation.

Pearl Millet Germplasm

We added 711 accessions from Burkina Faso (113), India (270), Tanzania (299), and Togo (29) raising the total number of cultivated accessions in the gene bank to 19 796 (Table 1). In collaboration with SADCC/ICRISAT, Bulawayo, Zimbabwe, we collected 803 cultivated and 10 wild

Figure 2. Evaluation of 2000 short-duration sorghum germplasm from ICRISAT at Bonka Agricultural Research Station, Baidoa, Somalia. Sixty-nine most promising accessions were selected for use in the Somalian and East African sorghum breeding programs.

Pennisetum samples from Zimbabwe during March-May, mainly in Matabeleland North. We organized collection missions in collaboration with NBPGR to northeastern Andhra Pradesh, Haryana, and Tamil Nadu. In Andhra Pradesh, we collected 93 early-maturing samples called 'Pittaganti' in September. We collected 189 samples comprising primitive forms called 'bajri', dual purpose forms called 'Dholsari', and large-headed forms from Haryana during September-October. In December, we collected 50 samples from Tamil Nadu, India, in collaboration with NBPGR.

We evaluated and characterized 2320 accessions at ICRISAT Center during the rainy season. All the new additions from Burkina Faso, Karnataka, and Tamil Nadu (India) were classified into different cultivar groups based on flowering, plant height, spike, and grain characters.

We further evaluated 2000 diverse accessions, 500 from Rajasthan and 81 potentially drought-tolerant accessions at NBPGR, Issapur, New Delhi and NBPGR-RS, Jodhpur, and 2000 accessions at the All India Coordinated Pearl Millet Improvement Project (AICMIP), Pune. The results of these are being processed. We identified IP 4021, IP 4349, and IP 7848 from India; IP 6096 from Niger; IP 9265 from Togo; IP 9534 from Ghana; and IP 12649 from Chad that flowered earlier than Tift 13E. Among them, IP 4021 collected from Bhilodi in Gujarat was the earliest to flower (33 days). A comparison of the phenology of parents and F_1S revealed that late flowering is either partially dominant, dominant, or overdominant. The F_2 segregation revealed that differences in flowering time between parents are controlled by one or two genes.

We identified three spontaneous midribless mutants, characterized by leaf blades that tend to droop because of the absence of a keel in the midrib portion of the leaf lamina. Studies indicated that a single recessive gene controlled the midribless character. Further, among the midribless mutants, we found that IP 15946 derived from J 561 (India), and IP 15947 derived from IP 6534 (Mali) have the same gene, designated mrl_1 for this character; and IP 15948 from IP 10154 (Mali) has a different gene, designated mrl_2.

Purple color on stems, leaves, bristles, and glumes in IP 8073 was found to be controlled by a single dominant gene. Purple color of nodes and auricles is monogenically dominant to green nodes and auricles. Color of the node showed complementary gene interaction. The chlorina-virescens mutant was found to be monogenically recessive to normal. Hairy nodes were monogenically dominant while glabrous leaf sheaths and blades were monogenically recessive. Bristle length was intermediate in F_1 and showed continuous variation in F_2, indicating additive gene action.

We have 371 accessions of 21 wild species belonging to the genus *Pennisetum.* To study genomic relationships, we crossed 12 different wild species in 32 combinations. The species crossed were P. *ramosum* (2n=2x=10), P. *violaceum* (2n=2x=14), *P. mollissimum* (2n=2x=14), *P. mezianum* (2n=2x=16), *P. hohenackeri* (2n=2x=18), *P. setaceum* (2n=3x-27), *P. orientate* (2n=4x=36), P. *polystachion* (2n=4x=36), and *P. squamulatum* (2n=6x=54). These 12 species were crossed with cultivated pearl millet in three backgrounds: (a) male-sterile, (b) purple stem, and (c) tetraploid (2n=4x=28).

Out of the 134 crosses made, we obtained seeds from 75. The F_1 seed of the 62 crosses was sown in pots in a greenhouse. Cytological studies of the F_1 between *P. violaceum* and *P. glaucum* revealed the formation of 7 bivalents and regular meiosis. The F_1 of the same cross with the purple P. *glaucum* produced plants with purple background. The F_1 plant was selfed and F_2 seed obtained.

The hybrid between the P. *purpureum* and *P. glaucum* was taller than either of its parents. Except for its height, this hybrid morphologically resembled P. *purpureum* (Fig. 3). Cytological studies confirmed that it was a triploid (2n=3x=21) with 21 chromosomes which formed 7 bivalents and 7 univalents. A number of meiotic irregularities including laggards were observed. Pollen of the F_1 hybrid was sterile and the hybrids produced no seeds. To induce fertility, colchiploidy has been attempted to produce hexaploids. The analysis regarding the other crosses and the progeny testing of the new crosses are in progress.

Chickpea Germplasm

We registered 318 chickpea samples in the gene bank during the year. These include 187 samples of Moroccan origin, 119 from Iran, 6 from India, 3 from Australia, and one each from Bangladesh, Ethiopia, and Spain (Table 1). With these new additions, chickpea germplasm strength is now 15 564 accessions from 42 countries.

We organized two germplasm collection missions. During a mission to Gujarat, in collaboration with the Gujarat Agricultural University, Junagadh, and NBPGR, we collected 50 seed samples of vanishing chickpea landraces from the farmers'seed stock. In Syria, jointly with the International Center for Agricultural Research in Dry Areas (ICARDA) and the Genetic Resources Unit of the Ministry of Agriculture, Syria, we collected 85 samples of kabuli and desi chickpeas, 2 samples each of *Cicerjudaicum* and C. *pinnatifidum,* and one sample of *C. bijugum* (Fig. 4).

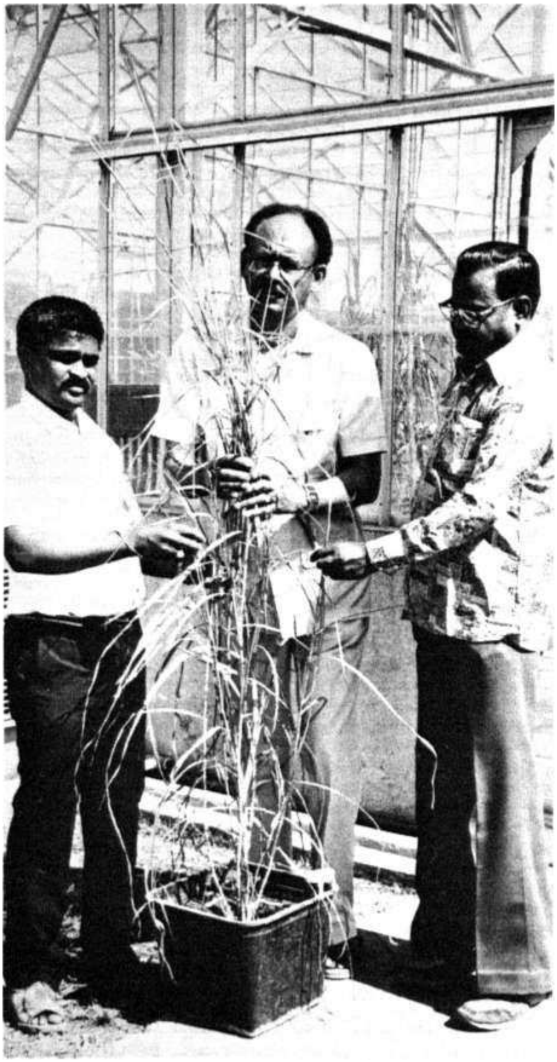

Figure 3. The hybrid between P. purpureum *and* P. glaucum *is taller than either of the parents, but morphologically resembles* P. purpureum.

At ICRISAT Center, we sowed 945 accessions for characterization and 2027 for seed increase. Further, sets of accessions from Tamil Nadu (India), Bangladesh, and kabuli chickpeas of Ethiopian origin were screened for their agronomic performance and we identified five accessions (ICCs 12589, 14231, 14264, 14498, and 14507) with high seed yields. Collaborating with NBPGR, a set of 1320 short-duration accessions was satisfactorily evaluated at ICRISAT Center and Akola, and another set of 1320 long-duration chickpeas at Gwalior and Issapur (Table 2). We evaluated 1034 accessions at Debre Zeit, Ethiopia, in collaboration with Alemaya University of Agriculture, and identified ICCs 4918 (Annigeri), 4958 (JGC 1), 8619, 12268, 12269, and 12707 as agronomically elite.

Pigeonpea Germplasm

We added 6 accessions of pigeonpea originating from India (1), Jamaica (3), and Venezuela (2)

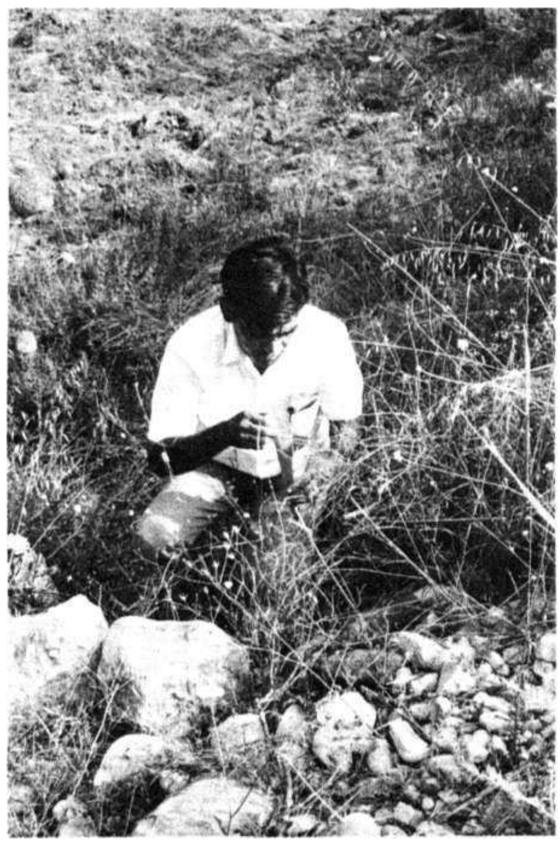

Figure 4. Collecting wild Cicer *species in Syria. These species are tiny plants and often grow between rocks. Pods shatter soon after maturity and timing of collection is very important for the seeds of these species.*

raising the gene bank total to 11 040 accessions from 52 countries. Seedlings of 74 samples from Thailand were transplanted in PEQIA for inspection and subsequent release to ICRISAT. We added two *Atylosia* species, *A. cinerens* from western Australia and *A. elongata* from the northeastern hill region of India, to our wild species collection. We sowed 824 accessions for evaluation. These included 216 new accessions and 608 accessions from previous years for which data were incomplete. We grew 1332 accessions for rejuvenation and seed increase.

In an experiment to screen pigeonpeas for high biomass, we tested 16 accessions in three replications. ICP 6443 ranked first for seed and fuelwood yields. The second most promising accession was ICP 13424. We screened 556 new accessions for photoperiod insensitivity and identified 13 less-sensitive accessions. Eighty-one accessions identified as having low sensitivity to photoperiod in previous years, were further screened under extended photoperiod, and low sensitivity confirmed in 59 accessions.

In collaboration with NBPGR, we evaluated a set of 350 short-duration pigeonpeas at Issapur (Fig. 5) and 300 medium- and long-duration accessions at Akola. A number of promising accessions for yield were identified.

Figure 5. Evaluating pigeonpea germplasm jointly with NBPGR/ICAR at Issapur, India.

Groundnut Germplasm

We added 308 accessions from 12 countries raising the total groundnut accessions in the ICRISAT gene bank to 12 160. The new additions included 156 accessions from Mali that we collected during 1986 (Table 1). In October-November, we collected 14 groundnut samples in Nepal in collaboration with the National Oilseeds Development Programme (NODP), Nepal, and the Asian Grain Legumes Network (AGLN). We mainly explored the mid-hills region of eastern Nepal. In the same period, in collaboration with NBPGR, we also collected 80 samples mainly from tribal and hilly areas of Madhya Pradesh, India.

During May, we obtained 94 samples of wild (64), and cultivated (30) groundnuts from Texas Agricultural Experiment Station (TAES), Stephenville, USA. These accessions were part of previous collections in South America, in some of which 1CRISAT had participated.

We sowed 3623 accessions during the rainy season and 1841 during the postrainy season for rejuvenation and characterization. The 3623 accessions sown in the rainy season were checked for peanut mottle virus (PMV) infection in the field. Field inspection was carried out twice during the season to ensure that only PMV-free plants were harvested.

The joint ICRISAT/NBPGR groundnut germplasm evaluation progressed further with the evaluation of 1500 accessions at the NBPGR Regional Station, Jodhpur, and 1500 accessions at Akola (Table 2). The results of these trials are being processed.

We examined the fresh-seed dormancy of 1060 accessions that were harvested in March-April and October, and found 43 accessions belonging to ssp *fastigiata* with a dormancy period exceeding 30 days. This information is useful in breeding short-duration groundnut cultivars with fresh-seed dormancy (ICRISAT Annual Report 1987, p. 18).

We supplied a total of 2000 accessions to scientists in Indonesia to be screened for resistance to peanut stripe virus (PStV), and participated in the collaborative project between the Central Research Institute for Food Crops (CRIFC), Bogor, Indonesia, and the Australian Centre for International Agricultural Research (ACIAR). We also supplied 3076 *vulgaris* accessions to the ICRISAT Malawi Program to be screened for early leaf spot resistance.

We completed computerization of passport data on 31 descriptors for 12160 accessions. Data on 24 evaluation descriptors are now on computer for all accessions, and data on 26 more descriptors are being computerized. The seed stock position of all the accessions is also available on computer along with seed distribution data. Efforts to finalize the groundnut germplasm catalog manuscript are underway.

Minor Millets

We assembled 153 new accessions of four crop species of minor millets from Burundi (4), Cameroon (19), and India (130) during the year, raising our total gene bank holdings to 6610 (Table 5). We received 188 accessions of finger millet from Zimbabwe and 17 from Tanzania; these were sown in the PEQIA for inspection and release. A total of 1540 accessions of finger millet (887), kodo millet (257), foxtail millet (234), and little millet (162) were evaluated and rejuvenated (Fig. 6).

Table 5. Additions to the ICRISAT minor millets collection in 1988 and cumulative totals, 1976-88.

Species	Accessions in 1987	Cumulative total
Eleusine coracana (finger millet)	87	2848
Setaria italica (foxtail millet)	24	1 404
Panicum miliaceum (proso millet)		831
Panicum sumatrense (little millet)	24	401
Echinochloa spp (barnyard millet)		582
Paspalum scrobiculatum (kodo millet)	18	544
Total	153	6610

We supplied 1970 accessions to Yugoslavia, 494 to the SADCC/ICRISAT Sorghum and Millet Improvement Program, Zimbabwe, 200 to Nepal, 64 to Pakistan, and 572 to Indian institutions for evaluation and use in their breeding programs. In all, we distributed 577 samples to scientists in India and 3514 samples to scientists outside India.

West Africa-IBPGR

The IBPGR Office for West Africa is located at ISC and is charged with implementing IBPGR's mandate in 23 countries of Central and western Africa.

Collection

During this year, a collection mission in Niger was carried out in conjunction with the Institut national de recherches agronomiques du Niger (INRAN) and explored the pastoral Sahelian and Saharo-sahelian zones between 14°N and 19°N. Priority was given to species with known

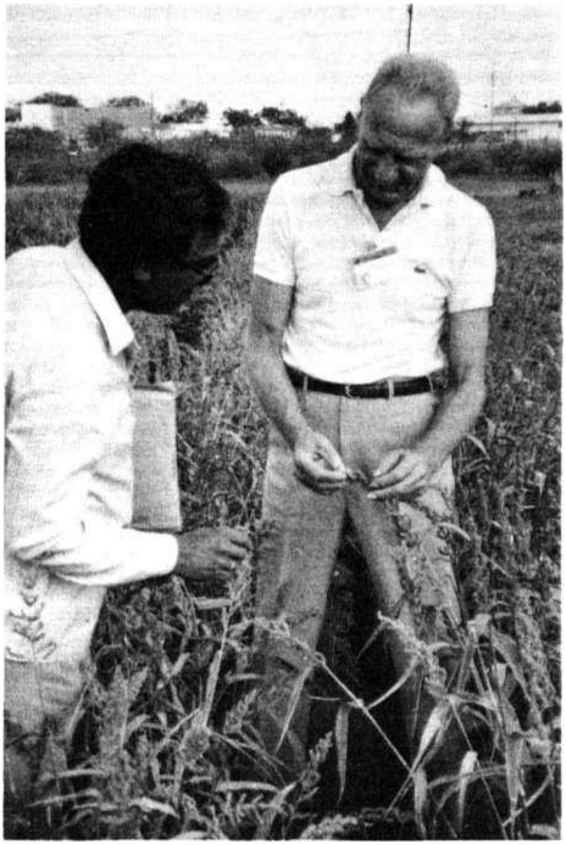

Figure 6. Director, Cereals Program, (right,), *and Senior Botanist, GRU,* (left), *classifying the* Echinochloa *spp, one of the six small millets conserved in the ICRISAT gene bank.*

high forage value, but thought to have restricted or diminishing ecological diversity and under risk of genetic erosion. A total of 83 samples were collected from 63 sites including perennial grasses (*Andropogon gayanus, Cenchrus ciliaris*), legumes (*Alysicarpus ovalifolius*), the wild relatives of crops (*Pennisetum violaceum, Sorghum aethiopicum*), and browse species. Most of these forage accessions are under preliminary testing with RMP at ISC.

In Mali, a joint mission with the Institut national de la recherche zootechnique forestiere et hydrobiologique (INRZFH) explored northwestern and northeastern regions of the country between 15°N and 20°N including the Adrars des Iforas. More than 600 samples representing over 100 species were collected including wild relatives of millet, sorghum, rice, watermelon, and forage grasses, legumes, and browse trees.

Conservation

In areas, where electricity is expensive and unreliable, it is not possible to comply with standardized recommendations for drying seeds for conservation. Therefore, ambient drying under conditions of cool shade may well be an acceptable method for the Sahelian countries. To investigate this, the collaboration of ISC was sought to undertake some experiments on the effects on long-term seed viability of shade drying. Some preliminary experiments were conducted in 1988, and these will be continued in 1989.

Characterization

One characterization project was finalized in 1988 on pearl millet in Burkina Faso. This has resulted in characterization of 341 accessions for 38 descriptors. The samples have been distributed to ICRISAT and institutes in Burkina Faso, Canada, and the USA.

Documentation

ISC has taken the initiative to translate into French the IBPGR-ICRISAT descriptors for sorghum, pearl millet, and groundnut. It is expected that these descriptor lists will be jointly published by IBPGR and ICRISAT.

During 1988, the IBPGR Office made a major effort to install, update, and complete the IBPGR databases on institutes involved with plant genetic resources and germplasm collected, and computerize the collection data for missions in the region since 1986. This will enable the office to provide a better information service about activities on plant genetic resources in West Africa.

Plant Quarantine

The Plant Quarantine Unit continued to assist the National Bureau of Plant Genetic Resources (NBPGR), the national plant quarantine services, in the processing and expeditious export of healthy and disease-free seed and plant material through a series of meticulous internationally laid examination procedures. The Unit also provided assistance in the clearance of healthy imported seed and plant samples, and the subsequent surveillance of crops in the post-entry quarantine isolation area (PEQIA) for healthy first-generation seeds. An important contribution of the Unit was a report on a seedborne bacterial disease caused by *Xanthomonas campestris* on chickpea, resulting in seed rot and wilt symptoms in infected plants (Fig. 1). For effective functioning of plant quarantine, we felt a need for research on quarantine risk, and carried out growing-on tests related to this bacteria in the quarantine greenhouse. We also utilized the greenhouse for carrying out research on efficacy of seed treatment chemicals on new seedborne fungal and bacterial interceptions.

Plant Material Exports

During the year, we exported 55 505 seed samples of our mandate crops, minor millets, maize (*Zea mays*), teosinte (*Euchlaena mexicana*), black gram (*Phaseolus radiatus*), *Atylosia* sp, *Rhyncosia* sp, and *Dunbaria ferruginea,* a sample of *Striga asiatica,* 2 isolates of pearl millet smut (*Tolyposporium penicillariae)* spores, 6 pigeonpea dhal samples, 87 units of rhizobial and

Figure 1. Symptoms of bacterial wilt of chickpea caused by Xanthomonas campestris *on K-850 variety* (left); *healthy plants of the same variety* (right).

mycorrhizal cultures, and 712 samples of plant material to cooperators and scientists in 100 countries (Table 1). The material comprised germplasm accessions from the gene bank, 402 sets of 62 different types of trials and nurseries, promising genotypes resistant to pests and diseases, lines for screening against viruses, and samples for food quality, mycotoxins, and biochemical analyses.

Plant Material Imports

The NBPGR released 4720 seed and plant samples of our mandate crops and minor millets from 26 countries. It also released 36 soil samples for chemical analysis; a sample of *Rhizopus oligosporus,* 9 samples of sorghum uji, maize meal, teff (*Eragrostis teff*), and barley seeds for food quality and biochemical analyses; 131 herbarium specimen of *Arachis* sp, 24 units of *Rhizobium* cultures, and 19 seed samples of crops that are not on ICRISAT's mandate (such as bambaranut, maize, sunflower, and cowpea), collected by ICRISAT botanists during their collection missions, for the benefit of Indian programs (Table 2).

Post-entry Quarantine Isolation Area (PEQIA)

We raised all imported seed and plant samples and screened them for one season in the PEQiA with a view to preclude the entry of locally existing plant pests and pathogens, and to prevent the escape of those that may have accompanied the introduced material. We raised 3735 samples of our mandate crops and minor millets during the year and made healthy seeds available to ICRISAT scientists for utilization in their research activities.

Table 1. Seed and plant material exports of ICRISAT mandate crops, 1988.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
AFRICA							
Benin	205			4	89	6	
Botswana				5	48		
Burkina Faso	481				34		
Burundi	96						
Cameroon	263			49			
Comoro Islands				10			
Cote d'Ivoire	114						
Djibouti				5			
Ethiopia	432		756	503		317	
Gabon					4		
Ghana	5	3		71	49		
Guinea	6	31			58		
Kenya	2514	40	587	79			1
Lesotho				13			
Madagascar				9			
Malawi	407			314	3461		
Mali	790						

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Morocco	144						
Mozambique	193			61	79		
Niger	3 324	1911		138	609		
Nigeria	10	2		4			
Republic of South Africa				96			
Rwanda	248				126		
Senegal					25		1
Sierra Leone					100		
Somalia	2 697			91			
Sudan	406		124	6			
Swaziland		13			39		
Tanzania				10			
The Gambia	69	34		4			
Togo	57				1		
Tunisia			129				
Uganda	192				136		
Zaire	45			10			
Zambia	161	267		18	50		32
Zimbabwe	1516	2 260		336		494	
ASIA							
Afghanistan			123	126			
Bangladesh	72	28	847	54	22		1
Bhutan	72				22		
Burma	129	7	630	54	286		
Indonesia	288	102	48	491	4260		
Iran			959				
Japan	1		4	15			
Jordan	72	17					
Korea				16	71		
Malaysia	78				101		8
Maldives	1						
Nepal	2		922	286	44	200	1
Oman	3						
Pakistan	464	461	517	142	22	64	4
People's Republic of China	796			42	122		4
Sri Lanka	3		21	160	231		
Syria			155				
Taiwan		17					
Thailand	513	128		9	120		
The Philippines	520	25	484	10	108		
Vietnam	72		60	226			
Yemen Arab Republic	86	51	125				
THE AMERICAS							
Antigua			84				

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Argentina	445		120	30	42		
Bahamas				3	33		
Barbados				42			
Belize				71	28		
Bolivia			5				
Brazil				1	15		
Canada	14	12	10	52			
Chile			10		24		
Colombia	51				55		
Cuba	24						
Dominican Republic				30			
Ecuador				20	20		
El Salvador	144			5	23		
Guatemala			5		64		
Guyana				42			
Jamaica				228			
Mexico	806	77	385		120		
Nicaragua	47		60				
Panama		17		90			
Peru				40	15		
Trinidad and Tobago				86			
USA	947	215	352	340	147	22	592
Venezuela	3			1109			6
EUROPE							
Belgium	18		10	1	3		1
Denmark	5		71				
Federal Republic of Germany	1	6	12	6			1
France	9			42	39		
Greece			31				
Hungary					500		
Italy	4		18				
Portugal			29		25		
Spain			236				
The Netherlands	10						
Turkey			148				
UK	25	100	26	19	15		15
USSR				18	18		
Yugoslavia		150				1970	
OCEANIA							
Australia	195		356	99	6		164
Fiji				30	125		
New Zealand				168			
Vanuatu				8			
Total	20295	5974	8 375	6131	11634	3073	831

Table 2. Seed and plant material imports of ICRISAT mandate crops, 1988.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
AFRICA							
Burkina Faso	100						
Cameroon	248						
Ethiopia	2			30			3
Kenya	159			1			5
Malawi					66		
Morocco	19						
Niger		642					
Nigeria		6					
Somalia	26						
Sudan	110						
Swaziland					1		
Tanzania			5	25	16	17	
Zambia		5			34		
Zimbabwe		867			31	30	11
ASIA							
Bangladesh			1				
Indonesia							1
Nepal			1	1	4		23
Pakistan	7	30					
Syria			464				
Thailand				77			
AMERICA							
Brazil	3						131
Mexico			5				
USA	7	355			418		
EUROPE							
The Netherlands			1	1			1
UK	10	598		1	77	200	9
OCEANIA							
Australia			19				
Total	691	2 503	496	136	647	247	184

Farm Development and Operations

ICRISAT Center

Effective field support is essential for meaningful experimentation. Early and timely planting of crops in the second half of June proved valuable in establishing good crop stand prior to heavy monsoon rains. An extremely wet rainy season allowed limited 'window' to carry out crop cultivation and pest control operations.

An abrupt end of rains at the end of September proved tricky for the land preparation and establishment of chickpea and nonirrigated sorghum in the receding soil moisture. It required expeditions and innovative cultivation methods to establish good crop stand.

The area under experimentation during 1988 is given in Table 1.

Integrated weed control using mechanical, chemical, and cultural practices proved cost effective and there was a marked reduction in the actual number of temporary farm labor (TFL) man-days during 1988. However, real saving can only be realized over the years through reduction in weed intensity in general. Weed control through herbicides in sorghum and groundnut was excellent. We controlled insect pests through regular monitoring and use of integrated pest-control measures.

Table 1. Area under experimentation, excluding watersheds, during 1988.

Crop	Rainy season (ha)	Postrainy season (ha)	Total (ha)
Pearl millet	41	29	70
Sorghum	57	59	116
Groundnut	62	38	100
Chickpea	2	63	65
Pigeonpea	62	3	65
RMP fields	26	17	43
Trainees' fields	13	1	14
Others	3	10	13
Total	266	220	486

Table 2. Weeding by temporary farm labor (TFL) and man-days ha^{-1}.

	Weeding		
Crops	Area (ha)	Man-days	Man-days ha^{-1}
Pearl millet	90	4 102	46
Sorghum	87	3068	35
Groundnut	160	12002	75
Chickpea	36	615	17
Pigeonpea	21	1 140	54
GRU fields	14	1010	72
Trainees' fields	3	133	44

Hand weeding and TFL man-days per hectare are given in Table 2.

Very little irrigation was required during the rainy season. It was mainly required to create high humidity essential for disease nurseries. We irrigated postrainy-season crops. During the year, we irrigated about 1300 ha and used 65 hectare-meter volume of water from the harvested runoff.

We spent more than 80% machine hours (> 12 000 h), on land preparation and farm maintenance jobs and 1300 h on crop cultivation and protection, of the total 15000 machine hours spent on tillage. On an average, we spent about 30 machine hours ha^{-1} on experimental crops during 1988.

We provided harvesting, threshing, and seed drying facilities for the areas under cropping. We threshed and dried about 100000 plot samples and extensively used plot combines for plot harvest. We developed and used precision space vacuum planter to plant four rows of groundnut and chickpea at a spacing of 30 cm. An electronic plot-length measuring device was installed on a planter to save TFL man-days for field layout.

We completed the construction of the southern boundary road and upgrading of peripheral fence and paved some important road sections. We maintained roads and drains during the rainy season. We upgraded drain crossings and culverts and constructed safety barriers. We graded some fields having drainage problems to improve drainage. We constructed drainage and runoff monitoring structures to establish land and water management experiments of the Resource Management Program. We improved the drainage layout at Gwalior cooperative research station; it worked well under extremely wet conditions this year and resulted in successful experimentation. We also participated in the preparation of a land reclamation funding proposal for the Hisar cooperative research station. We visited and developed plans for station development at Kiboko (Kenya) and Rampur (Nepal).

We supported all greenhouse experiments by installing new equipment and indigenously developing prototype environment monitoring equipment for use in the greenhouses. We maintained the landscape within the campus, developed new landscapes, and drew plans for tree plantation and establishment of greenbelts on the station.

We identified and appointed a Consultant to review operations at Farm Development and Operations (FDO), who successfully completed his task and gave useful suggestions (Fig. 1).

Training on Station Management was given to Station Managers at SADCC/ICRISAT, Bulawayo (Fig. 2) and at ICRISAT Center. Staff

Figure 1. Consultant to FDO discussing precision planting with a scientist, ICRISAT Center, 1988.

Figure 2. Station Managers from SADCC countries learning field operations in a training program at SADCC/ICRISAT, Bulawayo, 1988.

of FDO actively contributed towards the Legumes On-Farm Testing and Nursery (LEGOFTEN) training workshop and in training in-service trainees.

ISC, Niger

During 1987, we stubble-mulched/chisel-plowed the pearl millet fields and completed a drainage system around all fields. We carried out ridging on more than 200 ha of land. Timely ridging with sufficient moisture is critical to avoid sand-blast damage to young plants. Good June rainfall permitted us to complete all pearl millet sowing and ridging for cowpeas before the end of the month. We cropped a total of 265 ha. We carried out field operations mechanically except within-row weeding and thinning (5 man-days ha^{-1}) and fertilizer application (2 man-days ha^{-1}). Animal traction (AT) played a major role and we used this for all operations, including the bulk of the weeding and interrow cultivation for sand-blast control. Horses were particularly effective. One man covers 2.5 ha day^{-1} with a horse for weeding or interrow cultivation. The jab planter mounted on the Nikart tool carrier was effective for seeding in high-residue situations.

We irrigated 7 ha in the dry season by trucking water from the river. We provided supplementary irrigation to groundnut breeding, groundnut pathology, millet pathology, and agroclimatology experiments during the rainy season.

Animal traction was used by all the programs and in the rotation fields for weeding, fertilizer incorporation, and reridging. We used oxen, cows, donkeys, and horses for these operations. It saved considerable temporary labor cost.

We grew saplings and *Andropogon* plants in plastic pots to replace missing plants in the windbreaks.

Nigeria

Kadawa

All the 39 ha allocated to the West African Sorghum Improvement Program (WASIP) at Kadawa were released to us. Due to unusually heavy rainfall and water-logging, we could erect only half of the peripheral fencing by August. We cleared irrigation channels of overgrowth. The three subprograms sowed off-season sorghum trials in the 1 st week of November.

Bagauda

We planted first rainfed trial on temporarily allocated land within the Bagauda Cattle Ranch. Although the land development was not complete and fields not well laid for research, we collected some useful data and gained one year of useful experience. During the year, we renovated the two office rooms and the lodgings. Fencing is expected to start immediately after land clearing commences.

SADCC/ICRISAT, Zimbabwe

We acquired additional land at Mzrabani (Zimbabwe) for off-season experimentation and began land development work. We provided assistance in developing field research facilities at Pandamatanga (Botswana) to start collaborative research on sorghum. We developed land at Golden Valley (Zambia) to establish disease screening work. Staff housing plans are under active consideration to support millet research in the western province (Zambia).

We provided assistance to the collaborating Southern African Development Coordination Conference (SADCC) countries by placing some vital field equipment to run trials and also by appointing local staff to supervise development and project experiments.

At Matopos, we constructed a field shelter-cum-crop work area and the construction of grain quality and crop utilization laboratory, offices, training dormitory, and simplex houses is nearing completion.

Statistical Services

The Statistics Units at ICRISAT Center and ISC provide consultancy services to scientists/ research associates from collaborative projects at various stages of their research, including planning and designing experiments, analyzing data, and drawing inferences. We deliver lectures on experimental designs to the trainees. We also conduct training courses for the scientific staff on the use of statistical packages like GENSTAT and SAS, both for main frame and microcomputers. We develop statistical software for different methodologies. We participate in in-house reviews, planting plan meetings, and visits to experimental trials at various locations. We review the annual report, scientific papers for the Editorial Committee, and articles for newsletters.

During the year, we consulted experts on topics of our current research interest. These include "inter-site transfer of varieties" and "biological growth curves", which resulted in papers being published in journals. Our consultancies with scientific staff and collaborators during the year averaged over 75 per month.

We processed large data sets for various programs and for collaborators. We also assisted MSc and PhD students in data analysis.

Our statistician has proceeded on sabbatical leave in July to work as a visiting professor at the Virginia Polytechnic Institute and State University, USA.

One staff member was trained in MASS-11 (a word processing package) at MICROSYSTEMS Engineering Corporation at Illinois in USA for 1 week.

Computer Services

The Computer Services Unit provides timesharing to the ICRISAT research personnel on a VAX-11/780 computer system, and to the ICRISAT administration on a MicroVAX 3600 computer system. The VMS operating system is used on both computer systems, and the systems are connected as a network. We develop interactive systems, provide data-entry services, install VAX software packages and microcomputer software, and give seminars and individualized instruction on computer usage to all staff members.

On the research side, PC versions of the widely used statistical analysis packages SAS and GENSTAT were installed on AT-class microcomputers in each research department; an Institute Publication Selection System, building on the Journal Articles Records System, was developed for scientists' use; and the following PC-based applications were completed: manuscript line numbering for WordStar files, RUNOFF to WordStar conversion, institute mailing list (patterned after the VAX version), Genetic Resources Unit (GRU) seed despatch and inventory, plot history records, and a comprehensive record-keeping system for the Asian Grain Legumes Network (AGLN). On the administrative side, the supplies management system was completely revised; a leave travel assistance records system was developed; microcomputer-based transport records, room reservation, vehicle loans, hospitalization, and accident insurance systems were completed.

The MicroVAX 3600 computer system was installed in August, replacing the administrative VAX-11/750. An additional terminal server, and an ethernet multiport repeater were added to the network, providing more versatile terminal access and more capability for networking microcomputers with the VAXs. New high-performance modems were installed, which permit better throughput for our international electronic mail.

An electronic mail capability was established in the East African Regional Sorghum and Millet (EARSAM) office in Nairobi using their existing IBM PC hardware and an error-correcting modem. Access to electronic mail is via London.

Computer Services conducted a course on dBASE III Plus for 31 staff members, and presented a seminar on 'Using PC DOS', attended by over 100 staff members.

The Department Head attended the Spring DEC Users' Society meeting in May at Cincinnati, Ohio, USA. He also attended the Fall DEC Users' Society meeting in October in Anaheim, California, USA. One staff member attended the System 1032 Users' Group meeting in November at Cambridge, Massachusetts, USA. Another staff member attended the SIGDOC 88 conference on systems documentation at Ann Arbor, Michigan, USA, and the last 2 days of the DECUS meeting in October. Four staff members attended the Computer Society of India annual meeting in January at Madras. One staff member attended a workshop on modeling during February at Bombay. Four staff members attended training courses of 1-2 weeks duration in India, and three staff members attended training courses in the USA.

A plan has been developed over the next five years which includes incorporation of the majority of microcomputers into the VAX network. Next year, we will install the necessary hardware to physically extend the network to the main laboratory buildings. The two VAX systems will be further interconnected as a local area VAX-cluster to facilitate system management, sharing of resources, and the flexible addition of new future VAX systems. The VAX-11/780 is expected to be replaced by a more powerful VAX system in 1989.

Publications

Institute Publications

Germplasm Catalogs

Pundir, R.P.S., Reddy, K.N., and Mengesha, Melak H.1988. ICRISAT chickpea germplasm catalog: evaluation and analysis. Patancheru, A. P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 100 pp. ISBN 92-9066-154-2. (GCE002)

Remanandan, P., Sastry, D.V.S.S.R., and Mengesha, Melak H. 1988. ICRISAT pigeonpea germplasm catalog: evaluation and analysis. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 95 pp. ISBN 92-9066-152-6. (GCE 001)

Other Publications

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. La quarantaine a l'ICRISAT. (In Fr.) Patancheru, A.P. 502 324, India: ICRISAT. (GAF 011)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Cuarentena vegetal en el ICRISAT. (In Es.) Patancheru, A.P. 502 324, India: ICRISAT. (GAS 011)

Journal Articles

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

Appa Rao, S., Mengesha, M.H., and Rajagopal Reddy, C.1988. Characteristics, inheritance, and allelic relationships of midribless mutants in pearl millet. Journal of Heredity 79(1): 18-20. (JA 639)

Appa Rao, S., Mengesha, M.H., and Rajagopal Reddy, C.1988. New sources of early-maturing germplasm in pearl millet (*Pennisetum glaucum*). Indian Journal of Agricultural Sciences 58(10):743-746. (JA 724)

Appa Rao, S., Mengesha, M.H., and Rajagopal Reddy, C.1988. Inheritance and linkage relationships of qualitative characters in pearl millet (*Pennisetum glaucum*). Indian Journal of Agricultural Sciences 58(11):840-843. (JA 641)

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

Ramanatha Rao, V. 1988. Botany. Pages 24-64 *in* Groundnut (Reddy, P.S., ed.). New Delhi, India: Indian Council of Agricultural Research. (JA 313)

Singh, M., and Gilliver, B. 1988. Statistical analysis of intercropping data using a correlated error structure. Journal of Applied Statistics 15(1):53-61. (JA 372)

Singh, M., Gilliver, B., and Rao, M.R. 1988. Stability of genotypes in intercropping. Biometrics 44:561-570. (JA 492)

Singh, M., and Kanji, G.K. 1988. Fitting a non-linear model with errors in variables and its application. Journal of Applied Statistics 15(3):267-274. (JA 738)

Conference Papers

Mengesha, M.H., and Remanandan, P. 1988. The genebank at ICRISAT and its significance for crop improvement in Africa with special reference to Ethiopian germplasm. Pages 333-339 *in* The conservation and utilization of Ethiopian germplasm: proceedings of an International Symposium, 13 16 Oct 1986, Addis Ababa, Ethiopia (Engels, J.M.M., ed.). Addis Ababa, Ethiopia: Plant Genetic Resources Centre. (CP 327)

Varma, B.K., and Langerak, C.J. 1988. Seed-transmitted pests and diseases of legumes in rice-based cropping systems. Pages 189-201 *in* Rice seed health: proceedings of the International Workshop, 16 20 Mar 1987, Los Banos, Philippines. Laguna, Philippines: International Rice Research Institute. (CP 338)

ICRISAT Governing Board-1988

ICRISAT Senior Staff-as of 31 Dec 1988

ICRISAT Center

Administration

L.D.Swindale, Director General
J.S.Kanwar, Deputy Director General (until Mar)
M. Goon, Assistant Director General (Administration)
K.B.Srinivasan, Assistant Director General (Liaison)
B.C.G.Gunasckera, Advisor to Director General
for Donor Relations
S.J.Phillips, Special Assistant to Director General
for Educational Affairs (until May)
P.Reavey, Special Assistant to Director General
for Educational Affairs (from Nov)
V.Balasubramanian, Sr Executive Officer
(Director General's Office)
Joyce Gay, Sr Adm Secretary to DG
Surendra Mohan, Sr Adm Officer, Office
of the DDG (until Dec)
P.Subrahmanyam, Sr Adm Officer, Office of the DDG
(from Dec)
K.Sampath Kumar, Adm Secretary, Office of the DDG
S.Krishnan, Asst Manager (Admn) Office of Advisor
to DG for Donor Relations (until Feb)
C.Geetha, Adm Secretary, Office of the ADG (Admn)
P.Sosamma Nair, Adm Officer, Office of the ADG (Liaison)
D.Mitra, Fiscal Manager
A.Banerji, Assistant Manager (Fiscal)
(on special leave from Nov)
V.S.Swaminathan, Sr Accounts Officer
A.N.Venkataswamy, Sr Accounts Officer (until Dec)
C.P.Rajagopalan, Accounts Officer
P.A.V.N.Kumud Nath, Accounts Officer
K.Narayana Murthy, Accounts Officer
B.K.Vasu, Accounts Officer
T.Kulashekhar, Accounts Officer
T.K.Srinivasan, Accounts Officer
N.V.V.Rao, Accounts Officer (from Nov)
B.K.Johri, Personnel Manager (until Nov)
P.M.Menon, Personnel Manager (Acting)
N.S.L.Kumar, Sr Personnel Officer
P.Suryanarayana, Sr Personnel Officer
A.Hameed, Personnel Officer (until Dec)
A.J.Rama Rao, Adm Secretary (Personnel)
R.Vaidyanathan, Purchase and Stores Manager
C.R.Krishnan, Asst Manager (Purchase and Stores)
K.P.Nair, Sr Purchase Officer
D.K.Mehta, Sr Stores Officer
D.V.Rama Raju, Sr Purchase Officer
K.C.Saxena, Sr Stores Officer
K.R.Natarajan, Shipping and Purchase Officer
J.Banji, Purchase Officer (on secondment to ISC
from Jan)
T.Gopalakrishnan, 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 (until Mar)
K.K.Vij, Asst Manager (Admn)(Deihi Office)
K.Santhanam, Manager (Internal Audit)
(on contract from Feb)
N.Surya Prakash Rao, Sr Resident Medical Officer
K.Jagannadham, Transport Officer
A.Rama Murthy, Travel Officer
V.V.Ramana Rao, Adm Officer
V.Satish Kumar, Audit Officer (from Dec)

Research Programs

Cereals

Program Office

J.M.J. de Wet, Program Director, Cereals
K.Santhanam, Asst Manager (Adm) (until Jan)
S.Krishnan, Asst Manager (Adm) (from Feb)

Sorghum Group

S.Z.Mukuru, Principal Plant Breeder (until Jun)
L.K.Mughogho, Principal Plant Pathologist
J.M.Peacock, Principal Plant Physiologist
(on sabbatical until May)
K.F.Nwanze, Principal Cereals Entomologist
C.M.Pattanayak, Coordinator CCRN (from Aug)
R.Stumpo, Asst Principal Plant Physiologist
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
H.D.Patil, Sr Research Associate
K.David Nicodemus, Sr Research Associate

D.J.Flower, International Intern (until Jan)
C.S.Busso, Postdoctoral Fellow (from Jun)
H.Kokubu, Postdoctoral Fellow
M.A.Osman, Postdoctoral Fellow (from Feb)
S.O.K.Trichur, Research Scholar (until Aug)
K.G.Kausalya, Research Scholar (from Nov)
Mohd Hassan Aden, Research Scholar (from Aug)
Hassan A. Hassan, Research Scholar (from Aug)

Pearl Millet Group

F.R.Bidinger, Principal Plant Physiologist
S.B.King, Principal Plant Pathologist
J.R.Witcombe, Principal Plant Breeder
C.T.Hash, Associate Principal Plant Breeder (until Jun)
K.N.Rai, Plant Breeder
B.S.Talukdar, Plant Breeder
Pheru Singh, Plant Breeder (until July)
S.B.Chavan, Plant Breeder
G.Alagarswamy, Plant Physiologist
V.Mahalakshmi, Plant Physiologist
S.D.Singh, Plant Pathologist
R.P.Thakur, Plant Pathologist
K.R.Krishna, Microbiologist
B.P.Reddy, Sr Research Associate
M.Peterschmitt, Postdoctoral Fellow (from May)
E.Weltzien, Postdoctoral Fellow (from Nov)

Kenya

V.Y.Guiragossian, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa
S.Z.Mukuru, Principal Sorghum Breeder (from Jul)

Mexico

C.L.Paul, Team Leader and Principal Sorghum Agronomist (on sabbatical from Oct)
C.T.Hash, Principal Sorghum Breeder (from Jul)
R.Clara, Scientist, Sorghum Breeder

Legumes

Program Office

Y.L.Nene, Program Director, Legumes
D.G.Faris, Principal Coordinator, Asian Grain Legumes Network (on sabbatical until Sep)
C.L.L.Gowda, Acting Coordinator (until Oct) and Legume Breeder, AGLN
D.M.Pawar, Sr Agricultural Officer (Cooperative Trials, LEGOFTEN)
Sheila Vijay Kumar, Sr Research Associate (from Mar)
P.Rama Murthy, Adm Officer (until Jan)
G.J.Michael, Adm Officer

Pulses Group

C.Johansen, Principal Agronomist
H.A.van Rheenen, Principal Plant Breeder, Chickpea
Laxman Singh, Principal Plant Breeder, Pigeonpea
A.B.S.King, Principal Entomologist, ICRISAT/ODNRI (until May)
M.Pimbert, Principal Entomologist (from Jul)
J.Arihara, Associate Principal Physiologist
N.Ae, Associate Principal Microbiologist
K.Okada, Asst Principal Microbiologist
H.J.Hansen, Asst Principal Plant Pathologist, ICR1SAT/DANIDA (until Jun)
K.C.Jain, Plant Breeder, LEGOFTEN
Onkar Singh, Plant Breeder, Chickpea
M.P. Srivastava, Sr Plant Breeder (on contract from Aug)
K.B.Saxena, Plant Breeder, Pigeonpea
V.K. Sehgal, Sr Scientist (Ent) (on contract from Feb)
S.S.Lateef, Entomologist
M.P.Haware, Plant Pathologist
S.C.Sethi, Plant Breeder, Chickpea
N.P.Saxena, Agronomist (Physiology)
O.P.Rupela, Agronomist (Microbiology)
J.V.D.K.Kumar Rao, Agronomist (Microbiology) LEGOFTEN
G.V.Subba Rao, Research Scholar (until Oct)
C.S. Pawar, Entomologist, LEGOFLEN
A.M.Ghanekar, Plant Pathologist
Jagdish Kumar, Plant Breeder, Chickpea
S.Sithanantham, Entomologist (until Jul)
S.C.Gupta, Plant Breeder, Pigeonpea
P.N.Thapliyal, Sr Scientist (Pathology) (on contract from Apr)
M.V.Reddy, Sr Plant Pathologist
Y.S.Chauhan, Agronomist (Physiology)
S.B.Sharma, Plant Nematologist
M.D.Gupta, Sr Research Associate
N.V.Ratnam, Sr Research Associate
J.H.Miranda, Sr Research Associate, Chickpea
Sheila Vijay Kumar, Sr Research Associate (until Feb)
L.Krishna Murthy, Sr Research Associate
M.Chenchi Reddy, Sr Research Associate
Nandita Sarkar, Postdoctoral Fellow (until Sep)
S.K.Singh, Postdoctoral Fellow
F.B.Lopez, Postdoctoral Fellow
Sashi Gupta, Postdoctoral Fellow (from Oct)
G.S.Chipiengahalo, Research Scholar (from Mar)
Bele Gopal, Research Scholar
A.Schroth, Research Scholar

Groundnut Group

D.McDonald, Principal Plant Pathologist
J.P.Moss, Principal Cytogencticist
D.V.R.Reddy, Principal Plant Virologist
J.H.Williams, Principal Plant Physiologist (on sabbatical until May)
J.A.Wightman, Principal Entomologist
S.N.Nigam, Principal Plant Breeder
F.Waliyar, Asst Principal Plant Pathologist
L.J.Reddy, Plant Breeder
P.Subrahmanyam, Plant Pathologist (on leave)
P.T.C.Nambiar, Microbiologist
P.W.Amin, Coordinator and Entomologist, LEGOFTEN
G.V.Ranga Rao, Entomologist
A.K.Singh, Cytogeneticist
V.K.Mehan, Plant Pathologist (on sabbatical from May)
D.C.Sastri, Cytogeneticist (on sabbatical from Jan)
M.J.Vasudeva Rao, Plant Breeder
S.L.Dwivedi, Plant Breeder
R.C.N ageswara Rao, Plant Physiologist
V.M.Ramraj, Plant Physiologist
N.Sivananda Reddy, Sr Research Associate
Y.Sudhakar, Postdoctoral Fellow
C.S.Gold, Postdoctoral Fellow
R.A.Naidu, Postdoctoral Fellow
W.R.Sacks, Postdoctoral Fellow (from May)
J.Watterott, Research Scholar
T.Shanower, Research Scholar
Zhang Xinyan, Research Scholar (from May)
Ulrich Hartman, Research Scholar
Ngugen Hai Nam, Research Scholar (from Jun)

Syria

K.B.Singh, Principal Chickpea Breeder
M.P.Haware, Principal Chickpea Pathologist

Pakistan

M.S.Rahman, Principal Chickpea Breeder/ Plant Pathologist

Resource Management

Program Office

J.L.Monteith, Program Director
S.K.Sharma, Sr Research Associate
L.Mohan Reddy, Sr Research Associate
R.S.Aiyer, Sr Adm Officer
S.Ramachandran, Adm Officer

Agronomy Group

S.M.Virmani, Principal Agroclimatologist
C.K.Ong, Principal Agronomist
D.R.Butler, Principal Microclimatologist (from Jul)
M.M.Anders, Principal Production Agronomist (from Dec)
R. Tabo, Principal Agronomist (until Apr)
Piara Singh, Soil Scientist
A.K.S.Huda, Agroclimatologist
A.Ramakrishna, Agronomist
A.A.H.Khan, Engineer
J.N.Daniel, Postdoctoral Fellow (from Sep)
J.C.W.Odongo, Postdoctoral Fellow (from Nov)

Soil Group

J.R.Burford, Principal Soil Chemist
K.B.Laryea, Principal Soil Physicist
G.D.Smith, Principal Soil Scientist, ICRISAT/QDPI
K.K.Lee, Principal Microbiologist
A.Schutt, Asst Principal Engineer (ICRISAT/ University of Hamburg)
K.L.Sahrawat, Soil Chemist
T.J.Rego, Soil Scientist
D.P. Verma, Soil Scientist/Soil Chemist, ICRISAT/IFDC (on contract from Jul)
Sardar Singh, Soil Scientist
Prabhakar Pathak, Agricultural Engineer (on sabbatical from Sep)
K.L.Srivastava, Agricultural Engineer
R.C.Sachan, Agricultural Engineer
R.K.Bansal, Agricultural Engineer (until Oct)
N.K.Awadhwal, Agricultural Engineer/Soil Physicist
V.M.Mayande, Engineer (until Jun)
S.P. Wani, Microbiologist
M. Bonsu, Postdoctoral Fellow
G.W.L.Jayakumar, Research Scholar
S.Shailaja, Research Scholar (until Dec)

Economics Group

T.S.Walker, Principal Economist
P.J.Matlon, Principal Economist (until Aug)
R.A.E.Muller, Principal Economist
J-J.Baidu-Forson, Assistant Principal Economist (until Nov)
A.A.Adesina, Assistant Principal Economist (from Dec)
N.S.Jodha, Sr Economist (on leave)
R.P.Singh, Economist (on sabbatical until Apr)
M.Asokan, Sr Research Associate (on study leave)
K.G.Kshirsagar, Sr Research Associate (on study leave)

K.V.Subba Rao, Sr Research Associate
M.J.Bhende, Sr Research Associate (until Jan)
V.Bhaskar Rao, Sr Research Associate
P.Parthasarathy Rao, Sr Research Associate
A.G.Mengesha, Research Scholar
Jan Everet Bakker, Research Scholar (from May to Dec)

Support Programs

Biochemistry

R.Jambunathan, Principal Biochemist and Program Leader
Umaid Singh, Biochemist
V.Subramanian, Biochemist (on leave from Nov)
S.Sivaramakrishnan, Biochemist
P.Subrahmanyam, Sr Adm Officer (until Dec)
Santosh Gurtu, Sr Research Associate
M.S.Kherdekar, Sr Research Associate
S.Suryaprakash, Sr Research Associate
T.R.K.Satyanarayana, Adm Officer (from Dec)

Electron Microscopy

A.K.Murthy, Engineer

Genetic Resources

M.H.Mengesha, Principal Germplasm Botanist and Program Leader
K.E.Prasada Rao, Sr Botanist
R.P.S.Pundir, Botanist
V.Ramanatha Rao, Botanist
S.Appa Rao, Botanist
P.Remanandan, Botanist (on sabbatical from Jul)
T.R.K.Satyanarayana, Adm Officer (until Dec)
Y.Saideshwara Rao, Postdoctoral Fellow (until Dec)
Abid Sultana, Research Scholar
Surendra Mohan, Sr Adm Officer (from Dec)

Plant Quarantine

N.C.Joshi, Chief Plant Quarantine Officer (on contract)
Upendra Ravi, Sr Research Associate
N.Rajamani, Sr Adm Officer (until Mar)
V.S.Raju, Adm Officer (from Dec)

Fellowships and Training

D.L.Oswalt, Principal Training Officer and Program Leader
B.Diwakar, Sr Training Officer
T.Nagur, Sr Training Officer
S.K.Dasgupta, Sr Training Officer
Faujdar Singh, Training Officer

Information Services

D.A. Fuccillo, Head (until Aug)
J.B.Wills, Research Editor (on sabbatical, Jun-Dec)
Susan D. Hall, Research Editor (Acting Head Aug-Dec)
S.M.Sinha, Asst Manager, Art and Production
D.R.Mohan Raj, Sr Editor
J.J.Abraham, Editor
V.Sadhana, Editor
G.K.Guglani, Sr Art Visualizer
T.R.Kapoor, Sr Composing Supervisor
A.Antonisamy, Printshop Supervisor
A.B.Chitnis, Sr Photographer
N.V.N.Chari, Adm Officer (until Dec)
A.N.Venkataswami, Sr Adm Officer (from Dec)

Statistics

Murari Singh, Statistician (on sabbatical from Aug)

Computer Services

J.W.Estes, Computer Services Officer
S.M.Luthra, Manager (Computer Services)
J.Sai Prasad, Asst Manager (Computer Services)
T.B.R.N.Gupta, Senior Computer Programmer/Analyst
S.V.Nanda Kishore, Computer Programmer/Analyst (from Dec)
E.A.Vinod Kumar, Computer Programmer/Analyst
G.Subba Raju, Computer Programmer/ Analyst (from Nov)

Library and Documentation Services

L.J.Haravu, Manager
P.K.Sinha, Sr Documentation Officer-II
P.S.Jadhav, Sr Library Officer
S.Prasannalakshmi, Sr Library Officer
R.G.Naidu, Documentation Officer
V.Venkatesan, Library Officer (on leave)

Housing and Food Services

D.A.Evans, Manager
S.Mazumdar, Asst Manager (Food Services)
B.R.Revathi Rao, Asst Manager (Housing)

D.V.Subba Rao, Asst Manager (Warehouse)
D.N.Sar, Canteen Officer
N.V.N.Chari, Adm Officer (from Dec)

Physical Plant Services

V.P.McGough, Manager (on secondment from Jul)
W.B.Symons, Principal Engineer (until Jun)
Sudhir Rakhra, Chief Engineer (Civil)
D.Subramaniam, Chief Engineer (Electrical) Manager (Acting) (from Jul)
N.S.S.Prasad, Sr Engineer (Electronics and Instrumentation)
A.R.Das Gupta, Sr Engineer (Communication) (on leave from Apr)
D.C.Raizada, Sr Engineer (Airconditioning)
A.N.Singh, Engineer (Heavy Equipment and Tractors) (on leave from Nov)
S.W.Quader, Engineer (Office Equipment)
K.R.C.Bose, Engineer (Civil)
K.Satyanarayana Raju, Engineer (Machineshop)
V.Madhusudan Rao, Engineer (Electronics and Instrumentation)
Y.Chiranjeevi Rao, Engineer (Electrical)
R.Parameswaran, Engineer (Auto) (from Aug)
S.P.Jaya Kumar, Sr Adm Officer

Farm Development and Operations

D.S.Bisht, Manager
S.N.Kapoor, Manager (Farm Operations) (on leave from Nov)
S.K.Pal, Sr Plant Protection Officer II
K.Ravindranath, Sr Engineer (Farm Machinery)
M.Prabhakar Reddy, Sr Agricultural Officer
N.V.Subba Reddy, Sr Horticulture Officer
M.C.Ranganatha Rao, Sr Engineer
S.Abid Ali Khan, Agricultural Officer
C.Rama Reddy, Agricultural Officer
Akbar Pasha, Engineer
S.C.Gupta, Engineer
V.S.Raju, Adm *Officer* (*until Dec*)
A. Hameed, Adm Officer (from Dec)

West African Programs

ICRISAT Sahelian Center, Niger

Administration

R.W.Gibbons, Executive Director, West African Programs, and Director, ICRISAT Sahelian Center
M.G.Wedeman, Regional Adm Officer (on special assignment until Feb)
A.R.Das Gupta, Manager, Physical Plant Services (from Nov)
A.Jagne, Regional Adm Officer (from Apr)
M.Adjei-Fah, Adm Secretary
M.D.Diallo, Regional Fiscal Officer
J.Banji, Purchase Officer (On special assignment, from Jan)
I.Agani, Accountant
Solange Delanne, Executive Asst (Liaison)
I.J.Cachalo, Bilingual Secretary
K.A.Moussa, Personnel and Transport Officer

Research Programs

Pearl Millet Improvement Program

K.Anand Kumar, Principal Millet Breeder and Team Leader
L.K.Fussell, Principal Millet Agronomist
S.O.Okiror, Principal Millet Breeder/Regional Trials Officer
J.Werder, Principal Millet Pathologist
M.J.Lukefahr, Principal Millet Entomologist
M.Mahamane, Bilingual Secretary
L.Marchais, Principal Geneticist (ORSTOM)
S.Tostain, Principal Geneticist (ORSTOM)
T.J.Stomph, Sr Research Asst (until Nov)
A.A.Cisse, Research Asst (from Jul)

Groundnut Improvement Program

B.J.Ndunguru, Principal Groundnut Agronomist and Team Leader
D.C.Greenberg, Principal Groundnut Breeder
P.Subrahmanyam, Principal Groundnut Pathologist

Resource Management Program

C.Renard, Principal Agronomist and Team Leader
M.C.Klaij, Principal Soil and Water Management Scientist
M.V.K.Sivakumar, Principal Agroclimatologist (on sabbatical until Nov)
R.J.Van Den Beldt, Principal Agronomist/Agroforestry
A.Bationo, Principal Soil Chemist (IFDC)
B.R.N'tare, Principal Cowpea Breeder/Agronomist (IIIA)
Jane C.Hopkins, Visiting Scientist (IFPRI)
J.Lambourne, Principal Animal Nutritionist, Special Consultant (ILCA) (from Sep)
M.Welte, Program Corodinator, University of Hohenheim (from May)
Jane Toll, IBPGR Field Officer for West Africa
V.Watt, IBPGR Collector for the Sahel (until Aug)
P.Ouedraogo, Sr Research Asst

Support Programs

Farm Operations

P.G.Serafini, Research Farm Manager
(on sabbatical from Aug)
R.Van Midde, Technical Asst (SNV)
P.Koudogbo, Chief Mechanic (until Jul)
J.Henry, Training Consultant (Mechanic) (from Nov)

Construction

B.D.Marvaldi, Project Development Officer (until Jul)
V.P.McGough, Facilities Unit Manager (from Aug)
A.Schulz, Project Development Officer (until Oct)

Statistics

B.Gilliver, Principal Statistician
G.Ouoba, Computer Programmer

Information/ Documentation

C.Giroux, Regional Information Officer

West African Sorghum Improvement Program (WASIP)

Mali (transferred from Burkina Faso in June)

Administration

C.M.Pattanayak, Principal Sorghum Breeder
and SAFGRAD/ICRISAT Coordinator (until Aug)
A.Schulz, Administrator (from Oct)

Research

K.V.Ramaiah, Principal Cereal Breeder—*Striga*
and Acting Team Leader (from Aug)
D.S.Murty, Principal Sorghum Breeder (until Apr)
M.D.Thomas, Principal Sorghum Pathologist (Burkina Faso until Dec)
S.N.Lohani, Principal Millet Breeder
(on sabbatical from Apr)
G.Hoffman, Principal *Striga* Agronomist (CIRAD)

Nigeria

Administration

O.Ajayi, Principal Sorghum Entomologist
and Team Leader
A.Banerji, Adm Officer (from Nov)

Research

D.S.Murty, Principal Sorghum Breeder (from Apr)
R.Tabo, Principal Sorghum Agronomist (from Apr)
S.N.Kapoor, Farm Manager (from Nov)

Mali Bilateral Program

S.V.R.Shetty, Principal Agronomist and Team Leader
N.F.Beninati, Principal Breeder

Southern Africa Programs

SADCC Regional Sorghum and Millet Improvement Program, Zimbabwe

L.R.House, Executive Director, Southern Africa
and Project Manager, SADCC/ICRISAT Program
S.P.Ambrose, Regional Adm Officer
A.B.Obilana, Principal Sorghum Breeder
S.C.Gupta, Principal Millet Breeder
W.AJ.de Milliano, Principal Cereals Pathologist
M.Osmanzai, Principal Cereals Agronomist
K.Leuschner, Principal Cereals Entomologist
D.Rohrbach, Principal Economist (from Feb)
H.Ssali, Soil Scientist (IFDC)
Manel I. Gomez, Principal Food Technologist (from Jul)
F.York, Station Development and Operations Officer
C.M.Matanyaire, Station Management
and Development Officer (from Aug)
E.Monyo, Postdoctoral Fellow
W.K.Morgan, Asst Adm Officer (until May)
Z.M.Mhlanga, Asst Adm Officer (from Sep)
R.Nxumalo, Sr Accountant (until Jun)
N.Mwamuka, Research Technician - Grade II
P.Chingombe, Research Technician - Grade II
F.Munaku, Research Technician - Grade II

Regional Groundnut Improvement Program, Malawi

K.R.Bock, Principal Groundnut Pathologist
and Team Leader
G.L.Hildebrand, Principal Groundnut Breeder

Acronyms and Abbreviations Used in this Annual Report

AARD	Agency for Agricultural Research and Development (Indonesia)
ABCD	Attapulgite-Based Clay Dust
ACIAR	Australian Centre for International Agricultural Research
AGLN	Asian Grain Legumes Network
AGRHYMET	Centre regional de formation et d'application en agrometeorologie et hydrologie operationnelle (Niger)
AGRIS	International Information System for Agricultural Sciences
AICORPO	All India Coordinated Research Project on Oilseeds
AICPIP	All India Coordinated Pulses Improvement Project
AICPMIP	All India Coordinated Pearl Millet Improvement Project
AICRPDA	All India Coordinated Research Project for Dryland Agriculture
AICSIP	All India Coordinated Sorghum Improvement Project
AIT	Asian Institute of Technology
ARC	Agricultural Research Center, Debre Zeit (Ethiopia)
AUDPC	Area Under Disease Progress Curve
AWHC	Available Water-Holding Capacity
AYT	Advanced Yield Trial
BA	Benzyladenine
BEC	Bristled Early Composite
BND	Bud Necrosis Disease
BSEC	Bold Seeded Early Composite
CABI	Commonwealth Agricultural Bureaux International (UK)
CATIE	Centro Agronomico Tropical de Investigacion y Ensenanza
CCATD	Crop canopy air temperature difference
CCRN	Cooperative Cereals Research Network
CDA	Controlled droplet applicator
cDNA	complementary Deoxyribonucleic Acid
CD-ROM	Compact Disk-Read Only Memory
CDZ	Cool Dry Zone
CEC	Cation Exchange Capacity
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico)
CILSS	Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (Mali)
CIRAD	Centre de Cooperation internationale en recherche agronomique pour le developpement
CLAIS	Comision Latinoamericano de Investigadores en Sorgo (Guatemala)
CRIDA	Central Research Institute for Dryland Agriculture (India)
CRIFC	Central Research Institute for Food Crops
CRSP	Collaborative Research Support Program (USA)
CSCRTI	Central Soil Conservation Research and Training Institute
CT	Cold Tolerant
CV	Coefficient of Variation
cv	cultivar
DAE	Days after Emergence
DAF	Days after Flowering
DAS	Days after sowing

DBCP	Dibromochloropropane
DM	Downy Mildew
DSR	Disease Severity Ratings
EARSAM	East African Regional Sorghum and Millet (Network Program and Advisory Committee)
EC	Electrical Conductivity
EC	Early Composite
ELISA	Enzyme-Linked Immunosorbent Assay
ELPN	Elite Products Nursery
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (Brazil)
EMVT	Early-Maturing Varieties Trial
FAO	Food and Agriculture Organization of the United Nations (Italy)
FYM	Farmyard Manure
GCA	General Combining Ability
GCVT	Gram Coordinated Varietal Trial
GIET	Gram Initial Evaluation Trial
GLIP	Grain Legume Improvement Programme (Nepal)
GLM	Groundnut Leaf Miner
GRAV	Groundnut Rosette Assistor Virus
GRU	Genetic Resources Unit
GRV	Groundnut Rosette Virus
GSND	Groundnut Streak Necrosis Disease
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (Federal Republic of Germany)
HAU	Haryana Agricultural University (India)
HDZ	Hot Dry Zone
HI	Harvest Index
HP	Hill Placed
HPC	High Protein Composite
HSPs	Heat Shock Proteins
HiTIP	High Tillering Population
IAA	Indole Acetic Acid
IARI	Indian Agricultural Research Institute
IBA	Indole Butyric Acid
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas (Syria)
ICHRN	International Chickpea *Helicoverpa* Resistance Nursery
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)
IIT	Indian Institute of Technology
ILCA	International Livestock Centre for Africa (Ethiopia)
IMZAT	ICRISAT Pearl Millet Zone Adaptation Trial
INERA	Institut national d'etudes et de recherches agricoles (Burkina Faso)
INIFAP	Instituto Nacional de Investigadores Forestales Agropecuarias (Mexico)

INRAN	Institut national de recherches agronomiques du Niger
INRZFH	Institut national de la recherche zootechnique forestiere et hydrobiologique (Mali)
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
I-PCV	Indian Peanut Clump Virus
IPDR	Insitut pratique de developpement rural (Niger)
IPMAT	International Pearl Millet Adaptation Trial
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery
IPMRN	International Pearl Millet Rust Nursery
IPMSN	International Pearl Millet Smut Nursery
IRA	Institut de la recherche agronomique (Cameroon)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrieres (France)
IRHO	Institut de recherches pour les huiles et oleagineux (France)
ISC	ICRISAT Sahelian Center (Niger)
ISHAT	International Sorghum Hybrid Adaptation Trial
ISRA	Institut senegalais de recherches agricoles (Senegal)
ISSBN	International Sorghum Stem Borer Nursery
ISSFN	International Sorghum Shoot Fly Nursery
ISTN	International Sorghum Trials and Nurseries
ISU	Intercrack Structural Units
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)
KARI	Kenya Agricultural Research Institute
KKU	Khon Kaen University (Indonesia)
LAI	Leaf Area Infected
LEGOFTEN	Legumes On-Farm Testing and Nursery
LER	Land Equivalent Ratio
LSW	Leaf Surface Wetness
LWS	Leaf Wetness Score
MARIF	Malang Research Institute for Food crops (Indonesia)
MASVYT	Mesoamerican Sorghum Variety Yield Trial
MC	Medium Composite
MDMT	Mean daily maximum temperature
MDMV	Maize Dwarf Mosaic Virus
MESRES	Ministere de l'Enseignement superieur et de la recherche scientifique
MORIF	Moros Research Institute for Food crops (Indonesia)
MOU	Memorandum of Understanding
MRZSM	Mean root zone soil moisture
MS	Murashige and Skoog
NAA	Napthalene Acetic Acid
NAL	US National Agricultural Library (USA)
NARC	National Agricultural Research Centre (Pakistan)
NARS	National Agricultural Research System
NBPGR	National Bureau of Plant Genetic Resources (India)

NEDCAP	Non-conventional Energy Development Corporation of Andhra Pradesh
NGLIP	National Grain Legume Improvement Programme
NODP	National Oilseeds Development Program
ODNRI	Overseas Development Natural Resources Institute (UK)
ODZ	Often Droughted Zone
OPSCAR	Operational Scale Research
ORD	Organisme regional de developpement (Burkina Faso)
ORSTOM	Institut francais de recherche scientifique pour le developpement en cooperation (France)
PAGE	Polyacrylamide gel electrophoresis
PARP	Partially Acidulated Rock Phosphate
PAU	Punjab Agricultural University
PB	Phytophthora Blight
PBLT	Potential B-lines Trial (Topcross Trial)
PBLT-3	Potential B-lines Trial (Topcross Trial)
PCV	Peanut Clump Virus
PEQIA	Post-Entry Quarantine Isolation Area
PGRC/E	Plant Genetic Resources Center/Ethiopia
PMBPN	Pearl Millet Bulk Progeny Nursery
PMHT	Pearl Millet Hybrid Trial
PMV	Peanut Mottle Virus
PNUD	Programme des Nations Unies pour le developpement
PRP	Parc-W Rock Phosphate
PStV	Peanut Stripe Virus
PVCD	Peanut Veinal Chlorosis Disease
PVT	Preliminary Variety Trial
R&D	Research and Development
RBD	Randomized-Block Design
RCB	Randomized Complete Bolck
RH	Relative Humidity
rmp	random-mating population
RNA	Ribonucleic Acid
RUE	Radiation Use Efficiency
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
SPP	Single-Plant Progenies
SRCSS	Section de reglementation et de controle des semences selectionnees
SSP	Single Super Phosphate
TADD	Tangential Abrasive Dehulling Device
TAES	Texas Agricultural Experiment Station
TDM	Total Dry Matter
TFL	Temporary farm labor

TGMR	Threshed Grain Mold Rating
TRP	Tahoua Rock Phosphate
TSP	Triple Superphosphate
TSWV	Tomato Spotted Wilt Virus
USAID	United States Agency for International Development
VAM	Vesicular-Arbuscular Mycorrhizae
VLS	Village Level Studies
WADMON	West African Downy Mildew Observation Nursery
WADMVN	West African Downy Mildew Variability Nursery
WASIP	West African Sorghum Improvement Program
ZEA	Zeatin

Cumulative list of currently cultivated ICRISAT cultivars and parents issued before 1988 by the Plant Material Identification Committee (PMIC).

Original name	ICRISAT name	Release name	Remarks	Notice
Sorghum cultivars/varieties				
SPV 351	ICSV 1	CSV 11	Released cultivar in India (1384).	84/8
SPV 386	ICSV 2	ZSV 1	Released cultivar in Zambia (1983).	84/15
SPV 475	ICSV 112	SV 1	Released cultivar in Zimbabwe (1985). Recommended for release in India (1987).	86/1
		UANL-1-187	Released cultivar in North Mexico (1987).	
SAR 1	ICSV 145	ICSV 145	Resistant to *Striga asiatica* in India. Recommended for cultivation in *Striga*-endemic areas of India, except Karnataka.	87/1
Sorghum hybrid				
CSH 11 (SPH 221)	ICSH 153	CSH 11	Released cultivar in India (1986) (Male sterile, 296A, from AICSIP).	86/3
Pearl millet cultivars/varieties				
WC-C75	ICMV 1	WC-C75	Released cultivar in India (1982). Released cultivar in Zambia (1987).	84/1
IBV 8001	ICMV2	-	Cultivars in prerelease stage in Senegal.	84/2
IBV 8004	ICMV 3	-		
ICMS 7703	ICMV 4	ICMS 7703	Released variety in India (1985).	86/4
ITMV 8001	ICMV 5	ITMV 8001		86/5
ITMV 8002	ICMV 6	ITMV 8002	Released cultivars in Niger (1985).	86/6
ITMV 8304	ICMV 7	ITMV 8304		86/7
Pearl millet male-sterile and maintainer lines				
81A	ICMA 1	-	Female parent of ICMH 451.	86/8
81B	ICMB 1	-		86/8
834A	ICMA 4	-	Parent of ICMH 501.	84/3
834B	ICMB 4	-		84/3
Pearl millet hybrids				
ICMH 451	ICMH 451	ICMH 451 (MH 179)	Released cultivar in India (1986).	87/2
ICMH 501	ICMH 501	ICMH 501 (MH 180)	Released cultivar in India (1986).	87/3
Chickpea cultivars/varieties				
ICCC 4	ICCV 1	ICCC 4	Released cultivar in Gujarat state, India (1983), and Nepal (1987).	84/9
ICCC 32	ICCV6	-	Identified for release in India.	86/11
Pigeonpea cultivars/varieties				
ICP 8863	ICPV 1	Maruti	Recommended by AICPIP as source of resistance to wilt (*Fusarium udum*). Released in Karnataka state, India (1985).	84/11

continued

Cumulative list. *continued.*

Original name	ICRISAT name	Release name	Remarks	Notice
ICPL 87	ICPL 87	Pragati	Short-duration, high-yielding variety. Released in India (1986).	86/9
ICPL 151	ICPL 151	Jagriti	Short-duration, high-yielding variety. Prerelease in India as Jagriti.	86/10
Groundnut cultivars/varieties				
Robut 33-1-7-4	ICGS 1	-	A selection from ICGS J 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

ICRISAT material identified by the Plant Material Identification Committee (PMIC) in 1988.

Original name	ICRISAT name	Release name	Justification/Present status	Notice
Sorghum hybrid				
AGRO CONSA I	AGRO-CONSA1	AGRO-CONSA I	Resistant to pathotype 1 of downy mildew, macrophomina, and tolerant of rust and cercospora.	88/7
Pearl millet cultivars/varieties				
MP 124 (ICTP 8203)	MP 124 (ICTP 8203)	MP 124 (ICTP 8203)	High grain yield in Maharashtra and Andhra Pradesh, India. Highly resistant to downy mildew.	88/3
Pearl millet male-sterile lines				
ICMA 841 ICMB 841	ICMA 841 ICMB 841	ICMA 841 ICMB 841	Highly resistant to downy mildew, high grain yield, released by the Ministry of Agriculture, Government of India, as seed parent of hybrids Pusa 23 and ICMH 423.	88/1
Pearl millet hybrid				
ICMH 423	ICMH 423	ICMH 423	Released hybrid in India (1987).	88/2
Chickpea cultivars/varieties				
ILC 464	ILC 464 (ICARDA)	"Kyrenia" in Cyprus	Tolerant of ascochyta blight, under Tel Hadya conditions. Released cultivar in Syria.	88/4
ILC 482	ILC 482 (ICARDA)	"Ghab 1" in Syria	Released cultivar by the Ministry of Agriculture and Agrarian Reform, Syria. Recommended for winter sowing in Syria.	88/5
ILC 3279	ILC 3279 (ICARDA)	"Yilousa" in Cyprus, "Ghab 2" in Syria, "ILC 3279" in Tunisia.	Resistant to ascochyta blight and cold. Recommended for winter sowing.	88/6

ICRISAT

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