
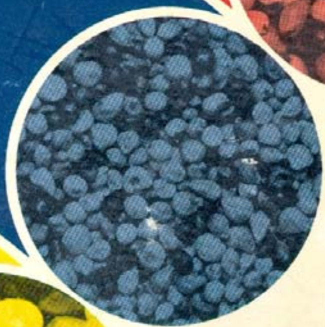


ICRISAT Annual Report 1989

International Crops Research Institute
for the Semi-Arid Tropics

Cover: *The colors selected reflect the color codes for ICRISAT's mandate crops used in the Genetic Resources Unit.*

ICRISAT
ANNUAL REPORT
1989

International Crops Research Institute for the Semi-Arid Tropics
(ICRISAT), Patancheru, Andhra Pradesh 502 324, India
1990

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual Report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

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Design: **G.K. Guglani**
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Phototypesetting: ICRISAT Composing Unit

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ISSN 0257-2478

ICR 90-0023

Contents

ICRISAT's Objectives

ICRISAT's mandate is to:

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

About This Report

This Annual Report covers the 1989 calendar year. It includes work done at ICRISAT Center near Hyderabad, India, at research stations on the campuses of agricultural universities in different climatic regions of India, and at national and international research facilities in six countries of Africa, and in Mexico and Syria, where ICRISAT scientists are posted. Pertinent information on ICRISAT's mandate crops and agroclimatic environment is presented in the section titled 'ICRISAT Crops and their Environment', which is a merger of two old sections—'ICRISAT's Five Crops' and 'Agroclimatic Environment'.

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

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

ICRISAT uses the 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* (Hu'bner), had been changed to *Helicoverpa armigera* (Hubner) in 1988 and this Report and other ICRISAT publications now use the new name. (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 in 1988.

A list of elite ICRISAT plant materials issued by the Institute's Plant Material Identification Committee during 1989 appears at the end of this Report, together with a listing of previously named material that are now in cultivation.

Introduction

As in 1988, in 1989 also there has been good rainfall in India and in West Africa, and satisfactory rainfall in southern and eastern Africa. Farmers of the semi-arid tropics (SAT) contributed significantly to economic growth in their countries and to increased stocks of food grains, paving the way for new opportunities in 1990. ICRISAT has made impressive progress by contributing to great improvement in food grain production in India, and is beginning to have an impact on sustainable food grain production in Africa.

ICRISAT has given increased attention this year to the sustainability of agriculture in the SAT. A sustainability perspective will become increasingly important in all our research and training in future.

New Research Complexes

On 7 March this year, the President of Niger, General Ali Saibou, inaugurated the ICRISAT Sahelian Center (ISC), the research complex located at Sadore, Niamey, established on 500 ha of land made available in 1981 by the Government of Niger. The facilities include laboratories, a conference center, a library, classrooms, a cafeteria, a medical center, physical plant workshops, stores, and administrative offices. The work of the ISC is aimed at resource-poor farmers in the southern Sahelian agroecological zone of West Africa. These farmers are the major agricultural producers of the region who can contribute to increased production if they are provided with better technology.

The foundation stone for an ICRISAT regional research complex for sorghum improvement in West Africa was laid at Samanko in Mali on 11 August by the Cabinet Director of the Malian Ministry of Agriculture, Mr Cheik Bougadary Bathily. The Samanko Center, which will be completed by 1 September 1990, is one of two ICRISAT Centers for the improvement of

The administrative block of the ICRISAT Sahelian Center complex on the inauguration day.

sorghum in West Africa. Jointly supported by the United States Agency for International Development (USAID) and the Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), it will house the West African Sorghum Improvement Program (WASIP) that will concentrate its efforts in the northern Guinean agroecological zone.

Another regional center for sorghum improvement in West Africa is located near Kano in Nigeria and serves the Sudanian agroecological zone.

Strengthening Sorghum and Millet Research in Mali

In Mali, in addition to the regional project, we have a small bilateral team working within the national agricultural research system since 1977. This project terminates in 1990 and an evaluation of its achievements brought out the following points:

(1) Improved pearl millet varieties introduced or developed by the team now cover more than 15% of the millet area in the main millet-growing regions of Mali.

(2) The development of CSM-388 and the Malisor series, sorghum varieties derived from the local guinea sorghums, represents a significant breakthrough.

(3) The maize/pearl millet cropping system developed for the wetter agroecological zones of the country consistently outyields local monocultures and, by 1987, was being used by farmers on more than 20 000 ha.

(4) Fifty-seven Malians have participated in the ICRISAT in-service training program since the commencement of the project, 50 have served research internships with the project, and 11 have taken advanced degrees with assistance from the project.

These are truly commendable achievements by such a small project.

Cooperation with Other Countries

During the last 12 months, ICRISAT has strengthened its cooperation with Asian countries, particularly in relation to our legume crops. In September, we signed a memorandum of understanding with Vietnam's Ministry of Agriculture and Food Industry (MAFI), represented by Dr Vu Tuyen Hoang, Vice Minister of Agriculture. This provides for an ambitious program for training Vietnamese scientists and for research cooperation for all our crops, particularly groundnut and pigeonpea.

We have also drawn up annual workplans with China and for the first time, with India. Training, exchange of plant materials, exchange of scientists and research cooperation are included in the workplan with China. We expect to work closely with the Chinese Academy of Agricultural Sciences on groundnut diseases including the use of biotechnology to obtain bacterial wilt resistance. The workplan with India is for cooperative research. Earlier this year, a meeting of ICAR and ICRISAT representatives, organized by the DDG of ICRISAT and two DDGs of ICAR, was a productive one and many proposals for cooperative research were made. The cooperative program, when finally approved, will enable ICAR to contribute to international research for the SAT.

Double Cropping in the Sahel

In 1989, the Resource Management Program (RMP) at ISC showed again, as in 1986, that it is possible to exploit a forecast of the duration of seasonal rainfall based upon the date of onset of rains. Early identification of wetter years with longer growing seasons allows crop production to be maximized by double cropping. Early this year, during a 4-week stay at ISC, agrometeorologists from the national programs in Senegal and Mali analyzed rainfall data from their countries and prepared reports which showed clearly that considerable potential for double cropping also exists in their countries.

In field trials during 1986 and 1987, RMP at ISC showed that a relay crop of millet-cowpea can be grown in years when rain arrives early. Cowpea is sown between the millet rows 15-20 days before the harvest of millet.

The millet-cowpea relay crop is complementary to the traditional practice of intercropping long-season millet with cowpea. However, millet yields in the intercrop are less than sole millet yields and they are affected by such factors as sowing density, plant population, sowing dates, and spatial arrangement of both component crops. Moreover, the relay crop of cowpea growing late in the season faces fewer problems with diseases and insects. A relay crop is feasible when farmers adopt improved short-duration millet cultivars that mature in 90 days as opposed to the traditional cultivars that mature in 110-120 days.

In 1989 at ISC, we sowed millet on ridges when the first rains of 34 mm came on 20 May, 23 days before the average date of onset. The millet survived despite a 23-day dry spell that followed. We could not sow cowpea in the intercrop treatment until 30 June due to infrequent rain, resulting in suppression of cowpea growth by millet. In contrast, a relay crop sown on 20 August, 15 days before the harvest of millet, benefited from 198 mm of rain in September and 28 mm in October. Millet in the relay crop gave 1.2 t ha^{-1} compared with 0.9 t ha^{-1} for the intercrop millet. Relay cowpea gave 0.13 t ha^{-1} of grain and 0.26 t ha^{-1} of hay compared with 0.09 t ha^{-1} of grain and 0.10 t ha^{-1} of hay for the intercrop.

The potential of the growing season when rain arrives early is much higher in the Sudanian climatic zone than in the Sahelian zone. We are initiating trials with relay cowpea in the Sudanian zone and will examine residual effects of a relay crop on the following millet.

New Research Network

Progress is being made on formalizing a pearl millet research network in West Africa. This network is aimed at strengthening research of the national institu-

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tions in the region. In 1988, the annual regional pearl millet improvement workshop, held in Nigeria in cooperation with IAR of the Ahmadu Bello University, Zaria, in which 13 African National Agricultural Research Systems, Semi-Arid Food Grain Research and Development (SAFGRAD), Institut du Sahel (INSAH)/Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (CILSS), and ICRISAT were represented, recommended that a West and Central African Pearl Millet Research Network be established in the region. ICRISAT was given the task of initiating this network with the involvement of SAFGRAD, INSAH, and organizations such as USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL).

Participants of the annual regional workshop held at ISC in September 1989 have formalized the network. They outlined its objectives and the responsibilities of the steering committee. The first meeting of the steering committee was held at ISC in December. The committee worked on the preparation of a detailed questionnaire to elicit information on constraints to production, staff, and facilities available for millet improvement research in the 13 member countries. Information from these questionnaires will be used by the participants of this network to prepare a document which will be used to solicit funding.

Southern Africa

The expansion of the Southern African Development Coordination Conference (SADCC) Regional Sorghum and Millet Improvement Program in Zimbabwe in the areas of utilization, food technological input, market economics, and input into forages—including local farmers' interest in the pearl millet by napier grass cross—is significant.

There has been increased participation of scientists from all SADCC countries in the improvement of sorghum and millets. This includes a continuing and expanded contribution in reporting results of research and contributing varieties and hybrids for regional evaluation.

Strategic Plan to the Year 2000

A new Strategic Plan to the year 2000 is being developed. This is part of a new process in which each CGIAR Center will draft a Strategic Plan for the next 10 years for study and review by two external panels, one dealing with research programs and the other with management. They will take as their frame of reference, an overall, generalized set of strategies and priorities developed by the TAC for the CGIAR system and judge how the draft ICRISAT plan fits into the larger plan. Following their suggestions, we will modify our draft and finally present our plan to the CGIAR in mid-1991. When the final strategic plan has been approved, we will revise our medium-term operational plan.

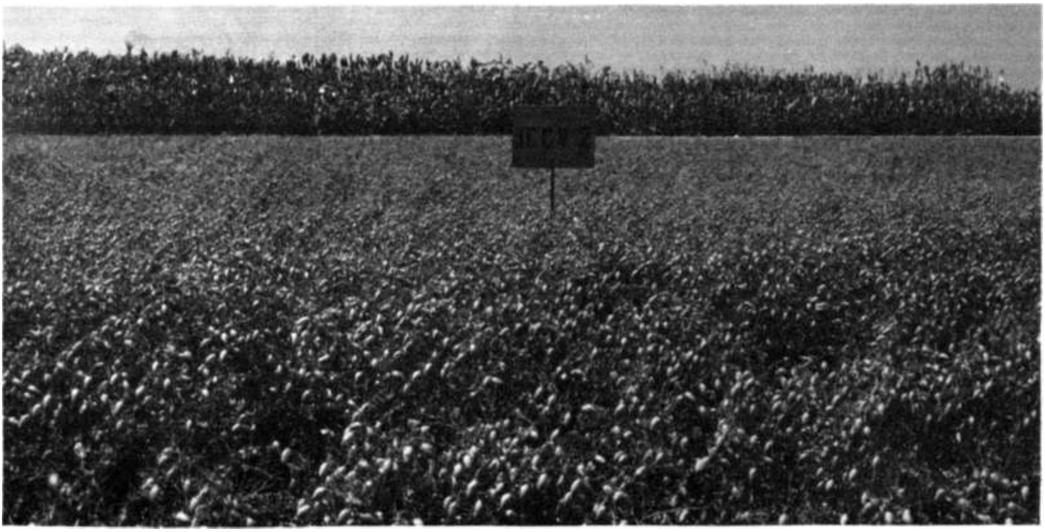
Revival of Research Program

A feature of 1989 has been the revival at ICRISAT Center of the research program in production agronomy that operated so effectively under the late Dr Bert Krantz in previous years, and was largely responsible for the development of the watershed double cropping technology for Vertisols for Central India. In accordance with the new emphasis on sustainable agriculture, the new program will emphasize low-input strategies matched to the soils and climates of the Asian SAT, enhancing farmers' technologies rather than replacing them.

New Cultivars

New cultivars from each of our five mandate crops were released or tested by national programs in various parts of the world during this year. Sorghum variety ICSV 145 was released as SAR 1 by the Indian government for use in Striga-endemic areas and ICSV 745 is being tested in farmers' fields in areas where midge is a serious problem. ICSV 112 was released as CSV 13 for general use in India and as SV 1 in Zimbabwe. Sorghum releases in the SADCC region included SDS 1513 and SDS 1594-1 in Swaziland. In Mozambique, SDS 3220 was released as Macia and IS 8571 as Mamonhe.

Pearl millet variety ICMV 84400 (MP 55) has been identified for cultivation in all Indian states this year. A selection from pearl millet variety 1CTP 8203, developed at ICRISAT in India, was released in the millet-growing region of Namibia as Okashana 1. In Zambia, the pearl millet variety ICMV 82132 and the finger millet variety IE 2929 were released. Pearl millet cultivars based on ICRISAT breeding lines continue to lead the way in most of the millet-growing areas of India except in the northwestern states. Pearl millet scientists have



ICCV 2 (Swetha), a chickpea variety approved by the Andhra Pradesh Ministry of Agriculture, for release to farmers in the state during 1989.

accepted the implied challenge and have set up a research unit in the state of Rajasthan.

In West Africa, varieties of pearl millet developed by ICRISAT in collaboration with national programs in West Africa are gradually spreading onto farmers' fields. These are now grown by farmers in Burkina Faso, Chad, Senegal, and Togo. Varieties are also in advanced trials (multilocational or on-farm) in Cameroon, Mali, and Niger.

Two chickpea varieties have been approved by the Andhra Pradesh Ministry of Agriculture for release to farmers in Andhra Pradesh — ICCV 2 (Swetha) and ICCC 37 (Kranthi). Chickpea lines ILC 5566 and FLIP 85-17C were selected from the ICRISAT/ICARDA nurseries and released in Portugal.

A pigeonpea selection, ICPL 332, which is tolerant to pod borer *(Helicoverpa armigera),* has been released as Abhaya in Andhra Pradesh and ICPL 151 (Jagriti), a short-duration variety, was released in India. Variety ICPL 87 is now well established and is spreading throughout India.

The ICRISAT Groundnut Variety, ICGS 76 (ICGV 87141) was accepted for release for cultivation in rainy season by the Government of India this year. ICGS 76, a Virginia bunch variety, has 2-seeded, medium-sized pods with tan seeds and has good recovery for pod yield from midseason drought. The groundnut variety, BARD 699 has been approved for release by the National Agricultural Research Center's Varietal Evaluation Committee of Pakistan. BARD 699 is a composite variety containing ICRISAT lines ICGS 44 and ICGS 37.

Workshops and Meetings

Several workshops, conferences, and other gatherings were held during 1989. Two major meetings held at ICRISAT Center included the second International Chickpea Workshop where, in a week of active and intensive discussion, 142 delegates coming from 29 countries agreed on the work needed to bring about a sustained and substantial increase in global chickpea production and provided valuable guidance to ICRISAT and International Center for Agricultural Research in the Dry Areas (ICARDA) on directions for chickpea research programs. It was agreed that chickpea production was likely to move from traditional areas of low productivity to areas of high potential where farmers were willing to adopt modern technologies and use higher levels of management skills.

The other important meeting dealt with the extension of the successful legume on-farm research project in India (Legumes On-farm Testing and Nursery—LEGOFTEN) to other Asian countries. A proposal has been submitted to the United Nations Development Programme (UNDP) to extend this highly successful program to four Asian countries over the next 3 years.

Fifty-one delegates participated in a symposium on Industrial Utilization of Sorghum at Kano, Nigeria, organized jointly by Nigeria's Institute for Agricultural Research and ICRISAT. A training workshop was conducted in Mali from

19 to 30 September by the West and Central African Sorghum Research Network on Agronomic Research and On-farm Testing.

The sixth Annual SADCC Regional Sorghum and Millets Workshop was held in September in Bulawayo. There were 57 participants for this 5-day meeting from all nine SADCC countries. In addition there were 14 SADCC/ICR1SAT staff, two scientists from ICRISAT Center, one from Eastern Africa Regional Cereals and Legumes (EARCAL) network, one from Namibia, and two from the USA. This workshop is an annual reporting and planning session and is important in fostering interactions between national and regional centers.

We held a workshop on Market Grades and Standards for Sorghum with invitees from Botswana, Zambia, and Zimbabwe. Fifteen participants came from industries, ministries, and grain marketing boards; food technologists, and crop improvement scientists. This meeting was timely because processing and marketing activities in these three countries are increasing and grain quality has been an issue of concern.

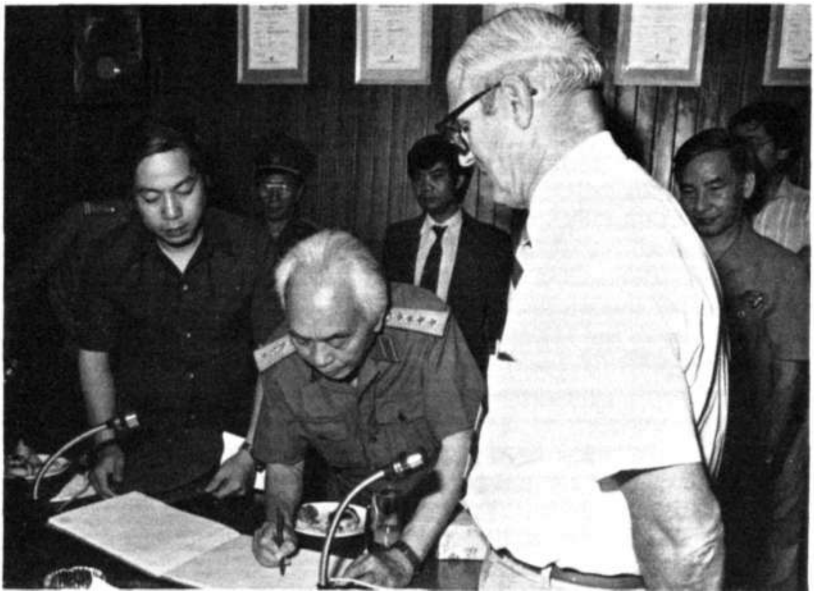
Awards to ICRISAT Scientists

During 1989, several ICRISAT scientists were honored or were given awards for their research achievements. They include: Dr C.Renard, ISC, who was awarded with the title 'Chevalier de l'Ordre de Leopold' by the King of Belgium; Dr J.L.Monteith who was awarded the Rank Prize for Nutrition and Crop Husbandry and an Honorary D.Sc. from the University of Edinburgh; Dr S.Appa Rao who was conferred the Dr Harbhajan Singh Memorial Award by the Indian Society of Genetics and Plant Breeding; Dr D.V.R.Reddy who will be awarded, in January 1990, the first M.S.Pavgi Award constituted by the Indian Phytopathological Society, the announcement of which was made in December; Drs R.P.Thakur and V.P.Rao who were nominated for the 1989 Best Paper Award by the journal Indian Phytopathology. Finally, Dr D.P.Verma was awarded the Fertiliser Association of India's Silver Jubilee Award 1989 for 'outstanding doctoral research in fertiliser usage' jointly with a scientist from the Nuclear Research Laboratory, Indian Agricultural Research Institute.

Training and Human Resources

Development of human resources is a very important aspect of technology transfer. During 1989, 258 participants from 51 countries were given long-term training. Among the regional and national human resources activities were the training of 116 participants in subjects such as cereal pathology for eastern Africa technicians, detection and identification of legume viruses, Vertisol management technology, legume pathology, cereals entomology, hybrid pigeonpea production, legume breeding, management, and production, and sorghum hybrid seed production.

In the SADCC Regional Sorghum and Millet Improvement Program, Zimbabwe, 103 participants from 11 countries benefited from the training programs offered at Bulawayo, including courses on insect and disease identification and scoring station development and management, and food technology.



General Vo Nguyen Giap, Deputy Prime Minister of Vietnam (center) signing the visitors' book at ICRISAT Center, as his delegation and Dr L.D.Swindale look on.

Mr He Kang, Minister of Agriculture, Animal Husbandry, and Fisheries, the People's Republic of China (second from right), shares a light moment with his delegation while viewing a genetic resources display.

Visitors to ICRISAT Center and ISC

Among important visitors to ICRISAT Center this year were General Vo Nguyen Giap, Deputy Prime Minister and Vice Chairman of the Council of Ministers of the Socialist Republic of Vietnam, Mr Masao Fujioka, President, Asian Development Bank; Ms Priscilla Williams, New Zealand's High Commissioner to India; His Excellency He Kang, Honorable Minister of Agriculture, Animal Husbandry, and Fisheries, People's Republic of China; Mr Mohammed Abdulrahman Namadina, Honorable Minister of Agriculture, Sokoto State, Nigeria; Sir John Thomson, G.C.M.G., Director, Grindlays Bank plc; and Dr Oumar Tall, Director General, Institut d'economie rurale, Bamako, Mali.

At ISC, some of the important visitors included two Ambassadors to Cote d'Ivoire, Mr B.P.Agarval of India and Ms Veronica Sutherland of the UK, and four Ministers of Agriculture: Mr Cheik Cissoko (Senegal), Mr Gaoura Lassou (Chad), Mr Djigma Albert (Burkina Faso), and Mr Briji Ratini (Niger).

ICRISAT thus continues its steady progress, looking forward to the last decade of this century with enthusiasm, and preparing with confidence to welcome the new century that is just round the corner.

W.T. Mashler
Chairman, Governing Board

L.D. Swindale
Director General

ICRISAT CROPS AND THEIR ENVIRONMENT

ICRISAT CROPS AND THEIR ENVIRONMENT

Most of the research reported in this publication was done at ICRISAT Center, the Institute's main research facility located near Hyderabad, in India, and at ICRISAT Sahelian Center (ISC) in Sadore, Niger. Also included are important contributions from ICRISAT scientists posted at cooperative stations in India, in five other African countries: Kenya, Mali, Malawi, Nigeria, and Zimbabwe and in Mexico and Syria. Material in this section is intended to serve as a background to our research reports. It presents a brief description of ICRISAT's mandate crops and agroclimatic environments, and includes monthly rainfall and temperature records for most locations during 1989.

The Five Crops

Cereals

Sorghum

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

Sorghum is the fifth most important cereal in the world and a major staple in the diets of the people of the semi-arid tropics (SAT). It is a leading cereal in Africa and is next in importance to rice and wheat in India. Sorghum is grown on over 40 million ha in both temperate and tropical regions. It is a hardy and dependable crop that grows well under adverse conditions and can thus play a major role in increasing food production in the SAT. Sorghum has many uses: as a human food it is ground into flour and made into porridges or unleavened bread, the grain is also used as feed for animals, particularly in the Americas, and for processing into beer and other local beverages in Africa. Sorghum stalks provide fodder, fuel, shelter, sugar, and syrup.

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.

Pearl millet is the sixth most important cereal in the world. Among the millets, pearl millet is the most important in the SAT and thus requires major attention. It is grown as a staple cereal on an estimated 25 million ha. Pearl millet is a hardy cereal suited to the drier regions with sandy infertile soils where rainfall is low and erratic, that is, areas too dry for sorghum. The grain is used to make chapatis in the Indian subcontinent and prepared as gruel, dumplings, couscous, and beer in Africa. It is also used as animal feed and forage.

Legumes

Chickpea

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

Chickpea is one of the most important pulse crops of the developing world and of the SAT. It is the most important pulse crop on the Indian subcontinent, where 80% of the chickpea crop is produced.It is important throughout West Asia and North Africa along the Mediterranean Sea, and in parts of East Africa and Latin America. It is grown on 9.6 million ha annually with a production of 5.6 million t. Among all pulses, chickpea accounts for 15% of the world area and 13% of the world production. A growing market in the United States for chickpea is supplied principally from the semi-arid regions of Mexico. Much of the world's chickpea crop is grown on small farms with minimum or no inputs. Chickpea is used as food by millions of people in areas where it is produced and is also becoming popular in other parts of the world. It is high in protein (approximately 20%) and essential vitamins. When combined with rice, sorghum, millet, or wheat, chickpeas provide an adequate balanced protein-calorie diet.

Pigeonpea

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

Ranging from a backyard crop to a major field crop, pigeonpea is grown by subsistence farmers in the tropics. On the Indian subcontinent, where about 90% of the crop's global growing area (2.9 million ha) is located, it is the second most important pulse crop, with an annual production of 2 million t. It is drought- and high temperature-tolerant and is grown on marginal soils. Where the crop is grown for cash, it is usually intercropped with a shorter-season cereal, cotton, or other legume crop. The crop mix is seeded at the onset of the rainy season and the pigeonpea is harvested during the dry season, well after the harvest of the companion crop. It has a high protein content (about 20%) and is a staple food in parts of the SAT, usually eaten combined with rice, sorghum, or other cereals. It is also used for forage, green manure, nitrogen fixation, cover, windbreak, and fuelwood.

Groundnut

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

Groundnut is an important cash crop for the SAT farmer. Areas in excess of 12 million ha in developing countries are planted to groundnut. As a combined oilseed and food crop, groundnut ranks second only to soybean, and it is the most important oilseed in the developing world. With 25% protein and 50% oil, groundnut is one of the world's major sources of edible oils. Groundnut is also used as animal feed, forage, and as a confectionery food. Of the several million tonnes of groundnut produced in the world, hull forms about 25% of the harvested pods and is used in cattle feed, as a carrier of insecticide, in the manufacture of particle-board, in the production of pulp, and as a fiber component in human food.

Locations of ICRISAT Centers, Teams, Network Bases, and Cooperative Research Stations, 1989.

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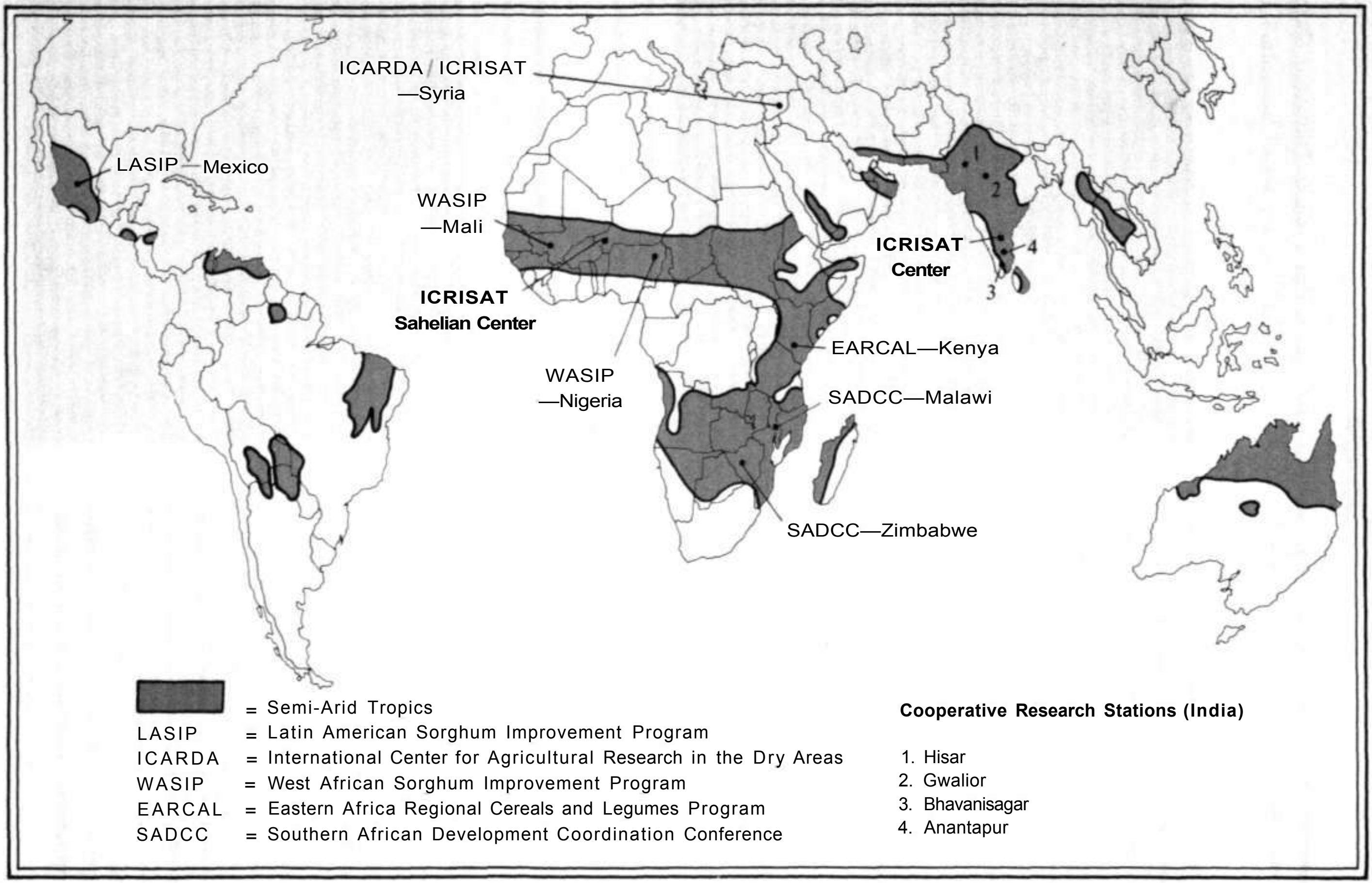


The citation for this report is ICRISAT (international Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

Agroclimatic Environment

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: 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 180230 mm. Availability of both soil types provides an opportunity to conduct experimental work on two predominant tropical soils on our mandate crops and on 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 begins in February and lasts until rains begin in June; crops grown in this season require irrigation.

Crops. ICRISAT's five mandate 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 it 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. At ICRISAT Center, as in normal farming practices, intercropping and relay cropping of our mandate crops are common.

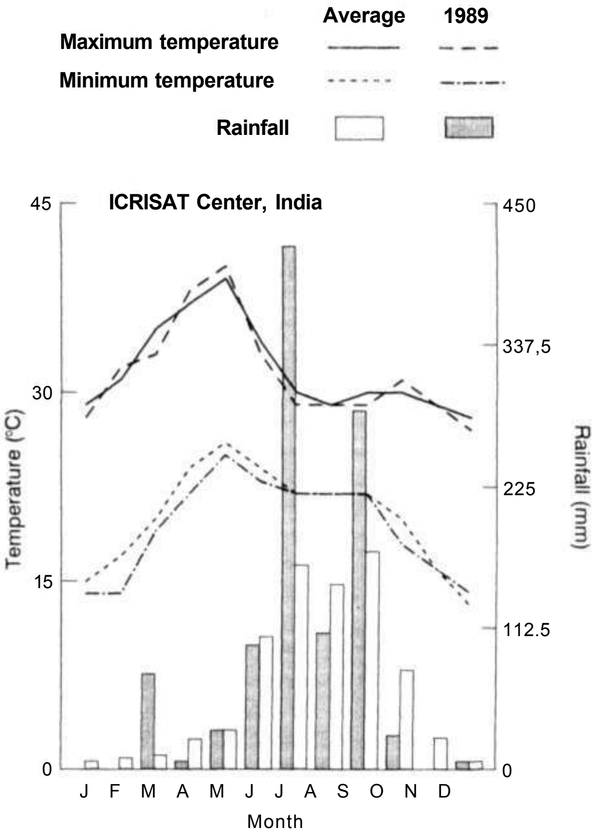
Weather. In 1989, annual rainfall at Patancheru was 1056 mm, 35% above average. Rainfall during the rainy season was 40% above average but because October was exceptionally dry, prospects for establishing postrainy-season crops were not good. Daily maximum and minimum air temperatures were within ±2 °C of the average for all months.

On Vertisols, infrequent showers early in the rainy season resulted in mixed germination and uneven plant stands in many dry-seeded crops. Sorghum and maize were the crops most affected, while pigeonpea and groundnut were less affected. Final plant stand was not affected, but growth remained uneven throughout the rainy season. The initial rains were followed by frequent, heavy rains for the rest of the season. These heavy rains made mechanical weeding nearly impossible so weeds became a problem in nearly all sowings. Where some degree of weed control was possible, good yields were obtained. With little time between rains, insect sprayings were less effective and *Helicoverpa* damage was as high as 98% in some extra-short-duration pigeonpea sowings.

Rainfall stopped abruptly in September leaving little time to prepare plots for the postrainy-season sowings. Sequential cropping plots that were infested by weeds during the rainy season required additional cultivation prior to postrainy-season sowing. This resulted in an accelerated seedbed drying and poor plant establishment. Plots sown to sorghum, sunflower, and chickpea shortly before rainfall ceased yielded above average, while the same species sown later yielded poorly and suffered severe drought stress.

The exceptionally wet rainy season prevented timely sowing and weeding activities even on the Alfisols. Many pigeonpea stands were badly affected by inadequate drainage, resulting in low seedling emergence and later, by high mortality due to bacterial wilt and phytophthora blight. In contrast, stands of groundnut, pearl millet, and sorghum were relatively unaffected resulting in above-average yield. In pigeonpea-based intercrops, e.g., groundnut/pigeonpea and upland rice systems, the lush growth of pigeonpea caused considerable reduction in the yield of the companion crops.

As a consequence of the abrupt cessation of rains in September, late-maturing crops such as pigeonpea and castor experienced drought stress during grain-fill. Medium-duration pigeonpea gave yields that were 20-30% below those of the previous year. Early pigeonpea suffered heavy damage by insects such as blister beetles but the second flush provided 0.7-0.8 t ha^{-1} of grain.

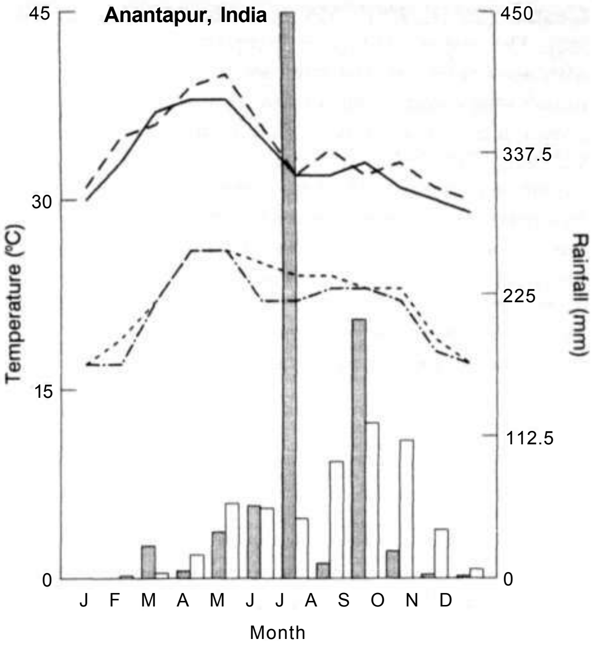


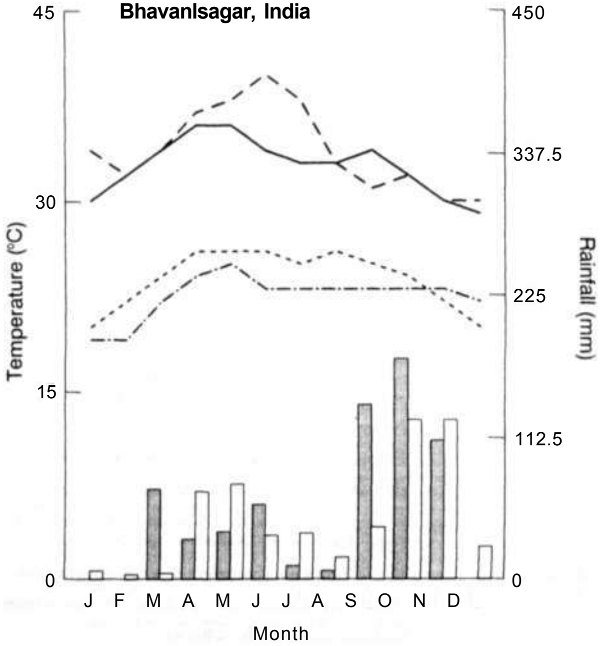
Other Research Locations

India

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

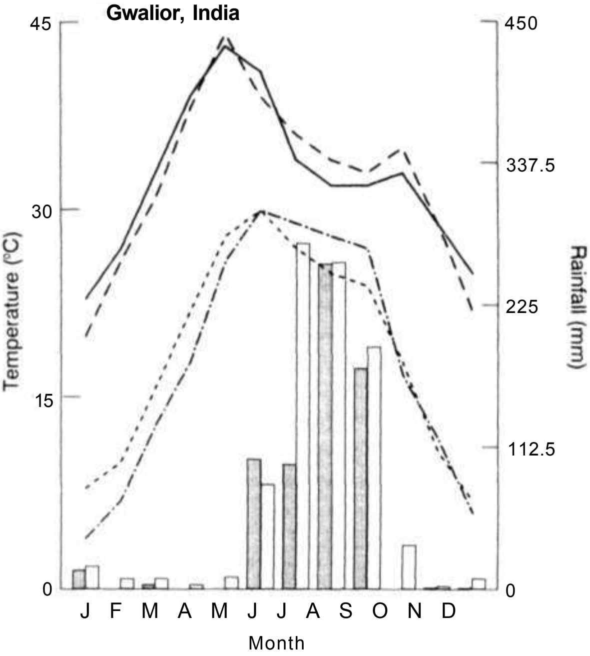
Anantapur (15° N, 77° E, 562 mm rainfall). This is a drought-prone area where we screen pearl millet, sorghum, and groundnut under low rainfall on Alfisols (AWHC 50 mm). Annual rainfall was 824 mm, 47% above average. Rainfall in July was almost ten times above average, August was very dry, but September was very wet. Because of the shallower soils in Anantapur, there was much runoff and soil erosion during July and September. However, only 22 mm of rain fell in October so there was drought at the end of the season. Early-sown crops yielded well. Sorghum yields were about 2 t ha^{-1}. Crops grown on Vertisols were affected by iron chlorosis. Daily maximum and minimum air temperatures were within ±2 °C of the average for all months.

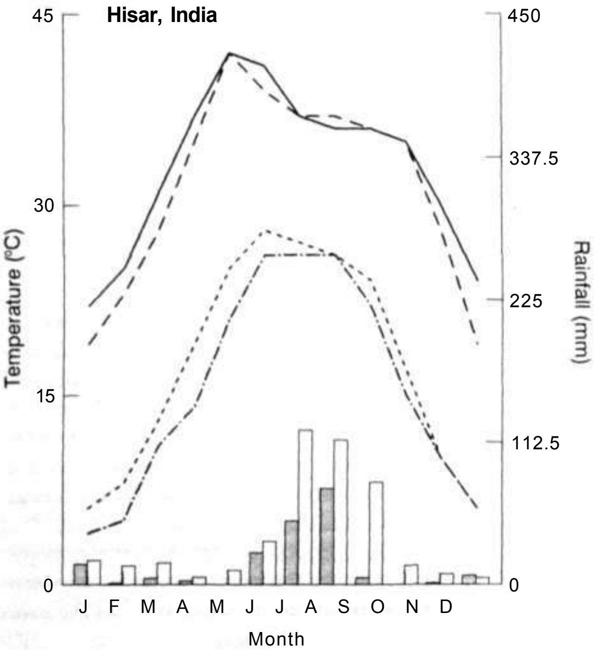




Bhavanisagar (11°N, 77°E, 574 mm rainfall). Here we screen sorghum for diseases and pests and test pearl millet on Alfisols (AWHC 80 mm), at a day-length similar to the Southern Sahelian bioclimatic zone of Africa. Annual rainfall was 645 mm, about 10% in excess of the long-term average of 574 mm but the distribution differed from the average. For example, September rainfall was three times more than average. October and November rainfall was also in excess of the long-term average. Daily maximum and minimum air temperatures were within ±3 °C of the average for all months.

Gwalior (26° N, 78° E, 899 mm rainfall). The major soil type is Inceptisol with an AWHC of 150 mm. Most of India's long-duration pigeonpea crop is grown in this area. Annual rainfall was 655 mm, 28% below average for the second successive year. Total rainfall during the rainy season (June-October) was 535 mm, 37% below average. Therefore maximum and minimum temperatures during the rainy season were 2 °C above average. Crop performance during the rainy season was average.

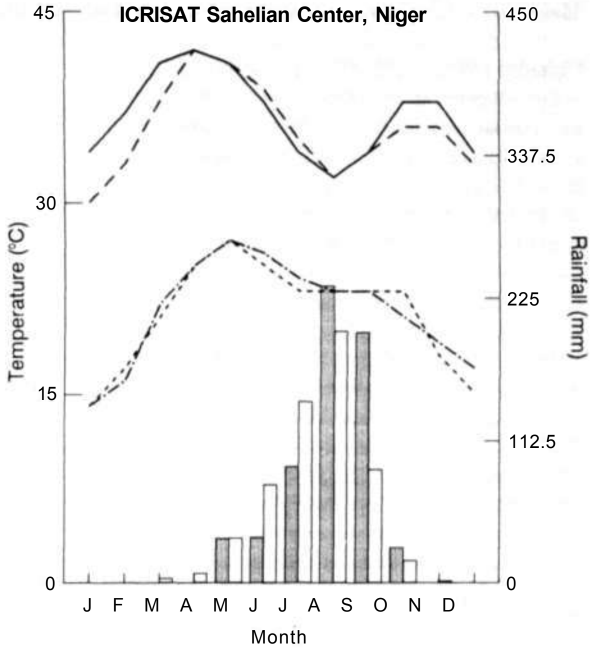




Hisar (29° N, 75° E, 447 mm rainfall). Here chickpea and pearl millet are tested under the climatic conditions in which they are mostly grown, and short-duration pigeonpeas are tested in a region where they are increasingly being grown in rotation with wheat. The soils are Entisols with an AWHC of 150-200 mm. Annual rainfall was 189 mm, 58% below average. Rainfall during June to September was 156 mm compared with the corresponding average of 366 mm. Daily maximum or minimum temperature during June to October was within ±2 °C of the average. Crop yields were badly affected by persistent drought during the rainy season.

ICRISAT Sahelian Center, Niger

The ICRISAT Sahelian Center 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 Sadore 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 Alfisols (AWHC 50-75 mm) with low native fertility and low organic matter.



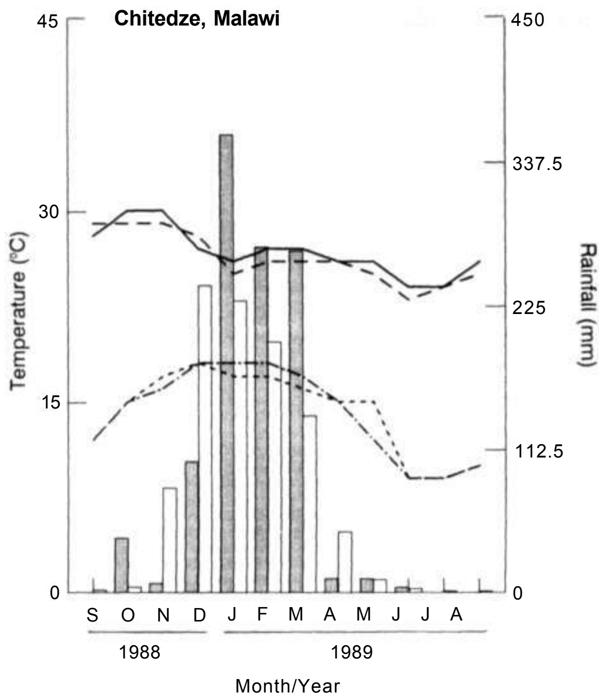
Seasons. The climate is characterized by a June-to-September rainy season of about 90 days, often including long dry spells. The average annual rainfall (570 mm) at Niamey is irregular and normally comes in the form of convective storms. During the dry season 'harmattan' winds bearing dust from the north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

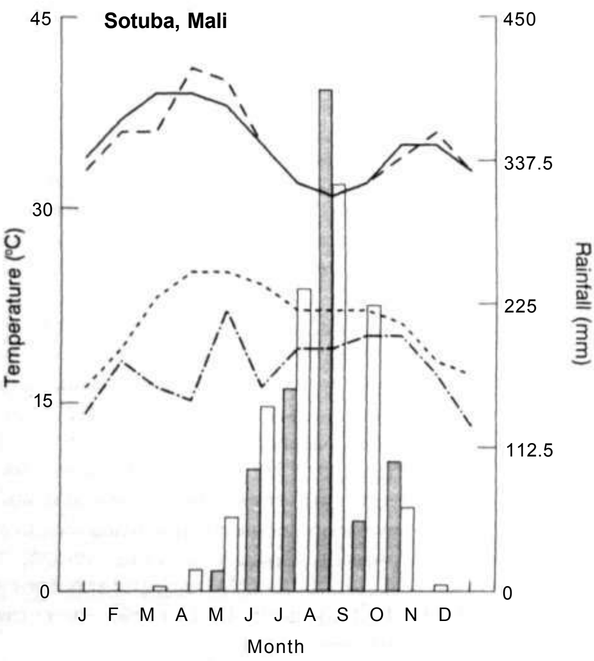
Crops. The main crop grown in the Niamey region is short-duration pearl millet (90-110 days' duration), sown with the first rains, towards the end of May until the end of June. To advance generations and to help in seed multiplication at ISC, an irrigated off-season nursery is grown from January to April. 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 623 mm, 10% above average for the second consecutive year after several years of below-average rainfall. Rainfall during June to October was 588 mm against the average of 525 mm. However, onset of rains this year was delayed till the end of June and sowing was carried out on 29 June. Rainfall was not well distributed. Rainfall in June and July was below average; and that in August and September was above average, and a considerable proportion of rainfall was lost as runoff. A 15-day dry spell occurred in July, affecting crop stands. Crop yields were fairly good. Above-average rainfall in August and September led to high incidence of diseases and pests. Daily maximum and minimum temperatures during the rainy growing season were about average; in the winter months, temperatures during the day were 4 °C cooler than the average.

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 1988 to August 1989 was 1077 mm, 12% above average. Rainfall during the growing season (November 1988 to April 1989) was 11% above average (888 mm). As rains started late, the sowings could be completed only by mid-December. Rainfall in December was about half of the average. This delayed emergence in some trials. Rainfall during January to March was 58% above average. The season was exceptionally wet and the yields were very low.





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 length of the growing season is about 140 days from May/June to October/ November. Sorghum, maize, groundnut, and pearl millet are the major crops. Soils are tropical ferruginous, leached to hydromorphic types (loam and clay loam), with an AWHC of 150-200 mm. Total rainfall in 1989 was 821 mm, 25% below average. Rainfall during the growing season (June-October) was 805 mm, which is about 20% less than the average growing-season rainfall (991 mm). The crop yields were above average in 1989.

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, some are humus-bearing hydromorphic loams and sandy loams (AWHC 120-150 mm).

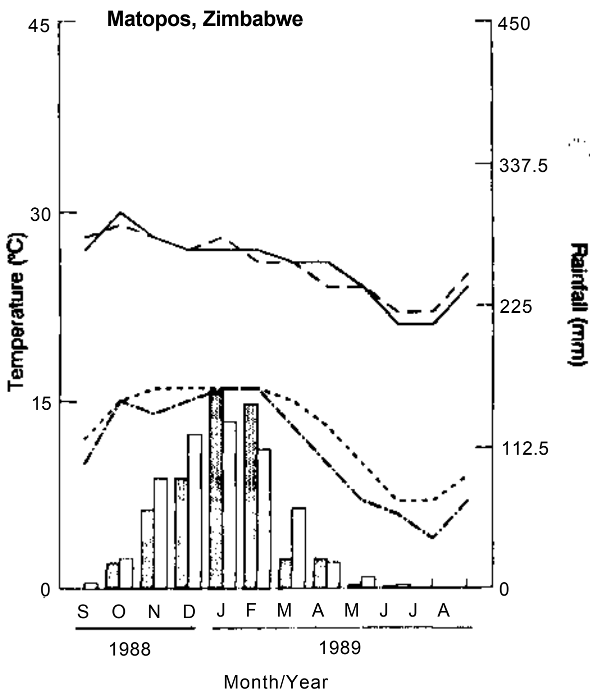
Kenya

Nairobi (1°S, 37°E, 1066 mm rainfall). This is the center for one of ICRISAT's regional networks, the Eastern Africa Regional Cereals and Legumes (EARCAL) network in four major agroecological zones: high, intermediate, and low elevations, and very dry lowlands. Some research on pigeonpea crop has been initiated recently. In Kenya, research on screening sorghum, pearl millet, and pigeonpea for dry short-season adaptation in the long rains, and intermediate adaptation in the short rains is conducted at Kenya Agriculture Research Institute's (KARI) National Dryland Research Center at **Katumani** (altitude 1575 m, 718 mm rainfall — bimodal, March-May; October-December).

From 1990, experiments will also be laid out at **Kiboko,** National Range Research Center of KARI, located in South Central Kenya.

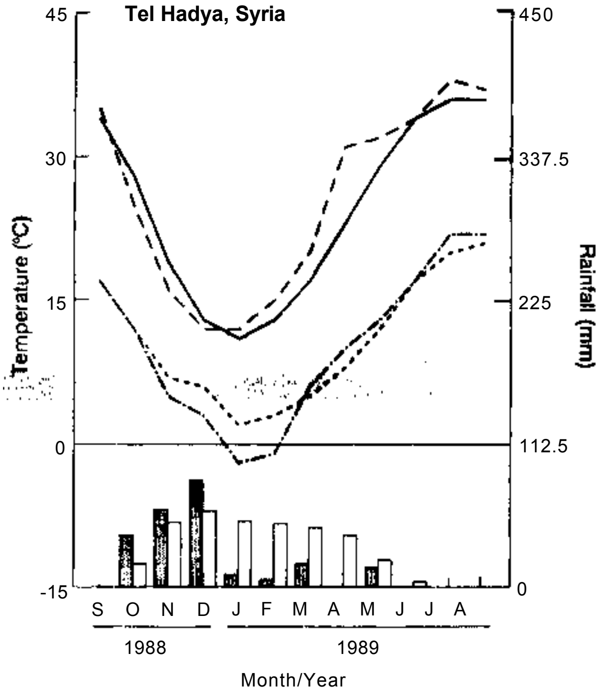
Zimbabwe

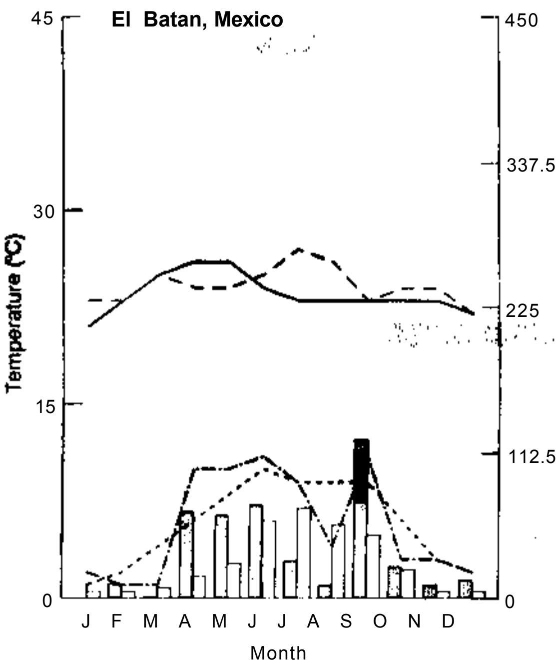
Matopos near Bulawayo (20° S, 29°E, 588 mm rainfall). Our cereals improvement program for the nine African countries of the SADCC region is based at Matopos Research Station. Sorghum, millet, maize, and cowpea are the important crops in the region. The growing season is from October/November to March/April. Soils range from sandy soils with an AWHC of 60 mm to deep-clay soils with an AWHC of 180 mm. Annual rainfall (September 1988 to August 1989) was 533 mm, 10% below average. Rainfall during November and December was below average, while rainfall during January and February was above average. A large proportion of the rainfall was received in two heavy showers. March was drier than average. Daily maximum temperatures in January were 1°C higher while daily minimum temperatures during the growing season were 1-2 °C lesser. Crop performance was good. The season was wet in Tanzania and Zambia. Early frost damaged the late-sown sorghum crop in Lesotho.



Syria

Tel Hadya near Aleppo (36° N, 37°E, 340 mm rainfall). Here our staff work with the International Center for Agricultural Research in the Dry Areas (ICARDA) on kabuli-type chickpea for spring or winter sowing in the Mediterranean region, and South and Central America. The growing 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 1988/89 was 235 mm, 32% below average. The rainfall distribution was quite erratic during the season. More than 8% of the rainfall was received before December. The growing season was cool and dry. Crop yields were poor. There was a significant reduction of area under chickpeas in Syria.



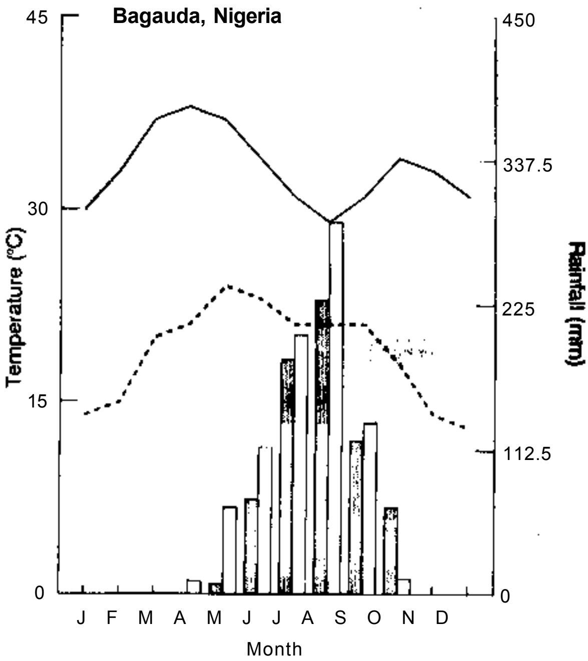


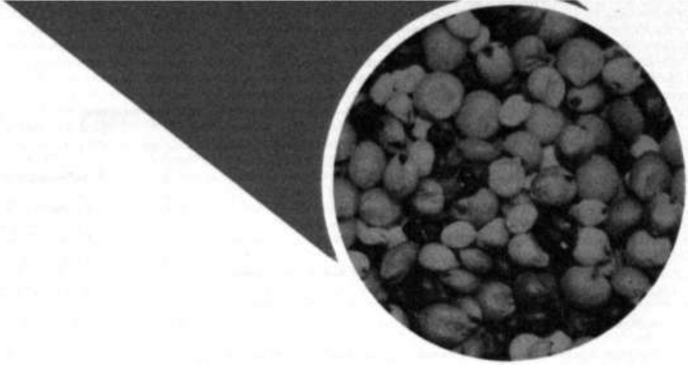
Mexico

El Batan (19°N, 99°W, 750 mm rainfall). Our breeder (based at Centro Internacional de Mejoramiento de Maiz y Trigo [CIMMYT]) and agronomist work on high-altitude, cold-tolerant sorghums adapted for low and intermediate elevations in Central and Latin America, and the Caribbean. At El Batan, sowing was delayed and frosts occurred earlier than normal, therefore the available growing season was quite short. Most sorghum cultivars were in soft-dough stage at the time of the frost.

Nigeria

Bagauda near **Kano** (12°N, 9°E, 832 mm rainfall). Our West African Sorghum Improvement Program (WASIP) base has been located at Bagauda near Kano. In 1989, total rainfall was 681 mm, 18% below average. Rainfall during June to October was 673 mm (average 753 mm). Rains were late this year. This caused some delay in sowing. However, the season extended well into October (1989 rainfall 68 mm; average 12 mm). This helped the crop, particularly late-maturing local sorghum cultivars at the grain-filling stage. At the research station, ICRISAT sorghum varieties yielded 4.3 t ha*[1], on an average; hybrids yielded about 5 t ha^{-1} while local controls produced a grain yield of 2.8 t ha^{-1}. Head bug infestation reduced grain yields slightly. Crop performance was generally satisfactory. Temperature data were not collected.





SORGHUM

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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SORGHUM

ICRISAT's research in sorghum improvement is conducted by multidisciplinary teams of scientists located in Asia at ICRISAT Center (India), and at regional centers in West Africa at Bamako (Mali) and Kano (Nigeria), eastern Africa at Nairobi (Kenya), southern Africa at Bulawayo (Zimbabwe), and Latin America at El Batan (Mexico). These teams conduct strategic, applied, and adaptive research to provide the national agricultural research systems (NARS) of countries in the semi-arid tropics (SAT) with: (1) screening and other breeding technologies, (2) breeding lines to facilitate development of cultivars, (3) seed and pollen parents for hybrid seed production, and (4) cultivars adapted to the various agroecosystems in the regions they serve.

Sorghum is widely used in different food preparations and as livestock feed or forage. In recent years, its use in commercial brewing has increased; there is also interest in the production of sorghum starch and other industrial products. Research on the malting and brewing quality of sorghum is conducted in cooperation with NARS and the local brewing industry in Nigeria. Milling products, malted and fermented foods, and composite flour are being studied in Zimbabwe, and ICRISAT Center in India is collaborating with local industry in studies of starch production from sorghum.

As the uses of sorghum become more diversified, so will be the demand for increased production. This has led to increased research efforts to produce stable cultivars with high yield, resistance to important pests and diseases, and increased resistance to physical stresses such as drought that are acceptable to end users. This report contains highlights of research towards meeting this goal. We conduct this research in consultation and close collaboration with NARS in the SAT. Some notable achievements during the year include: (1) identification of sources of earliness and photoperiod insensitivity, (2) adoption of two midge *(Contarinia sorghicola)*-resistant cultivars, ICSV 745 and ICSV 743, by the Department of Agriculture, Karnataka state, India, for cultivation in midge-endemic areas, (3) identification of sources of resistance to ergot *(Claviceps sorghi)* in Ethiopia in collaboration with the Ethiopian national sorghum program, (4) identification and development of high levels of resistance to head bug *(Eurystylus sp)* in cultivars CMS 388 and Malisor 84-7 in Mali as a collaborative activity between ICRISAT and the Mali national program, and (5) the successful introduction of downy mildew *(Peronosclerospora sorghi)* resistance into hybrids in the Southern African Development Coordination Conference (SADCC)/ ICRISAT program.

Physical Stresses

ICRISAT Center

Drought

The Influence of Soil Water Deficits and Soil Strength on the Growth of Sorghum Plants

Seeds of sorghum lines IS 1347 were sown in small acrylic cylinders (6.5-cm diameter by 10-cm height) containing sieved soil packed to bulk densities of 1.29 and 1.69 Mg^{-3}. The cylinders were watered on alternate days with Hoagland's solution at half strength and placed in a controlled environment room (relative humidity [RH] of 60%, photoperiod of 14 h and light intensity of 400 $\mu mol\ m^{-2}\ s^{-1}$). Water was withheld from 20-day-old plants and measurements on soil water content, root growth rate, leaf water potential, and leaf extension rates were made over a period of 7 days. Measurements on soil water potentials were made with filter paper method and soil strength was made with a penetrometer constructed from a plastic syringe and calibrated by applying a range of pressures to the surface of an electronic balance.

The moisture contents of the soils were 24.3% in the low-bulk density and 19.0% in the high-bulk density treatments at the beginning of the experiment. The experiment ended on day 7 when soil water usage was small and many plants had no viable leaves. On day 7 the soil moisture contents were 7.7% in the low-bulk density and 8.6% in the high-bulk density treatments.

Leaf water potentials fell below 11% in proportion to soil water potentials at soil moisture contents below 11%.

Leaf extension rates were linearly related to soil water contents and were less than 15%. The slope of this relationship was however dependent on the treatment (Fig. 1). Leaf extension rates were also linearly related to soil strength.

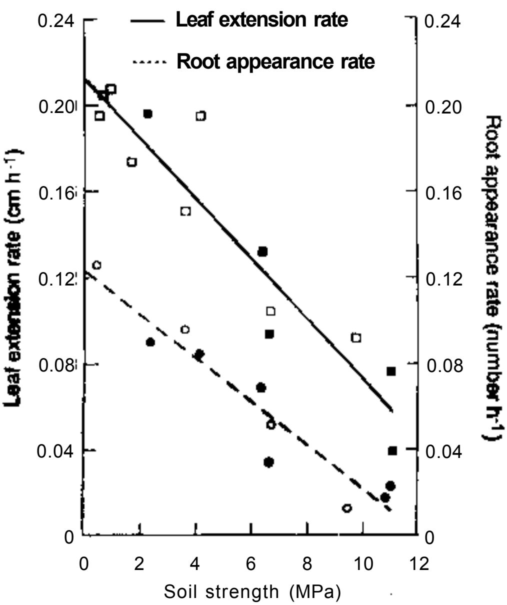


Figure 1. Relationship between (a) soil strength and leaf extension rate (□, ■) and (b) soil strength and root appearance rate (o, ●). Nonshaded symbols represent lo w-, and shaded symbols represent high-bulk density treatments.

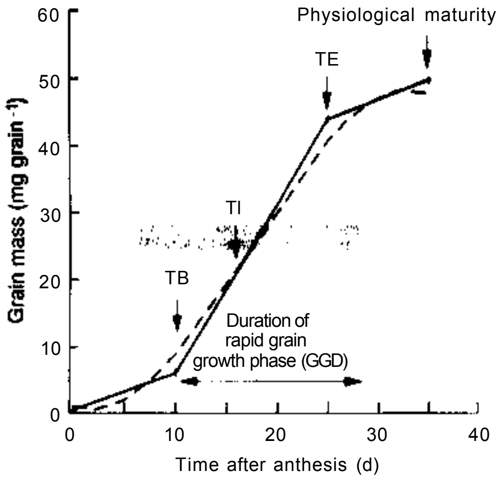
The decrease in leaf extension rate coincided with the decrease in the rate of root appearance in both treatments. Root appearance rates lower than 0.13 roots plant^{-1} were also linearly related to soil strength (Fig. 1). Roots of plants with no reduction in leaf water potential exhibited morphological changes consistent with the effects of mechanical impedance (i.e., swelling, distortion, and deflection). It is suggested that soil strength decreases root growth and development by reducing the effectiveness of root turgor potential. It is postulated that the reduction in root activity affected leaf growth by the reduced translocation of growth hormones to the shoot.

Terminal Drought Stress: Grain Growth Characteristics of Sorghum Genotypes

Knowledge of the mechanism of assimilate production and distribution in plant parts, especially during the grain-filling stage, is essential for understanding genotype differences in resistance to biotic and abiotic stresses. Last year we reported (ICRISAT Annual Report 1988, pp. 3-4) the difference in translocation of photoassimilates to the developing grain in stalk rot-resistant and-susceptible genotypes. We followed that study with a detailed analysis of grain growth in these and other contrasting genotypes. For this, the usual S-shaped grain growth curve (Fig. 2) was divided into three segments using the following equation in which the grain dry mass (Y) was fitted to the time after anthesis in days (DAA) (t):

$$Y = \frac{A}{(1 + eb^{kt})} \qquad \text{Equation 1.}$$

From equation 1, the point of inflection in the curve (TI; Fig. 2) was computed. The slope of the curve at this point represents maximum grain growth rate (RT). TB represents the time of beginning of rapid and linear grain growth phase (DAA), and TE, the time of end of that phase. TB was taken to be (b-2)/K, and TE to be



Leaf extension rate y = 0.2116-0.0138 x; r^2 = 0.88
Root appearance rate y = 0.1225-0.0101 x; r^2 = 0.91

Figure 2. Schematic diagram representing the three different phases of grain growth in sorghum. Arrows indicate the timing of different events during plant or grain growth. TI is the point of inflection of the whole grain growth curve. TB and TE are the times of beginning and ending of rapid grain growth phase.

(b+2)/K. This gave respective grain masses of 12% and 88% of the estimated asymptotic grain masses (A) which accomodated most of the growth period. The difference between TE and TB represents the duration of rapid grain growth (GGD in days) at RT (in mg $grain^{-1}$ day^{-1}). The middle phase accounts for about three-quarters of the final grain mass, as growth rates during the other two phases are low. The beginning and end of this middle segment (TB and TE in Fig. 1) and its slope (RT) are most useful for comparing genotypes.

We sampled 10 grains (caryopses) each from the mid-portions of the panicles from 16 plants tagged at anthesis. This was followed by sampling at 2-3 days' interval till physiological maturity. All genotypes flowered within 59-65 days, except CSH 6 (flowered early; Table 1). Hence the environmental conditions during grain filling were similar for all the genotypes except CSH 6. Genotypes showed substantial variation for TB, TE, GGD, and RT (Table 1). The RT varied from 0.83 to 1.51 mg $grain^{-1}$ day^{-1}. Genotypic differences in GGD were small. Midge-resistant lines began rapid grain growth soon after flowering (low TB; mean = 7.7±1.2 DAA), while the root and stalk rot-resistant (nonsenescent) lines began late (12.3±0.5 DAA). It is known that rapid ballooning of grain is useful for midge resistance, and slower initiation of grain filling for stalk rot resistance. Both hybrids were intermediate between the above two groups of genotypes with respect to this character.

Final seed size was highly correlated with RT (r=0.964; *P* <0.001), but poorly with GGD (r=0.287; P>0.05) in the present data set. However, the importance of GGD should not be underestimated. For example, in the two midge-resistant lines, ICSV 197 showed a GGD of 18.7 days, its seed size being 1.9 g $(100\ seeds)^{-1}$ and ICSV 745 showed a GGD of 25.4 days with a seed size of 2.8 g $(100\ seeds)^{-1}$. Thus, short TB and long GGD may be useful in selecting bold-grained midge-resistant cultivars. GGD and RT were not correlated, suggesting the possibility of simultaneously improving both these component traits while breeding for bold seeds.

In a second study, we found that terminal drought stress reduced both TE and TB (hastening grain growth), but had little effect on GGD in ICSV 197 and ICSV 745. However, the rate of grain growth decreased by an average of 27% under drought stress. Similarly a third study indicated that nitrogen (N) stress significantly reduced RT. The changes in GGD due to N stress levels were small and not significant.

Photoperiod

Screening for Identification of Sources of Earliness and Photoperiod Insensitivity

At present we are breeding sorghums for earliness and photoperiod insensitivity. In the dry season, we screened 170 sorghum genotypes

Table 1. Grain growth characteristics and other agronomic traits of sorghum genotypes at ICRISAT Center, in the 1988 postrainy season.

Group/ genotype	Rapid grain-filling phase Start (TB[1]; DAA[2])	End (TE3; DAA)	Duration (GGD[4]; days)	Rate RT[5]	GS3[6] (days)	Seed size g (100 seeds)$^{-1}$	Time to 50% flowering (days)
Hybrids (controls)							
CSH 6	8.3	30.8	22.2	1.10	33	2.84	56
ICSH 110	10.7	29.9	19.2	1.08	38	2.50	63
Stalk rot resistant							
E 36-1	12.1	33.1	20.9	1.51	41	3.90	59
Q 102	11.4	33.0	21.6	0.95	41	2.62	60
Q 104	13.3	36.9	23.5	1.31	40	3.45	60
Midge resistant							
PM 1562	7.7	26.9	19.2	0.95	37	2.45	65
ICSV 197	9.8	28.5	18.7	0.83	34	1.92	60
ICSV 745	5.6	31.0	25.4	0.95	37	2.77	61
Mean	9.86	31.3	22.3	1.09	38	2.81	61
Minimum	5.60	26.9	18.7	0.83	33	1.92	56
Maximum	13.30	36.9	25.4	1.51	41	3.90	65
SE	±0.90	±1.09	±0.83	±0.08	±1.1	±0.22	±0.9
CV (%)	26	10	11	21	8	22	4

1. TB = Beginning of rapid grain-filling phase,
2. DAA = Days after anthesis.
3. TE = End of rapid grain-filling phase.
4. GGD = Duration of rapid grain growth phase in days.
5. RT = Rate of dry matter accumulation in grain (mg grain^{-1} day^{-1}).
6. GS3 = Grain-filling phase (from anthesis to physiological maturity) in days.

grown under irrigation for these two traits. We monitored flowering time (days) under both normal daylength (ND; 13 h at sowing including twilight) and artificially extended daylength (ED; 17 h, by using a bank of tungsten lamps placed above the canopy in the field). We identified genotypes that flowered within 55 days after sowing (DAS) under both ND and ED, as sources of earliness and photoperiod sensitivity; they included IS 24439, IS 12919, IS 24421, and IS 2322. ED suppressed tillering in most genotypes except in the following: IS 21962, IS 3075, IS 9761, and IS 1347; these were also early and relatively photoperiod insensitive.

Screening Seed Parents (B- and R-lines) for Photoperiod Response

Knowledge of the photoperiod response of seed parents is a prerequisite for breeding hybrids of appropriate maturity for different adaptation zones. During the rainy season we screened 66 B-lines and 274 R-lines for their responses to photoperiod under both ND (13.5 h at sowing) and ED (17 h). We observed a maximum delay of 38 days in a B-line, and a delay of 42 days in a few R-lines under ED. We found maximum variation in photoperiod response in the lines flowering between 60-75 days under ND. Among the R-lines, 46% of the lines were considered as either photoperiod insensitive or least sensitive (no delay or delay of less than 10 days under ED), 36% of the lines were moderately sensitive (delay of >10 days, but <20 days), and 18% of lines highly sensitive (delay of >30 days). Among B-lines, 45% were either insensitive or least photoperiod sensitive, 37% moderately sensitive, and 21 % highly sensitive.

Biotic Stresses

Diseases

ICRISAT Center

Breeding for Resistance to Grain Mold

We evaluated 31 advanced breeding lines, which had been resistant in the previous year's trials, under sprinkler irrigation to enhance grain mold development. Twelve lines gave a threshed grain mold rating (TGMR) of 3 or less on a 1-5 scale, where 1 = no mold and 5 = more than 50% of grain surface area molded, but they were uniformly poor agronomic types.

We screened 257 F_4-F_6 progenies, also under sprinkler irrigation, and selected 671 single plants and 26 bulks with a TGMR less than 3 and height less than 2.5 m. In contrast to our previous approach, we selected colored- as well as white-grain segregants. The development of mold-resistant, white-grain lines with good grain yield and agronomic aspect has remained elusive, and we feel that development of colored grain lines offers more immediate chances of successfully combining resistance with acceptable yield potential and agronomic characteristics.

We random mated the grain mold-resistant population which was initiated in 1987. By the end of the year, four random matings had been carried out.

Breeding for Resistance to Downy Mildew *(Perenosclerospora sorghi)*

The elite male-sterile line 296A, which was developed by the All India Coordinated Sorghum Improvement Project (AICSIP), has consistently generated successful hybrids but has shown susceptibility to downy mildew (DM). We crossed the corresponding B-line, 296B, to the DM-resistant line, QL 3. We evaluated the F_2 at Dharwad and the F_3 at ICRISAT Center, and screened 21 selected F_4 progenies for resistance in the greenhouse. We found five progenies where all plants were resistant and 13 that were segregating resistant types. We transplanted the selected resistant plants and backcrossed them to 296B and at the same time testcrossed them on to cytoplasmic male-sterile lines to identify maintainer lines. By this means, and by repeating the backcrossing procedure, we hope to identify a DM-resistant variant of 296B for conversion to male sterility.

Anthracnose *(Colletotrichum graminicola)*

Greenhouse inoculation technique. We developed procedures to create leaf anthracnose in the greenhouse. Inoculum of *C. graminicola* was produced as follows. Small pieces of green leaves of sorghum were moistened and autoclaved in flasks at 120°C for 25 min, cooled, then seeded with a spore suspension of the pathogen and incubated at 26±2°C for 7 days when abundant conidia were produced. To identify a suitable plant growth stage for infection and disease development, 11 stages (from four fully expanded leaves stage to hard-dough growth stage) of the susceptible sorghum line H 112 (IS 18442) were incubated at 22-28° C and >90% RH under diffused light in a specially built cloth chamber in the greenhouse for 48 h before inoculation. Plants were spray-inoculated with a conidial suspension (4×10^5 conidia mL^{-1}), incubated in the same cloth chamber environment for 48 h, and returned to the greenhouse bench for symptom development. Symptoms developed 4-6 days after inoculation at all the 11 plant growth stages. However, plants at growth stages earlier than the 8-10 leaves stage died from infection and plants at later growth stages were uneconomical to maintain in the greenhouse. Therefore, we selected the 8-10 leaves stage for inoculation in greenhouse screening for resistance to anthracnose.

Infection and colonization of leaves and symptom expression. We standardized the histopathological methods to investigate the process of infection and colonization of sorghum leaves by *C. graminicola.* Plants of the susceptible sorghum line H 112 were inoculated as stated above, under the greenhouse inoculation technique. The sixth leaf was sampled every 2 h up to 12 h, then every 4 h up to 48 h, and finally every 24 h up to 168 h of inoculation. Leaf samples were processed by a modification of the chloral hydrate and lactophenol leaf-clearing technique for light microscopic examination. The aseptate conidia of *C. graminicola* became bicellular and germinated by 1-4 germ tubes within 12-24 h after inoculation. Germ tubes produced dark brown appressoria upon contact with the host epidermis. The appressorium became lighter in color on the side appressed to the epidermis and a peg appeared that penetrated through the cuticle into the epidermal cell. Upon penetration, a bulbous primary vesicle was formed that further branched into a secondary vesicle and colonizing hyphae. Fungal hyphae were seen in the colonized tissues 36-48 h after inoculation, and disease symptoms appeared 60-72 h later.

Resistance screening. We screened 1324 breeding lines under natural infection conditions at Pantnagar, Uttar Pradesh, where, in addition to anthracnose, other leaf diseases, notably zonate, gray, and oval leaf spots appeared. Therefore test entries were scored for all four leaf diseases together. Eighty-four advanced breeding lines were resistant (6-10% of leaf area damaged) including nine (A 2252, A 2267-2, A 904, A 905, A 909, ICSA 37 x MR 933, ICSVs 162, 173, and 208) which were resistant for the second year.

Ergot (*Claviceps sorghi)*

Relationship of pollination, fertilization and ergot infection. We conducted field experiments to study the relationship between pollination, fertilization, and ergot development in the protogynous sorghum genotype Bulk-Y inoculated 4, 3, 2, and 1 day before or after pollination (anthesis), and also at anthesis. We also sampled spikelets from each pollination treatment at 24-h intervals to observe the germination of pollen and of ergot conidia on stigmas and the growth of pollen tubes and infection hyphae in styles and ovaries using fluorescence microscopy (FM). The percentage of spikelets with pollen on stigma (pollinated), and pollen tube in ovule (fertilized) were calculated from the FM data. The percentage of infected spikelets (ergot severity) was calculated from records of the number of inoculated and infected spikelets in the field.

Conidia germinated on the stigma and infection hyphae reached the style in 24 h, partially colonized the ovaries in 48 h and extensively colonized the ovaries in 72 h. Pollen germinated on stigmas and most of the pollen tubes reached the ovaries in 24 h. Thus the rate of growth of pollen tubes was faster than that of infection hyphae. However, in a few cases, infection hyphae and pollen tubes grew simultaneously in the pistils; this explains why both grain and fungal stroma can grow together in sorghum (ICRISAT Annual Report 1988, pp. 5-6).

Data in Table 2 show that spikelets inoculated 1-4 days after anthesis were all pollinated, but 7.8% were not fertilized and thus remained susceptible, as confirmed by data showing 4-10% ergot severity in the field. Ergot severity increased to 87-95% in spikelets inoculated 2-4 days before anthesis. Among these spikelets 91-100% were pollinated but only 11-14% were fertilized. Therefore, efficient pollination did not ensure high fertilization rates. Data in Table 2 also show that ergot severity increased in treatments with low levels of fertilization. Therefore, pollination per se did not control ergot. The data also show that fertilization was effective in controlling ergot but did not prevent the pathogen from colonizing a few pistils.

Infection through ovary wall. We conducted an experiment to determine if *C. sorghi* conidia can infect pistils through the ovary wall. We

Table 2. Pollination, fertilization, and infection percentages of spikelets inoculated with *Claviceps sorghi* 1-4 days before and after anthesis and at anthesis, ICRISAT Center, postrainy season 1988/89.

	Spikelets (%)		
Inoculation	Pollinated[1]	Fertilized[1]	Infected
Days before anthesis			
4	91	14	95±2.2
3	100	11	92±2.2
2	96	11	87±2.4
1	75	54	52±2.5
At anthesis	100	77	32±3.7
Days after anthesis			
1	100	83	10±2.6
2	100	97	5+2.8
3	100	91	6±3.2
4	100	98	4±1.95
Noninoculated control	-[2]	-	0
Correlation			
% pollinated spikelets		0.292	-0.332
% fertilized spikelets			-0.991**

1. Based on observation of pollen tube growth in softened and squashed pistil tissues under fluorescence microscopy.
2. - Data not taken.
** Significantly different from 0, $P < 0.1$.

inoculated ovaries of the genotype IS 10558 by carefully placing a micro-droplet of conidial suspension (10^6 conidia mL^{-1}) on each ovary when the glumes gaped to expose the ovaries at the time of pollination. All inoculations were done under a stereoscopic binocular microscope to ensure that conidial inoculum did not touch any part of the pistil except the ovary wall. Results showed that 17% of spikelets were infected if ovaries were inoculated directly. These results indicate the possibility of direct infection of pistils through the ovary wall under natural infection conditions.

Sorghum Stripe Disease

A disease characterized by chlorotic stripes and bands (sorghum stripe disease, SStD) was observed on sorghum at several locations in India with over 10% incidence. The affected plants were dwarfed and either had poor panicle exsertion or their panicles were not formed. This disease SStD could be transmitted by the delphacid plant hopper *(Peregrinus maidis)* to sorghum but not to finger millet *(Eleusine coracana), Pennisetum glaucum, Pennisetum violaceum,* wheat *(Triticum aestivum),* and maize *(Zea mays).* The disease was seen to be caused by a tenuivirus serologically related to maize stripe virus (MStV). Virus particles were filamented, less than 10 nm in width. The purified virus preparation contained only one polypeptide of 38 000 daltons. Eight species of nucleic acids (4 ssRNA of 1.20, 1.05, 0.99, 0.86 x 10^6 daltons and 4 dsRNA of 2.5, 1.75, 1.45, 0.71 x 10^6 daltons) were extracted from purified virus preparations. When denatured, the 4 dsRNA species migrated along with the 4 ssRNA species indicating that dsRNA contained duplex RNA of the same molecular weight as the 4 ssRNA. In the Enzyme-Linked Immunosorbent Assay (ELISA) and Western blots, the virus reacted strongly with MStV isolates from USA, Reunion, and Venezuela and weakly with an antiserum to rice stripe virus from Japan. The virus was named MStV-Sorg to distinguish it from MStV which readily infects maize. This is the first report of the occurrence of a tenuivirus in the Indian subcontinent.

Bacterial Stalk and Top Rot *(Erwinia chrysanthemi* pv. zeae)

A stalk and top rot disease of sorghum was observed during the 1987 and 1988 crop seasons at Pantnagar, Uttar Pradesh. The disease was severe on several genotypes with 6080% incidence. Infected plants showed signs of wilting of apical leaves and yellowing of lower leaves. Infected stalks turned brown, were full of bacterial exudate, and collapsed from rotten internodes. Rotting was fast, and plants were killed within 2-3 days after the appearance of symptoms. A bacterium consistently associated with disease symptoms was identified as *Erwinia* *chrysanthemi* pv. zeae. Its pathogenicity as the cause of the disease was proved in greenhouse tests. This is the first report of this bacterium as a cause of stalk and top rot disease of sorghum under natural conditions in India.

Striga asiatica

Effect of soil temperature and moisture on the germination and viability of *Striga* seeds. Experiments were conducted in the laboratory to investigate the effect of soil temperature and moisture on *Striga* seeds. Moist and dry seeds were incubated at 20°, 30°, 40°, 50°, 60°, and 70° C after which they were tested for germination using freshly extracted sorghum root exudate. Seed viability was also examined using triphenyl tetrazolium chloride solution. Results showed that soil moisture and temperature had a significant influence on seed germination. Moist seeds incubated above 40° C did not germinate and were also nonviable. The germination of dry seeds was 14% (SE ±1.0) at 20°C and increased to 64% (SE ±2.5) at 70°C. Seed viability in the dry treatment was not affected by the range of temperatures used in this study and remained constantly high (89 ± 1.1%). Neither temperature in the range of 20-70° C nor moisture was effective in killing or reducing seed viability when applied separately.

Laboratory findings were tested under field conditions during the hot dry season on a Vertisol. *Striga* seeds in nylon bags were buried 20 mm below moist soil surface. Plots were covered with clear polythene, hay mulch or left bare in order to vary soil temperature and moisture content. The mean daily maximum temperatures recorded at 20 mm soil depth were 60° C for the polythene, 48° C for the hay mulch, and 37° C for the bare soil. Because evaporation rate was reduced in polythene and hay-covered plots, soil moisture at a depth of 100 mm remained within the range of 25-30%, whereas in bare soil, moisture content was less than 15% throughout the experiment. After 34 days of incubation, the exhumed seeds from polythene-covered soils did not germinate or show viability when exposed to sorghum root exudate. Seeds buried under hay mulch or bare soil were not affected, probably due to the absence of lethal temperatures as observed under hay mulch, or lack of sufficient moisture as in the case of the bare soil treatment. In Vertisols, optimum soil moisture content in the range of 25-30% (w/w) was probably necessary to weaken seed coats, thus making the seeds vulnerable to soil temperatures exceeding 45° C. In addition, under constantly moist conditions, the rate of seed deterioration was inversely proportional to both the duration and intensity of temperature.

These results indicate that the large reservoir of *Striga* seeds stored in the upper 100 mm of infested soils (a major problem in the SAT), can be greatly reduced if fields are kept moist for 2-3 weeks in the off-season when soil temperature is sufficiently high (>45°C). However, since in most soils, temperatures above 40° C are rarely observed below 100 mm soil depths, seeds buried at deeper layers may escape the combined lethal effects of high temperature and moisture, but may be affected if brought to the surface during land preparation.

Southern Africa

Downy Mildew (*Peronosclerospora sorghi*)

After four years of selection for local adaptation and DM resistance, 72% of the entries in the SADCC Advanced Hybrid Trial and 70% in the SADCC Elite Hybrid Trial had a mean DM incidence below 5% at Matopos, Zimbabwe. In the SADCC preliminary hybrid trial which received a higher selection pressure for DM resistance, up to 90% of the entries had DM incidence below 5%. The A-lines, ATx 623 and D2A, gave many resistant hybrids. Highly resistant hybrids (DM incidence below 1%) were MMSH 178 (Zambian hybrid), ATx 623 x SV 1 (Zimbabwe hybrid selected from ICSV 112), D2A x D8R, SDSHs 2, 3, 6, 38, 47, and 48 from the SADCC/ICRISAT breeding program.

We began screening for DM resistance in forage and sweet stem sorghums. About 20% of the 130 SADCC forage sorghums and only one of the 90 sudan grass introductions had mean DM incidence below 5% at three testing sites in Zimbabwe. The sudan grass SDSG 101 [(TAM BK 50(79-1934)] was highly resistant. SDSG 30 (IS 722), SDSG 96 (silk sorghum), SDSG 97 (Shangani sudan grass), and SDSG 98 (QL 18) had DM incidence below 10%. Sixty-two percent of the 327 forage sorghums from Mississippi, USA, and 21 % of the 500 in the world collection of sweet stem sorghums from Georgia, USA, had less than 5% DM incidence.

Ergot (*Claviceps sorghi*)

During surveys made from 1985 to 1989, we observed ergot in all SADCC countries at altitudes from 100 to 2000 m, and at sites with total annual rainfall ranging from 500 to 1080 mm. Rainfed as well as irrigated dry season crops were affected. Ergot occurred even during June and July, when night temperatures were as low as 0°C, but with maximum day temperatures ranging from 12 to 27° C. Only at some locations we observed ergot annually, and here severities ranged from low (Aisleby Farm near Bulawayo, Zimbabwe) to high (Gwebi College near Harare). In Botswana, epiphytotics occurred in 1977 and again in 1988. Local and introduced sorghum (cultivars, populations with male sterility, hybrids, and A-lines) were affected. In A-lines and also in susceptible cultivars and hybrids, almost all of the spikelets in a panicle were affected.

West Africa (Mali)

Gray Leaf Spot (*Cercospora sorghi*)

We reported earlier that initial symptoms of gray leaf spot (GLS) appeared late in several sorghum genotypes and that the disease progressed slowly becoming severe towards crop maturity (ICRISAT Annual Report 1988, p. 6). We had inferred that GLS might not cause serious yield losses. In order to assess the effect of the disease on grain mass, we grew 13 susceptible genotypes at Longorola (Mali) in fungicide-treated and nontreated plots with three replications, and plot size of two rows 4-m long. Plants in treated plots were periodically sprayed to runoff with a fungicide mixture of 50% maneb and 25% methylthiophanate at 3 kg ha^{-1}. Plants in the nontreated plots were sprayed to runoff with water each time the other plots were treated with the fungicide. Fungicide-treated and nontreated plots were separated by four rows of a tall local pearl millet genotype. Disease severity rating (DSR) was carried out weekly during an 8-week period for the top four leaves of 12 tagged plants in each plot. Disease ratings were based on a 1-6 scale, where 1 = no GLS symptoms, and 6 = more than 75% of leaf area infected. Grain masses were taken from the 12 tagged plants. Data were analyzed with fungicide treatments as main plots and genotypes as subplots, using the final DSR taken at 75 DAS. Leaf anthracnose masked symptoms of GLS in six of the genotypes. We did not include these genotypes in the data. All the seven genotypes analyzed flowered between 59 and 72 days.

Grain masses reduced by 5% for IS 25074 and by 27% for 1CSV 16-3 BF in nontreated plants. Grain masses for the remaining five genotypes were either similar in treated and nontreated plants, or were slightly higher in nontreated plants (Table 3). These results suggest that under natural infection conditions, GLS may have little effect on grain mass in some sorghum genotypes. We had classified three of the six genotypes attacked by *C. graminicola* as highly susceptible (HS) to GLS because of either the early appearance or the more rapid development of the disease, or both, on these genotypes. The disease could cause more damage to these HS types.

Witch weed (*Striga hermonthica*)

We conducted an experiment to control *Striga* by soil solarization on a heavily infested farmer's field. We irrigated the plot to field capacity in April. Treatments consisted of covering the ground with a black polyethylene sheet for 15

Table 3. Effect of gray leaf spot *(Cercospora sorghi)* on grain masses of seven sorghum genotypes at Longorola, Mali, rainy season 1989[1].

Genotype	Grain mass (g) Fungicide treated	Grain mass (g) Nontreated	Weight loss (%)	Disease severity Fungicide treated	Disease severity Nontreated	Time to 50% flowering (days) Fungicide treated	Time to 50% flowering (days) Nontreated
Nagawhite	63.7	64.2	-	2.2	5.0	67	65
ICSV 16-3 BF	44.9	32.6	27	2.2	4.3	67	68
IS 25074	44.0	41.9	5	2.3	5.0	60	59
ICSV 1001 BF	42.4	45.5	-	1.8	4.7	62	72
CSV 13	42.1	43.3	-	2.3	4.0	63	61
IS 13922	35.3	37.8	-	2.2	4.5	69	70
IS 18445	29.8	29.7	-	2.2	4.7	71	72
SE (Fungicide)[2]	±2.22			±0.12		±0.34	
SE (Genotype)[3]	±4.41			±0.34		±1.88	
Mean	43.2	42.1		2.1	4.6	66	67
CV(%)[4]	18			18		5	

1. Fungicide treatments as main plots and genotypes as subplots. All values for grain mass and disease severity are means of 12 plants from three replications. Disease severity based on a 1-6 scale, where 1 = no symptoms and 6 = more than 75% leaf area infected, assessed at 75 DAS.
2. For comparing fungicides within genotypes.
3. For comparing genotypes within fungicides.
4. For subplots.

days (T_1), and 35 days (T_2), and control without polyethylene covering (T_3). We grew Tiemarifing, a local variety of sorghum. Five replications were made on a plot size of 22.4 m^2. The number of *Striga* plants that emerged 8 weeks after crop emergence was significantly reduced in T_2 (1.79) compared with T_1 (2.28) and T_3 (2.44, SE ±0.107). Similarly, grain yield was 1.72 t ha^{-1} in T_2 compared with 0.96 t ha^{-1} in T_1 and 0.87 t ha^{-1} in the control T_3 (SE ± 0.185).

Insect Pests

ICRISAT Center

Shoot Fly *(Atherigona soccata)*

Factors associated with resistance. In collaboration with sorghum physiology and the microclimatology unit of the Resource Management Program (RMP), we investigated the process of moisture accumulation on the central shoot leaf of sorghum seedlings. We modified the Mettler balance (model AE 160) for weighing excised seedlings on a hook system attached to the weighing plate, and weighed seedlings every 2 h between 1800 and 0600. Our results indicated that this moisture accumulation is due to guttation and not to the condensation of atmospheric moisture on the plant surface. Our studies also showed that peak leaf surface wetness (LSW) occurred between midnight and 0400 in both susceptible and resistant genotypes with a sharp decline after sunrise. This period also coincided with the hatching of shoot fly eggs after which larvae crawl into the leaf whorl and downwards between the leaf sheath and the central shoot towards the growing apex.

We also monitored LSW in weekly sown sorghum seedlings throughout the year and found that LSW was highest in the second week of August and coincided with the highest shoot fly incidence at ICR1SAT Center. We developed a methodology using strips of blotting paper for the quantitative measurement of LSW. The highest LSW (7 mg) was recorded on the shoot-fly susceptible CSH 1 and the lowest (<0.5 mg) was on resistant IS 18551. We also obtained a high correspondence between quantitative and qualitative (visual score) estimates of LSW. We analyzed data on LSW, trichome density, glossy leaf trait, and deadhearts obtained from 44 sorghum lines consisting of shoot-fly resistant resources, breeding lines, and susceptible controls (ICRISAT Annual Report 1988, p. 7). The correlation of leaf surface characters with deadhearts was low and nonsignificant $(P > 0.05)$ for the glossy trait (r=0.49) and trichome density (upper surface, r=-0.39; lower surface, r=-0.20) but high and significant (0.82 $P < 0.05$) for LSW.

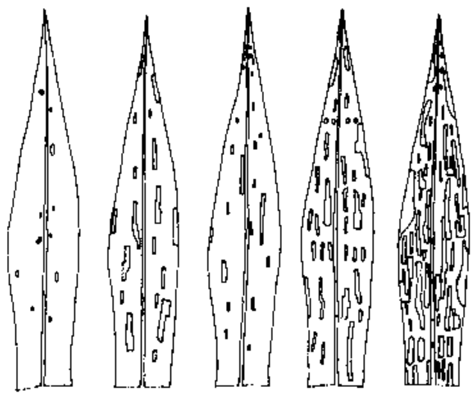
All genotypes with LSW <2 were resistant (<45% deadheart) irrespective of glossiness or trichome density. For example, IS 1046, although glossy but trichomeless, had a high LSW (4.4) and a deadheart incidence of 76.5%, while IS 1057, nonglossy but densely trichomed, had a low LSW (1.8) and a deadheart incidence of only 34.4%. Our results indicate that LSW is a more important factor in shoot fly resistance than the glossy leaf character or trichome density.

Introgression of useful genes from wild sorghum relatives. In order to introduce shoot-fly resistant genes from *Sorghum dimidiatum* (IS 18945) into grain sorghum, crosses were made with an adapted sorghum line (IS 2146). Segregating populations were advanced to F_3 generation (**ICRISAT** Annual Report 1987, p. 40) for shoot fly resistance screening in 1988. Shoot fly incidence was not adequate in 1988 and seed samples from all F_3 segregants were harvested and 3588 samples were sown as F_4 individual progenies in the 1989 late rainy season. Shoot fly infestation was high and a total of 587 individual plants was selected for resistance both in terms of egg-laying and deadhearts. Three hundred and fifteen of the selected plants produced seed and will be further tested under the 'cage technique'.

Breeding for resistance. We evaluated 22 advanced breeding lines, selected for resistance to shoot fly in the 1988 postrainy season, for agronomic eliteness. We selected seven lines for further testing in replicated yield trials. We also evaluated for agronomic eliteness 20 S_4 and S_5 progenies and 289 half-sib families selected from the shoot-pest resistant population. We selected five S_5 progenies and 71 half-sib families for further selfing and screening.

Stem Borer (*Chilo partellus*)

Biology. We standardized the *Chilo* leaf-feeding scoring system into a 1-9 scale, based upon the extent and severity of larval feeding in the leaf whorls of sorghum (Fig. 3). This scale is now used for systematic and uniform evaluation for stem borer resistance.



Score	1	3	5	7	9
No. of leaves showing these symptoms	1-2	2-3	3-4	4-5	5-6
Total leaf area damage (mm^2)	150	300-450	600-750	900-1050	1200

Figure 3. Leaf-feeding score system for damage by the stem borer Chilo partellus.

Studies on the effect of stem borer larval feeding in sorghum stems showed a loosening, yellowing, and browning of tissues that surround the feeding area. Under low feeding activity, only the pith area was damaged whereas under severe feeding activity, stem tunneling extended into the rind.

Natural field populations of stem borers usually result in multiple infestations of the same crop by 2-3 larval generations. Screening by artificial infestation at only 15-20 days after crop emergence (DAE) does not always provide a complete indication of genotype performance under field conditions. Therefore we simulated natural field conditions by reinfesting selected test material at 40 DAE with the "bazooka" applicator. Similarly, at the boot leaf stage we used the stem cage technique (ICRISAT Annual Report 1987, p. 42) with third instar larvae to evaluate the test material. Larval establishment in resistant ICSV 700 was much lower (24-51%) than that in the susceptible controls, Maldandi and SPV 422 (63-92%). Although this technique is rigorous, it provides a more reliable evaluation of genotypes selected only on the basis of deadheart formation resulting from artificial infestation at 15 20 DAE.

Breeding for resistance. We screened 81 advanced breeding lines, 35 F_5 progenies, and 169 S_4-S_6 selections from the shoot pest population for resistance under artificial infestation at ICRISAT Center and under natural infestation at Hisar. We selected 21 advanced breeding lines, 9 F_5 progenies, and 86 S_4-S_6 progenies that were resistant in both evaluations. We also screened 31 F_2, 44 F_3, and 76 F_4 populations under natural infestation at Hisar alone and made a total of 226 single plant selections.

We screened 36 derivatives of ICSP IBR/ MFR for resistance under artificial infestation at ICRISAT Center and found eight (A 25609, A 25610, A 25632, A 25640, A 25664, A 25666, A 25686, and A 25721) which continued to show resistance in a third screening. We also screened 32 advanced elite varieties and 34 population derivatives and identified two high-yielding lines, M 60386 and M 63134, and two population derivatives, A 16636 and A 35779, with less susceptibility to stem borer.

Midge *(Contarinia sorghicola)*

Biology. We monitored populations of sorghum midge during the postrainy season using newly emerged virgin females in tanglefoot-coated sticky traps to attract males. Ten traps were placed at intervals of 20 m on iron bars and at heights of 0.5, 1.5, and 2.5 m. Ten similarly placed traps, but without virgin females, served as a control. Midge populations rose to maximum in the third week of March. More males were trapped at 0.5 and 1.5 m than at 2.5 m above ground level.

We recorded adult fly emergence on CSH 1 from females reared on resistant and susceptible cultivars. Flies reared on resistant cultivars DJ 6514 and IS 3461 produced less than 33 flies per 10 females compared with 192 flies per 10 females produced from insects reared on susceptible cultivar ICSV 112. Flies reared on DJ 6514 and TAM 2566 had relatively lower number of eggs in their ovaries (49 eggs per female) compared with 64 eggs per female in ICSV 112.

Screening for resistance. We screened over 5000 segregating progeny for resistance and selected nearly 500 lines for further testing. We also screened 48 lines for resistance in advanced trials and 75 lines for resistance in multilocational trials, and selected 26 lines in the advanced and 65 lines in the multilocational trials as resistant. Based on the performance of resistant lines over the past five seasons, ICSVs 691, 692, 729, 730, 731, 736, 739, 743, 745, and 758 have been found to have stable resistance. These lines combine high levels of resistance in different backgrounds: height, maturity, and grain size.

Breeding for resistance. We evaluated 109 F_4 progenies for agronomic characteristics and yield potential and selected 31 for further screening for resistance. We screened 32 advanced varieties and 34 population derivatives and identified two high-yielding lines, M 63056 and M 63091, and two population derivatives, A 16636 and A 16638-1, that were resistant.

Two midge-resistant varieties, ICSV 745 and ICSV 743, were adopted by the Department of Agriculture, Karnataka state for distribution to farmers in midge-endemic areas.

Head Bug *(Calocoris angustatus)*

We studied the effect of insecticide sprays (demeton-s-methyl) (0.025% at 500 L ha^{-1}) on head bug population and grain damage in a resistant (IS 17610) and a susceptible (ICSH 153 [CSH 11]) cultivar. There were five levels of protection on each cultivar and three replications in a randomized-block design. Insecticide sprays had only a marginal effect on grain yield, seed germination percentage, and floater percentage in IS 17610 as compared with 38% losses recorded in ICSH 153. Three to four sprays were needed to minimize head bug damage on ICSH 153.

Screening for resistance. We screened 65 lines for resistance at two levels of infestation (5 and 10 pairs of bugs per panicle) under a headcage and under natural infestation at Bhavanisagar. Twenty lines had lower population buildup and/or suffered less grain damage. ISs 19948, 20740, 2098,17610,17618,25069, 21444,19950, and 17645 showed resistance across infestation levels and under natural infestation over two sowing dates.

We studied head bug preference for cultivars under multi-choice conditions in olfactometer tests. Fifty pairs of newly emerged adults were released in the center of the olfactometer. The number of bugs attracted to panicles of different genotypes was recorded between 0.5 h and 4 h after release, at intervals of 0.5 h. Each experiment was repeated ten times. Maximum head bug response was recorded 3.5 h after release in all cultivars. Maximum number of bugs (15 bugs per panicle) was recorded on CSH 9 compared to 6-7 bugs per panicle on ISs 16357, 14334, 21444, 19955, and 23718. We also studied the survival and development of bugs on resistant and susceptible genotypes. Nymphal development was prolonged on resistant genotypes, and a high nymphal mortality was recorded on IS 19955 and IS 21444.

Multiple Insect Resistance

Most germplasm and improved sorghum genotypes previously identified as resistant to shoot fly, stem borer, midge, and head bugs are resistant to only one of these insects which will usually infest the same crop. We developed a technique that will enable us to subject a crop of test entries to combinations of pest infestations and to evaluate them for resistance to one or more of these insects. In order to achieve optimum pest infestations, we manipulated and/ or augmented pest populations by adjusting sowing dates, split sowing, use of infestor rows, fish-meal baits, insecticide application, sprinkler irrigation, diapausing midge larvae, and artificial borer infestation. Seven treatments, comprising single, double, and triple combinations of infestations by shoot fly, borer, and midge were used.

We evaluated 220 entries consisting of 170 germplasm sources previously identified as resistant to single pests (shoot fly-60, stem borer-73 and midge-37), 42 improved breeding lines, and 8 commercial high-yielding cultivars. Results showed that less than 10% of shoot-fly resistant sources had acceptable resistance (<3, on a scale of 1-9) to shoot fly, but over 50% also showed good resistance (scores of 1-3) to stem borer (Fig. 4). IS 18551 and IS 2195 were the best entries with resistance to both shoot fly and stem borer. However, 80-90% of shoot-fly and stem-borer resistant sources were highly susceptible to midge (scores of >8). Similarly, all midge-resistant sources were highly susceptible to shoot fly but less to stem borer where seven midge lines had scores of <5 for stem borer. IS 22464 was the best midge-resistant line with a score of 3 for stem borer resistance. In general, resistance sources tended to combine resistance to stem borer with resistance to other pest species, consequently there was a higher frequency for

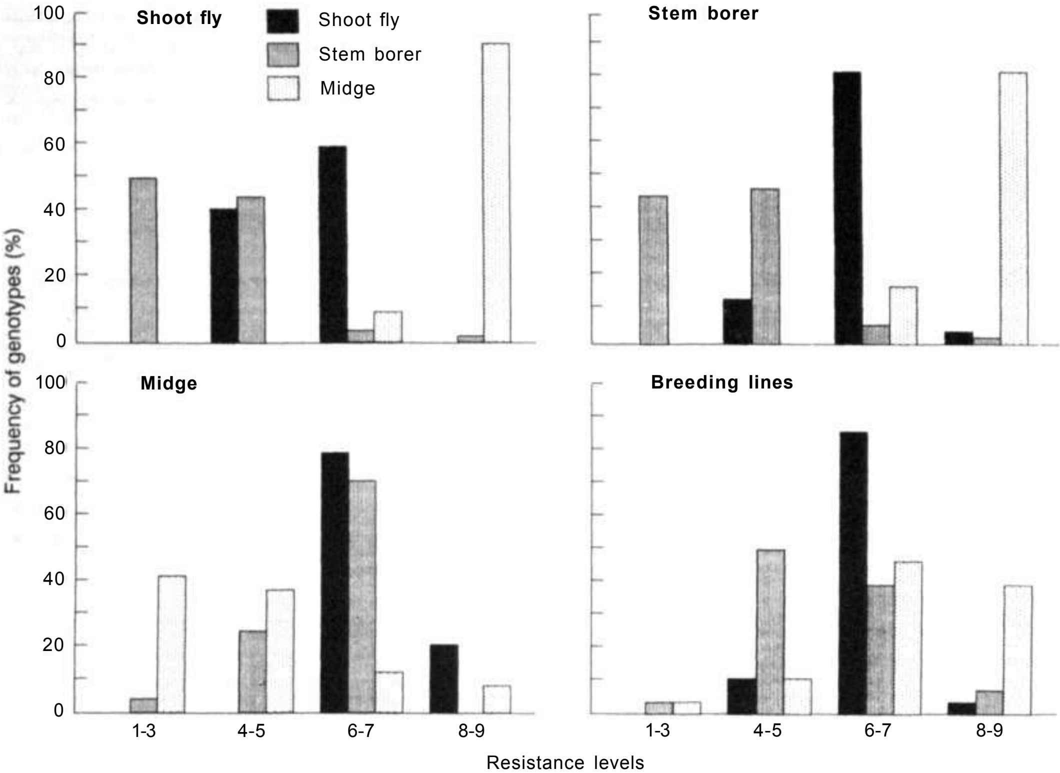


Figure 4. Performance of resistance sources under multiple insect infestation.

resistance to stem borer as a second component than for any other insect. Advanced breeding lines showed a wide range of resistance to shoot fly, stem borer, and midge with a higher frequency for resistance to stem borer.

Breeding for Multiple Insect Resistance

F_4 progenies derived from crosses among 10 germplasm and breeding lines with resistance to shoot fly, stem borer, and midge were screened in late-sown nurseries in 1988/89 for multiple insect resistance (MIR) and specific resistances to shoot fly, stem borer, and midge. From the 71 progenies evolved, we made 34 selections with MIR, 10 with only shoot fly resistance, four with only stem borer resistance, and 38 with only midge resistance. We screened the selections further this year and identified four lines (PMs 17945-3, 17967-2, 17969, and 17972-1-3) as resistant to all three insects.

West Africa (Mali)

Head Bug (*Eurystylus* sp)

Screening for resistance. To confirm levels and stability of head bug resistance across locations, we evaluated 12 sorghum cultivars (including S 34, a susceptible control) selected from the trials conducted since 1985 in Mali and Burkina

Faso (ICRISAT Annual Report 1988, p. 15). The trial consisted of three replications in a randomized-block design, two dates of sowing, and three locations: Samanko and Cinzana (both in Mali) and Farako-Ba (Burkina Faso).

Head bug infestation was maximum at Samanko, whereas it was moderate and variable at Cinzana and Farako-Ba. Under natural infestation, the overall mean head bug damage scores were lowest for CSM 388 (2.7) and Malisor 84-7 (3.3) compared to the susceptible control S 34 (6.2) (Table 4). Damage rating under artificial infestation using cages was lowest for these two varieties. Observations on the number of head bugs on open panicles and the buildup on panicles in cages after artificial infestation also confirmed high levels of resistance in CMS 388 and Malisor 84-7.

Grain yields at **Farako-Ba** were highest for CSM 388 (2.96 t ha^{-1}) compared to 2.17 t ha^{-1} for S 34. Malisor 84-7 was one of the lowest yielders (1.68 t ha^{-1}).

Breeding for resistance. At Samanko and Farako-Ba, we evaluated, under natural infestation, 90 F_6 progenies (including a resistant con-

Table 4. Head bug damage score under natural and artificial infestation and grain yield of 12 sorghum varieties of the advanced head bug screening trial conducted in Mali (Samanko [SA] and Cinzana [CZ]) and Burkina Faso (Farako-Ba [FB]), rainy season 1989[1].

	Damage rating[2] (natural infestation)								
Cultivar	SA1	SA2	CZ1	CZ2	FB1	FB2	Mean	FB (under cages)	Grain yield FBI (t ha^{-1})
ICSV 16-5 BF	4.0	5.7	6.3	4.7	4.7	4.3	5.0	6.0	2.40
Framida	4.0	7.7	7.0	5.7	5.0	6.0	5.9	7.0	2.91
ICSV 1143 BF	4.0	6.0	6.0	4.3	4.7	4.3	4.9	5.3	2.97
ICSV 1063	4.0	5.3	6.3	4.3	4.3	4.7	4.8	5.7	2.75
ICSV 2	3.3	6.0	7.0	4.7	6.0	4.0	5.2	5.3	1.82
ICSV 1166 BF	3.3	6.0	6.3	3.7	5.0	4.0	4.7	5.3	2.12
ICSV 1122 BF	4.3	6.0	7.0	5.0	7.0	5.7	5.8	7.3	0.63
Gadiaba	6.0	6.0	5.7	6.0	5.0	4.3	5.5	6.0	1.81
CSM 388	2.7	2.7	3.3	3.0	2.3	2.3	2.7	3.7	2.96
CSM 63	2.3	4.7	4.3	2.7	3.0	3.3	3.4	5.3	1.09
Controls									
Malisor 84-7 (resistant)	3.3	2.0	4.0	2.3	3.7	4.3	3.3	5.0	1.68
S-34 (susceptible)	4.3	7.0	6.7	7.3	5.3	6.3	6.2	7.7	2.17
SE	±0.39	±0.68	±0.50	±0.48	±0.48	±0.40		±0.40	±0.25
Mean	4.19	5.4	5.8	4.5	4.7	4.5		5.8	2.11
CV (%)	16	22	15	19	18	15		12	21

1. Randomized complete block design with three replications for each location and date of sowing, plot size 7.5 m^2; dates of sowing were: SA1— 5 Jul, FBI -11 Jul, CZ1 15 Jul, FB2 21 Jul, CZ2-24 Jul, and SA2—26 Jul.
2. Damage rating: 1 = grain with a few feeding punctures and 9 = grain showing more than 75% shrivelling.

trol) derived from crosses between high-yielding varieties and those with less susceptibility to head bug damage. Twelve entries had head bug damage scores of <4.0 (average over two locations), compared to 3.0 for Malisor 84-7 (resistant control), and 5.9 for 87W754, the highest susceptible entry (SE ±0.7 at Samanko, ± 0.3 at Farako-Ba). The most promising among them were 87W736, 87W776, and 87W807. The number of head bugs per five panicles at Samanko after square root transformation were 4.2 (19 actual number) for 87W736, 6.2 (45) for 87W807, and 8.4 (71) for 87W776, compared with 5.7 (37) for Malisor 84-7, the resistant control (SE ±1.8). Cultivars 87W736 (with 1.631 ha^{-1}) and 87W776 (with 2.01 t ha^{-1}) yielded well at Samanko compared to Malisor 84-7 (1.03 t ha^{-1}) (SE ± 0.30).

Southern Africa

Stem Borer *(Chilo partellus)*

At Matopos, Zimbabwe, under artificial stem borer infestation, we screened 225 lines selected in the previous season together with 98 advanced lines from the SADCC/ 1CR1SAT breeding program. The artificial infestation procedure used resulted in only 50% of the plants being infested. Therefore, selection pressure was kept low and 140 entries were selected, based on leaf-feeding symptoms, deadhearts, and productive main heads. The same nursery was also tested against stem borer and shoot fly *(Atherigona soccata)* at Panmure. Twenty-seven lines showed less than 10% deadhearts. The two controls. Red Swazi and Segaolane, showed 25% deadhearts. Based on the Matopos and Panmure selections, 13 entries had low stem borer leaf-feeding symptoms at both locations. Out of these 13 entries, six (IS 207, PS 31336, PS 30715-2, and three advanced Zimbabwe selections, 293-2, 310-2, 864-3) had low shoot fly damage.

Sugarcane Aphid *(Milanaphis sacchari)*

The sugarcane aphid is a common pest on sorghum in Botswana and Zimbabwe frequently causing economic yield losses. A host-plant resistance project was started with the following objectives: to identify resistant sources, to identify resistance mechanisms, and to determine mode of gene action. Resistance was rated on a 1-9 scale where 1 stood for the highest level of resistance and 9 for no resistance. Out of the 500 lines tested, TAM 428, SC 170, SC 109, SC 173, SA 1221, and SA 1469 had high levels of resistance (ratings of 1 and 2); selections SC 146, SC 210, SC 245, SC 451, SC 464, SC 497, and SC 984 were moderately resistant. In highly resistant lines, resistance mechanisms were antibiosis and nonpreference, while in moderately resistant lines pest buildup was slow. Studies involving TAM 428 and SC 170 crossed to susceptible parents showed that resistance was inherited and controlled by a single dominant gene.

Grain Weevil *(Sitophilus* spp)

We evaluated 400 entries comprising selected stem-borer resistant materials from Matopos and advanced breeding lines from SADCC/ ICRISAT for resistance to *Sitophilus* spp according to the method described in the ICRISAT Annual Report 1988, p. 10. Out of these lines, 86 had 40% less weevil progenies compared to the controls (Segaolane and Red Swazi), and 8 lines were significantly more resistant than the two controls *(P* <0.05 based on LSD test).

Angoumois Grain Moth *(Sitotroga cerealella)*

Sitotroga cerealella is, second to grain weevil, the most important storage insect pest in the SADCC region. We developed a method to screen breeding material and germplasm for resistance. Fifteen grams of grain samples were infested with 30 eggs and kept at 70% RH and 27° C for 28 days. Eggs for infestation were laid by cultured females on black crepe paper. The number of eggs laid per female increased 10 times when water was provided to the egg-laying jar.

Plant Improvement

ICRISAT Center

Varietal Improvement

Evaluation of Advanced Elite Varieties

We evaluated 14 advanced varieties in replicated yield trials at two sites (Alfisol and Vertisol) at ICRISAT Center and one at Bhavanisagar. Two test varieties, 1CSV 88032 with a grain yield of 4.44±0.20 t ha^{-1} and ICSV 88013 with 4.31 ± 0.20 t ha^{-1}, outyielded SPV 462, the best control variety overall with 3.95±0.20 t ha^{-1}, but outyielded it significantly only at one of the three sites. Another variety, ICSV 88014, with a grain yield of 3.74 t ha^{-1} and 71 days to 50% flowering, was earlier than the earliest control variety, SPV 462, at all three sites but not significantly different in yield at any site. All three selected varieties, ICSV 88032, ICSV 88013, and ICSV 88014, were sister-lines selected from the cross PM 11344 x SPV 351 and have resistance to midge.

Multifactor-resistant Populations (MFR)

We continued testing derivatives of the broad-based combined maintainer and restorer population (ICSP IBR/MFR) for rainy-season adaptation. We evaluated 660 S_2 lines in three replicated trials for grain yield, agronomic score, and shoot fly, stem borer, and midge damage. We selected 32 lines for high grain yield, moderate resistance to stem borer and good agronomic score; and another 25 for levels of shoot fly and stem borer damage lower than those of the resistant control. We also made 432 single plant selections for shoot fly and stem borer resistance and 225 for midge resistance and pooled these for recombination in the proportions 1:1:3 with the selected lines. We also retained the selected plants for advancement under pedigree selection. However, we did not split this population into two as reported in ICRISAT Annual Report 1987, p. 47. We do not intend to continue recurrent selection within the population but to use it as a source in its current form. We have also suspended recurrent selection within the corresponding population (ICSP 3BR/ MFR) for postrainy-season adaptation, after completing a first cycle.

Genetic Diversification

With the aim of broadening the genetic base of our breeding materials, we initiated a specific project for genetic diversification and also made efforts to introduce new variations into other individual projects.

We initiated development of a high-tillering population of sorghum by crossing the high-tillering lines IS 1347, IS 3075, and IS 3479 with genetic male steriles of the US/ B-C6 population. Three-way crosses using the F_1 of these crosses with different high-tillering lines will be made during the 1989-90 postrainy season.

Similarly, we crossed 10 large grain lines with genetic male steriles of the US/B-C6 population and made three-way crosses of the resulting F,s to different large-grained parents as a first step in developing a large-grained population.

We began development of near-isogenic lines with contrasting characteristics in order to determine the effects of the genes for those characteristics on other possibly related traits. We selected 91 single plants from 16 progenies segregating for height, 132 single plants from 32 progenies segregating for tan and nontan plants, 65 single plants from 5 progenies segregating for trichomed and trichomeless plants, and 91 single plants from 27 progenies segregating for glossy and nonglossy plants.

Hybrid Breeding and Evaluation

Evaluation and Development of Potential Parent Lines

We evaluated 32 lines in preliminary yield trials at three sites and selected seven (M 63054, M 63086, M 63084, M 63134, M 63070, M 63056, and M 63091) with grain yields between 3.11 ha^{-1}

and 3.7 t ha^{-1} compared to the control variety ICSV 112 with 3.1 t ha^{-1}. M 63086 and M 63134 showed less susceptibility to stem borer (<27% deadhearts) and M 63056 and M 63091 showed less susceptibility to midge (damage rating of <3). M 63056 was also free from rust. The selected lines will now be evaluated for restoration reaction on cytoplasmic male-sterile lines.

We screened 64 B-lines and 274 R-lines for glossiness, rust resistance, and reaction to photoperiod. We identified 6 B-lines and 24 R-lines that were glossy; 16 B-lines and 26 R-lines that were free from rust; ICSB 48, ICSB 93, A 36254B, and ICSR 35 were both glossy and free from rust. Eleven B-lines and 33 R-lines showed less than 3 days delay in flowering under ED, while 11 B-lines and 18 R-lines showed more than 24 days delay. The B-and R-lines with rust resistances will be used to make hybrids that will be screened for rust resistance, those that were glossy will be used to make glossy hybrids that will be screened for shoot fly and drought resistance, and the photoperiod-sensitive lines will be used to make hybrids with potential for postrainy-season cultivation. We will continue to screen potential parent lines for resistance to other biotic and abiotic stresses in order to identify those with potential for use in producing resistant hybrids.

To diversify our milo seed-parent and restorer material, we began introduction of *durra* germplasm. We made 45 crosses involving five *durra* germplasm lines and milo maintainer lines. We also made 17 backcrosses to *durra* parent lines. The F_2 progenies of the 45 crosses will be grown for selection in the 1989-90 postrainy season.

Evaluation and Development of New Milo Male-sterile Lines

We evaluated 13 new male-sterile lines for general combining ability at ICRISAT Center and Bhavanisagar. We selected four of these, ICSA 88004, ICSA 88010, ICSA 88013, and ICSA 89004, for use in the rainy-season hybrid program.

Our general strategy of varietal improvement involves introduction of resistance to various biotic and abiotic stresses into the high-yielding, agronomically superior lines, varieties, and hybrids that are currently available. We therefore made 100 crosses between elite B-lines and different sources of resistance in order to introduce individual resistances to shoot fly, stem borer, midge, rust, anthracnose, DM, *Striga,* and grain mold into milo male-sterile lines. We then used the F,s of these crosses to produce 70 three-way crosses with other B-lines. The F_2 progenies of the single crosses and the F_1s of the three-way crosses will be grown in the 1989-90 postrainy season for selection and further intercrossing.

We made a number of crosses between tillering lines and elite B-lines to attempt recovery of tillering maintainer lines for conversion to sterility. We produced five three-way cross F_1s and five F_2s involving IS 1347 and various B-lines for evaluation and selection and four F_1s involving IS 1347, IS 3075, and IS 3479, and B-lines for further crossing and advancing.

Development of New Nonmilo Cytoplasmic Male-sterile Lines

We made 232 testcrosses between known B- and R-lines and other cytoplasmic male-sterile lines. We identified five milo B-lines (ICSB 26, ICSB 37, ICSB 88001, ICSB 88004, and ICSB 88005) that also showed maintainer reaction on the A_2, A_3, and Maldandi cytoplasms. We have backcrossed these five lines to their F,s as a first step to producing male-sterile versions of each on all four sterile cytoplasms for use in comparative studies of the effects of the different cytoplasms. The remaining testcrosses are being evaluated for fertility restoration in the postrainy season to determine a minimum differential set of testers to characterize the different cytoplasms and also to confirm their classification.

We made 65 crosses between nonmilo restorers and milo maintainers and restorers to diversify available nonmilo male-sterile lines and develop new nonmilo restorers. We crossed selected F_1s with other milo maintainers and restorers to produce 18 three-way crosses. The

F_2 progenies of the 65 single crosses and F_1 progenies of the 18 three-way crosses will be grown in the 1989-90 postrainy season for selection and further crossing.

Hybrid Evaluation

In the 1988-89 postrainy season, we evaluated 73 hybrids in advanced trials conducted at Nandyal, Andhra Pradesh, and two sites at ICRISAT Center (Alfisol and Vertisol). We selected 22 hybrids on the basis of grain yield and agronomic aspect for further testing. The selected entries ranged in yields from 1.94 t ha^{-1} to 3.05 t ha^{-1} compared to 2.32 t ha^{-1} for the control hybrid SPH 280.

On the basis of their performance in the AICSIP preliminary hybrid trials in the 1988-89 postrainy season, three hybrids (ICSH 86646, ICSH 86647, and ICSH 86649) were promoted to advanced trials for 1989-90. ICSH 86646 was found to be resistant to stem borer when screened under artificial infestation at ICRISAT Center.

In the rainy season, we evaluated 19 hybrids in advanced hybrid trials at Bhavanisagar and two sites (Alfisol and Vertisol) at ICRISAT Center. We selected seven entries (ICSH 205, ICSH 228, ICSH 88065, ICSH 811, ICSH 831, ICSH 444, and ICSH 88078) on the basis of grain yield and agronomic appearance for further testing. The selected hybrids gave overall mean grain yields between 4.73 t ha^1 and 3.28 t ha^{-1} compared to yield of 4.26 t ha^{-1} for ICSH 153, the best control.

We also evaluated 135 hybrids in three preliminary yield trials at each of the three locations. We selected 29 on the basis of grain yield, agronomic score, and earliness for further testing. Of particular interest were eight selections which reached 50% flowering between 52 and 60 days and gave grain yields between 2.8 and 5.9 t ha^{-1} compared to the earliest-maturing control, CSH 6, which flowered in 64 days and yielded 5.4 t ha-'.

We evaluated 169 experimental hybrids evolved from three moderately shoot-fly resistant male-sterile lines as female parents, and 221 experimental hybrids from ICSA 1 and midge-resistant male-sterile lines (ICSA 88019 and ICSA 88020) as female parents for yield potential and agronomic eliteness. We selected a total of 38 hybrids for further testing, including 17 that had moderately shoot-fly resistant male-sterile lines as female parents and 21 with ICSA 1 as female parent.

Early-maturing Lines

The availability of early-maturing lines (75-100 days' duration) with high grain yield potential and other desirable characteristics is currently limited. Therefore we initiated a major thrust to develop early lines with acceptable grain yield and resistance to shoot pests and grain mold, in an attempt to make these lines available.

We evaluated a range of early material collected from within our existing breeding projects to identify suitable parent lines. We studied 182 germplasm and 87 advanced breeding lines and rated them for seedling vigor and earliness at ICRISAT Center, and for photoperiod sensitivity at ICRISAT Center and Bhavanisagar. We identified 16 lines (ISs 824, 3477, 8370, 10596, 10701,13724,18093,18197,22500,24025, ICSVs 88050, 88056, 88057, 88059, 88063, and 88065) with good seedling vigor, earliness, and less photoperiod sensitivity; 3 lines (IS 15119, IS 23585, and B 75047-2) for good seedling vigor and grain mold resistance; 5 lines (ICSV 702, ICSV 705, ICSV 445, PS 19349B, and PM 17682B) for good seedling vigor and shoot pest resistance; and 9 lines (ICSB 10, ICSV 521, ICSV 677, ICSV 421, ICSV 692, ICSV 111, MR 884, MR 925, and SPV 462) for seedling vigor, agronomic eliteness, and high grain yield.

We also examined 1009 F_2-F_4 and backcross progenies from crosses of elite breeding lines, diverse landrace material from Nigeria (farafara and kaura) and the Yemen Arab Republic (durra and durra-caudatums), and early lines; and 8 early FLR/FLB populations. We selected 1500 single plants that flowered in less than 60 days and had good grains and panicles for further selection for earliness.

West Africa (Mali)

Evaluation of Medium-duration Varieties

We conducted a multilocational yield trial of 15 lines at three locations in Mali and one location in Burkina Faso. The trial at Samanko (Mali) was sown on two dates and under low fertility. Most of the entries were selected for their superior performance (ICRISAT Annual Report 1987, pp. 54-55). The delayed sowing at Samanko was aimed at exposing the material to late-season incidence of insect pests and diseases. Most of the test entries outyielded the local control variety significantly at Samanko (on both dates of sowing), Cinzana, and Longorola (Table 5). Cultivar ICSV 1079 BF yielded significantly higher than the best control variety at Samanko (on both dates of sowing), at Cinzana, and Longorola. It ranked first in its mean yield performance over all the locations followed by ICSV 1063 BF and ICSV 1083 BF.

Breeding for Long-duration Varieties

We are improving the guinense sorghums for yield and caudatum types for resistance to grain mold using the population breeding method. We

Table 5. Mean grain yield (t ha^{-1}) of sorghum cultivars in the multilocational trial conducted in Mali and Burkina Faso, rainy season 1989[1].

	Locations						
	Samanko (Mali)			Cinzana	Longorola	Farako-Ba	
Cultivars	DOS 1[1]	DOS 2[2]	LF[3]	(Mali)	(Mali)	(Burkina Faso)	Mean
ICSV 1063 BF	2.99	2.38	1.51	3.77	2.35	2.60	2.60
ICSV 1079 BF	3.45	2.27	1.55	4.10	2.68	2.42	2.75
ICSV 1083 BF	3.25	1.74	1.33	4.06	2.16	2.33	2.48
ICSV 1049 BF	2.79	1.86	1.44	3.16	2.04	2.19	2.25
ICSV 1056 BF	2.78	1.21	1.49	3.42	1.54	1.93	2.06
ICSV 1173 BF	2.59	1.09	1.47	3.74	1.80	2.20	2.15
ICSV 1171 BF	2.52	1.05	1.10	3.50	1.60	1.92	1.95
87 W 20	2.87	2.01	0.77	3.52	1.79	2.39	2.23
87 W 18	2.16	0.66	1.65	2.67	1.35	1.77	1.71
87 W 12	2.34	1.18	0.95	3.27	1.64	2.45	1.97
87 W 19	2.01	1.16	1.69	2.51	1.26	1.17	1.63
87 W 5	2.61	2.06	1.78	3.24	1.87	2.75	2.39
Controls							
Malisor 84-1	2.71	1.45	1.81	3.49	2.14	2.38	2.33
S-34	1.94	1.16	1.32	2.95	1.63	2.63	1.94
Local variety	1.34	1.11	1.62	2.83	0.68	2.57	1.69
SE	±0.188	±0.185	±0.222	±0.178	±0.173	±0.248	
Trial mean (15 entries)	2.56	1.49	1.43	3.35	1.77	2.25	
CV (%)	18	30	38	13	24	27	

1. Randomized-block design with six replications, plot size ranged from 7.5 to 15.0 m^2.
2. First date of sowing (DOS 1) = Jun 24, second date of sowing (DOS 2) = Jul 22.
3. Low fertility (LF) = 100 kg of complex fertilizer (17 N:17 P:17 K).

evaluated 160 guinense and 111 caudatum accessions at Samanko. In general, the caudatum group flowered within 80 DAS and was more productive (a mean of 1.53 t ha^{-1} for 98 accessions) than the guinense group (a mean of 1.29 t ha^{-1} for 114 accessions). We selected 23 guinense accessions for creating a random-mating population. Under natural infection conditions, threshed grain mold rating was higher in the caudatum group than in the guinense group. Thirty accessions of caudatum had scores of <2 on a 1-5 scale where 1 = no mold, and 5 = more than 50% of grain surface severely molded. In the guinense group, 104 accessions received scores of <2. Nineteen accessions of caudatum were selected for developing a random-mating population.

Evaluation of Hybrid Parents

We introduced 176 restorer (R)-lines from ICRISAT Center and evaluated them for adaptation at Samanko. Several of them exhibited susceptibility to sooty stripe *(Ramulispora sorghi)* and head bug *(Eurystylus* sp). We selected 13 of them for further evaluation. The selected lines varied in time to 50% flowering (65-74 days), plant height (1.30-2.10 m), and grain yield (2.07-3.13 t ha^{-1}), while the standard control variety, ICSV 1063 BF which is an R-line, took 71 days to 50% flowering, grew to a height of 2 m and produced a grain yield of 2.38 t ha^{-1}.

We also evaluated 67 B-lines introduced from ICRISAT Center for adaptation. Most of them were susceptible to sooty stripe. We selected nine of them for multilocational evaluation and for hybrid combinations. The selected B-lines varied in time to 50% flowering (67-69 days), plant height (1.20-1.35 m), and grain yield (1.00-1.80 t ha^{-1}). The best of them were ICSB 1, ICSB 20, and ICSB 23.

Hybrid Evaluation

We evaluated 22 hybrids along with three variety controls at Samanko, Mali, in a randomized-block design with three replications. These hybrids were produced using our best high-yielding adapted varieties and the four male-sterile lines that we selected during the 1988 rainy season at Samanko for their resistance to leaf diseases. They were previously selected in Burkina Faso over a 3-year period (ICRISAT Annual Report 1987, p. 56). Five hybrids produced grain yields superior to the highest-yielding control variety, ISCV 1063 BF (2.62 t ha^{-1}). The two best hybrids were ICSA 39 x ICSV 1093 BF (2.98 t ha^{-1}) and ICSA 11 x IS 18495 (2.80 t ha^{-1}, SE ±0.322). In general, the hybrids were taller (range 2.11 -3.55 m with a mean of 2.89 m; SE ±0.008 m) than 2.15m of the best control variety, ICSV 1063 BF. The days to 50% flowering ranged from 62 to 74 days with a mean of 70 days (SE ±0.81).

West Africa (Nigeria)

Variety Trials

At Bagauda, we evaluated 20 early-maturing varieties (<70 days to 50% flowering) and 20 medium-maturing varieties (<80 days to 50% flowering) in advanced replicated trials using large plots and local control varieties of appropriate maturity. In the early-variety trial, the best improved local control, KSV 4 (BES) yielded 2.83±0.341 t ha^{-1} (CV % 17), while Nagawhite yielded 4.69 t ha^{-1} and ICSV 401 yielded 4.01 t ha^{-1}. In the medium-maturing variety trial, the recommended local control KSV 8 yielded 1.49 ± 0.340 t ha^{-1} (CV % 17.4) while Framida yielded 4.68 t ha^{-1}, ICSV 112 yielded 4.25 t ha^{-1}, and ICSV 361 yielded 4.07 t ha^{-1}. In the International Sorghum Variety and Hybrid Adaptation Trial (ISVHAT)-1989 trial, ICSV 401 was the highest-yielding variety (6.37±0.567; CV % 19).

Evaluation of Advanced Breeding Lines

We evaluated 86 F_6 generation lines derived from the second backcross of (improved early variety x Farafara local) x (early variety) at Bagauda. Most of the lines exhibited early flowering, tall plant height, lax panicles, and good grain quality. We selected 24 lines for preliminary yield trials. We evaluated 200 F_5 generation lines derived from single crosses of locally adapted improved varieties and compared them with improved varieties as control. We selected 53 individual panicles from among 31 progenies for preliminary yield trials next year. Some of these selections represent good grain derivatives from the popular control variety in the region, Nagawhite, which has poor grain quality.

Evaluation of Early-maturing Germplasm

With the objective of diversifying the genetic base of early-maturing varieties in the West African region, we evaluated 2000 and 100 select early-maturing germplasm accessions originating from various parts of the world at the Bagauda farm in single-observation rows under two dates of sowing: 27 June and 29 July. On the basis of leaf disease resistance, acceptable grain quality, early maturity, and acceptable agronomic scores, we chose 67 accessions, a majority of which performed equally well under very late sowing. These lines will be further multiplied for distribution to national programs in the region, where they can be used as introductions and crossing parents.

Hybrid Trials

We tested 17 advanced hybrids in replicated trials conducted at Bagauda. ICSH 507 ranked first in grain yield for the second successive year (5.48 ± 0.471 t ha^{-1}, CV % 18) and was followed by ICSH 780 (5.43 t ha^{-1}). The early-maturing control variety ICSV 111 yielded 3.34 t ha^{-1}. In preliminary hybrid trials, 35 entries were evaluated along with ICSH 507 as a control. ICSH 507 yielded the highest (7.77±0.496 t ha^{-1}, CV % 14) although hybrids ICSA 38 x MR 917, ICSA 39 x MR 906, ICSA 39 x MR 912, and ICSA 39 x MR 917 were statistically on par with the control.

East Africa

Evaluation for Adaptation

We evaluated a large number of breeding lines and germplasm lines at the Kiboko, Katumani, and Alupe Research Stations in Kenya during the long rainy season (March-July). The breeding material included A- and B-lines, populations, and diverse germplasm and breeding lines with a range of maturity and seed color introduced from Ethiopia, SADCC/ICRISAT, ICRISAT Center, Mexico, and USA. At Kiboko, the material was evaluated for earliness and terminal drought tolerance; at Katumani for cold tolerance and adaptation to intermediate and highland areas, and at Alupe for grain mold resistance and adaptation to intermediate altitude and humid areas. The material at Kiboko and Katumani received adequate rainfall up to flowering, but no rainfall during grain filling, which affected grain development. At Katumani, the material was also exposed to low night temperatures (below 10° C) during the flowering period, which reduced seed-set of unadapted genotypes. At Alupe, the material received adequate rainfall during all stages of plant growth; this gave us the opportunity to select genotypes resistant to grain mold and with adaptation to humid environmental conditions. At Kiboko, we selected 186 adapted genotypes and 32 A- and B-pairs tolerant to terminal drought. At Katumani, we selected 60 cold-tolerant genotypes with good agronomic attributes and having 90-100% seed-set compared to 0% for susceptible genotypes, whereas at Alupe, we selected 50 adapted genotypes least damaged by midge and free of grain mold.

Southern Africa

Varietal Improvement

In the breeding nursery, we selected 7 sets for advancement: 23 F_1s (1 brown, 22 white) to F_2, 98 F_2s (1 brown, 97 white) to F_3, 11 S_1s (6 red/brown, 3 white, 2 yellow) to S_2, 331 F_3s (3 red, 327 white, 1 yellow) to F_4, 39 S_2s (17 red/brown, 22 white) to S_3, 58 F_4s (35 red/brown, 23 white) to F_5, and another set of 54 S_1s (25 red/brown, 16 white, 13 yellow) to S_2. Selections for promising types in F_1 and F_2/S_1 early generations were made in a high-input environment at Aisleby in Zimbabwe, while further selections for superior lines in F_3 and advanced F_4/F_5 generations were made at Matopos and Makoholi under rainfed conditions. F_2s and F_3s from these breeding lines are sent to the SADCC national programs which requested them for their use in further selection and identification of superior genotypes.

Variety Trials

We evaluated 232 F_5 lines in advance generation testing (AGT) at Matopos, Makoholi, Mzarabani (Zimbabwe), and Sebele (Botswana); and also evaluated 25 previously selected crossbred lines in preliminary variety trials at Matopos (Zimbabwe) and Sebele (Botswana) under rainfed conditions.

From the AGT, 49 lines (21% of the entries), of which 45 were white-grain, 2 red-grain, and 2 brown-grain, were selected with average grain yields ranging from 5.02 to 9.75 t ha"^{1} across locations, relative to average control yields of 4.65 t ha"' (DC 75) and 5.40 t ha^{-1} (Serena). The highest-yielding lines were white-grain lines including SDSL 88154 (9.75 t ha^{-1}), SDSL 88220 (9.25 t ha^{-1}), SDSL 88152 (8.75 t ha^{-1}), SDSL 88084 (8.58 t ha^{-1}), SDSL 88166 (8.25 t ha^{-1}), and SDSL 88153 (8.00 t ha^{-1}). The best red-grain variety was SDSL 88238 with a yield of 7.75 t ha^{-1}. The SE for the above means was ±1.38. Fifteen of the 49 selected lines performed very well at all four locations indicating possible wide adaptability. We believe the remaining 34 lines had some specificity in adaptation because they were selected and performed well at only two locations.

Mean grain yields (6.00 t ha^{-1}) and crop residue yields (11.97 t ha^{-1}) for the preliminary varieties in the preliminary variety trials (PVT) were higher at Matopos than at Sebele (4.31 t ha^{-1} for mean grain yields and 8.89 t ha^{-1} for crop residue yields). Averaged across the two locations, the highest grain yielders were SDSL 87040 (7.09 t ha-^{1}), SDSL 87012 (6.11 t ha^{-1}), SDSL 87032 (5.98 t ha^{-1}), and SDSL 87035 (5.93 t ha') compared to the control varieties SV2 (5.87 t ha'), Segaolane (4.99 t ha^{-1}), SV1 (4.89 t ha^{-1}), and the hybrid control PNR 8311 (4.30 t ha^{-1}). The SE for these means was ±0.79. For the crop residue yields, SDSL 87040 had 9.22 t ha^{-1} on average, SDSL 87012 had 12.96 t ha^{-1}, SDSL 87032 had 13.91 t ha', and SDSL 87035 had 18.13 t ha^{-1}, compared with the control varieties' residue yields of 9.05 t ha^{-1} (SV2), 7.14 t ha^{-1} (Segaolane), 7.43 t ha^{-1} (SV1), and the hybrid control's yield of 6.43 t ha^{-1} (PNR 8311). The SE for these means was ±1.46.

Hybrid Breeding and Evaluation

A total of 815 experimental hybrids developed using male steriles from ICRISAT, India, and Texas A & M University, USA, and agronomically elite R-Lines from our SADCC/ICRISAT program and Texas A & M University, was evaluated in two trials, each at Matopos and Mzarabani in Zimbabwe, with three local commercial hybrids as controls.

The first set of trials, Sorghum Testcross Evaluation-1 (STCE-1), contained 130 entries, and the second set, Sorghum Testcross Evaluation-2 (STCE-2), contained 685 entries. The 35 best performing experimental hybrids in the first set of trials (involving ICRISAT male steriles, CK 74A, ATx 623, and mainly ICRISAT restorers) were selected across the two locations in the first set of trials for further testing. The selected 35 hybrids, all white-grain, yielded on average between 5.04 and 7.09 t ha^{-1} for grain and between 5.58 and 20.00 t ha^{-1} for crop residue compared with the local hybrids, PNR 8544, PNR 8311, and DC 75, which had yields ranging from 2.21 to 6.25 t ha^{-1} for grain and from 9.95 to 14.12 t ha-' for crop residue (SE ±0.99 for grain yield and ±2.66 for crop residue).

In the second set of trials, there were five groups of experimental hybrids in two categories for each source of male steriles and restorers. The groups included hybrids with ICRISAT male steriles (milo A, cytoplasm), Texas male steriles (milo A_1 cytoplasm and nonmilo A_2 cytoplasm), SADCC/ICRISAT Sorghum and Millets Improvement Program (SMIP) restorers and Texas restorers. Observations on comparative performance of the different sources of male steriles and restorers in the second set of trials showed that 340 fertile hybrids with Texas restorers crossed to the ICRISAT male steriles (n=340) gave the highest average yield of 6.41 t ha^{-1} (ranging from 3.42 to 9.33 t ha^{-1}) and were earliest maturing with 65 days to 50% flowering on average (range of 58 79 days) and shortest in height with an average of 1.29 m (range 0.86-1.60 m). Comparatively, out of the four groups of hybrids developed at Matopos, fertile hybrids with Texas male steriles (nonmilo A_2 cytoplasm) crossed with SADCC/ICRISAT restorers were tallest, ranging from 1.31 to 2.68 m (1.94 m on average), and relatively late maturing (77 days to 50% flowering) with a range of 70-85 days, but had second best average yields of 5.96 t ha^{-1} (with a range of 3.50 8.13 t ha^{-1}). A total of 167 new hybrids (76 white grains, 91 red grains/ brown grains) was selected, yielding between 6.25 and 9.08 t ha^{-1} compared to the yields of local commercial hybrids PNR 8544 (5.04 t ha^{-1}), PNR 8311 (2.21 t ha^{-1}), and DC 75 (6.25 t ha^{-1}). The SE for the above mean yields was ±1.31.

In the SADCC Preliminary Hybrid Trial-1 (SDPHT-1), 29 new hybrids were evaluated with local commercial hybrid DC 75 at Matopos and Mzarabani (Zimbabwe), Golden Valley (Zambia), Hombolo (Tanzania) and Pandamatenga and Sebele (Botswana). Seven white hybrids (SDSH 13, SDSH 17, SDSH 18, SDSH 19, SDSH 60, SDSH 62, and SDSH 71) yielded better when averaged across six locations (from 5.32 to 6.00 t ha^{-1}) than the local hybrid control DC 75 (4.89 t ha^{-1}) (SE ±0.51).

In all hybrid trials and in the variety trials, entries matured significantly ($P < 0.05$) earlier (average 10 days earlier), and grew taller (average 0.30 m taller) at Mzarabani (450 m asl and 5-8° C warmer than Matopos) than at Matopos (1347 m asl).

In two other sets of preliminary hybrid trials, SDPHT-2 and SDPHT-3, we evaluated 56 selected hybrids with two local commercial hybrids (DC 75 and PNR 8311) at Matopos and Mzarabani. Twenty-two of the test hybrids were white-grain, and yields averaged across locations ranged from 6.04 to 7.58 t ha^{-1} compared to the yields of controls PNR 8311 (3.55 t ha^{-1}) and DC 75 (5.92 t ha^{-1}). The SE for these means was ±0.58.

We evaluated 15 drought-resistant hybrids, developed by crossing two male steriles (CK60A and ATx 623) with the ten best restorer lines identified for drought resistance in the region at six locations: Lucydale, Makoholi, Matopos, and Mzarabani (Zimbabwe) and Sebele and Pandamatenga (Botswana). Two commercial hybrids DC 75 and PNR 8311, and two commercial varieties SV 1 and Segaolane were used as controls in the six drought test locations. When yields were averaged over six locations, three of the hybrids, SDSH 504 (6.321 ha^{1}), SDSH 508 (5.35 t ha-'), and SDSH 512 (5.42 t ha"1), outyielded the controls (4.25 t ha^{-1} for varietal controls SV 1 and 4.98 t ha^{1} Segaolane; 4.29 t ha^{-1} for hybrid control DC 75 and 5.09 t ha^{-1} for hybrid control PNR 8311). The SE for these means was ±0.74.

Forage Sorghum

Through consultations with the NARS scientists in the region, we identified two areas of research on which we will be concentrating for the next 5-10 years: (1) to improve the quality of crop residue while maintaining high grain yield and (2) to improve forage yield and quality of forage types for hay and silage.

Twelve sorghum grain varieties (SV1, SV2, Segaolane, ICSV I (CSV 11), Serena, Town, SDS 3472, SDS 170, SAR 16, SDS 2293-1, SDS 2690-2, and Tegemeo) have been crossed with a number of brown midrib *(bmr)* lines to transfer *bmr* gene into grain cultivars by backcrossing. The *bmr* gene reduces the lignin content in the plant and therefore increases the dry matter digestibility. Twelve forage sorghum and nine sudan grass lines have been crossed to a number of selected *bmr* lines. The progeny will be advanced through pedigree breeding. Four sorghum lines from Malawi were identified as new sources of *bmr* and then multiplied. These are named SDFSs 172, 173, 174, and 175.

Utilization

ICRISAT Center

Properties of Sorghum Malt

Two potential industrial uses of sorghum are in brewing and in the manufacture of starch. We identified sorghum cultivars with high diastatic activity in malted sorghum grain. Besides high enzyme activity, the quality of protein is also important in the malting and brewing process. Soluble N is important for the growth of yeast during the brewing process. We evaluated the protein quality of unmalted and malted grain by fractionating the proteins into different solubility classes. In cultivars with a high diastatic activity, fraction 1 (F1) which comprises albumin, globulin, and nonprotein N increased due to malting (Table 6). For most of the cultivars, a reduction was observed in the prolamin fractions (F2 and F3) except in the case of M 35-1. Diastatic activity and FI of malted grain were positively correlated ($r = 0.88$, $P<0.05$). Although variation for fractions 4 and 5 were observed among the cultivars, diastatic activity did not show significant relationship with these fractions.

Comparison of Properties of Sorghum and Maize Starches

Starch was isolated from 11 sorghum and five maize cultivars and their properties were compared. Swelling power, solubility, and viscosity measurements did not reveal any significant differences between maize and sorghum starches. Hot and cold paste viscosity properties were determined in a viscoamylograph. The peak viscosity of hot paste of sorghum starch, in general, was higher than that of maize starch. The consistency of starch paste under hot and cold condi-

Table 6. Diastatic activity and distribution of protein fractions in sorghum grains.

			Protein fractions (g [100 g]$^{-1}$ of protein)				
Cultivar	Treatment	SDU[1] g^{-1}	F1[1]	F2[1]	F3[1]	F4[1]	F5[1]
SPV 475	Unmalted		19.1	13.0	20.5	6.1	28.2
	Malted	21	27.7	10.2	13.1	9.1	26.4
IS 14384	Unmalted		19.9	10.8	15.8	10.1	28.2
	Malted	113	46.3	6.0	5.9	8.6	18.6
TAM2566	Unmalted		16.7	10.3	17.6	7.9	24.0
	Malted	114	40.6	7.1	12.1	7.5	19.2
M 35-1	Unmalted		15.7	10.1	22.2	5.2	34.3
	Malted	48	29.1	11.2	24.1	3.4	20.8
CSH 1	Unmalted		16.7	11.2	21.1	4.1	35.4
	Malted	45	30.0	6.7	20.3	4.5	30.9
IS 18519	Unmalted		15.9	13.5	17.3	7.7	30.7
	Malted	50	22.5	2.4	1.2	12.9	30.6
SE	Unmalted		±0.71	±0.58	±1.03	±0.88	±1.74
	Malted	±15.9	±3.64	±1.29	±3.50	±1.40	±2.30

1. SDU = Sorghum diastatic units; F1 = Albumin-globulin and nonprotein N; F2 = Prolamin; F3 = Cross-linked prolamin; F4 = Glutelin; and F5 = Glutelin-like.

tions is important as it influences the texture of foods. Starch with a high-paste viscosity has a stable consistency in foods, like porridge. Cold paste viscosity and setback values of maize and sorghum starches were similar. Thus, due to similarity in several properties of maize and sorghum starches, it appears that sorghum can supplement maize in industrial starch production.

Starch was extracted from a hard-grain sorghum cultivar SPV 472 and a soft-grain cultivar WS 1297 that were grown in the 1988/89 postrainy season. Their pasting characteristics were compared using a viscoamylograph. The hot paste viscosity of starch at 95° C was about 730 Brabender Units (BU) for both cultivars (Table 7). The reduction in viscosity of starch on prolonged heating at 95° C is called shear thinning. It is advantageous to have starch with a low shear-thinning property, with which the consistency of the prepared food can be maintained at a desired level. The shear thinning of starch from SPV 472 was only 25% compared to 54% in the case of WS 1297, indicating the superior quality of starch of SPV 472. The cold paste viscosity of starch measured at 40° C was 1302 BU for SPV 472 and 1003 BU for WS 1297. Similar results were also obtained from the grain of these two cultivars harvested from the postrainy season of 1984/85. These data indicate that hard- and soft-grain sorghum cultivars differ considerably in their viscoamylographic properties.

West Africa (Mali)

Food Quality

We analyzed the grain quality of the rainy season-grown sorghum varieties from a multilocational adaptation trial of 12 cultivars conducted at seven locations in Mali and Burkina Faso in the 1988 rainy season. We studied the percentage recovery of endosperm after dehulling for 5 min, using a Tangential Abrasing Dehulling Device (TADD), color of *to* (a local porridge) and its keeping quality. Results indicated that the percentage recovery of endosperm ranged from 56% (cultivar S 34) to 83% (local

Table 7. Viscoamylographic properties of starch isolated from hard- and soft-grain sorghums grown in the postrainy season.

Cultivar	Hot paste viscosity (BU)[1] At 95°C	Hot paste viscosity (BU)[1] After 60 min at 95°C	Shear thinning (%)	Cold paste viscosity (BU)[1] At 50°C	Cold paste viscosity (BU)[1] At 40°C
Hard sorghum					
SPV 472 (Postrainy 1984/85)	725	550	24	1110	1290
SPV 472 (Postrainy 1988/89)	730	545	25	1082	1302
Soft sorghum					
WS 1297 (Postrainy 1984/85)	740	350	53	810	924
WS 1297 (Postrainy 1988/89)	738	338	54	850	1003
SE	±3.5	±58.8	±8.4	±77.4	±97.4

1. BU = Brabender Units.

cultivar). Among the improved cultivars, ICSV 16-5 BF(76%), ICSV 1078 BF(72%), ICSV 1093 BF (71%), and ICSV 1079 BF (70%) were acceptable. Differences in the color of *to* were negligible (1-2 on a scale of 1-5, where 1 = excellent and 5 = worst). In general, white and shades of yellow were readily acceptable. The score for *to* keeping quality varied between 1.1 (ICSC 1078 BF) and 1.9 (ICSV 1083 BF) on a scale of 1-5, where 1 = highly stable and 5 = very soft and unacceptable. Cultivars ICSV 1079 BF and ICSV 1063 BF were highly stable in *to* keeping quality across locations.

Southern Africa

Use of Semi-wet Milled Flour in Composites for Bread

Semi-wet milling (SWM), developed by the Overseas Development Natural Resources Institute (ODNRI), consists of a one-step roller milling of sorghum grains conditioned to a moisture content of 20-22%. The conditioning enables bran to separate more completely from the endosperm resulting in a whiter flour, than in the two-step dry dehulling and milling process. The effect of the technology on flour quality for bread was evaluated in replicated single-blind laboratory taste panel tests using a 15% SWM composite of sorghum in a straight dough bread formulation for evaluation against a 100% wheat flour control. When the responses of the replicated 10-member panels were analyzed by using a t test, no significant difference $(P < 0.05)$ in general acceptability was observed between the 15% SWM composite (mean hedonic score of 6.4) and the wheat flour control (mean hedonic score of 6.5) on a scale of 1-7, where 1 = strong dislike and 7 = strong liking. The trial demonstrates that SWM flour can be incorporated to the same levels (15%) in bread, as was shown in previous studies with dry dehulled and milled flour, without loss of acceptability. Studies will be continued to further test the possibility of incorporating higher levels (20-25%) of SWM flour in composites for bread.

Sugar from Sorghum

We evaluated 69 sweet-stemmed sorghum lines from the world sorghum collection at 1CR1SAT Center for sugar content of juice (brix), sugar yield in t ha^{1}, biomass yield (whole plant and stripped stalk in t ha^{-1}), plant height, and number of internodes under rainfed and irrigated conditions. Four sequential harvests were made at four successive stages of maturity from preflowering (boot leaf stage) to hard-dough stage. Thirty-one lines were selected primarily on the basis of either high brix (>15%) or high sugar yield (>4 t ha^{-1}) at either soft-dough or hard-dough stage of growth. Selections were made independently under irrigated and rainfed conditions. Further testing will be carried out at three locations including Chiredzi in the sugar-growing lowveld of Zimbabwe.

Food Quality

We continued physical characterization of 14 traditional sorghum foods from Zimbabwe and of 59 breeding lines, varieties, and hybrids from the SADCC/ICRISAT Program. Quantitative criteria used in characterization were grain size, size ratios (differential size screening as percentage of total), dehulling and milling yield, endosperm texture score, test mass, and density. Comparison of traditional germplasm to improved materials showed that a high proportion (93%) of both white- and red/brown lines had hard-to-intermediate endosperm texture (i.e., 3-5 on a scale of 1-5, where 1 = soft and 5 = hard). Seventy-one percent of the improved material had high milling yield (>70%), though only 50% had high kernel mass values (>2.5g [100 grains]$^{-1}$). The improved material showed different milling qualities in white- and red/brown lines.

Of the improved white-grain types, 90% showed high endosperm texture scores, 65% showed high milling yields, and 86% showed high kernel mass; however, for the improved red/brown-grain types, the respective percentages were only 30, 10, and 60. Traditional selections of food grain, both red and white, had milling properties comparable with those of improved white-grain lines but had low kernel masses.

The grain characterization program aims to develop a cumulative data base on the germplasm available in the region and to develop adequate data for correlation analysis to enable the derivation of an integrated grain quality index for milling quality.

A micromalting system and a diastatic power (DP) procedure were standardized to enable micromalting of up to 50 microsamples of 20 g each in one operation and up to 40 DP determinations per day. Methodology standardization is aimed at reducing sample size for malting and DP to a minimum, to adopt the techniques for screening purposes. It is also aimed at relating DP or sorghum diastatic units (SDU) to other indices of malting, such as malt modification, which are more easily and rapidly determined by physical or optical methods in order to eventually replace DP as a screening tool, and applying it only at more advanced stages of selection. Six sorghum lines, including two commercial brewing sorghums, Red Swazi (47.10 SDU) and Framida (41.20 SDU), two traditional brewing sorghums, Chimonda (17.80 SDU) and Brown Tsweta (31.75 SDU), and two improved white-grain varieties, ICSV 2 (ZSV 1) (36.75 SDU) and SV1 (36.60 SDU) have been screened for SDU and are being evaluated for malt modification in a cooperative trial with the Carlsberg Research Center, Denmark.

Collaboration with National Agricultural Research Systems

ICRISAT Center

Pink Borer *(Sesemia inferens)* in India

In collaborative studies at the Agricultural Research Station, Warangal, Andhra Pradesh, natural infestations of the pink borer, *S. inferens,* were very high on sorghum during the postrainy season. Two related species, *S. cretica* and *S. calamistis* are important stem borer species in Africa. Chilo-susceptible controls, 1CSV 1 and CSH 5, had over 80% deadhearts while *Chilo*-resistant lines, IS 1082, IS 18677, IS 23962, P 84, PS 14413, and PB 12450, were also resistant to *Sesemia* with less than 10% deadhearts. This indicates a good level of cross resistance to the different stem borer species.

International Sorghum Variety and Hybrid Adaptation Trial (ISVHAT-88)

ISVHAT-88 consisted of 10 test varieties and 10 test hybrids bred at ICRISAT Center. The controls were four established ICRISAT-bred hybrids and an entry contributed by the cooperating scientist at each test location. Trial seeds were dispatched to 20 locations, but data were received from eight locations: three locations in India, one in Myanmar, one in the Philippines, two in Thailand, and one in Vietnam. Table 8 shows the grain yield of the top 10 entries and their ranks at each location as well as the number of locations of each entry ranked in the top 20% and bottom 20% for grain yield.

At Bhavanisagar (India) ICSV 233 was the best yielder (9.22 t ha^{-1}), followed by ICSH 281 (9.18 t ha^{-1}) and ICSH 479 (9.02 t ha^{-1}). At Patancheru (India), ICSH 205 (3.67 t ha^{-1}) and ICSH 310 (3.51 t ha^{-1}) yielded well, whereas the control entry ICSH 153 (3.99 t ha^{-1}) yielded better. At Dharwad (India), ICSH 205 (7.28 t ha-') and ICSH 479 (7.09 t ha^{-1}) yielded well, whereas the control hybrids ICSH 110 had a yield of 7.44 t ha^{-1} and ICSH 566 of 7.38 t ha^{-1}. At Yezin Pyinmana (Myanmar), the two best test entries were ICSH 245 (4.34 t ha^{-1}) and ICSH 281 (4.25 t ha^{-1}). The control hybrid ICSH 153 (4.18 t ha^{-1}) also performed well. At Ilagan (the Philippines) ICSH 401 and ICSV 197 did well and had similar yields (4.26 t ha^{-1}), whereas the control hybrids, ICSH 110 (4.40 t ha^{-1}) and ICSH 566 (4.22 ha"[1]) also did well. At Packchong (Thailand) the best test entry was ICSV 112 (7.52 t ha^{-1}) compared to the best control entries ICSH 110 (7.98 t ha^{-1}), ICSH 566 (7.08 t

Table 8. Mean grain yield (t ha[1]) of the top ten entries in the 1988 International Sorghum Variety and Hybrid Adaptation Trial (ISVHAT 88)[1] at eight locations[2], three in India, one each in Myanmar and the Philippines, two in Thailand, and one location in Vietnam.

Entry	India 1 Mean	India 2 Mean	India 3 Mean	Myanmar 4 Mean	Philippines 5 Mean	Thailand 6 Mean	Thailand 7 Mean	Vietnam 8 Mean	No. of locations entry ranked Top 20%	No. of locations entry ranked Bottom 20%
ICSH 310	8.66 (5)[3]	3.51 (3)	5.83(14)	4.15 (4)	4.13 (6)	5.75(11)	7.79 (1)	3.05 (5)	5	0
ICSH 281	9.18 (2)	3.06 (9)	6.55 (8)	4.25 (2)	4.11 (7)	6.20 (7)	6.14(11)	2.73(12)	2	0
ICSH 479	9.02 (3)	3.07 (8)	7.09 (4)	3.33(14)	3.49(12)	5.67(14)	5.33(23)	5.09 (1)	3	0
ICSH 205	8.12 (7)	3.67 (2)	7.28 (3)	3.78 (9)	3.39(15)	5.68(13)	6.54 (4)	2.66(14)	3	0
ICSH 401	7.94 (9)	2.81(18)	6.20(10)	4.03 (6)	4.26 (2)	5.82(10)	5.86(14)	2.70(13)	1	0
ICSV 197	8.08 (8)	2.96(13)	6.59 (7)	3.27(15)	4.26 (3)	6.03 (9)	5.35(21)	2.83(10)	1	1
ICSH 245	7.06(14)	2.85(16)	6.78 (5)	4.34 (1)	3.41(14)	5.59(15)	6.68 (3)	2.35(23)	3	1
ICSH 229	8.62 (6)	2.92(14)	5.87(13)	3.93 (7)	3.01(20)	5.19(18)	6.98 (2)	2.53(19)	1	0
ICSV 233	9.22 (1)	2.87(15)	5.63(16)	3.14(19)	3.99 (8)	5.07(20)	5.83(15)	3.04 (4)	2	0
ICSV 112	6.52(18)	3.10 (6)	5.59(17)	2.80(21)	2.80(24)	7.52 (2)	5.73(17)	2.98 (8)	1	2
Controls										
ICSH 153	8.67 (4)	3.99 (1)	6.63 (6)	4.18 (3)	3.91(10)	7.04 (4)	5.71(18)	3.39 (2)	5	0
ICSH 110	7.86(10)	3.34 (5)	7.44 (1)	3.69(11)	4.40 (1)	7.98 (1)	6.07(12)	2.57(17)	4	0
ICSH 566	7.00(16)	3.43 (4)	7.38 (2)	2.67(23)	4.22 (4)	7.08 (3)	6.24 (8)	3.09 (3)	4	l
Local	5.81(22)	2.51(20)	4.83(23)	3.54(12)	2.59(25)	6.35 (6)	6.34 (6)	-	0	3
SE	±0.62	±0.25	±0.41	±0.66	±0.41	±0.45	±0.38	±0.43		
Trial mean (25 entries)	7.14	2.92	5.93	3.45	3.54	5.60	6.00	2.84		
CV(%)	15	12	33	20	14	11	26			
Efficiency (%)	100	149	108	100	111	100	102	-[4]		

1. 5 x 5 lattice, plot size ranged from 3.0 m^2 to 7.5 m^2.
2. Locations: 1=Bhavanisagar, 2=Patancheru (ICRISAT Center), 3=Dharwad, 4=Yezin Pyinmana, 5=Ilagan, 6=Packchong, 7= Suphanburi, and 8 = Tu Loc.
3. Numbers in parentheses are ranks.
4. Data from Vietnam were analyzed following a randomized complete block design.

ha-^{1}), and ICSH 153 (7.04 t ha^{-1}). At Suphanburi (Thailand) the best test entries were ICSH 310 (7.79 t ha^{-1}) and ICSH 229 (6.98 t ha^{-1}), whereas the best controls were local varieties (6.34 t ha^{-1}) and ICSH 566 (6.24 t ha^{-1}). At Tu Loc (Vietnam) the two best test entries were ICSH 479 (5.09 t ha"^{1}) and ICSV 233 (3.04 t ha^{-1}) compared to the best controls ICSH 153 (3.39 t ha^{-1}) and ICSH 566 (3.09 t ha^{-1}).

The top four test entries, based on mean over the eight locations, were ICSH 310 (5.42 t ha^{-1}), ICSH 281 (5.39 t ha^{-1}), ICSH 479 (5.26 t ha^{-1}), and ICSH 205 (5.15 t ha^{-1}). Among the controls the three best entries were ICSH 153 (5.44 t ha^{-1}), ICSH 110 (5.41 t ha^{-1}), and ICSH 566 (5.13 t ha^{1}). In 5 out of 8 locations, ICSH 310 ranked in the top 20% of the entries followed by ICSH 479 (three locations) and ICSH 205 (three locations).

Similarly, in five out of eight locations, the control entry ICSH 153 ranked in the top 20% of the entries followed by two control entries ICSH 110 (four locations) and ICSH 566 (four locations).

Protein Digestibility and Amino Acid Composition of *Uji* from Kenya

We determined the in vitro protein digestibility (IVPD) and amino acid composition of three *uji* samples received from our cooperator from the University of Nairobi, Kenya. The samples consisted of a fermented and drum-dried *uji,* a drum-dried *uji* made from germinated sorghum flour, and an unfermented *uji* (control). Fermented and drum-dried *uji* had an IVPD value of 57.4% (SE ± 2.19); drum-dried *uji* made from germinated sorghum flour had a value of 24.8% (SE ±2.07) while the value of the control was 35.4% (SE ±1.20). Results suggested that fermentation of *uji* considerably improved the IVPD compared to the other two *uji* samples, while the amino acid composition did not show much variation among the three *uji* samples.

West Africa

Leaf Anthracnose *(Colletotrichum graminicola)* in Burkina Faso

In collaboration with the Burkina Faso national program, we evaluated 80 sorghum cultivars at Farako-Ba. All local varieties (51) had anthracnose symptoms when evaluated at 59 DAS. Four improved varieties (ICSV 111, IS 21658, 84 S 82, and B 58585) had no anthracnose symptoms.

Wheat/Sorghum Composite Flour in Nigeria

In collaboration with the Institute of Agricultural Research (IAR), Samaru, we are determining the baking technology of wheat/sorghum composite flour. Flour from six different sorghum cultivars was used to substitute wheat flour at 30%, 40%, and 50% levels. In another experiment, we compared loaves of bread baked from wheat/maize and wheat/sorghum composite flour. The bread made of 100% wheat flour gave the best loaf with a specific loaf volume (SLV) of 3.31 cm g^{-1}. There was no significant difference in SLV up to 50% level of substitution by sorghum. Bread that had up to 50% level of substitution was acceptable. In general, bread made from wheat/ sorghum composite flour was better than that from wheat/maize composite flour in SLV, total bread score, and crude protein content.

West Africa Regional Variety and Hybrid Adaptation Trials

The West African Sorghum Variety Adaptation Trial (WASVAT-88) comprising early- and medium-duration cultivars, consisted of 20 entries. Entries were contributed by the West African Sorghum Improvement Program (WASIP), national programs of Ghana, Cameroon, Mali, and Senegal. Results were received from 10 locations. The cultivar Nagawhite had the highest overall mean yield of 3.53 t ha^{-1} followed by ICSV210 IN (3.41 t ha^{-1}) and ICSV 111 IN (3.27 t ha^{-1}). The mean yield of the local control variety was 2.37 t ha^{-1} (Table 9).

Entries from Cameroon, Mali, Burkina Faso, and Niger were included in the WASVAT medium-duration trial. We received results from 11 locations. Three cultivars, ICSV 1063 BF, Malisor 84-1, and ICSV 1089 BF produced overall mean grain yields over 3.0 t ha^{-1} compared to 2.15 t ha^{-1} for the local control variety (Table 10).

The West African Sorghum Hybrid Adaptation Trial (WASHAT-88) had 20 entries. Results from seven locations showed that the highest-yielding hybrids were ICSH 507 (3.32 t ha^{-1}), ICSH 330 (3.09 t ha^{-1}), and ICSH 88042 (3.03 t ha^{-1}). The local control variety produced 1.74 t ha^{-1} (Table 11).

Table 9. Mean grain yield (t ha⁻¹) of the highest-yielding early-duration cultivars in the West African Sorghum Variety Adaptation Trial (WASVAT) at 10 locations in West Africa[1], rainy season 1988[2].

	1		2		3		4		5		6		7		8		9		10		Overall	
Entry	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Nagawhite	4.78	1	2.88	19	2.86	1	2.59	7	3.79	5	6.35	3	3.60	2	3.00	6	2.98	5	2.44	4	3.53	1
ICSV 210 IN	3.90	7	4.57	1	1.98	14	2.72	6	4.32	1	5.93	4	3.05	4	3.18	5	1.95	8	2.54	3	3.41	2
ICSV 111 IN	4.18	4	3.57	9	2.11	13	2.09	15	3.56	6	5.45	11	3.12	3	2.81	8	3.19	3	2.60	2	3.27	3
S-35	3.32	13	3.51	10	1.69	17	1.93	17	4.15	3	5.55	9	3.69	1	2.44	16	3.19	3	2.81	1	3.23	4
ICSV 1087 BF	4.09	5	3.38	8	2.85	2	2.23	11	1.89	18	5.90	5	2.81	6	4.10	1	2.35	9	2.18	5	3.18	5
CE 180-33	2.95	15	3.77	3	1.83	16	3.36	1	4.25	2	5.50	10	2.39	11	2.61	13	3.31	2	1.68	8	3.17	6
ICSV 1078 BF	2.86	16	2.99	17	2.31	10	3.01	4	3.01	7	6.92	1	2.89	5	2.71	12	2.50	7	2.60	2	3.12	7
ICSV 1054 BF	3.82	9	3.21	15	2.40	6	1.89	18	2.07	16	6.42	2	2.81	6	3.47	3	2.88	6	2.10	7	3.11	8
ICSV 1083 BF	4.68	2	4.13	2	2.37	7	2.19	16	3.94	4	5.83	6	1.38	18	2.73	11	2.33	10	0.99	19	3.06	9
Controls																						
IRAT 204	3.66	12	2.76	20	2.23	9	2.41	10	0.72	20	5.27	15	2.22	12	3.39	4	2.16	11	1.36	14	2.62	16
Local	2.02	18	3.19	16	2.34	8	1.30	19	2.81	10	5.64	18	1.48	17	1.68	18	1.80	13	1.41	13	2.37	20
SE	±0.483		±0.344		±0.202		±0.289		±0.333		±0.442		±0.334		±0.339		±0.475		±0.194			
Trial mean (20 entries)	3.49		2.59		1.67		2.39		2.75		5.47		2.41		2.80		2.35		1.77			
CV (%)	24		23		21		21		21		14		24		21		35		19			

1. Locations: 1 = Saria, Burkina Faso; 2 = Bema, Mali; 3 = Cinzana, Mali; 4 = Bagauda, Nigeria; 5 = Tarna, Niger; 6 = Maroua, Cameroon; 7 = Farako-Bâ, Burkina Faso; 8 = Kolo, Niger; 9 = Bambey, Senegal; and 10 = Nyankpala, Ghana. Numbers following each yield value indicate the ranking of the cultivars.
2. Randomized-block design with three replications, plot size ranged from 6.4 m^2 to 19.4 m^2.

Table 10. Mean grain yield (t ha^{-1}) of the highest-yielding medium-duration cultivars in the West African Sorghum Variety Adaptation Trial (WASVAT) at six locations in West Africa, rainy season 1988[1].

	Burkina Faso				Mali				Nigeria					
	Farako-Ba		Saria		Sotuba		Samanko		Bagauda		Karewa		Overall	
Entry	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
ICSV 1063 BF	3.45	1	4.66	11	4.33	1	1.20	3	3.00	4	3.42	3	3.34	1
Malisor 84-1	3.16	2	4.38	13	3.10	13	1.27	1	2.67	8	3.91	2	3.08	2
ICSV 1089 BF	2.81	3	4.90	8	3.45	7	0.91	11	3.31	2	2.67	13	3.01	3
BF 80-7-7-2-1	2.78	4	5.18	5	3.71	5	1.23	2	1.83	12	3.11	4	2.97	4
ICSV 1092 BF	2.38	10	4.38	13	3.18	11	1.12	5	3.48	1	2.71	12	2.88	5
BF 80-9-8-3-1	2.59	7	4.56	12	3.10	13	0.95	10	2.91	6	2.98	7	2.85	6
Control														
Local	1.61	17	2.23	20	3.11	12	0.65	20	0.83	20	4.44	1	2.15	18
SE	±0.325		±0.529		±0.248		±0.164		±0.389		±0.279			
Trial mean (20 entries)	2.25		4.58		3.31		0.98		2.41		3.62			
CV(%)	25		20		13				28		16			

1. Randomized-block design with three replications, plot size ranged from 6.4 m^2 to 19.4 m^2.

West Africa Regional Disease and *Striga* Nurseries

We organized the West African Sorghum Disease Resistance Nursery (WASDRN) and the West African Sorghum *Striga* Nursery (WASSN) in 1988. The WASDRN consisted of 36 entries and was grown at six locations, Longorola (Mali), Farako-Ba and Niangoloko (Burkina Faso), Ferkessedougou (Cote d'Ivoire), Samaru (Nigeria), and Bengou (Niger). Three genotypes, 84 S 82, 84 S 130, and 84 W 838, were resistant to the prevalent leaf diseases at all locations. The WASSN consisted of 11 entries which we had previously tested in *Striga-sick* fields and of one local control. The nursery was sent to Cameroon, Ghana, Mali, Niger, Nigeria, and Togo. We received results from Ghana, Cameroon, and Mali. The results confirmed our earlier observation that IS 9830 and ICSV 1007 BF are resistant to *Striga hermonthica.*

East Africa

Long smut *(Tolyposporium ehrenbergii)* in Kenya

In collaboration with Kenya Agricultural Research Institute (KARI), Muguga, we identified one germplasm line, IS 8595, as free from long smut infection in 1988 (1CRISAT Annual Report 1988, pp. 13-14). We attributed this freedom from infection to its large glumes that completely cover the grain. To ascertain this, we screened 10 large-glumed germplasm lines from the Genetic Resources Unit (GRU) at ICRISAT Center for resistance and found one line, IS 5841, to be highly susceptible with 77% infection while two lines were less susceptible: IS 7669 with 11% and IS 7167 with 33% infection. The remaining eight lines were found to be free from long smut infection. These results indicate that complete grain glume coverage may not be

Table 11. Mean grain yield (t ha^{-1}) of selected hybrids in the West African Sorghum Hybrids Adaptation Trial (WASHAT) at seven locations in West Africa, rainy season 1988.[1]

	Mali				Niger				Nigeria		Burkina Faso		Côte d'Ivoire			
	Samanko		Cinzana		Kolo		Tarna-2		Bagauda		Farako-Bâ		Ferké		Overall	
Entry	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	mean	Rank
ICSH 507	3.67	4	3.16	2	3.54	2	4.14	11	3.98	1	3.05	1	1.66	2	3.32	1
ICSH 330	3.87	2	2.99	4	3.28	5	4.49	6	3.25	7	2.45	8	1.32	6	3.09	2
ICSH 88042	3.93	1	3.06	3	2.88	10	4.61	4	3.14	8	2.39	9	1.19	8	3.03	3
ICSH 88040	3.84	3	2.75	7	3.31	4	4.75	2	3.28	6	1.74	16	0.77	14	2.92	4
ICSH 88038	3.40	7	3.38	1	2.67	11	4.92	1	3.11	10	2.26	10	0.70	15	2.92	5
ICSH 780	2.62	13	2.23	14	2.59	12	4.25	8	3.89	2	2.76	4	1.61	3	2.85	6
Controls																
ICSV 111	2.47	14	2.49	10	1.50	19	4.32	8	3.58	3	3.04	2	0.56	17	2.57	14
Local	1.00	17	2.14	17	1.65	17	2.72	19	1.41	16	1.77	18	1.52	4	1.74	20
SE	±0.267		±0.337		±0.459		±0.370		±0.413		±0.289		±0.237			
Trial mean (20 entries)	3.08		2.54		2.57		4.01		3.11		2.28		1.08			
CV (%)	15		23		31		16		23		22		38			

1. Randomized-block design with three replications, plot size ranged from 6.4 m^2 to 19.4 m^2. Numbers following each yield value indicate the ranking of the cultivars.

directly linked with smut resistance since IS 5841, which also has large glumes covering the grain, was highly susceptible. However, it is surprising to find such a high percentage of large-glumed lines to be free from smut infection. We will screen more germplasm lines with large glumes to find out their reaction to long smut infection.

Studies of Covered Smut *(Sphacelotheca sorghi)* in Kenya

In collaboration with KARI, we initiated experiments on covered kernel smut aimed at developing a reliable method of inoculation to be used to screen sorghum for resistance to covered smut. We tried two methods of inoculation. The first method involved inoculating seeds of the susceptible sorghum variety Embu 11 with a spore suspension, while the second method involved inoculating seeds of the same variety with dry teliospores before sowing. Inoculation with a spore suspension gave no infection, while inoculation with dry teliospores gave some infection. We varied the amounts of dry teliospores (10 mg, 20 mg, 30 mg, 40 mg, and 50 mg) and mixed them with 10 g of seeds and sowed the treated seeds in pots maintained in the greenhouse. There was no infection when seeds were mixed with 10 mg or 20 mg of dry teliospores, while infection was 5.2% when seeds were mixed with 30 mg, 20.2% with 40 mg, and 70.8% with 50 mg of dry teliospores. We are now conducting experiments in order to achieve maximum infection by mixing seeds with large amounts (above 50 mg) of dry teliospores.

Ergot Resistance Screening in Ethiopia and Rwanda

In collaboration with the Institut des sciences agronomiques du Rwanda (ISAR) in Rwanda, we screened, for the second year, 63 lines at Karama Research Station and selected 15 lines with resistance to ergot. Visual ergot scores of selected lines were not more than 3 on a 1-5 rating scale, where 1 = no ergot and 5 = more than 50% of spikelets infected in a panicle. The resistant lines were ISs 25480, 25481, 25485, 25489, 25527, 25530, 25531, 25533, 25537, 25542, 25554, 24555, 25573, 25576, and 25583.

We studied the relationship between pollination and ergot infection and found that ergot incidence increased as the time interval between inoculation and anthesis increased. We also identified the common grasses *(Panicum maximum* and *Cenchrus ciliaris)* as alternate/collateral hosts of the sorghum ergot pathogen. These grasses may serve as primary sources of ergot inoculum.

In collaboration with IAR, Ethiopia, we screened, for the third year, 12 lines at Arsi Negele Research Station and selected six resistant lines (ETS 1446, ETS 2448, ETS 2465, ETS 3155, ETS 4457, and ETS 4927) with less than 15% infected spikelets compared to 100% in susceptible controls (ETS 4567 and ETS 2113).

East Africa Regional Yield Trials

Sorghum scientists from NARS who participated in East African Regional Sorghum and Millet (EARSAM) network's sixth regional workshop held in 1988 in Somalia recommended that regional sorghum yield trials should be initiated, and requested 1CRISAT to organize and coordinate these trials. We therefore organized and distributed to the NARS in eastern Africa two regional trials: EARSAM Elite Sorghum Yield Trial (EESYT) for lowland and intermediate elevations. The EESYT Lowland elevation consisted of 25 varieties and the EESYT Intermediate elevation consisted of 16 varieties contributed by the NARS in eastern Africa, the Semi-Arid Food Grain Research and Development (SAFGRAD)/ICRISAT, and iCRISAT Center. The EESYT Lowland was evaluated at 14 locations, while EESYT Intermediate was evaluated at nine locations throughout eastern Africa.

We received and analyzed data from only two locations each for EESYT Lowland and EESYT Intermediate. We expect to get data from the other locations in early 1990. Results showed that ICSV 112, an ICRISAT-bred sorghum variety, produced the highest mean grain yield (5.5 t ha^{1}, SE ±0.275) in EESYT Lowland. In EESYT Intermediate, Seredo contributed by NARS Uganda, produced the highest mean grain yield (3.1 t ha"[1], SE ±0.186). Varieties 5 DX 160, KAT/83369, CR:35:5, Framida, and Dinkmash in the EESYT Lowland, and 4 MX 11/9/2, IS 8193, 3 ZX 379/2, and IS 9302 in the EESYT Intermediate elevation were the other high-yielding entries.

Stem Borer *(Chilo partellus)* in Somalia

Stem borer infestation is very severe in the sorghum-growing areas of Somalia especially where the crop is ratooned. In response to a request from the Somalian national program, we assisted in the establishment of a *Chilo*-rearing facility at the Bonka Dryland Agricultural Research Station, and in training national program staff in screening for and evaluation of stem borer resistance.

Southern Africa

Leaf Blight *(Exserohilum turcicum)* in Zambia and Zimbabwe

Resistance screening was conducted in collaboration with the Zambia and Zimbabwe NARS and the USA1D Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), at Golden Valley (Zambia) and Henderson (Zimbabwe) Research Stations. After one inoculation with 1-year-old powder of leaf blight-infected leaves, applied at stem elongation, the control variety, Framida, had 60-90% severities. Highly resistant entries (severities below 1%) were SC 9 (IS 12526), SC 147 (IS 12527), SC 167 (IS 12658C), SC 322 (IS 6882C), and SC 326-6 (IS 2462 der.). Many entries with SC 326-6 as a male or female parent, including F_3s, had high levels of resistance at Henderson.

Witchweed *(Striga)* in Tanzania

Three species of *Striga* attack cereals in Tanzania. *S. hermonthica* is most common in the northern half of the country and parasitizes sorghum and maize. *S. asiatica* (red) and *S. forbesii* occur more commonly in the southern half and central areas of the country and also attack sorghum and maize. At the Ukiriguru location and other areas in the north, all three species were found parasitizing sorghum and damaging it. In the Serengeti plains, 5. *hermonthica* was found damaging finger millet in farmers' fields.

In a joint resistance screening trial with the national program at Ukiriguru, we tested 80 lines including three resistant lines from the SADCC/ ICRISAT program, some other *Striga*-resistant lines (SAR 16, SAR 19, SAR 23, SAR 29, SAR 33, and SAR 35) previously found resistant to *S. asiatica* (red) and *S. forbesii* in Zimbabwe and Botswana, and their hybrids evolved from our best-combining male steriles. The susceptible variety CK60B was used as a control. Observations showed that SAR 29 and its hybrid with SPL38A may be resistant to *S. hermonthica* since they had an average of only five *Striga* plants per plot for SAR 29 and 11 for the hybrid, compared with the experimental average of 55 plants and control average of 243 *Striga* plants per plot. In the test plots, *Striga* infestation was fairly uniform with *Striga* plants per replication ranging from 25 to 103 and *Striga* counts in control plots ranging from 182 to 304 plants.

Armored Cricket *(Acanthoplus speiseri)* in Zambia

In collaboration with the Mount Makulu Research Station (Zambia), a project on the armored cricket, which is a serious problem in Zambia, Zimbabwe, and Botswana, was developed in order to study the nymphal development, migration and egg-laying behavior, and to test different control methods. Experiments were conducted at Lusitu; the major findings were:

first instar nymphs hatch during the first week of February in fallowed fields and develop over five nymphal stages into adults in about 30-40 days; nymphal development depends upon feeding on the developing grain of grasses such as *Brachiaria dura;* leaf-feeding on leaves of grasses or cereal crops is rare; migration to sorghum, millet, or maize fields takes place during the last nymphal and adult stage when grass seed is mature (unsuitable as food for the cricket) and when cereal crops are in the grain-filling stage; egg pods are laid in shady places under trees or within the crop row, early plowing destroys egg pods, and clean-weeded fields are not attractive to the cricket during the vegetative growth stage of the crops. A 20 cm x 25 cm trench treated with Sevin® powder around the experimental area prevented migrating crickets from entering the field. In the insecticide control experiments in which two sprays were applied at 7-day intervals, Sevin® and Fastac® proved to be most effective (90% mortality).

SADCC Regional Yield Trials

Two Regional Sorghum Advanced Variety Trials (RSAVT-1 and RSAVT-2) and two SADCC Sorghum Hybrid Trials—SADCC Advanced Hybrid Trial (SDAHT) and SADCC Elite Hybrid Trial (SDEHT) were evaluated at several locations in the SADCC region. Out of the 23 white varieties tested in RSAVT-1 at four locations, in Botswana and Zimbabwe, the three

Table 12. Performance of six selected sorghum varieties from the Regional Sorghum Advanced Variety Trial-2 (RSAVT-2), at five locations in three SADCC countries[1], rainy seasons 1987/88 and 1988/89.

	1988/89			1987/88		
		No. of locations[3]			No. of locations[3]	
Entry	Grain yield[2] (t ha^{-1})	Top 20%	Bottom 20%	Grain yield[2] (t ha-')	Top 20%	Bottom 20%
SDS 3472	3.05 (1)[4]	5	0	3.59(1)	1	0
ZAM 1518	2.50 (5)	2	2	3.07(2)	2 0	
LARSVYT 19	2.40 (7)	1	2			
SDS 1710-1	2.16(9)	1	3	3.25 (3)	2	0
SDS 1948-3	2.15(8)	0	1	2.53 (7)	1	0
SDS 3487	1.76(10)	0	4	3.75 (4)	2	0
Controls						
Serena	2.70 (4)	2	0	2.63 (6)	0	0
Framida	2.46 (6)	2	2	2.96(5)	0	0
PNR8544(H)	3.03 (2)	3	0			
DC 75(H)	2.75 (3)	1	0			
SE	±0.142		±0.137			
Trial mean	2.51		2.72			
(10 entries)			(16 entries)			
CV (%)	24		36			

1. Cooperating countries : Tanzania, Zambia, and Zimbabwe.
2. 1988/89 means based on five locations, 1987/88 means based on two locations.
3. Number of locations in which entry ranked in the top 20% and in the bottom 20%.
4. Ranks of means within season are given in parentheses.

advanced varieties IS 23586-2 (SDS 2337-2) (4.11 t ha^{-1}), IS 23496-1 (SDS 2393-1) (4.01 t ha-'), and MP 623 (3.931 ha^{-1}) yielded higher on average than control hybrid DC 75 (3.90 t ha^{-1}; SE ± 0.21). In the RSAVT-2, at five locations in Tanzania, Zambia, and Zimbabwe, the best red variety SDS 3472 (SEPON 77 BULK selection) yielded as well as the control hybrid PNR 8544, and better than DC 75 and the other two control varieties Serena and Framida, when averaged across five locations in the 1988/89 season (Table 12). In the test season of 1987/88, the same variety, SDS 3472, had the highest yield when averaged across two locations in Zimbabwe. This variety was also highly adaptable, ranking in the top 20% in six of the seven locations over the two seasons. Variety Zam 1518 was the next best yielder when yields were averaged over the two seasons and across the seven locations in Tanzania, Zambia, and Zimbabwe (Table 12).

The SADCC Advanced Hybrid Trial (SDAHT) consisted of 23 advanced hybrids evaluated at nine locations in Botswana, Swaziland, Tanzania, Zambia, and Zimbabwe. These locations do not include one in Lesotho that had extremely low yields due to poor stands. Two commercial hybrids, PNR 8311 and PNR 8544, were used as controls. Table 13 shows that nine ofthe SADCC/ICR1SAT hybrids (SDSH) (4-4.5 t ha^{-1}) outyielded, on average, the two commercial hybrid controls (3.52 and 3.73 t ha^{-1}). The best of the advanced hybrids were SDSH 4, SDSH 48, SDSH 47, SDSH 2, SDSH 38, and SDSH 3. Entry SDSH 49 (red grain), though ninth in overall rank among selected hybrids, was best for plant type and seed quality.

Eighteen elite hybrids were evaluated in SDEHT with two commercial control hybrids PNR 8311 and PNR 8544 at four locations in three countries (Botswana, Zambia, and Zimbabwe). Within this trial three hybrids were

Table 13. Performance of nine selected sorghum hybrids from the SADCC Sorghum Advance Hybrid Trial (SDAHT) at nine locations in six SADCC countries, rainy season 1988/89.

	Location[1], grain yield (t ha^{-1}), and rank[2]									
Entry	PD	SB	MT	MZ	GW	HB	IL	GV	ML	Mean
SDSH 4	6.66(3)	2.61(7)	7.02(3)	6.25(1)	2.24(9)	5.32(4)	2.54(11)	3.07(3)	4.73(1)	4.50(1)
SDSH 48	5.66(4)	3.03(4)	7.12(2)	5.56(3)	2.93(6)	4.43(8)	4.68(2)	2.41(7)	4.46(3)	4.41(2)
SDSH 47	6.80(2)	2.02(8)	6.42(8)	5.85(2)	1.94(10)	5.37(3)	7.81(1)	2.27(8)	4.62(2)	4.34(3)
SDSH 2	7.34(1)	1.85(9)	6.56(5)	5.25(5)	2.53(8)	5.39(2)	3.19(4)	2.75(5)	3.87(6)	4.30(4)
SDSH 38	5.64(5)	2.66(6)	7.52(1)	3.87(9)	3.71(2)	4.32(9)	2.93(9)	3.42(1)	3.91(5)	4.22(5)
SDSH 3	3.92(9)	4.28(1)	6.37(9)	4.73(8)	2.95(5)	5.72(1)	3.08(5)	3.35(2)	3.60(8)	4.22(6)
SDSH 74	4.52(8)	2.67(5)	6.06(8)	5.40(4)	3.34(4)	5.19(5)	3.04(7)	2.55(6)	4.08(4)	4.09(7)
SDSH 8	4.68(7)	3.34(2)	5.94(9)	4.85(6)	2.80(7)	4.87(6)	2.90(10)	3.01(4)	3.65(7)	4.00(8)
SDSH 49	4.93(6)	3.29(3)	6.52(6)	4.77(7)	3.50(2)	4.85(7)	3.29(3)	1.45(15)	3.40(10)	4.00(9)
Controls										
PNR 8311	4.96(11)	1.72(24)	6.98(4)	4.33(11)	4.01(1)	3.33(22)	3.08(6)	2.23(9)	2.99(13)	3.73(10)
PNR 8544	3.69(20)	2.34(14)	6.48(7)	4.46(10)	1.84(18)	4.07(17)	3.02(8)	2.22(10)	3.54(9)	3.52(14)
SE	±1.354	±0.877	±0.980	±0.718	±0.629	±0.927	±0.503	±0.413	±0.660	±0.196
Trial mean (23 entries)	4.97	2.57	5.39	4.10	2.33	4.36	2.67	1.84	3.18	3.50
CV (%)	27	34	18	17	27	21	18	22	20	

1. PD = Pandamatenga and SB - Sebele, Botswana; MT = Matopos, MZ = Mzarabani, and GW = Gwebi, Zimbabwe; HB = Humbolo and IL = Ilonga, Tanzania; GV = Golden Valley, Zambia; and ML = Malkerns, Swaziland.
2. Ranks are in parentheses.

submitted from the Zimbabwe and four from the Zambia national programs. The other 11 hybrids were ones developed by the ICRISAT program at Matopos. The best elite hybrids based on average performance were SDSH 38 (5.211 ha^{-1}) and SDSH 48 (5.08 t ha^{-1}), both from the ICRISAT program, ATx 623 x SV1 (5.04 t ha^{-1}) from Zimbabwe, and MMSH 375 (4.68 t ha^{-1}) from Zambia; the yields of the controls, PNR 8544 and PNR 8311, were 3.22 t ha^{-1} and 2.89 t ha^{-1}.

Forage Sorghum Multilocational Trial

Eighty-one forage sorghum, 90 sudan grass, and 49 sorghum B-lines were evaluated in Zimbabwe, Swaziland, Zambia, and Malawi. Based on mean yields across locations, the following entries were selected for retesting: SDFSs 103, 33, 32, 96, 86, 81, 75, 36, 85, 35, 70, 149, 1097, 1047, 1033, 1059, 1083, 1087, 1043, 1041, and 1030.

Latin America

Regional Trial of Photoperiod-sensitive Sorghums for Intercropping

At Guaymango, El Salvador, the best entries in the 1988 regional advanced trial were 86 SLT-1377 (grain yield of 2.30 t ha^{-1}), ES 727 (2.29 t ha^{-1}), 86-SCP-805 (2.21 t ha^{-1}), and 86 SCP-311 (2.14 t ha^{1}) (SE ±0.239), compared with 2.08 t ha^{-1} for the landrace control Manzano I. No significant differences were noted in grain yields of the maize hybrid H-5 that was grown in association with each of the sorghum entries in this trial. However, associated maize yields for the 10 highest-yielding sorghum entries were below the trial mean of 1.74 t ha^{-1} (SE ±0.201) of maize.

Mesoamerican Sorghum Variety Yield Trial-1988 (MASVYT-88)

This trial consisted of 19 test and two control entries. Results from seven sites are presented in Table 14. At the only irrigated site at Los Mochis, Mexico, the highest-yielding entry 1CSV-LM 86523 (11.54 t ha^{-1}; SE ±0.511) was 2.08-m tall (SE ±0.0825) and took 84 days (SE ±0.918) to flower. This variety also outyielded all others in Panama. Under severe drought stress at Cuyuta, Guatemala, M-90946 yielded highest with only 1.49 t ha"[1] (SE ±0.170) and a plant height of 0.76 m (SE ± 0.0415).

Across the seven locations, ICSV 112 had the highest mean yield of 5.65 t ha^{-1} (SE ± 0.175) and responded well at all test sites. However, stability analyses indicated that M-82080-5 (5.48 t ha-', Bi = 1.0486, s^2d = 0.19283, P <0.05) and M-81996-3 (5.45 t ha^{-1}, Bi = 1.2271, s^2d = 0.09103, P <0.05) were the highest-yielding entries having stable performance across sites.

Mesoamerican Hybrid Yield Trial-1988 (MHYT-88)

This trial consisted of 26 test and two control entries. Across the 11 reporting locations (Table 15), 1CSH-LM 88503 yielded highest with 6.49 t ha^{-1} and a range of 4.66-11.14 t ha^{-1}, the higher value being under irrigated conditions.

Seed Exchange

ICRISAT Center

A total of 3294 seed samples of our improved varieties, hybrids, parents of hybrids, and resistant sources was supplied to the following countries: Chad(6),Cote d'Ivoire(14), Ethiopia (67), Grenada (24), India (2341), Iran (280), Italy (4), Mali (321), Mexico (37), Niger (47), Oman (6), Pakistan (29), the Philippines (54), Thailand (2), UK (8), USA (1), Vietnam (5), and Zimbabwe (48).

West Africa (Mali)

In response to seed requests, we provided 327

Table 14. Mean grain yield (t ha[1]) of the highest-yielding entries in the 1988 Mesoamerican Sorghum Variety Yield Trial[1] (MASVYT 88) across seven reporting locations.

	Location[2] and mean grain yield ($t\ ha^{-1}$)							
Entry	Iboperenda (Bolivia)	San Andres (El Salvador)	Cuyuta (Guatemala)	Los Mochis (Mexico) (irrigated)	Tlaltizapan (Mexico)	Alanje (Panama)	Isabela (Puerto Rico)	Mean
ICSV 112	7.24	5.30	0.75	8.77	4.22	5.68	7.56	5.65
M-82080-5	7.03	5.81	0.95	8.74	4.34	4.81	6.68	5.48
M-81966-3	8.80	4.40	0.86	9.31	4.73	4.88	5.17	5.45
ICSV-LM 86523	7.06	2.74	1.47	11.54	3.06	4.96	6.76	5.37
ICSV-LM 86502	7.58	3.79	0.86	11.28	4.37	4.08	5.00	5.28
ICSV-LM 86551	6.82	4.14	0.75	10.00	4.81	5.05	4.98	5.22
Controls								
PP-290	6.33	4.43	0.54	5.32	4.37	44.41	4.45	4.26
Local	3.74	5.03	0.96	7.48	4.50	5.05	5.03	4.54
SE	±0.427	±0.487	±0.170	±0.511	±0.438	±0.329	±0.696	±0.175
Trial mean	7.04	4.41	0.83	7.95	4.07	4.46	5.27	4.86
CV (%)	10	19	36	11	19	13	23	16

1. Randomized-complete block with three replications.
2. Location: Iboperenda = 19° 52'S, 117 m; San Andres = 13° 49'N, 464 m; Cuyuta = 14° N, 40 m; Los Mochis = 26° N, 40 m; Tlaltizapan = 19° N, 960 m; Alanje = 7° 57'N, 30 m; Isabela = 18° 30'N, 128 m.

seed samples of our improved varieties, breeding lines, and resistant sources to 12 countries: Argentina (38), Burkina Faso (3), Burundi (6), Cote d'Ivoire (2), Ghana (1), India (10), Kenya (38), Liberia (38), Mali (2), Nigeria (141), USA (11), and Zimbabwe (38).

West Africa (Nigeria)

In response to requests from the national programs in Ghana, Togo, and Cameroon, we supplied them with bulk seed samples of a white-grain mutant variety of Framida. We contributed seeds of four early-maturing varieties (ICSV 111, ICSV 247, ICSV 400, and ICSV 401) to state sorghum trials organized by IAR in the northern region of Nigeria. We supplied seeds of the same varieties to the Food and Agriculture Organization of the United Nations (FAO)/ United Nations Development Programme (UNDP)/ Agricultural Project in Chad. Seed samples of 14 selected A-, B-, and R-lines, and elite varieties were supplied to the Institut national de recherches agronomiques du Niger (INRAN), Niger. Seeds of selected A- and B-lines were also supplied to IAR, Nigeria. In addition, we distributed seeds of a dozen elite varieties to brewing, seed, and food companies in Nigeria.

Table 15. Mean grain yield (t ha^{-1}) of highest-yielding entries in the 1988 Mesoamerican Hybrid Yield Trial[1] (MHYT-88) at 11 locations in Latin America.

		Location[2]											
Entry	Pedigree	1	2	3	4	5	6	7	8	9	10	11	Mean
ICSH-LM 88503	ATx 623 x CS-3541 crosses-31	9.11	7.41	5.80	5.05	5.14	4.66	11.14	5.28	4.80	6.70	6.31	6.49
ICSH-LM 88506	1CSA 1 x ES-87 R	8.48	2.59	5.82	4.98	4.89	5.75	10.59	5.87	6.59	6.44	6.70	6.25
ICSH-LM 88508	ATx 623 x RTx 433	9.19	5.96	5.88	3.48	5.28	5.13	11.14	5.03	4.61	5.63	3.98	5.94
ICSH-LM 88510	ICSA 12 x VG-79	9.41	5.68	4.87	3.27	4.89	4.81	11.19	6.54	3.97	5.11	4.55	5.84
ICSH-LM 88519	ATx 623 x RTx 434	6.91	6.06	5.21	2.88	5.12	3.98	13.15	5.21	5.76	5.28	4.14	5.79
ICSH-LM 88501	ATx 629 x CS-3541 crosses-31	9.63	4.86	5.72	4.31	4.98	4.53	9.88	5.18	3.77	5.88	4.96	5.79
Control	ATx 378 x RTx 430	9.02	2.52	4.89	3.11	3.94	4.78	11.51	5.72	3.33	4.64	4.59	5.26
Local control		5.80	5.16	4.53	3.85	3.66	6.67	8.39	4.86	4.54	4.53	4.54	5.14
SE		±0.51	±0.55	±0.40	±0.69	±0.36	±0.34	±0.81	±0.41	±0.42	±0.59	±0.83	±0.17
Trial mean (28 entries)		8.17	4.05	4.79	3.53	4.68	4.55	10.01	5.21	4.31	5.35	4.61	5.39
CV (%)		12	27	17	39	15	15	16	16	19	22	36	21

1. Randomized complete block with four replications.
2. Location: 1 - Iboperenda, Bolivia; 2 = Canas, Costa Rica; 3 = Santiago, Dominican Republic; 4 = San Andres, El Salvador; 5 = Jutiapa, Guatemala; 6 = Comayagua, Honduras; 7 = Los Mochis, Mexico (irrigated); 8 = Tlaltizapan, Mexico; 9 = San Cristobal, Nicaragua; 10 = Alanje, Panama; 11 = Isabela, Puerto Rico.

East Africa

We provided seeds of breeding lines, varieties, hybrids, and parental lines to cooperators in Kenya (403), Ethiopia (141), Uganda (97), Tanzania (82), Burundi (77), Rwanda (70), and Somalia (25).

Southern Africa

We sent advanced breeding lines to Zambia (1600), Malawi (900), Mozambique (500), and Botswana (200); hybrid parents to Zambia (2) and Botswana (9); we also sent to Botswana, new varieties (6 SDSL lines), hybrids (16), and seeds of F_1 crosses from country-crossing block. We supplied to EARCAL seeds of three sets of SADCC/ICRISAT regional collaborative trials, five *Striga*-resistant varieties, three random-mating populations, 20 hybrids, and 20 new varieties. We also supplied 20 sorghum hybrids to WASIP, Kano (Nigeria), and 15 Chinese collections from our program to Tochigi in Japan.

We received seed samples for inclusion in nine SADCC regional collaborative trials from Botswana (3), Swaziland (4), Tanzania (5), Zambia (31), and Zimbabwe (15).

Latin America

In response to requests, we provided seed samples of sorghum populations, breeding lines, varieties, hybrids, and hybrid parental lines to the following countries: Argentina (3), Bolivia (10), Brazil (91), Cameroon (19), Canada (2), People's Republic of China (21), Colombia (169), Costa Rica (15), El Salvador (93), Guatemala (79), Honduras (18), India (54), Jamaica (4), Kenya (288), Morocco (18), Panama (7), UK (37), USA (400), and Venezuela (64).

ICRISAT Cultivars Released

India

Two ICRISAT midge-resistant varieties, ICSV 743 and ICSV 745, were adopted by the Department of Agriculture, Karnataka state, for distribution to farmers in midge-endemic areas.

Publications

Institute Publications

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT. 192 pp. ISBN 92-9066-145-3. (CPE 054)

Journal Articles

Kousik, C.S., Thakur, R.P., and Subbarao, K.V. 1988. Influence of environmental factors on production and dispersal of *Tolyposporium penicillariae* sporidia. Indian Journal of Acrobiology 1(2):85-91. (JA8I7)

Lynch, R.E., Nwanze, K.F., Wiseman, B.R., and Perkins, W.D. 1989. Fall armyworm (Lepidoptera: Noctuidae) development and fecundity when reared as larvae on different meridic diets. Journal of Agricultural Entomology 6(2):101-111. (JA 824)

Nwanze, K.F. 1988. Distribution and seasonal incidence of some major insect pests of sorghum in Burkina Faso. Insect Science and its Application 9(3):313-321. (JA 671)

Omori, T., Agrawal, B.L., and House, L.R. 1988. Genetic divergence for resistance to shootfly, *Atherigona soccata* Rond. in sorghum, *Sorghum bicolor* (L.) Moench and its relationship with heterosis. Insect Science and its Application 9(4):484-488. (JA 699)

Conference Papers

Agrawal, B.L., and Taneja, S.L. 1989. Breeding for resistance to stem borer *(Chilo partellus* Swinhoe) in sorghum. Pages 159 168 *in* International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 491)

de Wet, J.M.J. 1989. Cereals for the semi-arid tropics. Pages 79-88 *in* Plant domestication by induced mutation: proceedings of an Advisory Group Meeting of the Possible Use of Mutation Breeding for Rapid Domestication of New Crop Plants, 17-21 Nov 1986, Vienna, Austria. Austria, Vienna: International Atomic Energy Agency. (CP 324)

de Wet, J.M.J. 1989. Genetics of cereal adaptation to the man-made habitat. Pages 53-65 *in* Plant domestication by induced mutation: proceedings of an Advisory Group Meeting of the Possible Use of Mutation Breeding for Rapid Domestication of New Crop Plants, 17-21 Nov 1986, Vienna, Austria. Austria, Vienna: International Atomic Energy Agency. (CP 325)

de Wet, J.M.J. 1989. Origin, evolution, and systematics of minor cereals. Pages 19-30 *in* Small millets in global agriculture: proceedings of the First International Small Millets Workshop, 29 Oct-2 Nov 1986, Bangalore, India (Seetharam, A., Riley, K.W., and Harinarayana, G., eds.). New Delhi, India: Oxford and IBH Publishing Co. (CP 417)

Nwanze, K.F., and Mueller, R.A.E. 1989. Management options for sorghum stem borers for farmers in the semi-arid tropics. Pages 105-116 *in* International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 492)

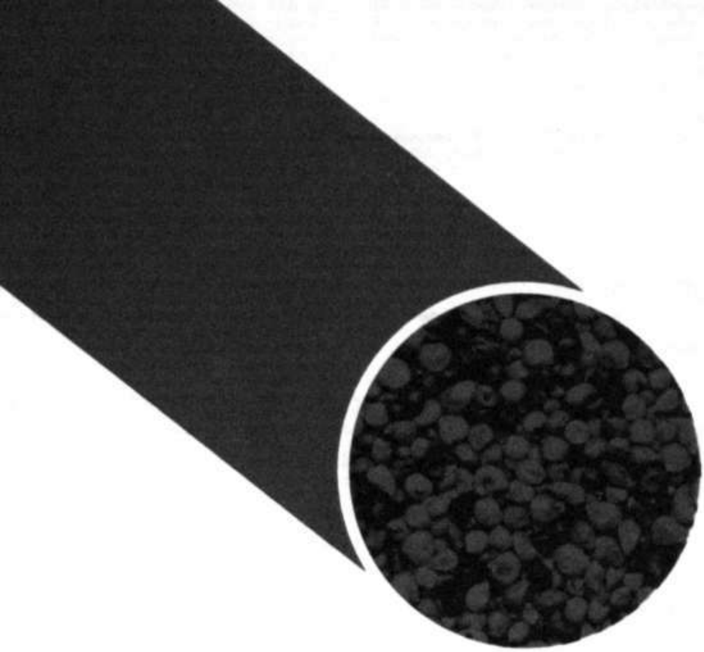
Taneja, S.L., and Woodhead, S. 1989. Mechanisms of stem borer resistance in sorghum. Pages 137-143 *in* International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 494)

Taneja, S.L., and Nwanze, K.F. 1989. Assessment of yield loss of sorghum and pearl millet due to stem borer damage. Pages 95-104 *in* International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 495)

Witcombe, J.R. 1989. Variability in the yield of pearl millet varieties and hybrids in India and Pakistan. Pages 206-220 *in* Variability in grain yields: implications for agricultural research and policy in developing countries (Anderson, J.R., and Hazell, P.B.R., eds.). Baltimore, Maryland, USA: Johns Hopkins University Press. (CP 281)

Thesis

Dayal, Shankar T.K. 1989. Host-plant preferences of the spotted stem borer, *ChiJo partellus* Swinhoe in different sorghum genotypes. M.Sc. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India. 119 pp.



PEARL MILLET

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

PEARL MILLET

As a part of the Institute's preparation for the External Program Review (EPR) to be held in 1990, ICRISAT's millet scientists have put considerable effort into preparing a strategic plan for millet research for the years 1990-1995. According to this plan, each of the three programs at ICRISAT Center, ICRISAT Sahelian Center (ISC), and the Southern African Development Coordination Conference (SADCC) Regional Program, will continue to serve as a regional center for millet improvement in the area in which it is located, and will also assume one or more additional responsibilities for ICRISAT's global effort on pearl millet. ICRISAT Center will assume major responsibility for strategic and basic research, because of its larger resources and the fact that it has much less need to carry out applied research in its region than do either of the African Programs. ISC will devote special efforts to work with the newly formed West African Millet Network in order to assist national programs in the region to build the capacity to produce their own technology. The SADCC program will assume responsibility for research on alternative uses for millet as food, feed, and industrial raw material, and for breeding forage varieties of millet and related species.

We have also made considerable progress in establishing research priorities for the regional responsibilities of each center. In the case of the SADCC Program, the priorities are: breeding new pearl millet and finger millet cultivars for direct human use, and the development of cultivars for alternative uses for the crop, since future increases in millet production in the SADCC region will depend on expanding markets for millet. In addition, scientists in the region have emphasized the need for new cereal species and varieties for fodder production to support improvements in animal production. Efforts will be increased in this area, as a number of introductions of *Pennisetum* species look promising in various countries in the region.

ICRISAT Sahelian Center will continue its long term program of broadening the genetic base of breeding materials available for use in the region, through the integration of screening techniques for seedling establishment, drought tolerance, resistance to downy mildew (DM), stem borer, and head caterpillar into the breeding program, to combine resistance to these problems with grain yield potential and grain quality. Because West Africa is the center of origin of both pearl millet and its host of pathogens and parasites, as well as having a harsh physical environment, progress on this objective will be incremental and not dramatic, and a long term, concerted effort is necessary. In addition, the responsibility for assisting the West African Regional Millet Network will demand resources and time from the ISC Pearl Millet Improvement Program and can also be expected to be a long term effort, because of the large element of human resource development involved.

The regional research priorities for the ICRISAT Center Millet Program will change most of the priorities of the three centers, because of changes in the perception of how ICRISAT can best support the Indian National Program, and because of the reduction in the size of the ICRISAT Center program with the continuing transfer of resources from Asia to Africa. The program at ICRISAT Center is greatly reducing its efforts in producing varieties and hybrids for national testing in order to concentrate on the production of hybrid parents, and on breeding material specifically for the marginal/arid areas in South Asia where pearl millet is likely to be more and more concentrated in the future. The hybrid parent breeding effort will include new materials such as F_1 male-sterile lines and topcross pollinators to attempt to improve the stability/longevity of DM resistance in hybrids. The breeding effort for the arid areas will include both very short-duration hybrids for grain production, and intermediate-duration, dual-purpose varieties for fodder as well as grain production because pearl millet stover is widely used to feed animals through the dry season in these areas.

Several research reports appearing in the following pages illustrate these new priority areas of work: drought response of Sahelian millets, F_1 male-sterile lines, and milling and malting quality of millet varieties.

Physical Stresses

Response to Drought in Sahelian Millets

Changes in rainfall pattern in Sahelian Africa during the last two decades have increased the requirement for adaptation to drought stress during the flowering and grain-filling period for new pearl millet varieties. This is due to both a shorter rainy season and a reduced amount of rainfall during August, when moisture customarily accumulates in the soil for use by the crop for grain filling.

We conducted experiments at ISC during the dry seasons of 1988 and 1989: (1) to determine if there were useful differences among Sahelian landraces and varieties in grain yield and drought tolerance under conditions of stress during flowering and grain filling, and (2) to attempt to identify crop responses to stress that might indicate tolerance or susceptibility to stress. The experiments compared the performance of the trial entries under a fully irrigated control treatment and a stress treatment in which irrigation was given only until 50% of the entries reached flowering.

There were significant differences in grain yield among entries in the stress treatment in each year (560 1360 kg ha^{-1} in 1988, and 970-1910 kg ha^{-1} in 1989). We correlated these differences in grain yield across entries to differences in yield potential (irrigated control treatment), drought escape (time to 50% flowering), and drought tolerance/susceptibility (drought response index, ICRISAT Annual Report 1982, pp. 65-66), to determine the relative importance of these three factors in yield differences under stress. Differences in drought response index and time to 50% flowering were significantly correlated to differences in yield under stress in both years (Table 1), indicating that both drought escape and drought tolerance/susceptibility were involved in differences in yields under stress. Yield potential was correlated to yield under stress only in one year.

A detailed harvest was done on all plots to compare grain yield and the expression of various yield components in the control and stressed treatments. Grain yields in the control were more closely related to differences in grain number produced per panicle than to either panicle number or individual grain mass whereas under stress, differences in both the number of panicles produced and the individual grain mass

Table 1. Correlations of grain yield under terminal drought stress with yield and time to 50% flowering in the control, drought response index, and yield components measured in the stress, ISC, Niger, dry seasons 1988 and 1989.

Variable	Correlation to yield under stress[1] 1988	1989
Yield (control)	0.17	0.54**
Time to 50% flowering (control)	-0.61***	-0.51**
Drought response index	0.65***	0.66***
Yield components (stress)		
Biomass	0.33*	0.33*
Harvest index	0.87***	0.69***
Panicle number	0.75***	0.51**
Yield $panicle^{-1}$	0.87***	0.87***
Grains $panicle^{-1}$	0.51**	0.61***
Grain mass	0.59***	0.53***
Threshing percentage	0.72***	0.80***
Grain growth rate	0.28	0.35*
Grain growth duration	0.73***	0.45**

1. n = 34 in each year.
* Significantly different from 0 with $P < 0.05$;
** Significantly different from 0 with $P < 0.01$; and
*** Significantly different from 0 with $P < 0.0001$.

were as closely related to yield differences as were differences in grain number per panicle (Table 1). This reflects the primary effect of stress on the development of later tillers and on grain filling, plus genotype differences in these two processes under stress.

Several of the yield components measured in the stress treatment were very closely related to grain yield and were thus of interest as potential means of identifying genotypes with better adaptation to stress during flowering and grain filling. These included harvest index, panicle number, grain yield per panicle, threshing percentage, and grain growth duration (Table 1). Additional correlations were done with these selected components to determine if they were preferentially related either to drought escape (i.e., correlated to time to 50% flowering) or to drought tolerance/susceptibility (i.e., correlated to drought response index), as grain yields have been shown to be influenced by both factors. Our main interest was in components related to drought tolerance, as drought escape can be determined directly from the relationship of yield and time to 50% flowering. Differences among entries in harvest index, grain growth duration, threshing percentage, and grain mass were more closely correlated to differences in time to 50% flowering than to drought response index (Table 2). Early-flowering (drought escaping) entries thus logically had a longer grain-filling period, a larger grain mass, and consequently a higher threshing percentage and harvest index. In contrast, differences in grain number and grain yield per panicle were correlated to differences in drought response index, rather than to differences in drought escape. This suggests that entries with an ability to maintain grain numbers per panicle under stress were those rated as more drought tolerant.

Because neither grain mass, nor grain growth rate, nor grain growth duration was closely related to drought tolerance, the difference between tolerant and susceptible entries does not seem to be due to differences in overall levels of assimilate supply during the stress period. Rather, the difference in maintenance of grain numbers suggests differences between resistant and susceptible types during the late stages of ovary development and/or the early stages of

Table 2. Correlation of variables related to grain yield under drought stress with time to 50% flowering (drought escape) and drought response index (drought tolerance/susceptibility), ISC, Niger, dry seasons 1988 and 1989.

	Correlation coefficient[1] to:			
	Flowering		Drought index	
Variable related to yield under stress	1988	1989	1988	1989
Harvest index	-0.78***	-0.68***	0.39**	0.20
Panicle number	-0.55***	-0.59***	0.51**	0.12
Yield panicle^{-1}	-0.31	-0.24	0.56***	0.73***
Grains panicle^{-1}	0.04	0.12	0.42*	0.57***
Grain mass	-0.46**	0.56***	0.29	0.38*
Threshing percentage	-0.62***	0.60***	0.41*	0.44**
Grain growth duration	-0.62**	-0.41*	0.45**	0.19
Grain growth rate	-0.36*	-0.35*	-0.15	-0.02

1. n = 34 in each year.
* Significantly different from 0 with *P*<0.05;
** Significantly different from 0 with *P*<0.01; and
*** Significantly different from 0 with *P*<0.001.

embryo development, which result in lower rates of failure of floret development or of embryo abortion, both resulting in better maintenance of grain numbers under stress. This difference could be a result of differential partitioning of assimilates to reproductive structures, as recently shown to occur in maize, or to various other causes such as differential abscisic acid accumulation in the reproductive structures.

Literature on breeding for improved adaptation to drought stress during flowering and grain filling suggests that the most efficient approach is concurrent selection for the various factors related to higher grain yield under stress: an improved yield potential, earlier flowering, and the expression under stress of traits that have been shown to be related to drought tolerance. Selection for improved yield potential and earlier flowering should obviously be done during the normal (rainy) season; selection for drought-tolerant traits requires an environment in which the occurrence of a flowering/grain-filling stress is predictable and similar from year to year. Sadore does not fulfill this requirement very well; what is needed is a very dry, short-season location in which stress before flowering can be avoided by the use of irrigation, but is almost certain at the end of the season. An alternative is to use the dry season as in these experiments, but this requires demonstrating that the expression of the trait used as a selection criterion is not affected by genotype x season interaction. The next stage in the work at ISC will be to identify a rainy-season location for selection for expression of yield components related to stress tolerance and/or to determine if the expression of such components under stress in the dry season is similar to their expression under stress in the rainy season, so that selection can be done in the dry season.

Seedling Emergence

We recently completed a study of evaluation methods, heritability, and response to selection for seedling emergence ability in pearl millet at ICRISAT Center. The material used was four selfed generations (S_1 to S_4) of progeny from the Bold Seeded Early Composite (BSEC). The objectives were to provide both basic data on the genetics of emergence ability and practical information on methods of selection for it. The study was confined to emergence in favorable conditions, in contrast to some of our previous work on emergence under stress conditions. Even under favorable conditions, emergence is often as low as 50% of seeds sown. Improvement in performance under favorable conditions would therefore be of interest, if this ability is under genetic control and is responsive to selection.

Field vs Greenhouse Evaluation

The first part of the study involved a comparison of evaluation of emergence ability under field and greenhouse conditions. In the greenhouse test we sowed 20 seeds in 15-cm pots filled with sieved soil, and placed them on a capillary matting which was kept moist at all times to assure an even supply of water to the germinating seeds. In the field test we sowed 50 seeds per row (of 2-m length) with a precision planter and applied an irrigation of 3 cm by sprinkler following sowing and light irrigations (1 cm) on several days following sowing to assure adequate moisture for germination and emergence. We replicated both tests thrice and counted emergence 6-7 days after sowing (DAS).

Phenotypic correlations between the greenhouse and field tests were significant for all three generations of BSEC progeny for which they were calculated, but the magnitude of the correlation declined with increased inbreeding of the progenies (Table 3). The results indicate that greenhouse screening, particularly in the S_2 generation, would be effective in discarding those progenies with poor field emergence. The value of the greenhouse test lies in the possibility of combining screening for emergence with screening for DM resistance by inoculating the emerged seedlings with a suspension of DM sporangia.

Table 3. Comparison of methods of assessing seedling emergence ability, ICRISAT Center, 1986-89.

Generation	N	Mean percentage of emergence (range) Greenhouse	Field	Correlation of two methods
S_1	475	67(0-100)	-[1]	-[1]
S_2	169	31(0-95)	19(0-92)	0.72
S_3	169	60(8-100)	74(0-100)	0.50
S_4	973	92(8-100)	36(0 73)	0.35

1. Not measured.

Heritability of Emergence Ability

We calculated heritabilities in two ways: within individual generations, using the expected mean squares for genetic and error variance from the analysis of variance of the emergence data; and across generations, by offspring-parent regression. The individual generation analysis was done on the basis of the means of the families of progenies derived from one individual progeny of the previous generation; e.g., the S_3 progeny data were analyzed according to the S_2 family means. This estimate of heritability is appropriate for selection between, e.g., S_2 families in the S_3 generation. In the offspring-parent regression method, heritability was estimated from the slope of the regression (b value), with no adjustment for inbreeding. This estimate of heritability is appropriate for selection between progenies in the parental generation. Heritabilities were calculated from both the greenhouse and field emergence data.

The heritability estimates for emergence were positive for all generations and for both the field and greenhouse evaluations (Table 4). For comparable tests, the mean heritability estimated from field data was 0.45, and that from greenhouse data was 0.44. There was a tendency for estimates from the analysis of variance to be less variable than those from the offspring-parent regressions, possibly because the analysis of variance estimates were based on family rather than individual progeny means. There was no effect of generation of inbreeding on estimated heritability. The results confirm that emergence ability is a genetic character, which means that selection for improved emergence ability should be possible.

Predicted Response to Selection

We calculated predicted genetic gains in emergence ability both from direct selection under field conditions and from selection based on evaluation of emergence ability in pots in the greenhouse. The latter calculation was based on

Table 4. Heritability estimates of seedling emergence ability from parent-offspring regression (regression) and from the expected entry mean squares in the analyses of variance (entry mean), ICRISAT Center, 1986-89.

Generations for		Heritability			
		Greenhouse		Field	
Regression	Entry mean	Regression	Entry mean[1]	Regression	Entry mean[1]
S_2/S_1	S_1	0.71	0.91	-[2]	-[2]
S_3/S_2	S_2	0.09	-[2]	0.07	-[2]
S_4/S_3	S_3	0.12	0.71	0.59	0.29
			0.86		0.85

1. Genotypes in S_1, families of S_{n-1} in other generations.
2. Not measured.

Table 5. Predicted genetic gains in seedling emergence from direct field selection and from correlated response based on greenhouse selection at three different selection intensities, ICRISAT Center, 1986-89.

		Selection intensity					
		10%		20%		30%	
Selection procedure	Generation	SD[1]	Gain[2]	SD	Gain	SD	Gain
Direct selection in field	S_3	12.1	3.5	9.8	2.8	8.3	2.4
	S_4	16.2	13.8	13.6	11.6	11.3	8.8
Correlated response based on greenhouse data	S_3	13.3	2.7	11.4	2.4	10.4	2.1
	S_4	5.7	2.4	4.9	2.0	4.5	1.9

1. SD = Unstandardized selection differential.
2. Gain = Percentage increase in emergence per cycle.

genetic correlations of greenhouse and field emergence derived from the expected mean squares from covariance analyses of the greenhouse and field data in the S_3 and S_4 generations. The predicted gain was calculated as:

Predicted gain = S1 * h(GH) * h(FL) * GC

where S1 is the unstandardized selection intensity, h(G H) and h(FL) are the square roots of the heritabilities derived from the greenhouse and field data, and GC is the genetic correlation of greenhouse and field emergence.

Predicted genetic gains for emergence by direct selection in the field averaged 2.9% in the S_3 generation and 11.4% in the S_4, across selection intensities using heritabilities and selection among families (Table 5). The predicted gains under field conditions based on correlated response to selection in the greenhouse were about the same in the S_3 and approximately 20% of those for direct selection in the field in the S_4 generation.

Thus, for populations needing improvement in emergence percentage, direct selection under field conditions should be very effective over the period of a few cycles. In comparison, the predicted response from selection in pots in the greenhouse is low (Table 5). Nevertheless, this procedure would be useful for maintaining mild selection pressure for emergence in composites in which seedling emergence is not a major problem. Moreover, because of the phenotypic correlation between emergence tests in pots in the greenhouse and emergence in the field, previous selection in the greenhouse helps to avoid missing plots in subsequent experiments. When combined with seedling selection for DM resistance, the greenhouse test provides a low-cost method for gradual improvement in emergence capability for selected composites. Field selection, however, is likely to be the most effective method.

Biotic Stresses

Downy Mildew *(Sclerospora graminicola)*

Oospore Germination

We have been successful in germinating oospores of *S. graminicola,* at ICRISAT Center, using a modified version of a method developed initially by a PhD student from the Andhra Pradesh Agricultural University. The method includes soaking oospores in water, treating the water-soaked oospores in sodium hypochlorite (NaOCl), followed by several changes of sterile distilled water, and resuspending in sterile distilled water at 28~30°C for germination. Germination initiates with the appearance of a wedge-shaped structure in the inner wall, which later develops into a germ tube. Each oospore produces a single germ tube which ends in an appressorium. The germ tubes are coenocytic, light brownish to transparent, and vary considerably in length and width (Fig. 1). Germination begins in about 2 h after the NaOCl treatment and continues for several days. Germination percentage is influenced by several factors including NaOCl concentration, oospore concentration in the germinating medium, time, and the temperature during germination. We obtained as high as 80% germination with 1-year-old oospores. Our ability to germinate oospores will be of great value: (1) in determining the longevity of oospores, (2) in clarifying the role of oospores in the annual recurrence of the disease, (3) in studies of resistance mechanisms and genetics of pathogen virulence.

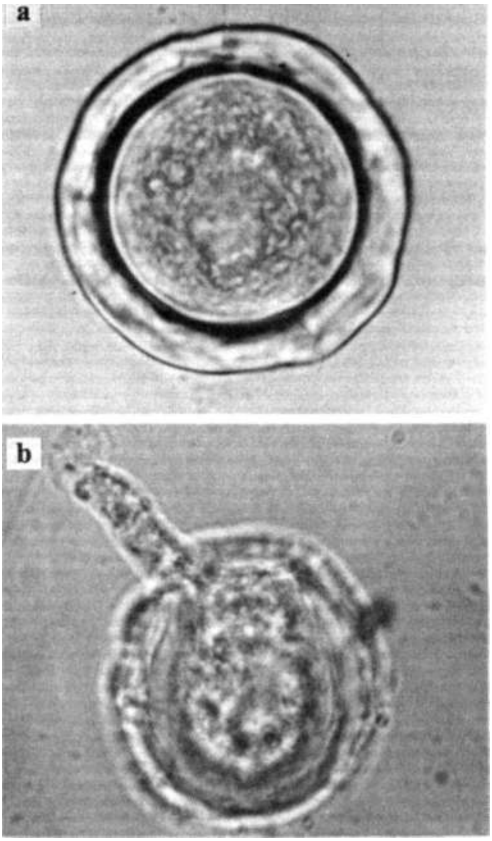


Figure 1. Germination of oospores of Sclerospora graminicola, *ICRISAT Center 1989: (a) an oospore after the NaOCl treatment and (b) a germinating oospore.*

Recovery Resistance

We evaluated 236 pearl millet accessions from Senegal, to determine the presence and frequency of recovery resistance to DM at 1CR1-SAT Center in pearl millet from a different geographic area. Eighty percent of the accessions showed some degree of recovery, but the level and the timing of recovery greatly varied among the accessions. Plants that recovered late had delayed flowering. There was a large variation within and among accessions for the occurrence of both asexual and sexual sporulation on the diseased leaves of plants that later recovered. Asexual sporulation was sparse to abundant and sporangia were normal. Plants with reduced asexual sporulation are important epidemiologically as they add less inoculum to the buildup of the disease during the season.

We also examined histologically the first two symptomless leaves of SDN 503, produced after recovery from systemic infection, for the presence of *S. graminicola* mycelium. No *sclerospora-type* mycelium was observed, indicating that the recovered plants do not carry latent mycelium.

Host-plant Resistance

Some of the entries previously classified as resistant had moderate to high levels of DM in the 1989 rainy-season DM nurseries at ICRISAT Center. This was due to the buildup of a very high disease pressure (>95% incidence in susceptible controls). A large proportion of the breeding material and finished products had much more than the acceptable 5% level of DM incidence. In the trials from the All India Coordinated Pearl Millet Improvement Project (AICPMIP), only 12 entries (including MHs 322, 342, and 328) of the 36 in the advanced hybrids trial, two entries (88004A and 863A) in the 25-entry male-sterile lines trial, and one entry (20 K-86) in the 22-entry restorer lines trial had <5% DM. The maximum levels of DM in these trials ranged from 48% to 92%. Widely used entries that showed high disease levels included 81A (40%), 843A (78%), and HHB 67 (48%). While the occurrence of such high disease pressure is not common in farmers' fields, this year's results clearly show the potential susceptibility of current breeding material. This calls for an intensive effort to increase the levels of resistance in ICRISAT material, to ensure that only resistant material reaches farmers, to minimize chances of occurrence of epidemics.

A Mycoparasite on Downy Mildew

For the last several years, we have observed a leaf spot disease that affects the DM-infected areas of pearl millet leaves at ICRISAT Center. The disease causes substantial damage in the DM infector rows in the disease nursery. Production of sporangia on the leaf spot-infected plants is either greatly reduced or totally stopped due to the death of the tissues, which considerably reduces the efficacy of the screening. The disease is characterized by the presence of spots of variable shapes and sizes. The spots begin as small, round, brownish dots that increase in size with time. Fully developed spots have gray centers surrounded by brownish margins (Fig. 2). Under conditions of high humidity, the spots coalesce, covering and finally killing the infected leaves. Premature death of young seedlings is also quite common. The disease has not been observed during the dry season. The pathogen was isolated on potato dextrose agar and identified as *Fusarium equiseti* (Wollenw. & Reinking) by the Commonwealth Agricultural Bureaux International Mycological Institute, Kew, Sur-

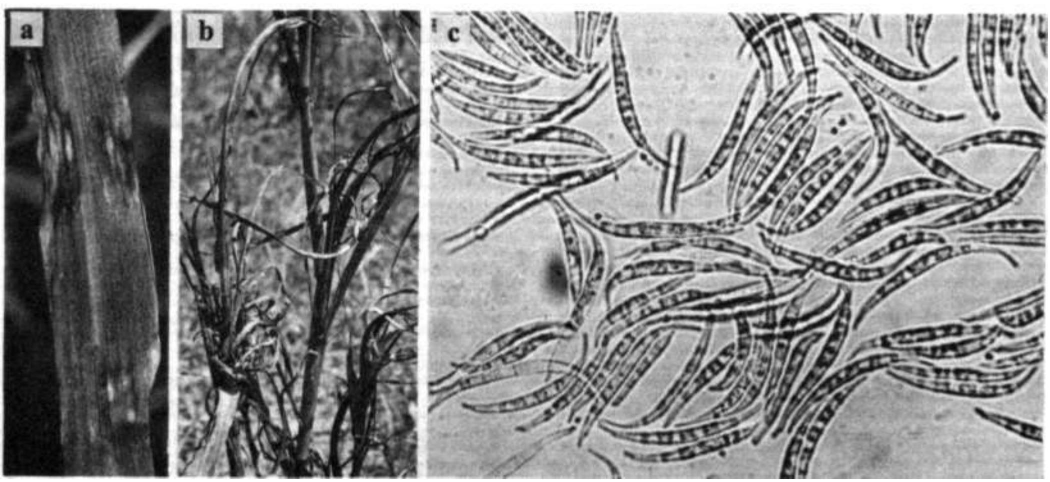


Figure 2. The mycoparasite Fusarium equiseti *on downy mildew-infected pearl millet, ICRISA T Center, rainy season 1989: (a) isolated spots, (b) a plant killed by the mycoparasite, and (c) conidia of the mycoparasite.*

rey, UK. Preliminary efforts to control the disease, without affecting DM, using benomyl have not been successful.

Smut (*Tolyposporium penicillariae)*

Variability among West African Isolates

We evaluated the reaction of seven smut isolates from West Africa on two pearl millet cultivars (BJ 104 and ICMS 8410) at ISC. The smut samples were provided by the national programs in Cameroon, Guinea Bissau, Mali, Nigeria, and Senegal. Sporidia were produced on malt extract agar from all the smut collections for artificial inoculation in the field and for measuring colony and sporidia size.

We found quantitative differences in the mean smut severity among some of the smut isolates. The differences were more noteworthy on BJ 104 than on the less susceptible variety ICMS 8410 (Fig. 3). The smut isolates from Maroua (Cameroon) and Bambey (Senegal) caused the highest smut severity with 70% (Maroua) and 61% (Bambey) on BJ 104 and 25% (Maroua) and 27% (Bambey) on ICMS 8410. We found the lowest smut rating with the isolate from Sadore (Niger) with 40% severity on BJ 104 and 14% on ICMS 8410. The other isolates produced between 54-60% smut on BJ 104 and 16-20% on ICMS 8410, and some of them did not differ significantly in their severity.

We found significant differences in the in vitro growth among the isolates. The largest colonies on malt extract agar were produced by the isolates from Samaru (402 mm^2) and Sadore (275 mm^2) as shown in Table 6. It was interesting to note that though the Bambey and Maroua isolates produced the lowest colony growth (25-34 mm^2), they caused the highest smut severity (62-70% on BJ 104) in the field.

The mean length of the sporidia for all isolates varied between 10.7 and 14.3 μm and the mean width between 2.5 and 4.0 *μm.* The variability in sporidial size was less distinct than the differences in colony growth and smut severity in the field.

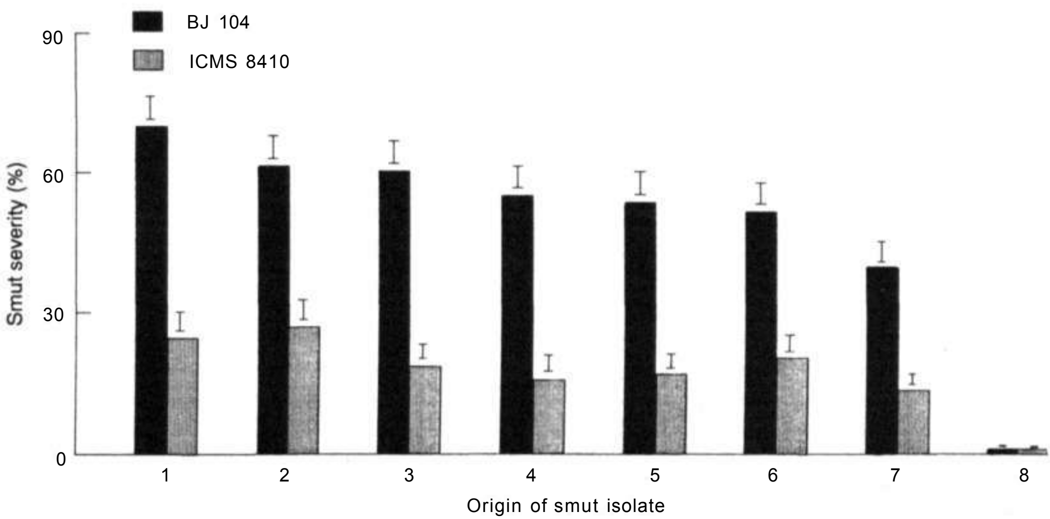


Figure 3. Smut seventy (%) on two pearl millet cultivars tested for their reaction to Tolyposporium penicillariae *isolates from West Africa, Bengou, Niger, rainy season 1989:1 = Maroua (Cameroon), 2 = Bambey (Senegal), 3 = Samaru (Nigeria), 4 = Cacheu Blute (Guinea Bissau), 5 - Cinzana (Mali), 6 = Bengou (Niger), 7 - Sadore (Niger), and 8 - Control (panicles not inoculated).*

Table 6. Comparison of in vitro growth and size of sporidia of different pearl millet smut isolates from West Africa, ISC, Sadore, Niger, rainy season 1989.

Origin of smut isolates	Area of colonies (mm^2)[1]		Length of sporidia (μm)[2]				Width of sporidia (μm)[2]			
Location	Mean	SE	Max.	Min.	Mean	SE	Max.	Min.	Mean	SE
Bambey, Senegal	24.8	±5.5	26.5	5.3	14.3	±0.6	5.3	1.1	2.5	±0.1
Maroua, Cameroon	34.1	±9.7	21.2	8.0	12.1	±0.4	5.3	2.1	3.0	±0.1
Cinzana, Mali	59.4	±9.4	21.2	5.3	12.3	±0.4	5.3	0.5	3.4	±0.1
Bengou, Niger	105.3	±3.8	21.2	5.3	12.5	±0.4	5.3	2.1	3.5	±0.1
Cacheu Blute, Guinea Bissau	179.2	±16.5	21.2	5.3	12.6	±0.3	5.3	2.1	3.2	±0.1
Sadore, Niger	274.6	±18.3	18.6	5.3	10.7	±0.3	5.3	2.1	3.4	±0.1
Samaru, Nigeria	401.7	±24.4	21.2	5.3	11.5	±0.3	5.3	2.1	4.0	±0.1

1. Mean of 10 petri dishes each with four colonics grown on malt extract agar at 15-30°C for 4 days. Area calculated by multiplying length and width of each colony.
2. Mean of 100 sporidia grown on malt extract agar at 30°C for 4 days.

These data show the variability in smut for spore morphology and pathogenicity in West Africa. However, they are not sufficient to prove the existence of different pathotypes of *T. penicillariae,* as has been shown for DM in West Africa (ICRISAT Annual Report 1988, p. 33).

Flowering Events and Smut Susceptibility

We studied the relationship between duration of three stages in the flowering process — boot leaf stage to stigma emergence, boot leaf stage to anther emergence, and stigma emergence to anther emergence — and smut development on resistant and susceptible cultivars under field conditions at ICRISAT Center, to determine whether differences in flowering habit were related to differences in smut resistance/susceptibility. All the entries were inoculated with smut sporidia (10^6 mL^{-1}) at the boot leaf stage. The number of hours required for the completion of each flowering stage and the final smut severities were recorded for each cultivar (Table 7). Differences in length of floral stages between resistant and susceptible groups were small. Mean smut seventy on susceptible cultivars was 86.7% in the 1985 dry season and 49.1% in the 1988 rainy season; the mean smut severity on resistant cultivars for the 1985 dry season was 0% and for the 1988 rainy season, it was 1%. The large differences in the smut severity values do not appear to be explainable by the very small differences in the mean number of hours that were observed between the resistant and susceptible cultivars for the different flowering stages. We concluded that the timing and duration of flowering events do not influence smut development in pearl millet in a major way.

Influence of Temperature on Smut Infection

Our attempts to operate a smut screening nursery at ICRISAT Center during the 1989 dry season were unsuccessful, possibly because of cool night temperatures «20°C) during January-March. We conducted a study to determine the effects of different temperatures on smut infection. All panicles were inoculated with smut and maintained at 95% relative humidity; treatments consisted of three different diurnal temperature sequences, varying both in mean and range.

Table 7. Mean time periods of flowering events and smut severities in smut-resistant and-susceptible pearl millet lines, ICRISAT Center, dry season 1985 and rainy season 1988.

Year/Cultivar group (n)	Time period (h)[1]			Smut severity[2]
	Boot-SE[3]	Boot-AE[3]	SE-AE[3]	(%)
Dry season 1985				
Resistant (5)	69.8± 9.68	160.8±10.91	90.8±10.06	0
Susceptible (3)	74.7±12.50	179.7±14.08	104.3±12.99	88.1± 1.86
Rainy season 1988				
Resistant (4)	85.0±10.32	158.5+ 12.20	75.0±11.25	1.01 1.0
Susceptible (8)	85.8± 7.65	173.2± 8.62	88.0+ 7.95	49.1111.97

1. Based on 10 panicles in each of two replications.
2. Based on a mean of 10 artificially inoculated panicles in each of two replications.
3. Boot = boot stage; SE = stigma emergence; AE = anther emergence; SE-AE = protogyne period.

At a mean temperature of 29.5° C, with a narrow diurnal range of 26-33° C, inoculated panicles developed 76% smut seventy. At a similar mean temperature, but a wider diurnal range of 20-38° C, smut severity was reduced to 30%. At a cooler temperature range of 15-32°C, including 8 h at less than 20° C, there was no smut development. The results suggest that cool «20°C) night temperatures are inhibitory to smut development, even when the daily mean temperature is near 30° C and maximum temperatures are well above 30° C. Dry-season screening with low night temperature is therefore likely to be less effective than rainy-season screening.

Scarabid Beetle *(Rhinyptia infuscata)*

Rhinyptia infuscata is a scarabid beetle that feeds on the stigmas of pearl millet at flowering time resulting in empty spikelets. While this insect has been identified as a pest of pearl millet, little is known of either its population density, or biology, or the damage it causes, partly because it has a nocturnal feeding habit, and is therefore difficult to study. During the past several years, we have monitored both larval and adult populations of this pest at ISC, and have attempted to estimate losses caused by it.

Biology of *Rhinyptia* in Field Cages

We introduced *Rhinyptia* adults into the field cages on 10 and 11 August, 1989 for a yield loss assessment study (see below). In order to obtain life history data on *Rhinyptia,* we initiated soil sampling for *Rhinyptia* larvae on 27 August and continued at weekly intervals until 21 November. The cages were irrigated every week beginning 26 September, 1989.

Eggs were laid in the soil at a depth greater than 5 cm. At least 7 days were required for the eggs to hatch. The developmental period *of Rhinyptia* larvae was approximately 45-50 days, when the larvae attained full size, at which point the color of the abdomen changed from a purplish shade to creamy white.

Larval Population Density

In June, following rains of approximately 20 mm, we sampled soil in a number of fields to determine the populations of *Rhinyptia* larvae following different cropping practices in the previous growing season. Sole cowpea and pearl millet fields supported high larval populations (>20 000 ha^1) while groundnut fields and noncultivated areas supported relatively few larvae (6000-7000 ha^{-1}). The population density in farmers' fields was also much lower than in the ones at ISC. Lower larval populations are probably the result of limited food supply: farmers' fields have approximately one-third the plant density as ISC fields, and the removal of the whole groundnut plant at harvest leaves considerably less root material in the soil compared to pearl millet and cowpea.

Adult Population Density in Field

During the 1989 growing season the adult population of *Rhinyptia* was determined by counting the number of adults on 720 m^2 of millet plants between 2100 and 2400. Counts were made on nine different dates between 28 August and 25 September. The results of these counts are shown in Table 8. The population estimates for 1987 and 1988 are also shown to make comparisons between the different growing seasons. Populations were considerably higher in 1989 than in 1988, and the peak emergence period was about 3 weeks later in 1989, probably due to the late onset of the rains in 1989.

Table 8. Estimated adult population (1000 ha^{-1}) of *Rhinyptia infuscata* on pearl millet panicles between 2100 and 2300 at ISC, Niger, rainy seasons 1987-89.

Time period	1987	1988	1989
Before 14 Jul	-[2]	7	-
5 22 Jul	-	66	-
23 31 Jul	-	-	-
1- 7 Aug	-	49	-
8-15 Aug	-	26	-
16 22 Aug	-	235	-
23-31 Aug	525	357	458
1-6 Sep	415	384	690
7-13 Sep	167	191	863
14 21 Sep	19	78	832
22-28 Sep	-	-	320

1. Plant population of 33 000 hills ha^{-1}.
2. Not recorded.

Light trap catches of adult beetles in 1988 and 1989 were consistent with the differences between 1988 and 1989 in the number of adults observed on pearl millet panicles.

Studies on Yield Losses from *Rhinyptia*

We conducted a yield loss study in six 3 m x 3 m x 9 m field cages, in which we maintained six different populations of adults for 15 consecutive days beginning in August. When the plants were harvested, we divided the main stems and tillers into five groups based on the estimated amount of damage on each panicle (Table 9). In addition, we harvested 400 panicles at the time of crop maturity from each of the five fields subjected to natural *Rhinyptia* infestation. We separated these into five groups as we did in the case of the cage study, threshed the panicles, and weighed the grain.

Yield losses in the cage study were somewhat lower than they were in the field sample, at all levels of damage (Table 9), but in both studies, there were major yield losses with damage ratings that were greater than 25%. Mean yield loss estimates for the actual fields sampled (based on the distribution of panicles in each category of damage) ranged from 37% to 57%.

Plant Improvement: ICRISAT Center

Population Improvement

Progress from Selection

We have previously reported the genetic gains made by recurrent selection measured in a progress evaluation trial conducted over three locations in a single year (ICRISAT Annual Report 1986, pp. 96-98). We have since analyzed progress evaluation trials in 1982, 1984, and 1985 at ICRISAT Center, Hisar, and Bhavanisagar on four composites—the Medium Composite (MC), Inter Varietal Composite (IVC), New Elite Com-

Table 9. Estimated yield losses from *Rhinyptia from* a cage study and from field sampling, ISC, Niger, rainy season 1989.

Damage rating (%)	Field sample[1] (% grain loss)	Cage yield loss study[2]			
		Main shoot		Tillers	
		Yield (g panicle^{-1})	Loss (%)	Yield (g panicle^{-1})	Loss (%)
0	0	29.7	-	15.9	-
1-25	38	29.5	1	15.5	3
26 50	64	20.8	30	12.8	20
51-75	80	14.2	52	10.6	33
76-100	97	8.9	70	2.9	82

1. Based on a sample of 400 panicles from each of five different fields.
2. Based on a complete sampling of plants in 18 m^2 in each of six field cages infested with different populations of *Rhinyptia* adults. Nonreplicated study.

posite (NELC), and Early Composite (EC). We evaluated the base populations and four to five selected populations in these composites for yield and a range of other characters (Fig. 4 and Table 10). Linear gains for grain yield made by recurrent selection varied from 23-96 kg ha^{-1} cycle^{-1} over all locations, which are increases of about 1-5% cycle^{-1} (Table 10). Some of the largest increases of grain yield occurred in the first cycle of selection (Fig. 4), but only in EC was there a declining response to selection over cycles.

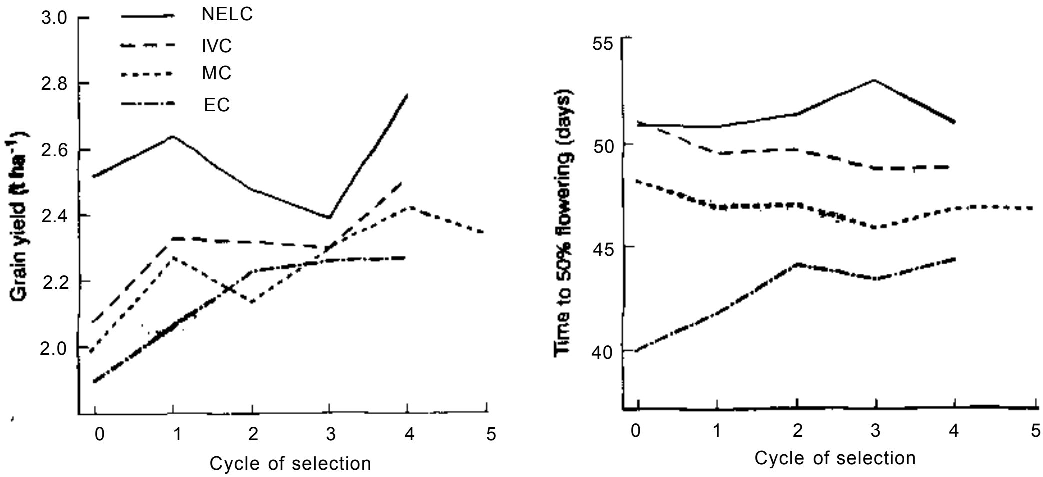


Figure 4. Response to selection in four pearl millet composites for grain yield and days to 50% flowering, averaged over three locations and 3 years. The largest SE for each trait is indicated. Slopes of regression lines and gains per cycle are shown in Table 10. MC = Medium Composite, IVC = Inter Varietal Composite, EC = Early Composite NELC = New Elite Composite.

Table 10. Progress in selection for three traits in four pearl millet composites[1]. Data are linear gains per cycle of selection (kg ha^{-1}) and percentage of gain per cycle, based on 3 years of testing at three locations.

		MC[3]		IVC		EC		NELC[4]	
Trait	Location[2]	b	Gain cycle^{-1} (%)	b	Gain cycle^{-1} (%)	b	Gain cycle^{-1} (%)	b	Gain cycle^{-1} (%)
Yield	HI	114**	5.0	92**	3.8	197**	9.5	47	1.8
(kg ha^{-1})	IC	63**	3.3	91**	4.6	3	0.2	11	0.5
	BS	38	2.1	65	3.5	81**	4.6	11	0.4
	Across[5]	72**	3.6	83**	4.0	96**	4.9	23	0.9
Time to	HI	-0.2	-0.3	-0.6**	-1.1	1.2**	2.7	0.3	0.5
50% flowering	IC	-0.3**	-0.7	-0.4**	-0.8	1.0**	2.5	0.1	0.2
(days)	BS	-0.3*	-0.7	-0.6**	-1.2	0.9**	2.4	0.4*	0.8
	Across	-0.3**	-0.6	-0.6**	-1.1	1.0**	2.6	0.3*	0.5
Height	HI	0.1	0.0	-1.8	-0.6	-2.5*	1.0	-3.5*	-1.3
(cm)	IC	-1.9*	-0.9	-2.1*	-1.0	3.1**	1.8	-1.8	-0.8
	BS	0.2	0.1	-0.3	-0.2	0.6	0.4	1.7	0.8
	Across	-0.6	-0.2	-1.4*	0.6	2.1**	1.0	-2.6*	-1.0

1. MC = Medium Composite, IVC = Inter Varietal Composite, EC = Early Composite, NELC = New Elite Composite.
2. HI = Hisar, IC = ICRISAT Center, and BS = Bhavanisagar.
3. Across five cycles in MC (four cycles in the other composites).
4. Data from 1984 and 1985 (data from 1982, 1984, and 1985 with other composites).
5. Across the three locations.

* Coefficients are significantly different from 0 at $P< 0.05$, and

** Coefficients are significantly different from 0 at $P<0.01$.

This rate of gain in grain yield is satisfactory, and is the same or better than the progress reported in other cross-pollinated crops. The rate of gain has been least in NELC, the composite which was initially the highest yielding (Fig. 4), indicating that perhaps its initial high yield was genetically narrowly based.

Gains in grain yield over selection cycles tended to be less when measured in southern India (Bhavanisagar) than in central India (Patancheru) or northern India (Hisar) for MC and IVC, but these differences were nonsignificant (P>0.05) (Table 10). Only in EC did the linear response to selection vary with the location of evaluation. It is encouraging that the genetic gains in IVC, MC, and EC have been across a broad range of environments, even though much of the testing, and all of the selfing and recombination had been done at ICRISAT Center.

Maturity is an important characteristic in pearl millet, as later-maturing pearl millet is less adapted to regions prone to end-of-season droughts. Time to 50% flowering was little changed or became less over cycles of selection in all the composites apart from EC (Fig. 4 and Table 10). In the later-maturing composites, the changes were small in IVC and MC, in the direction of increased earliness (Fig. 4). However, in EC there was an undesirable and significant increase in time to 50% flowering. This indicates that in EC, where there is a strong correlation between yield and lateness to flowering, selection is required both for earliness and yield. In later-maturing composites the correlation between lateness and yield will be weaker, as very late entries will not be allowed to mature before harvest, or will encounter end-of-season drought stress.

Plant height changed little over cycles in all the composites. In the taller composites, IVC and NELC, there was a small decrease in height over cycles of selection, while in the shorter EC, there was a small increase (Table 10). The changes in plant height resulting from recurrent selection generally occurred in the direction of the mean of all composites, thus diminishing the differences between them. As changes in plant height were generally small, or in a favorable direction, strong selection for this character does not have to be made during the recurrent selection cycles.

The progress made by recurrent selection in the composites is reflected in the progress made in the yield of released varieties made from the composites. In 1988, ICRISAT variety ICMV 155 (ICMV 84400) was recommended for release by the AICPMIP Workshop. ICMV 155 yielded 12% more than ICMV 1 (WC-C75) over 3 years of testing in the AICPMIP trials. This represents a gain of 1.3% per year, as the first year of test for ICMV 1 was 1975, while for ICMV 155 it was 1984. This gain is mainly a reflection of the gains made by the ICRISAT pearl millet population improvement project as a whole, as ICMV I was derived from the first cycle of selection of the World Composite, and ICMV 155 from the fourth cycle of selection of NELC.

Hybrid Breeding

Male-sterile Line (A-line) Breeding

F_1 Male-sterile Seed Parents

Inbred male-sterile lines (A-lines) have usually been used as seed parents to produce single-cross hybrids in pearl millet. However, because of inbreeding depression, inbred lines have reduced grain yield and seed-set, and have delayed maturity compared to less inbred material. To overcome the problems of inbreeding depression, F_1 male-sterile seed parents can be used to produce three-way hybrids instead of the single-cross hybrids produced on inbred male-sterile lines. An F_1 male-sterile seed parent, because of its hybrid vigor, will produce more seed in hybrid seed production plots than an inbred male-sterile seed parent.

Earlier data on the performance of three-way hybrids produced on an F, male-sterile seed parent, 5054A x 852B, indicated that it is possible to produce three-way hybrids as high yielding as single-cross hybrids (ICRISAT Annual Report 1988, p. 41). Encouraged by this observation, we initiated a study to investigate the advantages of F, male-sterile seed parents. In the 1989 rainy season we evaluated nine F_1 male-sterile seed parents and their parental inbred lines (usually represented by the A-line) (Table 11) for grain yield and other agronomic traits at four locations, and for DM incidence in a disease nursery at ICRISAT Center.

All the F_1 male-sterile seed parents yielded more grain (47%-90% more) than their best parental line (Fig. 5a). The highest-yielding F_1 male-sterile seed parent, ICMA 2 (843A) * 862B,

Table 11. Entries in trial of F_1 and inbred male-sterile seed parents across four locations[1], rainy season 1989.

Group[2]	F, male-sterile seed parent	Highest-yielding parental line of F_1[3]
1	ICMA 2 (843A) x 862B	862A
2	ICMA 1 (81A) x 852B	ICMA 1 (81A)
3	ICMA 88004 x ICMB 89111	ICMA 88004
4	5054A x 852B	5054A
5	ICMA 1 (81A) x ICMB 89111	ICMA 1 (81A)
6	ICMA 88006 x 863B	ICMA 88006
7	ICMA 88004 x 863B	ICMB 88004
8	AKM 1163 x ICMB 89111	ICMB89111
9	ICMA 2 (843A) x ICMB 89111	ICMB 89111

1. Bhavanisagar, ICRISAT Center, Gwalior, and Hisar.
2. Refers to number of group in Figure 5.
3. Parental lines were also in the trial and are represented always by the A-line except for ICMB 89111.

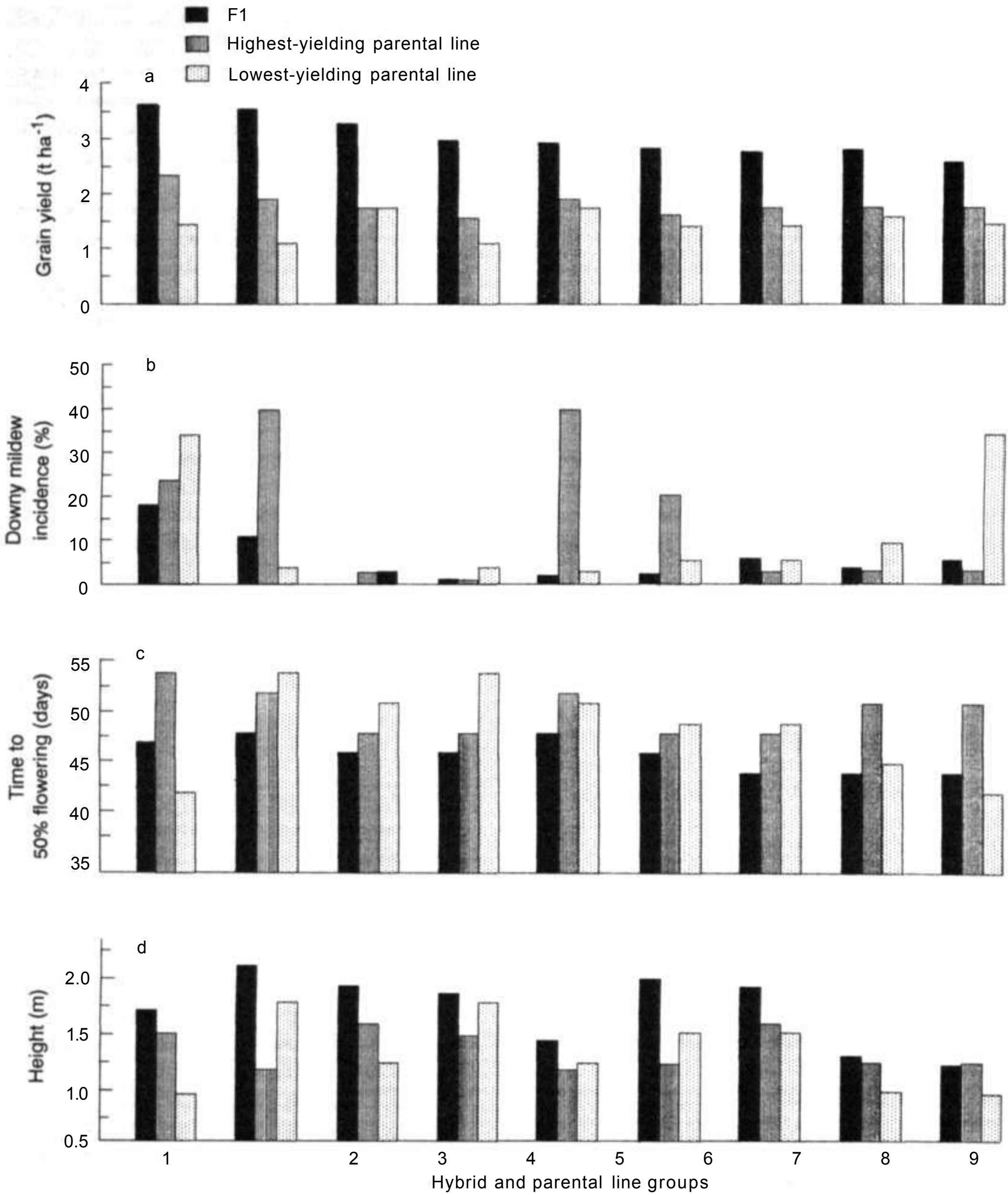


Figure 5. (a) Grain yield at four locations (SE = ± 0.16 t ha^{-1}), (b) downy mildew incidence at ICRISAT Center (SE= ±0.16%), (c) time to 50% flowering at three locations (SE = ± 0.4 day), and (d) plant height (SE = ± 0.02m), in nine F, male-sterile seed parents and their parental lines. For details of the trial and crosses see Table 11.

had parents which represented the two extremes of maturity in the trial (43 days to 50% flowering for ICMA 2, and 59 days to 50% flowering for 862A). The F_1 male-sterile seed parent, however, flowered only five days later than ICMA 2 and 11 days earlier than 862B. Thus, ICMA 2 x 862B can be used for producing three-way hybrids with early pollinators that flower too early to be used on 862A.

Most of the F_1 seed parents tended to be as resistant to DM as their most resistant parental line (Fig. 5b). Where both parents were susceptible to DM (e.g., ICMA 2 and 862A), the F_1 male-sterile seed parent was significantly less susceptible than either of its parental lines. All the F, seed parents flowered as early as or earlier than their earliest-flowering parental line (Fig. 5c) and most of the F_1 seed parents were significantly taller than their tallest parental line (Fig. 5d). This increase, both in earliness and height in the F_1 is because of the elimination of the effects of inbreeding depression, which causes late flowering and reduction in height. The increase in height may impose some limitation on the use of short-statured pollinators in the production of three-way hybrids, compared to their use in the production of single-cross hybrids on inbred A-lines. However, we would not expect any increase in the height of hybrids produced by an F_1 male-sterile line, compared to the hybrids produced by its tallest parental line. Although the data were not recorded, all the F_1 seed parents appeared to have better seed-set than the best parental A-line which should result in higher yields.

All the F, male-sterile seed parents were completely sterile, except for ICMA 2 x 862B which had a low frequency (<5%) of pollen shedders.

We selected three F_1 male-sterile seed parents (ICMA 88004 x 863B, ICMA 88006 x 863B, and ICMA 2 x ICMB 89111) for tests of the commercial viability of F_1 male steriles for the production of three-way hybrids. We will also use two of these (ICMA 88004 x 863B, and ICMA 2 * ICMB 89111) and an additional F_1 male-sterile seed parent (ICMA 2 x 862B) to study the performance of three-way hybrids in comparison to the single-cross hybrids made on their parental A-lines (ICMA 2, 862A, 863A, and ICMA 88004).

Hybrid Testing

Strategy for Breeding Downy Mildew Resistant Hybrids

We analyzed the DM resistance data from four experiments to examine the relationship between the resistance and susceptibility of parental lines and their F, hybrids. In each experiment the crosses have been divided into resistant * susceptible (where parents differed significantly for percentage of symptomless plants, Table 12) and resistant x resistant groups (where parents did not differ significantly, Table 13). 'Resistant' is used in a relative sense; a moderately resistant parent was considered resistant in cross combination with highly susceptible parent and susceptible in a cross combination with highly resistant parent. Parents differed less in magnitude in experiments 1, 2, and 3 than in experiment 4, where the differences between the parents were very obvious.

Resistant x Susceptible Crosses

In these crosses we have calculated the dominance percentage of the F_1 relative to the most resistant parent (Table 12). For example, if the dominance is 100%, then the F_1 is as resistant as the most resistant parent, while if the dominance is -100%, the F, is only as resistant as the most susceptible parent. Dominance is 0% when the F_1 equals the mid-parent value. Values above 100% occur when the F, is more resistant than the resistant parent. In the first three experiments the F_1s and the most resistant parents were usually statistically similar in their disease resistance. In only one case (in experiment 1) did the F_1 differ significantly from the most resistant parent. Consequently, the average dominance percentage was high (101%). In five cases the dominance of the F_1 exceeded 100%. These exceptions from the trend of partial or full dom-

Table 12. Downy mildew resistance and percentage of dominance in resistant x susceptible crosses in four experiments, ICRISAT Center, 1987-1989.

Cross[1]	Symptomless plants (%)[2]			Difference between F_1 and most resistant parent[3]	Dominance (%)
	PS[3]	PR[3]	F_1		
Experiment 1[1]					
7042 x ICMP 451	30	52	51	1	+91
7042 x 90/4-5	30	66	46	-20	-11
J104 x ICMP 451	41	52	52	0	+100
J 104 x 90/4-5	41	66	63	-3	+76
ICMP 85410 x ICMP 451	52	72	78	6	+160
P7 x ICMP 451	52	71	73	2	+121
SE		±3.5			
Experiment 2[1]					
843A x ICMP 85410	45	77	79	2	+113
862A x ICMP 87913	65	80	84	4	+153
843A x ICMP 851018	45	60	58	-2	+73
SE		±5.5			
Experiment 3[1]					
81B*852B	51	81	73	-8	+47
81Bx89111B	51	84	84	0	+100
88006Bx863B	65	79	85	6	+186
843B x 89111B	55	84	76	-8	+45
SE		±5.6			
Experiment 4[1]					
P7x7042	10	87	79	-8	+79
P7 x J104	7	82	78	-3	+89
700651 x 7042	11	84	80	-4	+89
700651 x J104	15	82	82	0	+100
SE		±3.6			

1. Experiment 1: ICRISAT Center downy mildew nursery, rainy season 1989 and greenhouse screen, 1989.
   Experiment 2: ICRISAT Center downy mildew nurseries rainy seasons 1988 and 1989.
   Experiment 3: ICRISAT Center downy mildew nursery, rainy season 1989.
   Experiment 4: Three greenhouse screens, Jan-Apr 1987.
2. Data are arc sine-transformed square roots of original percentage data.
3. PS = susceptible parent; PR = resistant parent.

inance may be due to genetic differences between crosses, but most likely are due to experimental error in this difficult-to-measure character. In none of the examples of numerically superior performance of F_1 over the more resistant parent, does the F_1 differ significantly from this parent, so the data do not indicate that overdominance occurs.

The fourth experiment differed from the others, in that, highly resistant material was crossed with highly susceptible material. The F_1 hybrid in these circumstances is not likely to be more resistant than the most resistant parent; consequently overdominance is not expected. The degree of dominance in the four crosses was between 79-100%, which implies that the domi-

Table 13. Downy mildew resistance in resistant x resistant crosses in three experiments, ICRISAT Center, 1989.

Cross[1]	Symptomless plants (%)[2] P1[2]	P2[2]	F_1	Difference between F_1 and most resistant parent[3]
Experiment 1[1]				
ICMP 85410x90/4-5	72	66	82	10
P7x90/4-5	71	66	76	5
ICMP 85410xP310	72	75	81	6
ICMP 85410xP1449	72	74	80	6
P7xP310	71	75	84	9
P7xP1449	71	74	82	8
SE		±3.5		
Experiment 2[1]				
863A x ICMR 87003	83	83	89	6
841AxICMP 423	80	82	79	-3
88004AxICMR 87003	79	83	90	7
81A xICMP 84122	61	70	63	-7
81AxICMP 451	63	70	65	-5
SE		±5.5		
Experiment 3[1]				
88004Bx89111B	85	84	90	5
5054Bx852B	87	81	87	0
88004Bx863B	85	79	79	-6
1163Bx89111B	76	84	81	-3
SE		±5.6		

1. See footnote 1 of Table 12.
2. P1 = parent 1; P2 = parent 2.
3. Data are arc sine-transformed square roots of original percentage data.

nance of resistance is complete or nearly complete in these four crosses.

Resistant x Resistant Crosses

In the resistant x resistant crosses all of the F_1 material was resistant (Table 13). In three cases (out of 15) the F_1 was significantly better than the most resistant parent.

Conclusion

We conclude that in most cases a hybrid will be as resistant as the most resistant parent. This means that it is not always necessary for both parents of a hybrid to be resistant. However, because there is evidence that in occasional crosses the F_1 can be considerably more susceptible than the most resistant parent, it is always necessary to thoroughly screen the hybrid and its parents. If, however, both parents are resistant, we have no example of the hybrid being susceptible.

Plant Improvement: ICRISAT Sahelian Center

The breeding subprogram of the Pearl Millet Improvement Program at ISC, has units that are responsible for breeding millet for the southern Sahelian zone (300-700 mm annual rainfall) and for the transition zone (700-900 mm) plus a regional breeding unit that is responsible for the coordination of our regional trials and nurseries. The breeding subprogram also hosts a team of two geneticists from the Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM) that investigates the origin and domestication of pearl millet.

Evolutionary Genetics of *Pennisetum*

During 1989 the ORSTOM team continued to investigate the genetic diversity in cultivated pearl millet (*Pennisetum glaucuni)* and wild millet *(P. violaceum)* and the genetic barriers to natural crossing between these two botanical forms.

Morphological and Enzymatic Analysis of *P. violaceum*

We extended studies on *P. violaceum* accessions from locations in Mauritania and Niger with accessions from Chad (20 samples), Nigeria (4), and Sudan (10). We also continued enzymatic comparisons of the cultivated and wild millets, using 14 samples from Chad and 11 early-maturing accessions from Mali.

Observations on time to flowering and several morphological characters were made in a nursery sown on 1 June 1989. Data obtained indicated that the wild millet accessions of Chad and Sudan are truly wild (because of the absence of the involucre pedicel and grains completely covered by glume). Wild millet from these two countries differed from wild accessions from other countries in terms of increased plant height, reduced tillering, and later flowering. Our results suggest that photoperiod-sensitive wild millet may occur frequently in Chad and Sudan.

The enzymatic analysis, using the same eight enzymes reported in previous years (ICRISAT Annual Report 1987, p. 111), also indicated that the wild millets from Chad and Sudan are distinctly different from other wild millets, particularly for a specific allele of the enzyme alcohol dehydrogenase. The wild accessions from Chad and Sudan add a new diversity to the wild gene pool that makes it statistically equivalent to that of cultivated millet gene pool: Table 14 shows nearly equal ranges of genetic diversity (Nei index) over all regions. In eastern Africa, in contrast, the diversity in wild millets is greater than that in cultivated pearl millets.

We performed a principal component analysis of the 46 allelic frequencies governing eight different enzymes studied. A bivariate plot of the first two principal components shows that the cultivated and wild forms fall into two groups whose diversities are quantitatively equivalent but qualitatively different. The total diversity in the wild and cultivated millets was more than the diversity present in either of these two groups. The diversity observed in the wild millets did not explain the nature of diversity present in the cultivated millets. Therefore we believe that the domestication of the wild species and its introduction into new environments have created new diversity in the cultivated millets. As a consequence, enzymatic diversity is probably partially governed by natural selection.

Table 14. Nei indices, in wild and cultivated millets from various locations in Sahelian Africa, based on polymorphisms in eight enzymes, ORSTOM, ISC, Niger, 1989.

	Nei diversity index[1]	
Region	Wild millet	Cultivated millet
Senegal	0.189	0.248
Mauritania	0.193	0.214
Western Mali	–[2]	0.225
Eastern Mali	0.240[3]	0.212
Niger, pastoral zone		
Niger, agricultural zone	0.240	0.244
Chad	0.243	0.227[4]
Sudan	0.229	
Total (ignoring region)	0.251	0.244
SE	±0.0030	±0.0037

1. Nei diversity index is a measure of the average level of the heterozygosity, a lower value indicating a lower level of heterozygosity.
2. - = Data not available.
3. Wild millets of eastern Mali and the pastoral zone of Niger are considered as one group.
4. Cultivated millets of Chad and Sudan are considered as one group.

The cultivated pearl millet cluster shows a unique association with the wild millet cluster in western Mali and Mauritania (note smallest marginal values in Table 15). Farther from this region, the genetic distance between these two forms increases with the maximum attained in Sudan and Chad. This is also supported by the observation of the large distances associated with the wild Sudan group. It seems that the main center of domestication of cultivated millet is in Mauritania and western Mali. This would require a revision of the noncenter hypothesis for pearl millet proposed by Harlan.

Recent analysis has indicated a 'discontinuity' in the cultivated millets of western Mali and those east of the central Niger delta. This discontinuity agrees well with the hypothesis that millet was first domesticated in Mali. To further confirm these results with additional samples, we

Table 15. Nei distances, based on polymorphisms in eight different enzymes, between various geographic collections of wild and cultivated millet, ORSTOM, ISC, Niger, 1989.

	Wild millet					
		Niger zone				
Cultivated millet	Senegal	Pastoral	Agricultural	Chad	Sudan	Total
Western Mali	0.237	0.281	0.246	0.168	0.493	1.425
Eastern Mali	0.111	0.421	0.256	0.334	0.822	1.944
Mauritania	0.207	0.317	0.190	0.352	0.646	1.712
Senegal	0.361	0.583	0.385	0.462	0.884	2.675
Niger	0.255	0.436	0.229	0.298	0.688	1.906
Chad and Sudan	0.550	0.818	0.555	0.599	0.953	3.475
Total	1.721	2.856	1.861	2.213	4.486	

recently undertook a mission to collect wild and cultivated millets in Mali.

Genetic Barriers Between Cultivated and Wild Millets

Because the existence of morphologic and enzymatic divergence between the cultivated and wild millets from within a geographical region was surprising in these allogamous species, we initiated studies to understand the mechanisms that maintain this divergence.

We conducted a study to compare the synchrony of flowering between the wild and cultivated millets in September 1989 at three sites in the Keita region of Niger. At each site we observed one wild millet population and two cultivated millet fields to compare flowering in these two forms. Seventy percent of the plants in the cultivated millet fields were found to be true to type and 77% plants in the wild millet populations conformed to the wild millet type. The plants that did not conform to either of these forms were *shibras* — the intermediate form.

Plants in each group were classified based on vegetative development: tillering, heading, appearance of stigmas, anthesis, grain filling, and maturity. The degree of coincidence in the distribution of these phenological stages was calculated using the Gregorius distance. The degree of coincidence for flowering within the cultivated millets was 90% and between the cultivated and wild millets was 77%, indicating that the difference in flowering time between these two forms does not form an adequate barrier to prevent intercrossing. The relatively high frequency of hybrids between cultivated and wild millets, which we observed, should therefore have allowed a total intermixing of the two forms, over a long period.

The formation of shrivelled grains in the crosses between cultivated (female) x wild (male) millets appears to be an important factor in the isolation of the two forms. In a cross between the cultivated pearl millet variety HKP from Niger, and Menaka, a wild pearl millet from the Azaouak valley in Mali, we observed grains that were shrivelled and defective, particularly in the scutellum of the embryo. These had a 1000-grain mass that was two-thirds that of normal grains and reduced germination percentage (Table 16). We are investigating the frequency of the occurence of this phenomenon using a series of cultivated x wild millet crosses; preliminary observations indicate that the phenomenon is widespread. The degree of shrivelling depends on the cultivated genotype and the environmental conditions during flowering/grain development. When plants were pollinated in May, the seeds

Table 16. Mass and germination of grains from the cross HKP (cultivated millet) x Maneka (wild millet), ORSTOM, ISC, Niger, 1989.

Cross	Number of panicles	Grain mass[1] (mg grain^{-1})	Germination[1 2] (%)
HKP x HKP	14	6.51 ± 1.38	89.2 ± 14.2
HKP x Menaka	20	4.05 + 0.70	36.0 ± 15.4

1. Mean ± standard deviation.
2. In petri dishes in ambient conditions.

were more severely shrivelled than when pollinated in November. The source (geographic origin) of the wild millet pollen does not appear to influence the shrivelling. In addition, we are studying the effects of pollen competition and degree of recombination in the cultivated x wild hybrids.

Variety Breeding

Population Improvement

We use recurrent selection to improve composites and produce a range of genetic products. We are generally using an S_1 selection method that takes 4 5 crop seasons per cycle, and involves multilocational progeny testing. The S_1 selection scheme (ICRISAT Annual Report 1985, p. 111) involves deriving S_1 progenies by selling half-sibs, testing these in replicated yield trials at one to two locations and in various screening nurseries to select superior progenies for producing the next cycle of the composite. Evaluation of the progenies for stand establishment and DM reaction is included at half-sib or S_1 progeny evaluation. Selected progenies are used in the development of varieties and as pollinators in inbred x variety hybrids.

Our southern Sahelian zone breeding unit conducted a composite bulks trial at Sadore and Tarna to identify gene pools for recurrent selection. Materials tested included five gene pools developed by the former Institut national de recherches agronomiques du Niger (INRAN)-ICRISAT Cooperative Program, Composite ISC 851, the Large Seeded Gene Pool (from ICRISAT Center), and two control varieties. Based on measurements of various characters and on visual assessment, we have retained gene pools INMG-1 and INMG-3. These two composites had yields similar to those of the controls, flowered in 60 days, and had only 10% DM (recorded by the pathologist in the DM nursery at Bengou).

In our regional breeding unit, we completed three generations of random mating on three composites, formed from germplasm evaluated in 1986 and 1987. The Early Maturity Composite was constituted from 84 advanced selections from our former Institute for Agricultural Research (IAR)-ICRISAT cooperative program in Nigeria. These selections matured in 75-90 days and originated from crosses involving Nigerian and West African parents. The selections, though variable for several plant characters, had a lower incidence of DM than the control C1VT. We plan to use the S_1 recurrent selection scheme to improve this composite and derive varieties for testing. The Medium Maturity Composite was constituted from 240 S_1 progenies derived from 35 accessions collected in northern Nigeria. The progenies matured in 90-110 days and were characterized by compact panicles and synchronous tillering. We plan to use gridded mass selection (GMS) to improve this composite. The Long Earhead Composite was formed with 312 S,s from 30 early-maturing accessions from Nigeria and Niger. All the lines chosen had panicles that measured no less than one-third of the plant height. We will also use GMS to improve this composite.

In the southern Sahelian zone breeding unit, we derived 1000 half-sibs from our Inter Varietal Composite ISC 851 (assembled from 193 F_1s involving 40 varieties and adapted landraces from West Africa, ICRISAT Annual Report 1987, p. 113); these were sown in the 1989 dry season to produce S_1s. On the basis of time to flowering, plant height, panicle length, and visual scores, 896 S_1s were selected from about 700 half-sib progenies.

These 896 S_1 progenies were evaluated in 1989, along with three controls (CIVT, P3 Kolo, HKP) and the C_0 composite bulk. We selected 354 progenies for a second stage of S_1 testing (ICRISAT Annual Report 1985, p. 111), based on time to flowering, plant height, panicle length and DM incidence. We eliminated progenies that showed >15% DM and <80% of panicle yield of the C_0 composite bulk. Panicle yield and DM incidence for all S_1 progenies and for those selected are shown in Table 17.

IKMP-1, a 135-day variety, was bred by our transition zone breeding unit in 1983 by the recombination of 18 selected progenies from an evaluation of 395 S_1 progenies derived from 1112 panicles of local cultivars selected from farmers' fields in central Burkina Faso. IKMP-1 has been recommended for extension in the 700-900 mm rainfall zone of Burkina Faso for normal sowing dates. We have initiated a further improvement in this population, for increased panicle length and reduction in days to maturity. A total of 760 S, progenies was evaluated at Samanko in the 1989 rainy season, and 132 entries were selected based on yield and visual assessment. Several plants were selfed in selected plots, and the resulting S_2 progenies will be further tested in replicated trials to identify lines for making varieties.

Our transition zone breeding unit composite IKM 85/86/ RPI was bred in 1986 by recombining progenies of 29 late-flowering F_4 lines from a cross between Kapelga, a photoperiod-sensitive, late-maturing cultivar from Burkina Faso, and GT-85, an early-maturing Iniadi millet from Togo. IKM-85/86/RP1 had a similar yield, lower DM infection (18% vs 41%) and longer panicle length than Kapelga. We initiated recurrent selection in this composite to improve yield and reduce the range in time to flowering, with 6000 spaced plants sown in the DM nursery at Kamboinse in 1987. Selfed seed was harvested from 450 selected plants. These were evaluated as S_1 progeny rows at Samanko in the 1989 season, from which 149 selfed plants were retained based on panicle length, tiller number, and visual assessment.

We multiplied seed in isolation for varieties SOSAT-C88 and SOSAP-S88, developed through cooperative recurrent selection in the Malian Composite Souna x Sanio (ICRISAT Annual Report 1987, p. 113), for further testing both at Cinzana and Sadore. At Sadore, we have noted considerable variation in the variety SOSAT-C88 for panicle length (coefficient of variation [CV] of 23%) and panicle circumference (CV of 14%), but a relatively uniform plant height (CV of 8%; all data based on 67 observations). We harvested half-sibs from the isolation plot to select uniform progenies in the following dry and rainy seasons at Cinzana and Sadore. Variety SOSAP-S88 will be further evaluated in our advanced variety, and postflowering drought tolerance trials next year.

Table 17. Panicle yield and downy mildew (DM) incidence of S_1 progenies of ISC composite 851, Sadore, Niger, rainy season 1989[1].

Character	Panicle yield ($kg\ ha^{-1}$)	DM (%)
All progenies (856)		
Range	205-4371	0-96
Mean + SD[1]	1741± 572	16±20.8
Selected progenies (354)		
Range	1094-4371	0-15
Mean ± SD[1]	2097± 467	4±4.4

1. Standard deviation.

Cooperation with National Programs

ICRISAT Center

Supply of Breeding Materials

In 1989 we sent 6034 seed samples to 13 countries (Table 18). Most of these lines were nursery or trial entries. The trials were the Pearl Millet Early Advanced Population Trial, the Pearl

Table 18. Pearl millet seed samples dispatched from ICRISAT Center by the Cereals Program, from January to December 1989.

		Trials and nurseries			
Country	Breeder seed	Sets	Entries	Breeding lines	Total samples[1]
Fiji	0	1	19	0	19
India	462	58	4096	1083	5641
Kenya	0	3	82	30	112
Korea	0	1	10	0	10
Mali	0	0	0	12	12
Mexico	0	2	28	0 28	
Namibia	0	0	0	1	1
Rwanda	0	1	17	0	17
Sudan	0	0	0	32	32
USA	0	0		1 1	
Vietnam	0	1		2	21
Zambia	0	0	0	73	73
Zimbabwe	0	0	0	67	67
Total	462	67	4271	1301	6034

1. Excludes replications in trials and nurseries.

Millet Advanced Hybrid Trial, the Pearl Millet Restorer Lines Nursery, the Pearl Millet B-Line Nursery, the Male-sterile Lines Trial, and our two Elite Products Nurseries, ELPN-1 and ELPN-2.

Varieties for National Trials

We contributed 18 entries to AICPMIP trials in 1989. Of these, eight were hybrids and 10 were open-pollinated varieties. Out of eight hybrids in the AICPMIP trials six were topcross hybrids.

Disease Nurseries

AICPMIP Trials

We evaluated 256 test entries in eight AICPMIP trials and nurseries at ICRISAT Center for their reactions to DM. Under the uniformly high disease pressure that occurred this year, only 20% of the entries that were either free from DM or had <5% DM-infected plants. Several test entries had >95% DM incidence.

Of the 241 entries that were evaluated for smut, only one entry, ICMSR 217, was completely smut-free. However, many entries had high levels of smut resistance (<10%), which is promising if these levels are confirmed.

International Nurseries

The International Pearl Millet Downy Mildew Nursery with 26 test entries was evaluated at five locations in India and four locations in West Africa. There were high levels of DM in Cinzana, Mali, Bengou and Sadore, Niger, and low levels at Aurangabad and Gwalior, in India. High levels of DM resistance were confirmed in two entries — P 1449-3 and P 310-17 — at all locations. Two pollinators from ICRISAT Center, ICMP 423 and BSEC TCP1 C2, also had high levels of resistance in most of the locations.

As in previous years, many test entries showed considerable differences in DM susceptibility between Indian and West African locations, probably in response to the presence of different pathotypes at different locations.

The International Pearl Millet Rust Nursery with 20 test entries was evaluated at three locations in India. Rust pressure was high at Kovilpatti and Bhavanisagar, and moderate at Aurangabad. There were high levels of across-location rust resistance in four entries (potential restorer [R]-lines), PRLNI/87-684, PRLNI/88-652, PRLN1/88-1026, and PRLNI/88-1059, and in five accessions including IP 548 and P24-1. ICMP 423 and ICMH 423 showed moderate to high susceptibility to rust at the three locations.

Table 19. Mean prevalence and incidence of downy mildew (DM) on six released cultivars across 25 locations in India. All India Coordinated Pearl Millet Improvement Project (AICPMIP), rainy season 1989.

Cultivar	Prevalence[1] (locations)	Incidence[2] (% plants)
BJ 104	22	29
BK 560	21	11
MBH 110	12	12
ICMH 451	10	2
ICMV 1 (WC-C75)	12	3
ICMV 4 (ICMS 7703)	17	5

1. Number of locations (out of 25) where cultivars had DM.
2. Percentage of plants infected at locations where cultivars had DM.

Disease Monitoring Nursery

We coordinated, on behalf of AICPMIP, a pearl millet disease monitoring nursery which contained six cultivars — BJ 104, BK 560, MBH 110, ICMH 451, ICMV l, and ICMV 4 (ICMS 7703) — to assess the prevalence, incidence, and severity of DM on released cultivars. The trial was grown by the AICPMIP Pathologists on 16 research stations and nine farmers' fields. BJ 104 showed the highest DM susceptibility (29% mean incidence; 22 out of 25 locations infected), followed by BK 560 and MBH 110 (Table 19). ICMH 451, ICMV 1, and ICMV 4 had < 5% mean DM incidence, but did record some DM at 10-17 of the 25 test locations. The results show that ICMH 451 and ICMV 1 are presently the least susceptible of the widely grown cultivars released by AICPMIP, in terms of prevalence, incidence, and severity of DM. However, as in the case of other entries in the trial, both showed moderate incidence (up to 15%) in some of the locations.

Performance of Released and Elite ICRISAT Varieties

In the AICPMIP Workshop in April 1989, ICMV 155 was recommended for release for cultivation in India. In 3 years of testing, in a total of 89 AICPMIP trials, this variety outvielded ICMV 1 by 12% for grain and 9% for stover. It has the same maturity, height, and DM resistance as ICMV l.

There are now four varieties bred by ICRISAT that have either been released in India or recommended for release by the AICPMIP Workshop. These are ICMV 1, ICMV 4, MP 124 (ICTP 8203), and ICMV 155. However, these varieties have been tested in different years in the AICPMIP trials, so they can only be compared with ICMV 1 which has been a continuing control in the trial, and not compared directly with each other. We have summarized the differences in time to 50% flowering and grain yield in these entries in relation to time to flowering and yield in ICMV 1 from the AICPMIP trials data (Table 20).

To obtain directly comparable data, we tested the same varieties in well-replicated trials (a minimum of 12 replications per entry in any location) in three locations in 1988 and 1989 (Table 21). Various breeder seed stocks of these varieties were tested, but we only present data for overall variety means here. In addition to the released varieties, we also tested ICMV 87901 in both years. ICMV 87901, derived from the

Table 20. Comparison of three ICRISAT varieties with ICMV I (WC-C75) in AICPMIP trials, 1979-1988.

Variety	Years in the AICPMIP trial	Number of trials	Time to 50% flowering (days)		Yield superiority over ICMV I			
					Grain		Fodder	
			Entry	ICMV 1	%	Frequency[1]	%	Frequency[1]
ICMV 4 (ICMS 7703)	1979-82	134	51.8	50.8	2	0.53	5	0.37
MP 124 (ICTP 8203)[2]	1984-86	30	49.0	53.6	8	0.50	-18	0.29
ICMV 155 (ICMV 84400)	1986-88	89	54.6	54.3	12	0.63	9	0.70

1. Proportion of trials in which entry is superior to ICMV I.
2. In Maharashtra and Andhra Pradesh only.

Table 21. Comparison of ICRISAT varieties across three locations[1], rainy seasons 1988 and 1989.

Comparison	Number of		All locations		ICRISAT Center	
	Trials	Replications	Grain yield ($t\ ha^{-1}$)	Time to 50% flowering (days)	Grain yield ($t\ ha^{-1}$)	Time to 50% flowering (days)
Two years' data						
ICMV 1 (WC-C75)	6	340	2.35	48	2.40	50
MP 124 (ICTP 8203)	6	204	2.26	47	2.33	47
ICMV 87901	6	136	2.54	51	2.60	46
SE[2]			±0.079	±0.4	±0.010	±0.4
One year's data						
ICMV 1	3	220	2.30	52	2.48	48
ICMV 4 (ICMS 7703)	3	132	2.40	50	2.64	47
ICMV 155 (ICMV 84400)	3	220	2.73	51	2.93	48
MP 124	3	220	2.17	48	2.31	44
SE[2]			±0.110	±0.7	±0.156	±0.4

1. ICRISAT Center with high and low fertility, and Hisar.
2. Conservative estimate of SE, based on location x variety interaction, using the method of unweighted means.

BSEC, has been commercially multiplied and is now grown in Maharashtra. Both ICMV 87901 and MP 124 have the same maturity and similar seed size but there is no comparable data for them from the AICPMIP trials. We conclude from the data presented in Table 21 that our results are in general agreement with those obtained in the AICPMIP trials (Table 20). Thus:

- ICMV 155, from the AICPMIP trials and ICRISAT data, is the highest-yielding variety, and is of the same maturity as ICMV 1.
- ICMV 4 is superior to ICMV 1 in yield, and

contrary to the AICPMIP data, is somewhat earlier than TCMV 1. This was confirmed in an experiment described below, and in 42 trials conducted by ICRISAT over three years and five locations where, on average, ICMV 4 flowered 1.3 days earlier than ICMV l.

- MP 124 is considerably earlier flowering than ICMV 1. In the ICRISAT trial it did not outyield ICMV 1 in 1988 and 1989, which, as wetter than average years at ICRISAT Center, favored later-maturing material. The years that MP 124 outyielded ICMV 1 in the AICPMIP trial, there was below-average rainfall.
- From the ICRISAT trial in 1988 and 1989, ICMV 87901 yielded more than MP 124, and is of the same maturity. This has been confirmed over three years, across 14 locations, and in 38 trials conducted by ICRISAT and ICRISAT's cooperators. In these trials ICMV 87901 yielded 13% more grain than MP 124 across the whole country and 19% more grain in south India.

In 1989, in eight replications of ICMV 1, ICMV 4, MP 124, and ICMV 155, we tagged individual plants as they flowered. There was no agronomically significant difference in the flowering distributions of ICMV 155 and ICMV 1; both had a time to 50% flowering of 49.5 days (Fig. 6), and differed in overall mean by only 0.5 day. ICMV 4 was significantly earlier than both ICMV 1 and ICMV 155, and MP 124 was the earliest.

We conclude that ICMV 155 is a higher-yielding replacement for ICMV 1, as it is in exactly the same maturity group. However, ICMV 4 provides an earlier alternative to ICMV 155, and is better adapted to the northern than to the southern Indian conditions. In the AICPMIP trials across the years, it yielded 106% of the trial mean in the north and 103% in the south. MP 124 is an earlier-maturing, large-grained variety which is adapted to southern India. We also conclude that newer varieties from BSEC, such as ICMV 87901, yield more than MP 124 whilst having the same maturity and comparable grain size. However, as there is no comparative data from AICPMIP for a direct comparison between MP 124 and ICMV 87901, there is insufficient data on which to propose the latter's release as an alternative to MP 124.

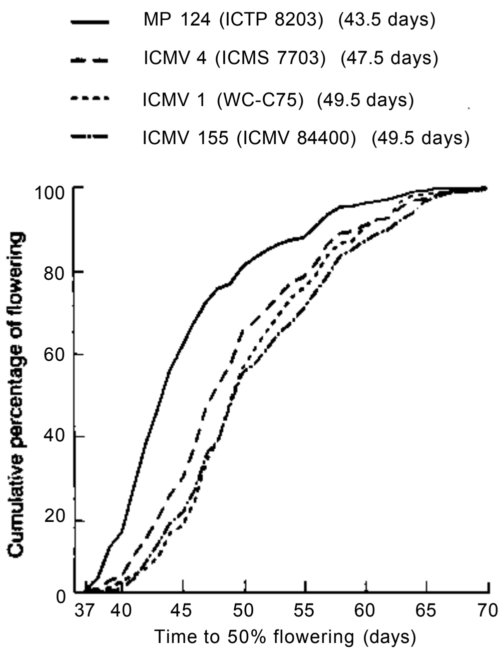


Figure 6. Cumulative percentage of flowering in four open-pollinated pearl millet varieties, ICRISAT Center, rainy season 1989. Figures in parentheses are times to 50% flowering.

Supply of Breeder Seed

We supplied 1644 kg of breeder seed of hybrid parents and varieties to both private and public sector seed producers (Table 22). Of this, 673 kg was of hybrid parents (81 A/B, 841 A/B, 1CMP 451, and ICMP 423). About 429 kg (64%) was of the parents of ICMH 451. We supplied a total of 915 kg of varieties ICMV 1, ICMV 4, MP 124, ICMV 155, and ICMV 87901. Of this, 419 kg (44%) was of ICMV 1, 267 kg (28%) of MP 124, and 106 kg (11%) of ICMV 87901.

Table 22. Quantities of breeder seed supplied by ICRISAT Center to seed producers during 1989.

Material	Quantity (kg)	Number of requests
Parents of ICMH 451		
ICMA 1 (81A)	190	59
ICMB 1 (81B)	95	57
ICMP 451	144	59
Parents of ICMH 423		
ICMA 841	117	41
ICMB 841	59	41
ICMP 423	68	33
Male-sterile lines		
ICMA 2 (843A)	13	4
ICMB 2 (843B)	7	4
Open-pollinated varieties		
ICMV I (WC-C75)	419	36
ICMV 4 (ICMS 7703)	114	20
MP 124 (ICTP 8203)	267	61
ICMV 87901	106	10
ICMV 155 (ICMV 84400)	45	15
Total	1644	440

ICRISAT Sahelian Center

Supply of Breeding Materials

We supply improved breeding material and varieties to cooperating national programs in the form of breeders' seed, elite breeding lines, and progenies at various levels of inbreeding. We also meet specific requests. During the year we supplied 193 seed samples to three national programs (Burkina Faso, Liberia, Mali) in the region.

Regional Disease Nursery

The West African Downy Mildew Observation Nursery was grown at six locations in West Africa in 1989; data from four locations have been received and analyzed. The trial included 41 entries contributed by eight national programs and by ISC for evaluation of DM resistance. This year the mean DM incidence for all locations was lower compared to that of last year. The highest DM incidence was 16% at Bengou followed by 9% at Sadore, 7% at Samaru, and 6% at Bambey. Seven entries had less than 3% DM incidence across all locations, 12 entries had less than 6%. The susceptible controls recorded 14% (NHB 3) and 84% (7042) DM (Table 23).

Regional Yield Trial

The ICRISAT Sahelian Center annually organizes the ICRISAT Pearl Millet Zone Adaptation Trial which is grown in a number of countries in West Africa. The 1988 trial had 15 test entries and one locally selected, improved variety (control) at each location. Three test entries were contributed by Institut national de recherches agronomiques du Niger, two by the Institute for Agricultural Research, Nigeria, and 10 by ISC. Seed for the trial was distributed to 14 locations in nine West African countries; data are available from six locations — Bawku, Cinzana, Bengou, Sadore, Samaru, and Bambey (Table 24).

Averaged over these six locations, the five highest-yielding test entries were ICMV 7 (ITMV 8304)(1.32 t ha^{-1}), ICMV IS 85333 (1.31 t ha^{-1}), IKMV 8201 (1.301 ha^{-1}), ICMV IS 85327 (1.28 t ha^{-1}), and C12 L (1.24 t ha^{-1}). However, varietal adaptation to specific sites was common (Table 24).

At the locations where they were among the five top-yielding entries, ICMV 7 yielded the following percentages of control varieties at different locations: Samaru (133%), Cinzana (95%), Sadore (89%), and Bambey (86%); ICMV IS 85333 yielded 146% at Bawku, 97% at Cinzana, and 94% at Sadore; IKMV 8201 yielded 146% at Bawku, 129% at Samaru, 125% at Bengou, 90% at Sadore, and 84% at Bambey; ICMV IS 8527 yielded 115% of control varieties at Bengou and 93% at Sadore.

Table 23. Downy mildew (DM) incidence and severity at the dough stage of selected pearl millet entries in the West African Downy Mildew Nursery (WADMON), at four West African locations, rainy season 1989.

		DM incidence (I)[1] (%) and severity(S)[2] (%)									
		Mean		Bambey		Bengou		Samaru		Sadore[3]	
Entry	Origin[4]	I	S	I	S	I	S	I	S	I	S
Local Nord Ouest	IDESSA, Cote d'Ivoire	0	1	0	0	1	2	0	0	0	0
SE 300	IAR, Nigeria	1	1	0	0	2	3	0	0	0	0
Local Nord Est	IDESSA, Cote d'Ivoire	1	1	0	0	4	1	0	0	1	1
Local Ferke	IDESSA, Cote d'Ivoire	2	1	0	0	0	0	6	3	1	0
IKM/CVP39/83/84/351	INERA, Burkina Faso	2	2	0	0	7	8	0	0	0	0
NPT 25	DGDR/DRA, Togo	2	1	0	0	4	2	0	0	4	4
SE 301	IAR, Nigeria	2	2	0	0	5	2	1	1	3	3
SE 303	IAR, Nigeria	3	2	0	0	8	5	3	2	1	1
Pool 9	IER, Mali	3	2	0	0	5	4	5	4	3	1
Toroniou Cl	IER, Mali	4	3	0	0	13	11	1	1	0	0
H-80-10-GR	INRAN, Niger	10	8	0	0	24	20	2	1	14	11
ICMV IS 86327	ISC, Niger	12	7	0	0	34	16	1	0	12	11
ICMV IS 85321	ISC, Niger	12	10	5	5	25	24	11	4	7	6
86 CZ SYN 5	IER, Mali	12	6	21	14	20	7	7	3	1	1
86 CZ 81 B HT	IER, Mali	43	38	5	4	92	83	12	8	63	58
Controls											
Improved		18	17	0	0	13	14	3	2	58	52
Local		30	21	50	31	36	29	17	11	18	14
NHB 3	India, AICPMIP	14	11	6	3	21	22	22	12	9	9
7042	Chad, reselected by ICRISAT	84	82	80	75	91	86	100	99	66	66
Trial mean (41 entries)		9	8	6	5	16	13	7	5	9	8

1. Based on the number of plants infected as proportion of total plants in a plot.
2. Based on a 1-5 scale, where 1 = no symptoms and 5 = symptoms on main stems and all tillers so that there are no productive panicles. Based on a mean of 19-82 plants from two replications.
3. Bambey = Institut senegalais de recherches agricoles (ISRA), Senegal; Bengou and Sadore = ICRISAT Sahelian Center (ISC), Niger; Samaru = Institute for Agricultural Research (IAR), Nigeria.
4. IDESSA = Institut des savannes, Cote d'Ivoire; INERA = Institut national d'etudes et de recherches agricoles, Burkina Faso; DGDR/DRA = Direction generate du developpement rural/Direction de la recherche agronomique, Togo; IER = Institut d'economie rurale, Mali; INRAN = Institut national de recherches agronomiques du Niger, Niger. AICPMIP = All India Coordinated Pearl Millet Improvement Project.

Varieties for National Programs

During the year we supplied 20-80 kg seed of varieties ICMV IS 85327, ICMV IS 85333, and GB 8735 to Chad and Togo. We are informed that 2 t seed of variety GB 8735 were multiplied in Togo for large-scale evaluation on farmers' fields. Variety ITMV 8001 supplied to Chad in 1986 has been recommended for multiplication and general cultivation by the Service national de semences of the Ministere de l'agriculture in Chad. In 1989 this variety was estimated to have covered 30000 ha following the production of 200 t seed by 1988. Encouraged by the stable, good performance of IKMV 8201 in the past

Table 24. Mean grain yields (t ha^{-1}) of the five highest-yielding pearl millet test entries in the ICRISAT Pearl Millet Zone Adaptation Trial (IMZAT), at six locations in five countries in West Africa, rainy season 1988.

Bawku (Ghana)		Cinzana (Mali)		Bengou (Niger)	
Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})
ICMV IS 88203	0.23	ICMV IS 85333	2.07	IKMV 8201	2.18
ICMV IS 86101	0.22	ICMV 7 (ITMV8304)	2.03	ICMV IS 85327	2.01
C-12 L	0.19	ITMV 8003	2.02	C-12L	1.94
ICMV IS 85333	0.19	CT-2	2.01	ICMV IS 88202	1.91
IKMV 8201	0.19	ICMV IS 85327	1.98	T-18L	1.86
Control[1]	0.13	Control	2.13	Control	1.75
SE	±0.36		±0.13		±0.22
Trial mean (16 entries)	0.16		1.78		1.74
CV (%)	44		14		25
Sadore (Niger)		**Samaru (Nigeria)**		**Bambey (Senegal)**	
ICMV IS 85333	2.30	ITMV 8003	0.61	ICMV 7 (ITMV 8304)	1.22
ICMV IS 88202	2.25	ICMV IS 85334	0.58	IKMV 8201	1.19
IKMV 8201	2.20	ICMV IS 88202	0.57	ICMV IS 88202	1.16
SE 2124	2.19	ICMV 7 (ITMV 8304)	0.56	SE Composite	1.16
ICMV 7	2.17	IKMV 8201	0.54	ICMV IS 8820 1	1.11
Control	2.44	Control	0.42	Control	1.42
SE	±0.13		± 0.11		±0.12
Trial mean (16 entries)	2.03		0.46		1.02
CV (%)	13		48		23

1. Locally selected improved variety.

several years of trials in Mali, the Institut d'economie rurale multiplied this variety on 0.5 ha and is planning pre-extension/demonstration trials next year. Four kg seed of each of the varieties, ICMV 87901 and GB 8735, was supplied to Aide de l'eglise Norvegienne, Mali. We have supplied seed of varieties IKMC I, ICMV 7, ICMV IS 85327, ICMV IS 85333, and GB 8735 to Senegal for preliminary evaluations and seed of varieties ICMV 5 (ITMV 8001), ICMV 7, ICMS IS 85327, and ICMS IS 85333 to INRAN for inclusion in the Essai comparatif des cultivars elites of INRAN. We also provided seed of ICMV IS 85327 and ICMV IS 85333 to Institut national d'etudes et de recherches agricoles (INERA), Burkina Faso, for inclusion in a variety trial that was conducted as a prelude to the Operational Scale Research trials.

SADCC/ICRISAT Regional Program

The regional program assists the collaborating national program with the supply of breeding materials, the organization of regional yield trials and disease nurseries, and the supply of promising cultivars of pearl millet, finger millet, and forage millets, for national evaluation. We report selected activities from this set.

Pearl Millet Grain Utilization

Malting/Brewing Quality

Micromalting procedures, including optimization of steeping and malting times and temperatures/humidity regimes, have been standardized, and determination of the diastatic power (DP) of 12 lines has been completed. The highest DP was obtained in ICMV 82132 (28.2 diastatic units) followed by SDMV 87014 (27.7), WGC (24.8), SDMV 87001 (24.6), SDMV 89005 (22.9), SDMV 87017(21.5), SDMV 89006(21.2), SDMV 87018 (20.5), ICNMV 156 (19.3), SDMV 89008 (15.6), ICMV 87901 (12.8), and ICMV 84421 (11.1). Promising selections will be differentially assayed and amylase activity measured to determine the extent to which pearl millet may be used to boost the amylase deficit in sorghum.

Milling Quality

Pearl millet from a commercial source was semi-wet milled (SWM) and a 20% composite was used in a preliminary bread trial using a straight dough formulation. The general acceptability of the SWM pearl millet composite was significantly lower (P >0.05) than that of the 15% SWM sorghum composite and the wheat control. The general acceptability score was, however, above the base line of acceptability (i.e., 4 on a scale of 1-7, where 1 = dislike extremely, to 7 = like extremely). When color texture and flavor scores were compared, texture and flavor were compatible with those of the sorghum composite and the wheat control, but color was significantly different (P>0.05). It is seen that with pearl millet, even SWM processing is not effective in reducing the grayish color; and for composite flour applications, a selection program for white grain is essential.

Finger Millet Breeding

In Southern Africa, finger millet is grown in Malawi, Tanzania, Zambia, and Zimbabwe, primarily for brewirig local beer and for food. The germplasm accessions from Malawi, Zambia, and Zimbabwe, have been evaluated in their countries for origin. Most of the accessions from Zimbabwe were early-maturing types whereas those from Zambia and Malawi were late-maturing types. In Tanzania, both maturity types are grown. Our breeding efforts are therefore focused on the production of varieties of early- and late-maturing types coupled with resistance to pests and diseases. This is achieved by purifying the best accessions, and the work on hybridization has begun. During 1989, we continued to acquire new germplasm from Ethiopia (3), India (81), Kenya (693), Malawi (15), Uganda (3), Zambia (58), and Zimbabwe (7), and we now have a total of 2569 accessions, but still there is need to put more emphasis on collecting from Tanzania and Uganda.

Forage Millet Breeding

The forage improvement program has the following three objectives: to improve the nutritive value of crop residue while maintaining high grain yields (dual purpose); to develop and produce interspecific hybrids between pearl millet and napier grass *(Pennisetum purpureum)* suitable for rainfed and irrigated conditions; and to improve forage yield and quality.

One of our major achievements has been the discovery of a new source of brown midrib (*bmr)* gene in Zimbabwe germplasm accession no. SDGP 1500 *bmr.* This gene reduces the lignin content in the plant, and thereby increases the dry matter digestibility.

Ten varieties of pearl millet have been crossed with an F_3 *bmr line* derived from a cross obtained from Purdue (USA) with the objective of transferring the *bmr* gene into grain varieties. A limited backcrossing procedure will be followed to transfer the bmr gene.

One composite population (SDFPMC 1), consisting of 38 lines, has completed a third generation of random mating. Nineteen forage lines have been crossed with *bmr* lines to incorporate the *bmr gene* in high-yielding varieties. Twenty-eight crosses among seven pearl millet and the *monodii* gene pool have been generated to improve the forage yield and quality.

Regional Pearl Millet Disease Nurseries

Several resistant pearl millet varieties developed at ICRISAT Center consistently had very low ergot severities in multilocational replicated tests under high natural disease pressures during the last 4 years in the SADCC region. Most other pearl millets, however, are susceptible. High ergot severities of entries were associated with long protogyny periods. ICMPES 28 and ICMPES 29 also had fairly good agronomic performance throughout the region. ICMPES 28 had false mildew and rust resistance in Malawi and Zimbabwe. It also had moderate resistance to certain leaf spot diseases at 11 locations, in three countries.

As expected, all 11 entries in the International Pearl Millet Ergot Alkaloid Nursery were affected by ergot in the 1988/89 and 1989/90 seasons. Entries differed in ergot severity; MP 124 and ICMH 501 had the lowest mean severity over locations. However, there was an interaction between locations and genotypes. Some genotypes with a low severity at one location had a high severity at another. Sclerotia also developed at all testing locations, sometimes immediately upon appearance of the honeydew symptoms, which occurred 9-19 days after inoculation.

As in previous years, there were differential responses for rust among genotypes, but there were also genotype x environment interactions within and outside the SADCC region. NHB 3 and P 24-1 were susceptible (severity 40% and above) at Ukiriguru, Tanzania, but only moderately susceptible at Lusitu, Zambia (severity below 10%), while NHB 3 was susceptible in India, and P 24-1 resistant. IP 5241-2-2 had low severities in Tanzania but was moderately susceptible in India. 7042 RR was also resistant (severities below 5%) in Malawi, Tanzania, Zambia, and Zimbabwe.

Regional Yield Trials

Regional Pearl Millet Trials

Based on five locations, SDMV 88006 was the highest-yielding entry in the preliminary trial (28% more than local controls) followed by ZPMV 87402, SDMV 88001, ZPMV 86121, and SDMV 88004. The highest-yielding entries across the 13 SADCC locations in the advanced yield trial were SDMVs 89007, 89005, 89006, and ICMV 82132. SDMV 89007 yielded 36% higher than the local controls when averaged over the region.

Collaborative Finger Millet Advanced Varieties trials

Based on mean over three locations, the highest-yielding entry in the early-maturity varieties trial was SDFM 937 (4.86 t ha^{-1}, 42% higher yield than that of local control when averaged over locations) followed by SDFM 1059 (4.5 t ha^{-1}), SDFM 1072 (4.15 t ha^{-1}), SDFM 44 (4.0 t ha^{-1}), and SDFM 957 (3.96 t ha^{-1}). All these entries were early-maturing types.

Based on mean over five locations, the highest-yielding entry in the late-maturing varieties trial was SDFM 723 (3.04 t ha^{-1}, 25% higher yield than that of control) followed by SDFMs 217, 1079, 396, 241, and 113 (Table 25). SDFM 217 (IE 2929), a late-maturing variety, was the highest-yielding entry in three locations, ranked third in another location but was the poorest yielding at Aisleby. We suggest the large-scale testing of SDFM 217 in Malawi and Tanzania as it had done very well in these countries. SDFM

Table 25. Grain yield of six selected entries of finger millet advanced late-maturing varieties trial at Aisleby and Marondera (Zimbabwe), Misamfu (Zambia), Chitedze (Malawi), and Gairo, (Tanzania) and time to 50% flowering at Aisleby, rainy season 1988/1989.

	Grain yield (t ha^{-1})						Time to 50% flowering
Entry	Aisleby	Marondera	Misamfu	Chitedze	Gairo	Mean	(days)
SDFM 723	4.66 (1)[1]	1.82(13)	4.05 (3)	2.77 (8)	1.88(10)	3.04(25)[2]	105
SDFM 218	1.46(20)	3.70(1)	4.81(1)	2.63 (3)	2.53(1)	3.03(25)	140
SDFM 1079	3.81 (5)	1.68(16)	4.70 (2)	2.64(12)	1.83(11)	2.93(21)	98
SDFM 396	3.03(14)	2.46 (6)	3.92 (5)	2.88 (6)	2.16(3)	2.89(19)	108
SDFM 241	3.79 (6)	2.51 (5)	2.89(16)	3.03 (4)	1.73(13)	2.79(15)	94
SDFM 113	3.86 (4)	2.58 (4)	2.86(18)	2.38(15)	2.12(6)	2.76(14)	94
Local control	3.18(11)	2.08 (8)	2.96(14)	2.69(10)	1.26(17)	2.43	88
SE	±0.223	±0.280	±0.425	±0.342	±0.202	±0.127	±3.0
Trial mean (20 entries)	3.29	2.06	3.36	2.70	1.79	2.64	100
CV (%)	14	27	18	25	23	20	6

1. Rank within each location.
2. Increase in percentage of yield over controls.

113 and SDFM 723, both early-maturing varieties, have proved promising in Zimbabwe.

Cereal Forage Yield Trial

Based on mean over six locations, the highest-yielding entry was Babala millet (28.61 of green fodder ha^{-1}) closely followed by SDMV 89101 (selection from PS 472), SDMV 89104 (PS 195) SDMV 89105 (PS 192), SDMV 89102 (PS 200), and SDMV 89103 (52-9 x 51-13). All PS varieties were introduced from Tifton (USA) as *monodii* selections. During the course of seed multiplication, we selected segregating plants of a pearl millet type with high tillers.

Variety Releases

Two pearl millet varieties have been released to farmers by national programs in the SADCC region. MP 124 was released in Namibia as Okashana I and ICMV 82132 in Zambia as Kaufelu. Both varieties were bred at ICRISAT Center and identified for release from the SADCC regional variety trials. Finger millet variety SDFM 217 has been released to farmers in Zambia with the name Lima. It originated from genetic resources accession IE 2929 from Malawi.

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Institute Publications

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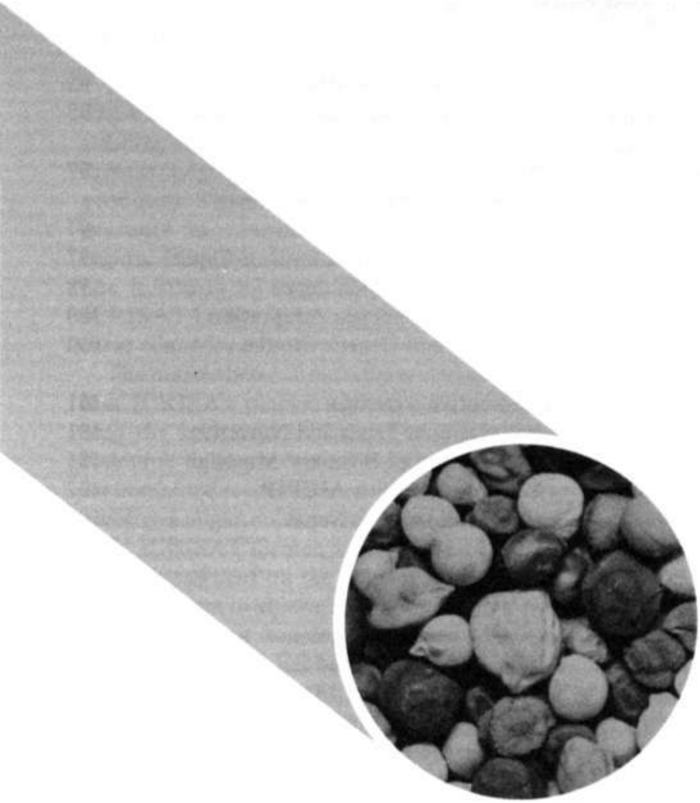


CHICKPEA

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

CHICKPEA

There are two main types of chickpea: desis constituting about 85% of the total production, and kabulis forming the remaining 15% of chickpea produced. The kabuli type is of particular importance in countries of the Mediterranean region. However, the demand for kabuli chickpea is strong in other countries as well and ICRISAT Center is increasing its efforts to serve these countries.

The major thrust of the collaborative research that ICRISAT carried out on kabuli chickpea with the International Center for Agricultural Research in Dry Areas (ICARDA) is to breed for combined resistances to stress factors such as ascochyta blight, cold temperatures, and drought.

At ICRISAT Center, work on desi chickpea has concentrated on the development of genotypes resistant to abiotic and biotic stresses. New drought-tolerant sources have been identified and some progress has been made in the genetic enhancement of drought tolerance. Tall, erect, and compact genotypes have been shown to be particularly useful for the management of botrytis gray mold — an increasingly severe disease in northeast India, Nepal, and Bangladesh. Pod borer attack was low in many areas this year but chickpea breeding will benefit from the insights that were obtained on the nutritional ecology of pod borer feeding on drought-stressed chickpea. Plant breeding methodologies will also benefit from research on plant nutrition which showed that under high soil nitrogen conditions, selection of poorly nodulating genotypes is favored.

The genetic improvement program concentrated on combining high yield with resistance to stress factors. Techniques for micropropagation and plant regeneration by somatic embryogenesis were refined and standardized.

Physical Stresses

Major emphasis was given to adapting chickpea to short-season, warm tropical winter, terminal-drought environments in South Asia and to the agronomic evaluation of low-temperature tolerant selections. In drought tolerance research, progress was made in genetic enhancement of drought tolerance, identifying new sources of tolerance, and in characterizing the physiology of drought-tolerant sources. In the cool winter regions of central and northern India, some of the selections made for cold tolerance with respect to pod-set outyielded conventional cultivars.

Drought Tolerance

Improvement of Drought Tolerance

We reported last year (ICRISAT Annual Report 1988, p. 60) that we made single plant selections for root traits in 832 F_4 plants of a cross ([Annigeri x ICC 4958] x ICC 12237), ICC 4958 being a drought-tolerant genotype. We selected 81 of the F_4s and advanced them to the F_5 generation in a nutrient sand-culture system during the off-season of July-October 1988. We made these selections on the basis of visual rating for root length and volume. We also evaluated the drought tolerance of the 81 F_4s in the 1988/89 postrainy season, on a Vertisol in a nonreplicated test using the field screening method described earlier (ICRISAT Annual Report 1982, pp. 110-111). We used ICC 4958 as a control sown frequently throughout the experimental area. Thirteen of the 81 entries had a degree of drought tolerance similar to or greater than ICC 4958, and five were rated as susceptible. In the population of plants selected for root traits, yield under stress (nonirrigated, except for a light postsowing irrigation to ensure uniform plant stand establishment) was very strongly correlated ($r=0.99$, $n=103$) with the drought tolerance indices. This suggests that the visual criteria of roots were effective in rejecting the drought-susceptible types in the segregating population. The F_5 generation is being evaluated for drought tolerance in replicated field tests on a Vertisol at ICRISAT Center in the 1989/90 season.

In the offseason (July-August 1989), we re-evaluated F_6 generation, advanced from F_5 selections made for root traits (ICRISAT Annual Report 1988, p. 60), for root characters by the nutrient sand-culture method and advanced it to F_7 generation. The seed of F_6 and F_7 selections are being multiplied in the 1989/90 season.

Screening Germplasm

We evaluated the relative drought tolerance of some selected germplasm entries of contrasting morphology, with respect to leaf size and shape. We used solarized plots to prevent fusarium wilt disease incidence (ICRISAT Annual Report 1985, pp. 145-147), as some of the entries were known to be extremely sensitive to this disease. We identified two new sources of drought tolerance, JG 62 and ICC 5680; in addition to the previously known sources, ICC 4958 and ICC 10448. The two new sources are, however, very susceptible to fusarium wilt disease and this perhaps prevented their earlier detection as drought-tolerant sources because drought screening fields at ICRISAT Center are affected by wilt.

Characterization of Drought-tolerant Sources

Further studies on physiological characterization of drought-tolerant genotypes revealed that ICC 4958, a genotype with a longer and more voluminous root system (ICRISAT Annual Report 1988, p. 60) and a large seed (100-seed mass = 31.7±0.67 g), also possessed a rapid rate of pod and seed development. It thus accumulates a greater proportion of seed mass earlier than Annigeri. This is another trait which perhaps enables ICC 4958 to escape from relatively more severe terminal soil and atmospheric drought.

Another drought-tolerant genotype, JG 62, has the unique feature of bearing twin pods at the basal nodes. This trait confers a greater sink strength at the basal nodes, where the character is well expressed (ICRISAT Annual Report 1976-77, p. 104). This character is, in a way, similar to the bold-seeded character of ICC 4958, where the seed mass at basal nodes is approximately twice that at more apical nodes.

Table 1. Mean pinnule number and leaf area per compound leaf in five chickpea genotypes on a Vertisol, ICRISAT Center, postrainy season 1988/89.

Genotype	Mean pinnule number	Leaf area (cm^2)
Annigeri	13.7	3.28
ICC 4958	13.9	6.44
ICC 10448	13.7	2.47
JG 62	13.0	3.95
ICC5680	8.1	2.59
SE	+0.22	±0.122
CV (%)	4.9	9.2

We found significant genotypic differences in leaf area (size) per compound leaf (Table 1). Smaller leaf size of ICC 5680 or ICC 10448 could be useful in reducing transpirational losses. The smaller leaf size in ICC 5680 was due to fewer pinnules (Table 1) and in ICC 10448, it was due to smaller pinnule size. On the other hand, ICC 4958 has the largest leaf size of the tested genotypes, and its adaptation to drought seems to be related more to the proliiicity of its roots, which perhaps extract more water, than to the conservation of water loss through reduced transpirational area.

Tolerance to Low Temperature During Flowering and Pod-set

We carried out agronomic evaluation of cold-tolerant selections at the ICRISAT Cooperative Research Stations at Hisar and Gwalior in India.

We studied the effects of two levels of irrigations (presowing irrigation only and no irrigation), two dates of sowing (13 October and 7 December), and two spacing + fertilizer treatments (30 cm x 10 cm + no fertilizer, and 20 cm x 10 cm + 200 kg diammonium phosphate ha^{-1}) with 14 cold-tolerant selections and two control cultivars, Pant G 114 and Gaurav, at Hisar. At Gwalior, we compared another set of 14 cold-tolerant selections and a promising ICRISAT variety, ICCV 6 (ICCC 32), with JG 315, the control variety of the region.

At Hisar, an above-average presowing rainfall (671 mm) and a well-distributed winter rainfall and moderate climatic conditions during the crop season encouraged profuse crop growth and caused widespread lodging, which masked responses to irrigation and overall performance of the genotypes. Although some of the cold-tolerant genotypes ranked higher in yield than the controls, the difference was significant only in the case of ICCV 88512, compared to Gaurav, at 20 x 10 cm with 200 kg diammonium phosphate ha^{-1} (3.03 vs 2.51 t ha^{-1}; SE ± 0.171) and in the October sowing (3.43 vs 2.61 t ha^{-1}; SE ±0.171). At Gwalior, only CTS 30521 and CTS 10886 significantly outyielded the control, JG 315. Promising genotypes are being reevaluated in these environments during the 1989/90 crop season.

We made preliminary observations on the physiological characterization of cold-tolerant selections during December 1988 and January 1989. Minimum grass temperatures during this period ranged from -5° to 2°C. We examined pollen fertility by the acetocarmine dye and by germinating the pollen in nutrient solution (10% sucrose, 10 mg kg^{-1} boric acid, 300 mg kg^{-1} $CaNO_3$, 200 mg kg^{-1} $MgSO_4$, and 100 mg kg^{-1} KNO_3). We found that pollen was viable in all the genotypes by both the methods. However, pollen grain germination was quickest in cold-tolerant selections with a rapid growth of the pollen tube, which ruptured and discharged its content in 30-45 min. Germination and growth of the pollen tube was very slow in the cold-susceptible genotypes during the same period. Detailed studies on these aspects are planned.

Early Growth Vigor

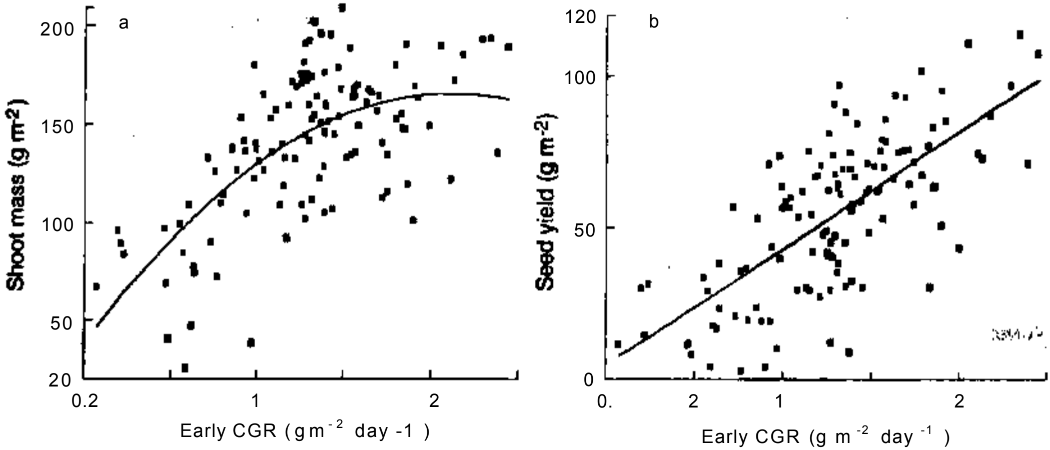
In short-season chickpea-growing environments such as those in the warm- winter tropical environments of South Asia, represented by ICRISAT Center, yield is limited by low shoot mass production. However, harvest indices are high. The only way yield can be increased in these and other similar environments is by increasing the shoot mass. Increasing shoot mass by using long-duration varieties has a penalty in lower harvest indices because of the terminal drought and heat stress.

Another approach to increase shoot mass is to identify genotypes with high initial growth vigor (shoot dry matter of seedlings around 20 days after sowing [DAS]) and faster early crop growth rates (CGR), that would contribute to a larger shoot mass at harvest. A set of 120 germplasm lines (including kabuli and desi, large and small seed, early and late flowering, and three controls for each region) were evaluated at three sites: 1CRISAT Center, Hisar, and Gwalior. Genotypic differences in initial vigor and early CGR were found in all the three environments, but these differences were related to shoot mass or yield at harvest only in the short-duration environments at ICRISAT Center (Fig. 1). This trait thus seems to be potentially useful for increasing chickpea yield in short-duration environments.

Screening for Multiple Stresses

Evaluation of Cultivated Species

Identification of resistant sources to physical and biotic stresses is one of the important activities of the ICARDA-ICRISAT kabuli chickpea project. Screening of germplasm was first started with ascochyta blight *(Ascochyta rabiei)* in 1978 and it was subsequently extended to fusarium wilt *(Fusarium oxysporum),* leaf miner *(Liriomy/a cicerina),* seed beetle *(Callasobruchus chinensis),* cyst nematode *(Hetcrodera ciceri),* and cold. Results of screening from 1978 to 1989 are shown in Table 2. Resistant sources



$y = 6.29 + 167.82x - 44.14x2$ ($r^2 = 0.43$)

$y = 5.00 + 47.94x$ ($r^2 = 0.50$)

Figure 1. Relationship between early crop gro wth rate (CGR) and (a) shoot mass, and (b) seed yield at harvest in 123 chickpea genotypes grown on a Vertisol, ICRISA T Center, postrainy season 1988/89.

have been found for all the stresses except seed beetle and cyst nematode.

Evaluation of Wild Species

During the 1988/89 season, we continued evaluation of eight wild annual *Cicer* species, which we began in the 1987/88 season. Results of 2 years' evaluation are summarized in Table 3. Higher susceptibility rating from the 2 years' evaluation was considered as the actual rating. We found sources of resistance for all the five stresses. Wild species are the only sources of resistance to cyst nematode and seed beetle. We also found higher levels of resistance in the wild

Table 2. Reaction of chickpea germplasm accessions to some biotic and abiotic stresses at Tel Hadya, Syria, between 1978 and 1989.

Scale[1]	Ascochyta blight	Fusarium wilt	Leaf miner	Seed beetle	Cyst nematode	Cold
1	0	5	0	0	0	0
2	0	1	0	0	0	0
3	16	2	0	0	0	15
4	16	9	8	0	0	114
5	1048	17	201	0	0	656
6	345	45	509	164	604	491
7	1814	40	1 167	185	808	704
8	1168	380	8	1551	0	1724
9	11284	1143	3585	3253	3856	1811
Total tested	15691	1642	5478	5153	5268	5515

1. Scale: 1 = free; 5 = intermediate; and 9 = killed.

Table 3. Reaction of germplasm accessions of *Cicer* spp to some biotic and abiotic stresses at Tel Hadya, Syria, during 1987/88 and 1988/89.

	Blight		Leaf miner		Seed beetle		Cyst nematode		Cold	
Scale[1]	No.[2]	Species[3]	No.	Species	No.	Species	No.	Species	No.	Species
1	0		0		20	1,3,4,5,7	0		1	1
2	5	5,6	15	2,5,8	12	1,5,6,7	0		20	1
3	63	1,3,5,6	36	1,4,5,6	4	1,7	12	1	24	1,4,5,6
4	2	4,6	25	1,4,5,6,7	3	1,6,7	0		15	4,5,6
5	25	1,4,5,6,7	28	1,5,6,7	2	3,5	11	1,7	8	6
6	14	1,5,6,7	9	6,7	8	1,5,7	0		7	5,6,8
7	12	1,2,4,5,7	6	1,5,7	18	2,4,5,7	5	7,8	11	2,5,6,8
8	2	1,3	0		53	2,5,6,7,8	30	1,5,6,7,8	13	5,6
9	8	5,7,8	2	1	10	5,6,8	79	2,3,4,5,6,7	38	2,3,5
Total	131		121		130		137		137	

1. Scale: 1 = free; 5 = intermediate; and 9 = killed.
2. Number of tested accessions falling into category scale.
3. Species code:1 = *C. bijugum,* 2 = *C. Chorassanicum;* 3 = *C. cuneatum;* 4 = *C. echinospermum;* 5 = *C. judaicum;* 6 = *C. pinnatifidum;* 7 - *C. reticulatum;* and 8 = *C. yamashitae.*

species for ascochyta blight, leaf miner, and cold than in the cultivated species. The most important species from the point of view of stress resistance is *C. bijugum.* Unlike cultivated landraces where resistance to only one stress was obtained, several wild species accessions were resistant to two or more stresses. Thus we identified lines with multiple stress resistance.

Biotic Stresses

Diseases

Yield Evaluation of Some Wilt- and Root Rot-resistant Chickpea Germplasm Accessions

We evaluated the yield of 36 chickpea germplasm accessions found resistant to wilt *(Fusarium oxysporum* f. sp *ciceri*) and dry root rot *(Rhizoctonia bataticola).* These were lines found resistant in the wilt and root rots nursery at ICRISAT Center during the past 10 years. The evaluation was carried out in the wilt and root rots nursery at ICRISAT Center and in normal fields at ICRISAT Cooperative Research Stations at Gwalior and Hisar during the 1988/89 season. Four released cultivars, ICCV 6, K 850, Annigeri, and Pant G 114, representing different maturity groups were included as controls. The trials were conducted under rainfed conditions at all the three locations.

Of the 36 resistant test lines, only ICC 13053 showed high mortality (88%) and all others showed 30% or less incidence. Among the four control cultivars, ICCV 6 and Annigeri showed less than 20% mortality but K 850 and Pant G 114 showed very high mortality (64-98%). In the wilt and root rots nursery at ICRISAT Center, 23 lines gave significantly *(P* < 0.05) higher yield than the highest-yielding control cultivar Annigeri. Some of the accessions such as ICCs 1437, 2595, 9023, 9032, 12460, 12989, 13024, 13114, and 13213 gave more than double the yield of Annigeri.

At Gwalior, in a normal field, the highest-yielding control cultivar was ICCV 6 (2.43 t ha^{-1}). ICC 11223 was the highest-yielding test line (2.72 t ha^{-1}) but it was not significantly (*P*>0.05) better than the control cultivar. At Hisar, the highest-yielding control cultivar was Pant G 114 (4 t ha^{-1}).

The germplasm accessions selected for yield evaluation were those with proven resistance/ tolerance to wilt and root rots. Though the yield was evaluated for only one season, the present study indicates that many of the wilt and root rot-resistant lines have good yield potential. It is surprising to find several lines outyielding the control cultivar Annigeri at ICRISAT Center.

New Wilt and Root Rot Resistance Sources of Chickpea and their Agronomic Evaluation

Several sources of resistance to fusarium wilt *(Fusarium oxysporum* f. sp *ciceri)* of chickpea are available. We evaluated new germplasm numbering 1283 accessions collected mainly from Madhya Pradesh and Rajasthan states of India, and Bangladesh in the wilt and root rot nursery at ICRISAT Center, during the past three seasons (1985/86-1987/88). During the 1988/89 season, we evaluated the wilt reaction and yield of the resistant accessions in the wilt and root rots nursery itself.

We evaluated 428 accessions during the 1985/ 86 season, 395 accessions during the 1986/87 season, and 460 accessions during the 1987/88 season. The procedure followed for evaluation was to sow 40 seeds per accession in a 4-m row in the first year and select lines with less than 20% mortality. We sowed the seeds collected from such accessions after eliminating susceptible plants in the next year in two 4-m rows replicated twice in a randomized-block design (RBD). The accessions with less than 10% mortality in the second year were considered resistant. A susceptible cultivar JG 62 was sown after every two test rows.

The final observations on mortality due to wilt and root rot were recorded at physiological maturity stage. The susceptible cultivar JG 62 showed 100% mortality in all the three years of evaluation. Dry root rot incidence was also high in all seasons. Several lines that showed resistance to wilt succumbed to dry root rot. The lines that showed <10% mortality were uprooted and examined for the extent of root necrosis due to dry root rot, and all of them were found to have very extensive root necrosis. Out of 1283 accessions evaluated, 117 accessions showed less than 20% mortality in the first year of screening, and of these 38 accessions showed less than 10% mortality in the second year of screening. Several resistant accessions showed higher yield potential than the resistant and high-yielding short-duration control cultivar Annigeri.

Chickpea lines with less than 10% mortality in a wilt-sick plot at ICRISAT Center are shown in Table 4.

Table 4. Chickpea lines found resistant to fusarium wilt and root rots in field screening at ICRISAT Center, 1985/86 - 1987/88.

Serial number	Chickpea lines	Serial number	Chickpea lines
1	ICC 12969	20	ICC 15075
2	ICC 12989	21	ICC 15081
3	ICC 13024	22	ICC 15090
4	ICC 14303	23	ICC 15094
5	ICC 14516	24	ICC 15105
6	ICC 14528 K	25	ICC 15108
7	ICC 14532	26	ICC 15125
8	ICC 14619	27	ICC 15127
9	ICC 14631	28	ICC 15133
10	ICC 14671	29	ICC 15135
11	ICC 14680	30	ICC 15140
12	ICC 14681	31	ICC 15146
13	ICC 14691	32	ICC 15166
14	ICC 14734	33	ICC 15168
15	ICC 14735	34	ICC 15178
16	ICC 14762	35	ICC 15228
17	ICC 14764	36	ICC 15230
18	ICC 14795	37	ICC 15233
19	ICC 15023	38	ICC 15236

Role of Tall and Erect Plant Type and Wider Row Spacing in the Management of Botrytis Gray Mold

Of late, the economic importance of botrytis gray mold disease of chickpea caused by *Botrytis cinerea* in northeast India, Nepal, and Bangladesh has been realized. To increase or stabilize chickpea production in this region, appropriate practices for the management of this disease need to be adopted. In our experience, all the lines that showed tolerance at Pantnagar, Uttar Pradesh, over five seasons (1982-87) were badly affected at Rampur in Nepal where conditions are more favorable for disease development. Botrytis gray mold is a disease favored by high relative humidity in the crop canopy. In a field trial conducted at Pantnagar during the 1988/89 postrainy season, we studied the influence of tall, erect, compact, and spreading chickpea genotypes and of interrow spacing on disease development and grain yield to determine their possible use in the management of the disease.

The two genotypes used were ICCL 87322 and H 208. ICCL 87322 is a newly developed breeding line with tall, erect, and compact growth habit. H 208 is a traditional bushy and spreading type. We sowed these genotypes in two sets of plots at two different row spacings: the normal 30 * 10 cm and an altered and wider 60 x 5 cm spacing. The experimental design followed was RBD with three replications. The plot size was 5.4 m^2. We artificially inoculated the whole trial with botrytis gray mold inoculum (40 000 conidia mL^{-1}) on 7 February and 14 February, 1989. We sprayed one set of these plots twice with 0.2% Ronilan® on 23 February and 10 March; and did not spray the others. We recorded grain yield and observations on botrytis gray mold severity at flowering and early podding stage using a 19 scale (1 = no symptoms; 9 = all plants killed).

We calculated the disease severity scores and grain yield in different treatments. Ronilan® spray significantly reduced gray mold severity in plots of H 208 sown at 60 x 5 cm but had no effect on any other treatment. However, the tall, erect, and compact genotype ICCL 87322 showed significantly ($P < 0.05$) less disease than H 208 irrespective of fungicide treatment or row spacings.

Both the genotypes gave significantly higher grain yields at wider row spacing under both sprayed and nonsprayed conditions. ICCL 87322 significantly outyielded H 208 in sprayed and nonsprayed conditions at both the spacings. It yielded over 51 ha^{-1} at the wider spacing of 60 x 5 cm. The results of the experiment clearly show that botrytis gray mold can be better managed by the use of tall, erect, and compact genotypes and wider row spacing without any yield loss.

Ascochyta Blight Resistance Screening at ICARDA

We sowed an area of 8.6 ha with segregating materials (F_2 - F_6) and breeding lines. We evaluated these materials against a mixture of six races (1 through 6) of *A. rabid.* Despite a very dry and warm spring, the disease development was satisfactory and allowed effective screening of the material. Out of a total of 14 451 F_4 - F_6 progenies, 449 progeny lines were rated 3 and 4096 rated 4 on a 1-9 scale, where 1 - free and 9 = killed. Out of 1078 newly bred lines (F_7 - F_9 generations), 72 lines had a rating of 3, 463 lines had a rating of 4, and 378 lines had a rating of 5.

Comparison of Screening at Seedling and Adult Plant Stage

We individually screened 352 germplasm and breeding lines found resistant (ratings 3 and 4) against a mixture of four races of *A. rabid in* the field against race 3, race 6, and a mixture of 1-4 races. The following conclusions can be drawn from the results presented in Table 5. First, screening lines up to adult plant stage is more reliable than screening only at seedling stage because many lines found resistant at the seedling stage became susceptible at the adult plant stage. Second, greenhouse screening is harsher than field screening against a mixture of races 1-4 because all the lines tested in the greenhouse were resistant in the field screening. Third, 0

Table 5. Reaction of lines having field resistance to ascochyta blight to races 1-4 in the greenhouse test at Tel Hadya, Syria, 1988/89.

	Reaction on 1-9 scale[1]									
Race	1	2	3	4	5	6	7	8	9	Total
					Seedling stage					
Race 3	0	6	41	101	105	42	17	3	0	315
Race 6	0	0	1	12	33	139	97	24	9	315
Mixture of 1-4 races	1	2	2	21	91	52	25	8	2	202
					Adult plant stage					
Race 3	0	0	0	33	56	51	60	70	45	315
Race 6	0	0	0	0	1	5	11	35	263	315
Mixture of 1-4 races	0	0	2	6	76	28	33	31	26	202

1. Scale: 1 = free; 5 = intermediate; and 9 = killed.

lines were resistant (1-4 rating) against race 6, 33 lines against race 3, and 8 lines against a mixture of races 1 -4. Fourth, only one selection, S 87110, was resistant to both race 3 and a mixture of four races, and the remaining lines were resistant to either race 3 or a mixture of four races.

Chickpea Virology

We further studied the luteovirus, isolated from chickpea plants showing stunt symptoms at ICR1SAT Center in order to understand its relationship with the bean leaf roll virus. We modified a purification procedure developed earlier (1CR1SAT Annual Report 1987, p. 147). We included treatment with organic solvents prior to polyethylene glycol (PEG) precipitation. We also modified the gradients for rate zonal density gradient centrifugation in sucrose solutions. We produced a polyclonal antiserum for purified virus, which had minimal reaction with healthy plant material.

We developed a simple method for processing the luteovirus for routine detection of the luteovirus in individual chickpea plants. Using this, it was possible to detect the luteovirus in direct antigen coating (DAC)- Enzyme-Linked Immunosorbent Assay (ELISA), which is by far the simplest of all ELISA procedures.

We studied serological relationships in ELISA, utilizing antisera of several luteoviruses. We used partially purified virus from single plants and purified virus extracted from several plants. The virus reacted with the homologous antiserum, bean leaf roll, subterranean clover red leaf, soybean dwarf, and legume yellow virus antisera. We are currently using protein A and F $(ab)_2$ fragments from the homologous antiserum in ELISA to obtain quantitative data.

We also collected chickpea plants showing stunt symptoms at Hisar. A luteovirus was purified and we are currently conducting comparative tests on the 1CRISAT and Hisar isolates.

We conducted transmission tests with stunt-infected plants utilizing *Aphis craccivora, Myzus persicae,* and *A. gossypii. Aphis craccivora* transmitted the virus efficiently from one chickpea plant to another. Additionally, *M. persicae* as well as *A. gossypii* transmitted the virus from one chickpea plant to another, but less effectively than *A. craccivora.*

Insect Pests

Pest Incidence

Although infestations were very low in 1988/89, *Helicoverpa armigera* was the dominant insect pest on chickpea at ICRISAT Center and at all the other locations surveyed in southern Asia.

In the Mediterranean region, as in previous years, the leaf miner *(Liriomyza cicerina)* was reported to be the most widespread field pest.

Pod Borer *(Helicoverpa armigera)*

Host Resistance

During 1988/89, we evaluated 1039 new germplasm accessions in nonreplicated plots in the pesticide-free Vertisol area at ICRISAT Center for *Helicoverpa* damage at podding stage. We also screened lines bred for *Helicoverpa* resistance and wilt as well as the breeders' elite material for borer susceptibility under pesticide-free conditions at ICRISAT Center and at Hisar. There was severe wilt incidence in one of our experimental fields, BM-8A, where several entries were affected. However, some of the selections survived up to maturity. These selections have been advanced for further testing.

We further tested our promising selections at different locations in India in collaboration with the All India Coordinated Pulses Improvement Project (AICPIP) entomologists. We supplied seeds of 6-8 selections of different maturities to 10 AICPIP entomologists for testing in nonprotected plots, along with selections from the national program. The results obtained from these tests are being processed to ascertain their suitability to different agroecological zones and to check the stability of their resistance to *Helicoverpa.*

We also supplied seeds for the International Chickpea *Helicoverpa* Resistance Nursery (ICHRN) trials in seven countries including India. Altogether we supplied 35 trials of different maturity durations to determine the relative importance of insect pests in different agroecological conditions.

In large isolation plots (0.1 ha each) on farmers' fields in Shirapur (Sholapur district, Maharashtra), the Helicoverrpa-resistant selections, ICCL 86102, ICCV 7, and ICC 506, showed 1.8%-4.4% pod borer damage under nonprotected conditions. In a choice situation in the same village, ICC 506 showed 0.3% pod damage, whereas 22.4% pod damage was recorded in the local cultivar. These results confirm the high level of borer resistance observed in the selections made at ICRISAT Center in small plot tests.

Mechanisms of Resistance

We continued our laboratory studies on the mechanisms of resistance to *Helicoverpa* in chickpea genotypes using moths and larvae produced under asceptic conditions. In studies of oviposition preference, using flowering twigs with green pods of resistant and susceptible genotypes, we found that there were, on average, 56% fewer eggs on ICC 506 and 36.7% fewer eggs on ICCX 730008-8 than on the control Annigeri. We noticed 46% fewer eggs on ICCL 86101 and 3.4% fewer eggs on ICCX 730008-8 compared with the susceptible genotype, ICCX 730266-3. In the medium-long duration group, we found 98.5% fewer eggs on ICCX-730020-11-1, 68% fewer eggs on ICCL 86111, and 56% fewer eggs on ICCL 86105 than on the susceptible ICC 3137. The kabuli selection ICCX 730244 had 33%) lesser eggs than the control L 550.

To study the antibiosis present in leaves and pods of borer-resistant selections, we separately reared freshly hatched *Helicoverpa* larvae on field-collected leaves and green pods of different genotypes. We measured larval mortality and mass of the freshly formed pupae reared on each diet to identify possible antibiotic effects in the borer-resistant genotypes. These studies showed that when *Helicoverpa* larvae were fed on food derived from resistant genotypes as opposed to the susceptible genotypes, both larval mortality and loss in pupal mass were higher.

Drought and Incidence of Pest Damage

Information available on the relationship between drought and insect-pest outbreaks suggests that drought-stressed chickpea may suffer greater pod borer damage than chickpea growing under optimum moisture conditions. We therefore set up experiments to study the influence of water deficits on *H. armigera* incidence in chickpea. Experiments carried out at ICRISAT Center in collaboration with the Biochemistry Unit showed that drought-stressed chickpea accumulates higher levels of proline, reducing sugars, and free nitrogen (N) than irrigated chickpea.

Differences between treatments increased around the time of flowering and podding. The highest proline and sugar concentrations were observed in the nonirrigated treatments during and after podding—the phenological stages most susceptible to damage by *H. armigera.* Results for one of the two genotypes tested are shown in Figure 2. We found no differences in levels of pod borer attack in irrigated vs moisture-stressed chickpea, mainly because the pest's incidence was low on ICRISAT farm in the 1988/89 postrainy season. However, when these osmolytes were tested separately in laboratory experiments, the caterpillars showed a significant (*P*<0.05, paired V-test) increased feeding response in the presence of sucrose and proline (Fig. 3). We intend to study this insect-plant-environment interaction further to obtain knowledge that will:

(1) help plant breeders select for cultivars that are not extensively damaged by pests under conditions of drought;

(2) indicate whether soil moisture conservation measures need to be included in an overall plan of integrated pest management.

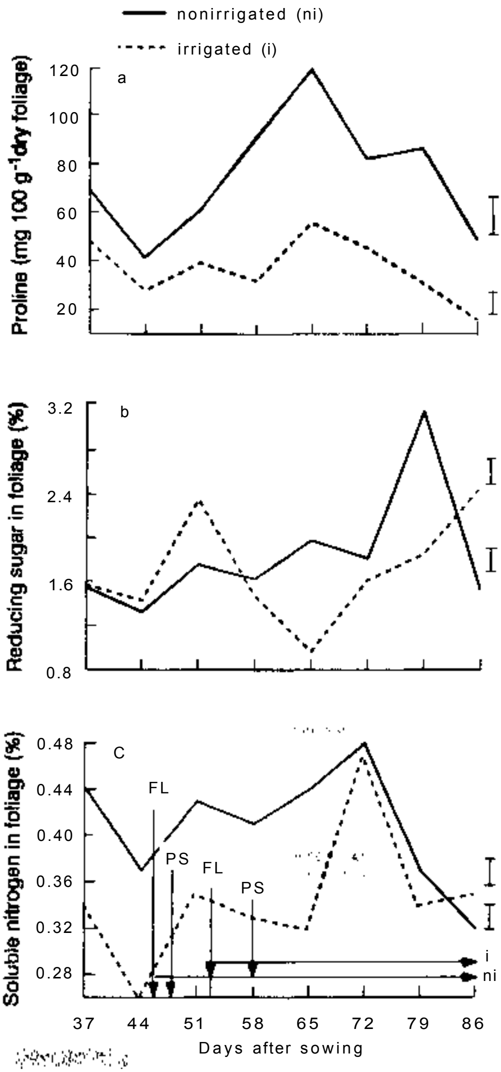


Figure 2. Effect of drought stress on (a) proline, (b) reducing sugar, and (c) soluble nitrogen accumulation in the foliage of chickpea cultivar Annigeri, ICRISAT Center, postrainy season 1988/89.

Plant Nutrition

Further Studies on Natural Nonnodulating Mutants

We studied further the natural nonnodulating mutants (nonnods) of four genotypes (suffixed by M) reported earlier (ICRISAT Annual Report 1987, pp. 155 156) to determine their suitability as reference nonfixing controls in biological nitrogen fixation (BNF) studies. We included all the mutants, their parents, barley *{Hordeum*

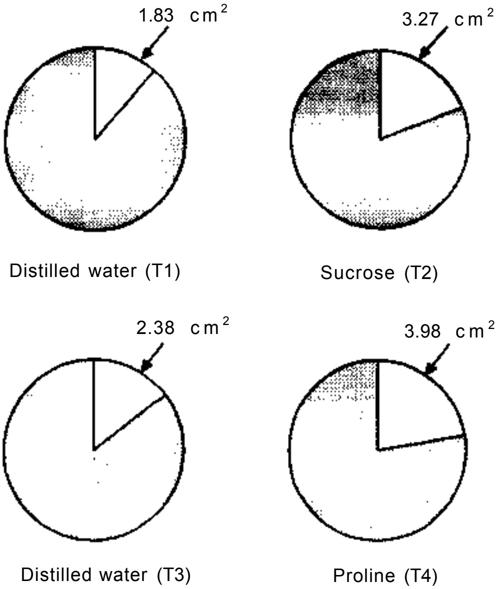


Figure 3. The effect of sucrose and proline on the feeding response of Helicoverpa armigera *caterpillars (4th instar), ICRISAT Center, 1989. Area shown in white is the disc area eaten; chemicals were presented to the insect on glass fiber discs (Whatman, GF/A, 4.25 cm diameter).*

vulgare L.), and linseed *(Linum usitatissimum* L.) in a field trial in 1988/89 at the ICRISAT Cooperative Research Station, Gwalior, with six N fertilizer (as urea) levels: 0, 20, 50, 100, 150, and 200 kg N ha^{-1} in three replications. We irrigated the trial twice during the crop growth period of about 126 days. Growth differences between N-fertilized and unfertilized nonnods were measurable only in the samples taken at 92 DAS, but not at 64 DAS. Nonnods fertilized with N to an optimum level had a growth pattern similar to their respective nodulating genotypes, suggesting that the nonnods were appropriate nonfixing controls. The growth of linseed was similar to that of the nonnods, both with and without N fertilizer, suggesting that this nonlegume would also be an appropriate nonfixing control for chickpea.

The nonnods showed apparent N deficiency symptoms at 58 DAS when grown without N fertilizer (Table 6). Unlike nonnod groundnuts (ICRISAT Annual Report 1981, p. 189), all the chickpea nonnod lines had apparently normal root hairs. Shoot mass and grain yield of nonnods responded to N-fertilizer application. Grain yield of high-nodulating lines K 850 and ICC435 decreased and those of low-nodulating lines Annigeri and Rabat increased with N application.

These interactions between nodulation and N fertilizer status have obvious implications on the methodology of evaluating breeding material. Under high soil N conditions, selection of poorly nodulating genotypes may be favored.

Grain and Food Quality

Flour Particle Size Index

The physicochemical characteristics of desi and kabuli types received increased attention. The distribution of flour particle size in ground flour, referred to as the particle size index (PSI), is related to grain hardness. We determined the PS1 in four desi (ICCV I [ICCC 4], ICCC 37, ICCC 42, and Annigeri) and five kabuli (ICCV 2, ICCV 3, ICCV 4, ICCV 5, and ICCV 6 cultivars. Whole seed and dhal samples of these cultivars were dried in an oven at 55° C for 2 h and ground in Buhler and Udy mills separately. Ground samples (10 g) were sieved through 250 and 150 µm mesh openings. Samples retained on each of the sieves were calculated as a weight percentage of the whole sample and expressed as PSI. As shown in Table 7, the PSI values were considerably higher in the whole seed than in dhal samples. The lower the proportion of fine particles in a flour sample, the harder is the grain. Udy mill yielded finer flour compared to Buhler mill. Although there were no clear differences in the PSI values between the desi and kabuli types, the differences among the cultivars of desi or kabuli types were significant ($P<0.01$ based on F test). The significance of this finding in relation to dehulling properties of desi and kabuli chickpea has to be investigated.

Table 6. Salient characters of nonnodulating mutants compared with their parents at 0 kg (0 N) and 100 kg N ha-[1] (100 N), Gwalior, postrainy season 1988/89.

Chickpea[1] line	Nodule mass (g rrr^2) at 58 DAS		Apparent N-deficiency symptoms[2]		Above-ground biomass (t ha-')		Grain yield (t ha')	
	ON	100 N	0N	100 N	0N	100 N	ON	100 N
Annigeri	7.0	2.6	-	-	9.33	8.93	2.91	3.20
Annigeri-M	0	0	+	-	5.73	5.35	1.56	2.57
ICC 435	10.8	7.1	-	-	7.59	6.17	3.57	2.87
ICC 435-M	0	0	+	-	4.70	6.70	2.24	3.02
K 850	12.3	6.1	-	-	6.87	7.02	3.70	3.42
K 850-M	0	0	+	-	7.59	7.62	2.69	3.69
Rabat	5.0	4.9	+	-	5.32	6.96	2.55	3.22
Rabat-M	0	0	+	-	6.70	7.52	2.06	3.44
SE	±1.161[3]				±1.657		±0.367	
CV (%)	38.2				32.1		19.2	

1. Genotype-M is the nonnodulating mutant of the genotype given.
2. Poor plant growth, small leaves with narrow leaflets, light green foliage, conspicuous red-brown margins in Annigeri-M but less conspicuous in other mutants.
3. Nonnods have been excluded from the analysis.

Table 7. Particle size index (PSI) of newly developed chickpea, ICRISAT Center, postrainy season 1987/88[1].

	Percentage of particles retained on sieve *(μm)*							
	Whole seed				Dhal			
	Buhler		Udy		Buhler		Udy	
Cultivar	250	150	250	150	250	150	250	150
Desi								
ICCV 1 (ICCC4)	13.6	30.3	12.4	16.0	0.9	18.2	1.5	4.6
ICCC 37	7.4	22.5	18.5	14.4	2.0	12.7	1.4	4.3
ICCC 42	6.2	20.1	16.3	14.6	1.3	11.0	1.5	3.8
Control								
Annigeri	13.4	27.1	16.6	14.6	1.1	12.5	0.8	2.9
Kabuli								
ICCV 2 (ICCL 82001)	8.9	29.4	8.8	14.7	1.0	20.4	1.3	3.3
ICCV 3 (ICCL 83006)	20.0	32.5	9.4	14.9	0.7	14.5	1.8	4.8
1CCV 4 (1CCL 83004)	4.3	16.9	6.6	12.8	1.0	18.9	1.1	3.9
1CCV 5 (1CCL 83009)	3.8	15.9	6.3	11.4	0.5	13.9	1.7	4.2
ICCV 6 (ICCC 32)	5.5	21.8	8.1	15.5	1.1	17.5	1.7	5.4
SE	±0.79	±1.07	±0.20	±0.46	±0.24	±0.79	±0.13	±0.29

1. Based on two determinations of each cultivar.

Effect of Scarification on Protein Fractions and Amino Acids

We studied the effect of scarification of chickpea cotyledons on protein quality. We scarified Annigeri cotyledon samples for 0, 2, 4, 8, and 12 min in a Tangential Abrasive Dehulling Device (TADD) and collected the resulting dhal and flour samples at each time interval. We estimated the distribution of various solubility fractions in dhal and powder fractions and determined the amino acid composition of dhal and powder fraction. The albumin fraction in dhal samples decreased with increased scarification time. Powder fractions contained a higher concentration of albumin and glutelin fractions compared to dhal fractions, and the reverse was true for the globulin fraction. Amino acid composition data revealed that the scarification process did not adversely affect the protein quality of dhal or powder fractions.

Chemical Composition of Chickpea Leaf

As part of our collaborative work with the Legumes Entomology unit on the nutritional ecology of *H. armigera,* we assessed the chemical composition of chickpea leaf. We freeze-dried leaf samples (collected at 40 DAS) of ICC 506 (resistant to pod borer) and Annigeri (susceptible to pod borer) grown in irrigated and nonirrigated fields. The leaf samples were analyzed for their proximate composition. Starch content of leaf samples of ICC 506 ranged between 15.9 (nonirrigated) and 19.7% (irrigated), while it ranged from 18.9 to 19.1% (SE ±0.32) in Annigeri showing no significant ($P>0.05$) differences between the two treatments. Moisture, protein, soluble nitrogen, soluble sugars, reducing sugars, and nonreducing sugar contents of Annigeri and ICC 506 did not reveal any significant ($P>0.05$) effects due to irrigation. Proline, which has a tendency to accumulate in drought conditions, was significantly higher in leaf samples of both Annigeri (69.0 mg $[100\ g]^{-1}$) and ICC 506 (79.5 mg $[100\ g]^{-1}$) from nonirrigated than those from irrigated fields (Annigeri — 47.6 mg $[100\ g]^{-1}$, ICC 506—59.0 mg $[100\ g]^{-1}$.

Plant Improvement

Breeding Short- and Medium-duration Desi Types

Fusarium wilt, dry root rot, *Helicoverpa* pod borer, and drought are the major stresses for short- (SD) and medium-duration (MD) chickpeas. We made crosses involving parents carrying resistances to one or more of these stresses. Populations thus developed are being screened. Line 1CCL 86111 combines high yield, wilt resistance, and *Helicoverpa* tolerance. ICCC 37, a wilt- and root rot-resistant cultivar, which had been performing well in SD environments, was named Kranti and was released by the Government of Andhra Pradesh for general cultivation. We contributed sixty-eight entries for international chickpea screening nurseries and SD and MD trials.

The success of extra short-duration (ESD) kabuli materials in SD environments led us to select similar lines in desi types. A number of such lines are being tested in advanced yield trials. We evaluated, for the first time, the newly developed wilt-resistant and ESD desi chickpea lines, ICCV 88201 and ICCV 88202, in replicated yield tests, and in relatively large plots of 600 m^2 at ICRISAT Center. In a rainfed, non-protected field, they yielded a little over 1 t ha^{-1} in 86 days. The seeds are attractive, yellowish, and medium-sized (seed mass 20 g $[100\ seeds]^{-1}$). By virtue of their ESD, they are expected to fit well in drought-prone environments and as a catch crop in various cropping systems.

Breeding Long-duration Desi Types

Long-duration chickpeas, grown in relatively cool climates, can be attacked by ascochyta blight and botrytis gray mold. Wilt, stunt, and *Helicoverpa* pod borer can also affect the crop.

The ascochyta blight screening nursery at Hisar, a facility maintained by the Haryana Agricultural University (HAU), enabled us to select three breeding lines with a rating of 3 on the 1-9 scale (where 1 - free from symptoms, and 9 = killed by the disease), and 36 with a rating of 5. The botrytis gray mold screening nursery at Pantnagar managed by G.B. Pant University of Agriculture and Technology gave a fairly uniform, not too severe disease infestation, and we identified, and selected for further testing, 19 progenies with a rating of 2-3.

We also recorded combined resistances. For instance, one line combined resistances against wilt, stunt, and ascochyta blight. The two most promising trial entries for Hisar had a mean yield of 4.4±0.27 and those for Gwalior 3.3±0.18 t ha^{-1}; they had a score of 5 for ascochyta blight, were wilt resistant, and outyielded the control, H 208, by 13% at Hisar and by 27% at Gwalior.

Breeding Kabuli Chickpea

Kabuli cultivation was extended to SD environments when the proposal from Andhra Pradesh Agricultural University (APAU) to release ICCV 2, an ESD kabuli cultivar, was approved by the Government of Andhra Pradesh in September 1989. We have also received reports of good performance of this cultivar from Maharashtra, Karnataka, Tamil Nadu, Orissa, and Madhya Pradesh. We were able to sow this cultivar as late as 10 January (with irrigation) and thus harvested two crops at ICRISAT Center between October 1988 and March 1989 (Fig. 4). This suggests that the cultivar can be sown at varying times in SD environments, thus giving farmers considerable flexibility in the cultivation of chickpea.

We gave greater emphasis to multiple resistance breeding by involving more than two parents with resistance to different stresses in crosses.

Winter Sowing

Chickpea is spring-sown in the Mediterranean region, but the yield can be substantially increased by sowing it in early winter using asco-

Figure 4. January-sown plots of extra-early chickpea at ICRISAT Center, 1989. October-sown crop is in the background.

chyta blight and cold-tolerant lines. A comparison of spring vs winter sowing has been made over 6 years (1983/84-1988/89) at three sites (Tel Hadya and Jindiress in Syria and Terbol in Lebanon), using common breeding lines ranging between 72 and 384 lines in all trials in each year. The winter of 1984/85 was one of the coldest in the last 50 years, and the springs of 1983/84 and 1988/89, especially at Tel Hadya, were the driest. Tel Hadya is the driest of the three sites, Terbol the wettest, and Jindiress intermediate, with long-term average seasonal rainfall being 330 mm for Tel Hadya, 575 mm for Terbol, and 475 mm for Jindiress. Tel Hadya is located at 282 m above sea level, Terbol above 980 m, and Jindiress 210 m above sea level.

The seed yield data in Figure 5 allow several conclusions: the winter-sown trials on average produced 1.63 t ha^{-1} compared with 1.0 t ha^{-1} for spring-sown trials, giving 62% more yield. The yield differences between winter- and spring-sown trials were larger during dry seasons than normal seasons, as in 1983/84 and 1988/89. During the abnormally cold year (1984/85), yields of winter-sown trials were lower than those of spring-sown trials. The yield potential of winter-sown chickpea is shown by its 10% increase in yield. On an average, the yield was 2.29 t ha^{-1} compared with 0.94 t ha^{-1} average yield of spring-sown chickpea in Lebanon and Syria.

Yield Performance of Newly Bred Lines

Out of 352 newly bred lines evaluated for yield in two seasons (winter and spring) and three locations (Tel Hadya, Jindiress, and Terbol), a large number of lines were found superior in yield, but only a few were at a significant level. Despite severe drought in 1988/89, many lines produced over 2 t ha^{-1} at Jindiress and Terbol and over 1 t ha^{-1} at Tel Hadya during winter sowing. In spring also, many lines produced higher yields than the control.

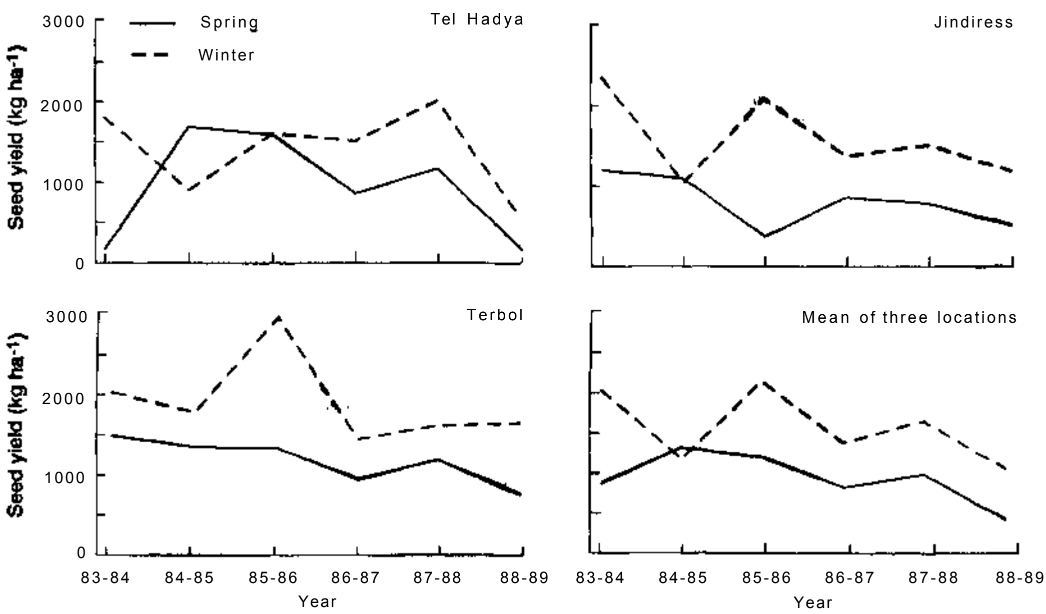


Figure 5. Mean seed yield (kg ha^{-1}) of chickpea grown in two seasons (winter and spring) and 6 year (1983/84-1988/89) at three locations (Tel Hadya. Jindiress, and Terbol).

Extending Chickpea Adaptation

Late Sowing at Higher Latitudes

Growing chickpeas after rice, cotton, maize, and other coarse cereals is becoming a common farming practice in the northern latitudes of the Indian subcontinent. The late harvesting of these crops in November or December often delays sowing of chickpeas beyond its optimum sowing date. The present day cultivars developed for adaptation to sowing at the normal time are poorly adapted to late sowing.

We continued our breeding and testing program, trying to combine adaptation to late sowing with resistance to biotic (wilt, stunt, ascochyta blight, and pod borer) and abiotic (cold and drought) stresses at our Cooperative Research Stations at Hisar and Gwalior. In an advanced yield trial at Hisar, two lines (ICCL 89861 and ICCL 89862) gave similar yields as the control cultivar, Pant G 114 (2.7±0.13 t ha^{-1}), but showed combined resistance to wilt, ascochyta blight, stunt, and pod borer. The best entry in the same trial at Gwalior yielded 3.0±0.12 t ha^{-1}, compared with 2.3±0.12 t ha^{-1} by Pant G-114, and recorded only 9% wilt and 14% stunt.

Breeding for Adaptation to High Fertility and Irrigation

When nutrients and soil moisture are not limiting, chickpeas tend to develop excessive vegetative growth, particularly in LD environments. This often results in lodging and poor yield. We evaluated 38 promising lines, earlier identified as tolerant to lodging (ICRISAT Annual Report 1988, p. 74), in replicated tests at Hisar, Gwalior, and a sewage farm near Gwalior. The crop showed excessive vegetative growth, particularly at the two former sites, and three lines (ICCLs 89851, 89852, and 89853) recorded a rating of < 2 (in a scale of 1-5, where 1 = no lodging and 5 = complete lodging) at all the three sites. One of these (ICCL 89851) produced the highest yield at all the three locations, the best being 4.05±0.19 t ha^{-1} compared with 2.98±0.19 t ha^{-1} produced by H 208, the control at Hisar. We plan to initiate a breeding program using the adapted lines.

Screening for Salinity Resistance

Naturally saline fields often show considerable variation in salinity over short distances, which makes screening for salinity resistance a difficult task. To minimize the effect of distance, a test entry and a standard control were sown in the same hole. The method requires the control to be clearly distinguishable from the test entry. Our test entries were $M_{4\ 5}$ (ICCV 6) progeny bulks with typical kabuli characteristics, and we used the desi variety H 208 as control. The experiment was conducted in saline land at Hisar during the 1988/89 postrainy season. As the visual comparison between test entry and control is rapid, the method of screening, that is, rejection of susceptible genotypes, is suitable for large-scale processing of material, but it can also be used to quantify the difference in salinity resistance between test entries. One way of doing this is by calculating the mean ratio between test entry and control for a character affected by salinity such as salinity symptoms, seed yield, and seed mass.

Breeding and Genetic Studies

Recombination Breeding Among Selected Parents

We continued to combine the desirable characteristics of a chosen set of parents. The parental cultivars are: Annigeri (high yield, wilt resistant), K 850 (high yield, wide adaptation, large seed, strong nodulation), JG 62 (high yield, double podded), and ICC 506 (resistant to pod borer). The procedure involves crossing in all possible two-way and four-way combinations, repeated cycles of intercrossing among desirable segregants, and selection of desired recombinants. In the 1987/ 88 postrainy season, we made selections and intercrosses in different recombination cycles, and evaluated lines derived from the second cycle of recombination in replicated yield tests under irrigated, nonirrigated, and nonprotected environments at ICRISAT Center. The highest-yielding entry gave a mean yield of 3.5±0.15 t ha^{-1}, while the control Annigeri yielded 3.1±0.15 tha^{-1}. We contributed 15 entries to the short- and medium-duration International Chickpea Screening Nurseries.

Tissue Culture

We conducted experiments to improve the technique for micropropagation and to standardize the techniques for plant regeneration from callus and embryo rescue.

Micropropagation

Multiple-shoot induction: We developed a medium to induce multiple shoots from shoot tip explants. Multiple shoots were produced from excised shoot tips of 15-day-old in vitro seedlings and 30-day-old greenhouse-grown plants of cultivated genotypes and wild *Cicer* species. One K 850 explant produced 134 shoots after three transfers.

Root induction: We used different concentrations of auxins in attempts to increase the frequency of rooting of shoot tips from 30- to 45-day-old plants. Roots were produced from some shoots of all the genotypes tested. However, *Cicer cuneatum* gave the best response and the plants were established in the greenhouse.

Regeneration: We induced callus from mature and immature cotyledons of cultivated genotypes and wild species. The callus was transferred to a medium with various hormone combinations for induction of differential structures. Shoot differentials were not produced; however, roots were produced from some callus cultures.

Interspecific hybridization: A major achievement in interspecific hybridization was the production of F_2 seeds between two crosses, *C. arietinum x C. echinospermum* and *C reticulatum x C echinospermum.* Further, in two cross combinations, C *bijugum x C. judaicum* and C. *pinnatifidum x C. judaicum,* very few seeds were produced. Fertilization failed in these because of the elongation of the style out of the keel before the dehiscence of the stamen. Hand pollination was employed to produce F_2 seeds.

Cooperative Activities

International Trials and Nurseries

In the 1988/89 postrainy season, we had seven types of international trials and nurseries, and dispatched 89 sets of genotypes to cooperators in 12 different countries. As in the previous seasons, we sent F_2 populations against specific request for disease resistance, maturity periods, and high yield. Along with trials and nurseries, we sent 614 samples of F_2 populations; thrice as much material as we supplied during 1987/88.

Genotype x environment interactions were high, especially for yield. The best entry 1CCL 86509 yielded an average of 2.96 ± 0.21 t ha^{-1} and exceeded the control by 25.6%.

Distribution of Breeders' Material

In addition to the trial and nursery sets and F_2 populations, we distributed 81 samples of parental lines and 260 samples of breeding materials to cooperators in response to specific requests. The ICARDA-ICRISAT project provided 15 595 entries to 42 countries for use in their breeding programs.

Release of cultivars by national program. One of the major objectives of the ICARDA-ICRISAT project is to strengthen the National Agricultural Research System (NARS) by providing

Table 8. Kabuli chickpea cultivars released by different national programs.

Country	Cultivar released
Algeria	ILC 482, ILC 3279
Cyprus	Yialousa (ILC 3279), Kyrenia (ILC 464)
France	TS 1009 (ILC 482), TS 1502 (FLIP 81-293C)
Italy	Califo (ILC 72), Sultano (ILC 3279)
Lebanon	Janta 2 (ILC 482)
Morocco	ILC 195, ILC 482
Oman	ILC 237
Portugal	Elmo (ILC 5566), Elvar (FLIP 85-17C)
Spain	Fardan (ILC 72), Zegri (ILC 200), Alemna (ILC 2548), Alcazaba (ILC 2555), Atalaya (ILC 200)
Sudan	Shendi(ILC 1335)
Syria	Ghab 1 (ILC 482), Ghab 2 (ILC 3279)
Tunisia	Chetoui (ILC 3279), Kassab (FLIP 83-46C) Amdoun 1 (Be-Sel-81-48)
Turkey	ILC 195, Guney Sarisi 482 (ILC 482)

diverse nurseries to enable them to develop and release varieties for their farmers. Six cultivars, namely TS 1009 and TS 1502 in France, Janta 2 in Lebanon, ILC 237 in Oman, and Elmo and Elvar in Portugal, were released by the NARSs. With these releases, the total number of released cultivars reached 27 in 13 countries (Table 8). An additional 42 lines have been identified from the international nurseries by scientists in 12 countries for prerelease multiplication and/or on-farm testing. These new lines meet the requirements of the national programs as far as seed size, plant height, and maturity are concerned. Further, all new lines are resistant to cold and ascochyta blight.

Cooperation with AICPIP

During 1988/89, ICRISAT was invited to participate in the national crossing program for chickpea. All the 13 crosses allocated to us were completed and F_2 seed will be supplied in 1990. We were asked to contribute ICCL 82108, a double-podded wilt-resistant line, for use in the national crossing block. We contributed 10 new desi lines for testing in AICPIP trials.

Twenty ICRISAT entries performed well in AICPIP coordinated trials and were retained or promoted to advanced yield tests in 1988/89. ICCV 10 performed particularly well in central and South India (Table 9). This line has also shown very good performance in Bangladesh as ICCL 83228. We supplied large quantities of ICCV 2, ICCV 6, ICCC 37, and ICCC 42 for multiplication as foundation seed in India.

Cooperation with Nepal

We continued our close collaborative research with the National Grain Legumes Improvement Programme (NGLIP) of Nepal. An ICRISAT Chickpea Breeder assisted the scientists of NGLIP in the formulation, sowing, and evaluation of trials and in selection work. The trials were conducted at various research stations and in farmers' fields. Several ICRISAT lines included in the replicated yield tests produced more than the control, the highest yielder (ICCL 86237) giving 3.58 ± 0.22 t ha^{-1} against 1.78 ± 0.22 t ha^{-1} of the control (Dhanush). An F_3-derived F_5 line from an ICRISAT cross between the local landrace Dhanush and a recently released cultivar Ska (ICCV 1) produced 3.87±0.28 t ha^{-1} compared with 2.62 ± 0.28 t ha^{-1} produced by the control (Sita). Another F_5 line, IC 4102-21, from an ICRISAT cross between Dhanush and K 850 was outstanding for its resistance to botrytis gray mold in the screening nursery. ICCL 82108 again gave a good performance in the on-farm trials and is likely to be identified for release.

Table 9. Mean seed yield (t ha^{-1}) of ICCV 10 and controls in AICPIP trial locations in Central and South zones in India during 1988/89.

Location	ICCV 10	Controls[2]		SE	Trial mean	CV (%)	No. of entries
		JG 315	BG 244				
Central zone							
Khargone	3.44(1)[1]	2.86	3.28 (4)	±0.125	3.09	8	16
Sardar Krushinagar	2.68 (2)	2.31	2.58 (4)	±0.161	1.99	13	16
Anand	3.93 (3)	3.63 (4)	2.87	±0.263	3.30	17	17
Junagadh	0.40	0.36	0.63	±0.017	0.59	6	16
Dahod	2.30(1)	2.14(3)	1.93	±0.157	1.80	18	17
Rahuri	1.91	1.98	1.41	±0.167	1.78	19	16
Akola	1.54(1)	1.29	1.30(5)	±0.138	1.24	22	17
Kota	3.23(1)	2.84 (5)	2.80	±0.132	2.77	10	15
Arnej	1.10(1)	0.80	0.80	±0.062	0.79	16	16
Pandharpur	2.23 (1)	1.83	1.67	±0.121	1.90	13	16
Powerkheda	2.64 (2)	2.47	2.27	±0.169	2.37	14	16
Derol	3.10(4)	2.72	2.96	±0.252	2.94	15	16
Badnapur	3.37 (4)	2.18	3.99(1)	±0.228	2.89	16	18
Jabalpur	1.22	1.60(2)	1.08	±0.006	1.34	10	16
Mean	2.36	2.07	2.11				
		BDN 9-3	Annigeri				
South zone							
Bangalore	2.87 (4)	–[3]	-	±0.172	2.65	13	11
Coimbatore	1.09(1)	0.92	0.93	±0.058	0.80	15	15
Gulbarga	1.47(5)	1.58(4)	1.63(2)	±0.110	1.39	14	14
ICRISAT Center	2.56(1)	1.68	2.13(5)	±0.174	1.90	18	14
Mean	2.00	1.39	1.56				

1. Values in parentheses are ranks for the top five entries in a trial.
2. The controls differ for both zones.
3. - = Data not available

Publications

Institute Publications

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Linking grain legumes research in Asia: summary proceedings of the Regional Legumes Network Coordinators' Meeting, 15-17 Dec 1988, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 112 pp. ISBN 92-9066-173-9. (CPE 056)

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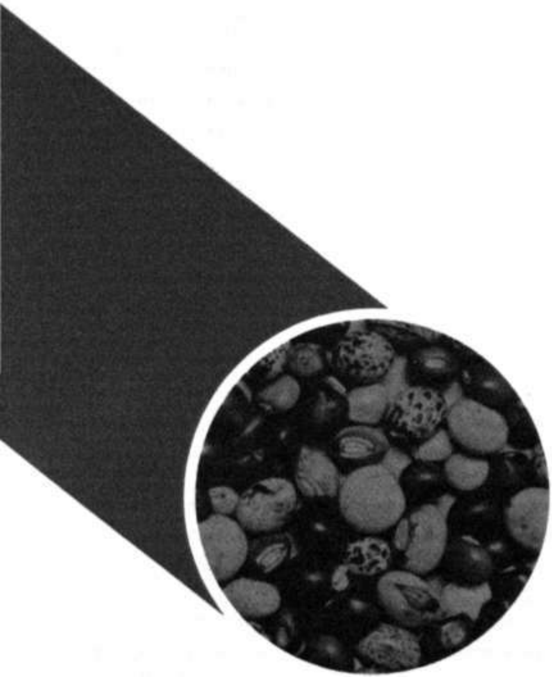
Waliyar, F., McDonald, D., Laxman Singh, and Jagdish Kumar. 1989. Recherches sur les legumineuses a graines a l'ICRISAT. (In Fr.) Pages 77-96 *in* Les legumineuses a graines: actes du Seminaire, 22-27 Feb 1988, Madagascar (Demarly, Y., ed.). Stockholm, Sweden: Fondation Internationale pour la Science. (CP 445)



PIGEONPEA

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

PIGEONPEA

ICRISAT's research on pigeonpea *(Cajanus cajan* (L.) Millsp.) aims at improving productivity per unit area and over time, with stability across environments and resistances to major stresses. At ICRISAT Center, we conduct research on short-duration (SD), medium-duration (MD), and perennial pigeonpea. We also maintain and evaluate germplasm, conduct operational-scale testing of improved genotypes in different production systems, and screen for particular biotic and abiotic stresses. Short-duration pigeonpea is also bred and tested at Hisar, Haryana, India, in cooperation with Haryana Agricultural University (HAU). We concentrate on developing long-duration (LD) types and on improving agronomic management of advanced SD material at Gwalior, Madhya Pradesh, India, in cooperation with Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) College of Agriculture.

We extend our cooperation to Asian countries through the Asian Grain Legumes Network (AGLN). Increased cooperation with eastern Africa is being facilitated by the appointment during this year, of a pigeonpea agronomist/breeder to the Eastern Africa Regional Cereals and Legumes (EARCAL) Network.

In the coming year we intend to continue evaluation of newly generated short-statured (dwarf) plant types in the three major phenological groups. We will continue to emphasize the development of hybrid pigeonpea in cooperation with the Indian national program. We will intensify germplasm enhancement efforts to increase tolerance of pod borer, podfly, and phytophthora blight. We will continue to develop integrated pest and disease management practices applicable to resource-poor farming situations. We will further extend testing of genotypes for host-plant resistance to insect attack to farmers' field situations and conduct studies on mechanisms of drought resistance with the hope of streamlining drought screening techniques. We will intensify studies on problems faced by pigeonpea when soils become temporarily waterlogged.

Physical Stresses

Alleviation of drought stress, both by improvement of drought tolerance and selection of genotypes that will escape stress, continued to receive our attention. For the first time, we used an automated rainout shelter facility at ICRISAT Center to investigate the effects of drought stress at different growth stages of SD pigeonpea. Lack of significant rainfall during the postrainy season enabled the assessment of MD pigeonpea for terminal drought tolerance. We also studied the effects of high temperature on flower drop and are continuing studies on adaptation of extra-short-duration (ESD) pigeonpea to different environments.

Drought Stress and Growth Stages of Short-duration Pigeonpea

Short-duration pigeonpea at any growth stage can face drought of varying intensity as a result of prolonged dry spells during the rainy season. Selection for drought tolerance under unpredictable drought conditions may only progress slowly because of interactions between genotypic responses and crop growth stages. We therefore attempted to identify the most drought-susceptible stage to better concentrate on improving drought tolerance for this stage.

A split-plot experiment was conducted on an Alfisol under a rainout shelter at ICRISAT Center during the 1988 rainy season (Fig. 1). Drought stress treatments (assigned to main plots) were imposed on nine pigeonpea genotypes (assigned to subplots) during the following periods: from

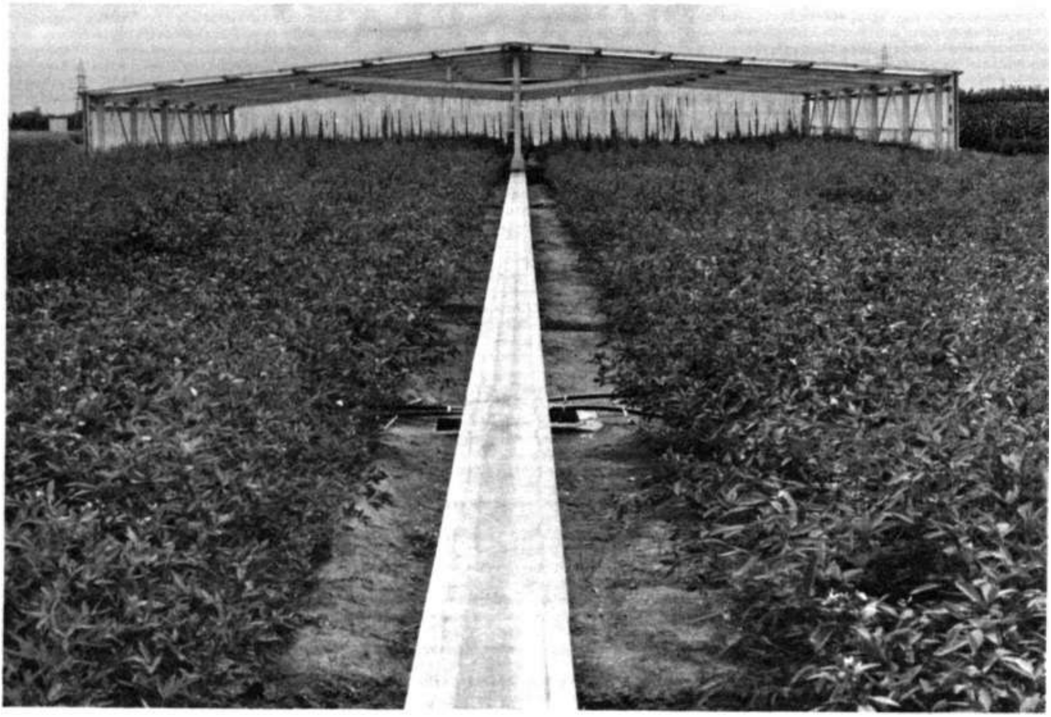


Figure 1. A view of the rainout shelter used at ICRISAT Center to study the effect of drought at different stages of crop growth of short-duration pigeonpea, rainy season 1988.

52 days after sowing (DAS) to 50% leaf abscission, from 50% flowering of ICPL 87 (control genotype) to 50% leaf abscission and from the mid-pod-filling stage of ICPL 87 until maturity. There was a control treatment that received irrigation throughout. Water was applied by drip irrigation at intervals of 2-4 days, depending on surface soil dryness in control plots. In most of the genotypes tested, the flowering stage was most susceptible to drought stress, followed by the preflowering stage. This was probably because the number of pods, which is the most important component influencing pigeonpea yield, was being determined at these stages. All genotypes appeared less vulnerable to drought stress in the pod-filling stage. There were genotypic differences in tolerance to stress at the preflowering stage. Of all genotypes, ICPL 151 was the most susceptible and ICPH 8, ICPL 85045, and ICPL 87 were relatively tolerant. All genotypes appeared uniformly susceptible at the flowering stage.

Drought Stress of Medium-duration Pigeonpea in Sole- and Intercrops

Medium-duration pigeonpea is commonly grown in intercrops where it normally faces terminal drought stress. We have earlier reported genotypic differences in tolerance to this terminal stress (1CRISAT Annual Report 1986, p. 176). In earlier years, however, the screenings were done in a sole crop situation and at two moisture regimes, stressed and irrigated. To determine the relevance of such screenings to intercropping situations and the responses over a range of soil moisture levels, a line-source irrigation experiment was conducted using four genotypes, ICPL 8357, ICPL 84071, ICPL 227, and MRG 66. They were grown either as sole crops or as intercrops with sorghum genotype CSH 6. Both ICPL 227 and MRG 66 had earlier shown a greater sensitivity to moisture deficits and a higher yield potential under irrigated conditions than the other two genotypes.

There was a strong interaction between cropping system (sole crop vs intercrop) and water regime in that the mean yield of all four genotypes was increased to a greater extent by water applied to the sole crop than to the intercrop (Fig. 2). However, genotype x water regime and genotype * water regime x cropping system interactions were not significant. High overall yields were obtained from MRG 66 and ICPL 227. It appears that both MRG 66 and ICPL 227 were better able to take advantage of the higher-than-normal rainfall during the rainy season than ICPL 8357 and ICPL 84071. The relative ranking of genotypes, however, did not change in sole cropping and intercropping, indicating that performance observed in a sole crop may be relevant to that in an intercrop.

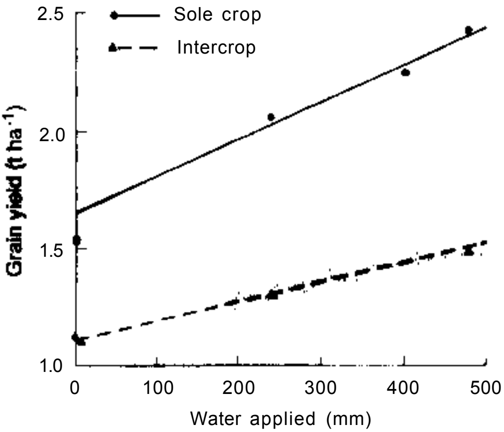


Figure 2. Effect of applied water on the mean yield of four medium-duration pigeonpea genotypes grown as sole crop and intercropped with sorghum, in an Alfisol, ICRISAT Center, rainy season 1988/89.

The relative advantage of the intercrop, as indicated by land equivalent ratio (LER) which ranged from 1.39 to 1.68 at different water regimes, was slightly greater at the drier end of the plots, although the differences were not significant. In addition to the yield of intercropped ICPL 227 being high, the yield of its companion crop, sorghum, was higher compared to those of sorghum when intercropped with the other pigeonpea genotypes. Such positive interactions are important to improve productivity of sorghum-pigeonpea intercrops and need to be examined further.

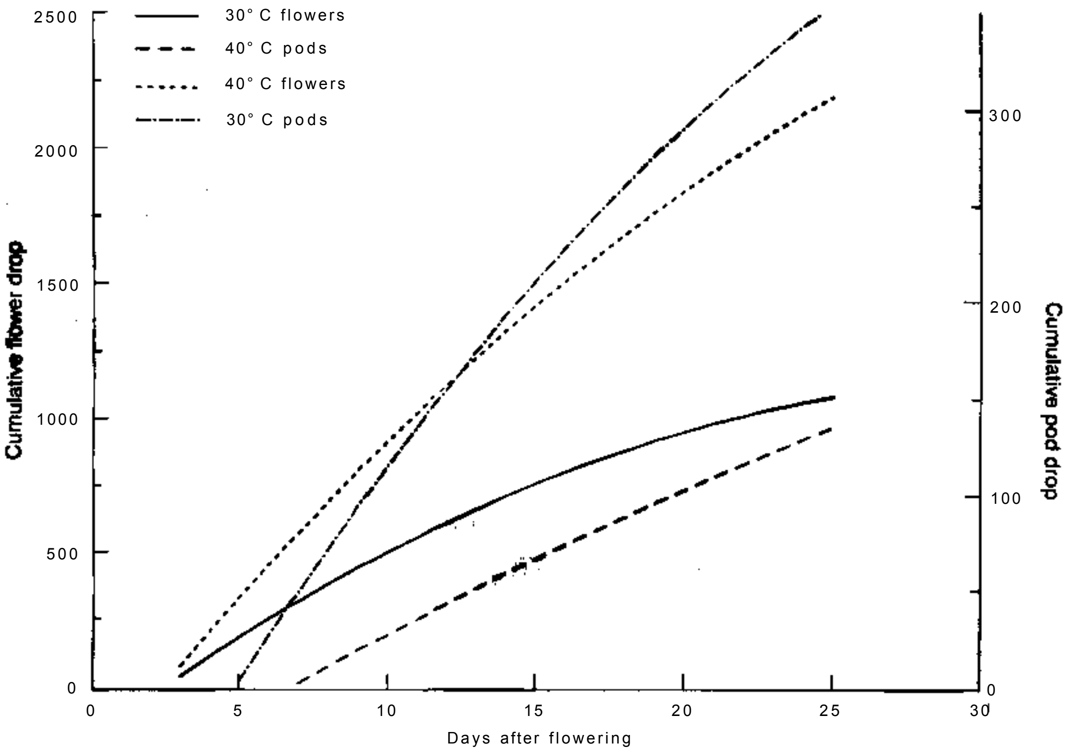
Effect of Temperature on Flower and Pod Drop

Pigeonpea has a high degree of flower drop which, to some extent, can be attributed to unfavorable environmental conditions. In a controlled environment study, we found that flower drop in four SD pigeonpea genotypes was twice as much at 40°C as at 30°C (Fig. 3). However, more pods dropped at 30° C than at 40° C, probably because of the inherent tendency of the pigeonpea plant to adjust pod load according to availability of assimilates. Genotypic variation in ability to set pods at high temperature was apparent; ICPL 4 was relatively more tolerant than other genotypes such as ICPL 151, UPAS 120, and ICPL 87.

Extra-short-duration Pigeonpea in Contingency Cropping

Last year we reported that ESD pigeonpea can be adapted to rainfed conditions in peninsular India (ICRISAT Annual Report 1988, p. 89). This year we compared the performance of ESD pigeonpea with that of other short-season legumes when grown as a catch crop or contingent crop.

We conducted a split-plot designed experiment under rainfed conditions in an Alfisol at



Flower drop at 30°C $y = -203.3+82.8x-1.26x^2$, $r^2 = 0.99$
Flower drop at 40°C $y = -334.1+140.2x-157x2$, $r^2 = 0.98$
Pod drop at 30°C $y = -127.4+27.5x-0.33x^2$, $r^2 = 0.99$
Pod drop at 40°C $y = -63.2+9.65x-0.0686x^2$, $r^2 = 1.00$

Figure 3. *Effect of day temperature (30° C and 40° C) on mean flower and pod drop of four pigeonpea genotypes collected from an area of 13.9 m^2 in two controlled-environment greenhouses, ICRISAT Center, 1987/88.*

ICRISAT Center. We assigned two sowing dates to main plots and nine genotypes that included five ESD genotypes, one SD pigeonpea genotype and three short-season legumes, green gram *(Vigna radiata),* horse gram (*Macrotyloma uniflorum),* and cowpea (*Vigna unguiculata)* were assigned to subplots.

A delay in sowing date generally caused a significant reduction in the length of the reproductive phase and in the total dry matter produced. Pigeonpea genotypes yielded 2-31 ha^{-1} in the first sowing, which was significantly higher than the yield of short-season legumes (Table 1). In the delayed sowing, however, owing to a significant reduction in growth and terminal water deficit, yield of ESD and SD pigeonpeas declined to about 1 t ha^{-1}. Yield of cowpea was significantly higher than yields of pigeonpea genotypes in the late sowing, but yields of green gram and horse gram were still lower. Relatively high cowpea yields in the late sowing seem to result from faster initial growth and early anthesis of this species, enabling it to tolerate as well as avoid drought. For greater stability of pigeonpea yield across sowing dates, these two traits will need to be improved.

Table 1. Effect of sowing date and genotype on seed yield (t ha^{-1}) of pigeonpea and other short-season legume crops on an Alfisol, ICRISAT Center, rainy season 1988.

	Seed yield (t ha^{-1})		
	Sowing date		
Genotype	20 Jun	5 Aug	Mean
Pigeonpea			
ICPL 83015	2.86	1.02	1.94
ICPL 84023	1.96	1.01	1.48
ICPL 85015	2.87	0.89	1.88
ICPL 85037	2.50	0.73	1.61
ICPL 85014	2.84	0.87	1.86
ICPL 87	2.47	0.78	1.62
Short-season legumes			
Green gram	0.68	0.40	0.54
Horse gram[1]	-	0.99	-
Cowpea	1.26	1.41	1.34
SE	±0.127[2]		±0.089
CV (%)	16.5		
Mean	2.18	0.89	
SE	±0.050[3]		

1. Yield of horse gram was not included in the analysis as data for the first sowing were not available.
2. Standard error to compare genotype means within sowing date or sowing date means within same genotype.
3. Standard error to compare sowing date main effect means.

Biotic Stresses

Diseases

Increased Incidence of Sterility Mosaic in Gujarat and Maharashtra

Gujarat and Maharashtra are important pigeonpea-producing states of India with 318 700 ha under cultivation in Gujarat and 763 300 ha in Maharashtra. Medium-duration types are the most commonly grown varieties. Roving surveys conducted by ICRISAT between 1975 and 1980 showed that sterility mosaic (SM) disease was a minor problem in these states (Gujarat 12.2%, Maharashtra 1.1%). However, a visit to these states in December 1989 revealed that the SM problem is increasing. In a single village of Mandala of Dabhoi Tehsil in Baroda district in Gujarat State, 25 ha had 100% SM infection. Large-scale cultivation of BDN 2, a wilt-tolerant but SM-susceptible cultivar, appears to be one of the reasons for the increased incidence of SM. In Gujarat, this cultivar has replaced the local cultivar T 15-15 which is resistant to SM but susceptible to wilt. Perennial cultivation of pigeonpea, though conducted on a very limited scale, also appears to be another reason for the SM increase. Perennial pigeonpea harbors both the SM pathogen and its mite vector during summer and serves as a source of inoculum for the main season crop. At ICRISAT Center, we have some medium-duration lines with wilt and SM resistance, such as 1CPL 227 and ICPL 87107, and testing these lines in these states could lead to the control of these diseases.

Fusarium Wilt (*Fusarium udum* Butler)

Root-dip Inoculation Technique

Lack of a rapid and reliable laboratory technique for inoculating pigeonpea with wilt has hindered progress on basic studies such as identification of physiologic races and inheritance of disease resistance. We have now standardized a simple, rapid, and reliable root-dip inoculation technique. This technique involves raising pigeonpea seedlings from chlorox-treated seeds (2.5% chlorox for 1 min) in sterilized sand filled in polythene bags. When the seedlings are 7-10-days old, they are uprooted by cutting open the polythene bags. The roots are trimmed to a length of 8 cm and dipped in *Fusarium* spore suspension (1000 000 mL^{-1}) for 1 min. The seedlings are then transplanted into a 3:1 sterilized sand and Vertisol mixture in plastic pots (15-cm top diameter) at five seedlings per pot. The pots are kept in a greenhouse at 15-30°C and irrigated with deionized water. The reactions of susceptible and resistant cultivars were the same

Figure 4. From left to right, resistant (ICPV l [ICP 8863], ICP 9174), tolerant (ICP 9145), and susceptible (ICP 2376) pigeonpea cultivars inoculated with Fusarium udum *by the root-dip method.*

as previously observed in wilt-sick plots. Susceptible cultivars such as ICP 2376, ICP 6997, and LRG 30 showed 100% mortality within 3 weeks. Resistant cultivars such as ICPV 1 (ICP 8863) and ICP 9174 showed no mortality even at 6 weeks after transplanting (Fig. 4). ICP 9145 showed chlorosis, stunting, and late-wilting symptoms. The seedlings of all these cultivars, which were similarly transplanted without inoculation, did not show any mortality, indicating that pigeonpea can withstand transplantation shock.

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

Diseased-debris Inoculation Technique

We report here an additional inoculation technique, 'diseased-debris method', for evaluating pigeonpea genotypes for their resistance to phytophthora blight (PB) in the field. The technique consists of sowing pigeonpeas on flat beds in a well-leveled Alfisol field at the beginning of the rainy season. Rows of susceptible control cultivars, such as ICP 2376 and ICP 7119, were sown alternately after every four test rows (germplasm and segregating breeding lines). One month after sowing, the field was inoculated with PB by scattering, at a rate of 250 kg ha^{-1}, diseased pigeonpea debris collected in the previous season from naturally infected fields and stored in a field shelter. By the first fortnight of August, both the susceptible controls showed very high mortality (93-100%) in all the three seasons (1987-89) when the technique was tested. There was no need for either perfo- or flood-irrigation to enhance infection. Even though the total rainfall during June-August 1987 was below average (384.6 mm), PB developed well. When the diseased plants were incorporated in the field at the end of the first season, it was found that an extremely blight-sick plot had developed without the need for any additional inoculation.

Along with the 'leaf scar', 'drench', and 'stem-rub' inoculation methods, which are quite effective to screen a limited amount of material in pots or in the field, the 'diseased-debris method', which is simple, effective, and less laborious, can be used for large-scale field evaluation of germplasm and breeding materials against PB.

Field Resistance Sources

During the 1981/82 rainy season, in field evaluation at ICRISAT Center, we found that most of the germplasm accessions that showed resistance in the earlier seasons were susceptible. The fungus isolated from the diseased plants (P3 isolate) was more aggressive than the isolate identified earlier (P2). In order to identify genotypes resistant to P3 isolate, we evaluated about 7000 germplasm accessions in pots using the 'drench inoculation method', but none of them was found to be resistant. However, 10 of the 80 P2-isolate resistant germplasm accessions showed either resistance (0-10% blight) or tolerance (11-30% blight) when evaluated in the field (Fig. 5) by the 'diseased-debris method' of inoculation of both P2 and P3 isolates (Table 2). The line KPBR 80-2-1 also showed resistance at Delhi, Kanpur, Sehore, Vadodara, and Varanasi in India where P2, or P3, or both the isolates were prevalent. One of the reasons for susceptibility of pigeonpea in pot tests appears to be the age at which plants are infected. In pots, plants are inoculated at 7-10 days after emergence (DAE) but under field conditions, the disease usually appears after 45 days. Susceptibility of pigeonpea to the disease is known to decrease with plant age.

Nematodes

Screening Technique for Cyst Nematode

We standardized a greenhouse screening procedure to evaluate pigeonpea genotypes for resistance to the pigeonpea cyst nematode, *Heterod-*

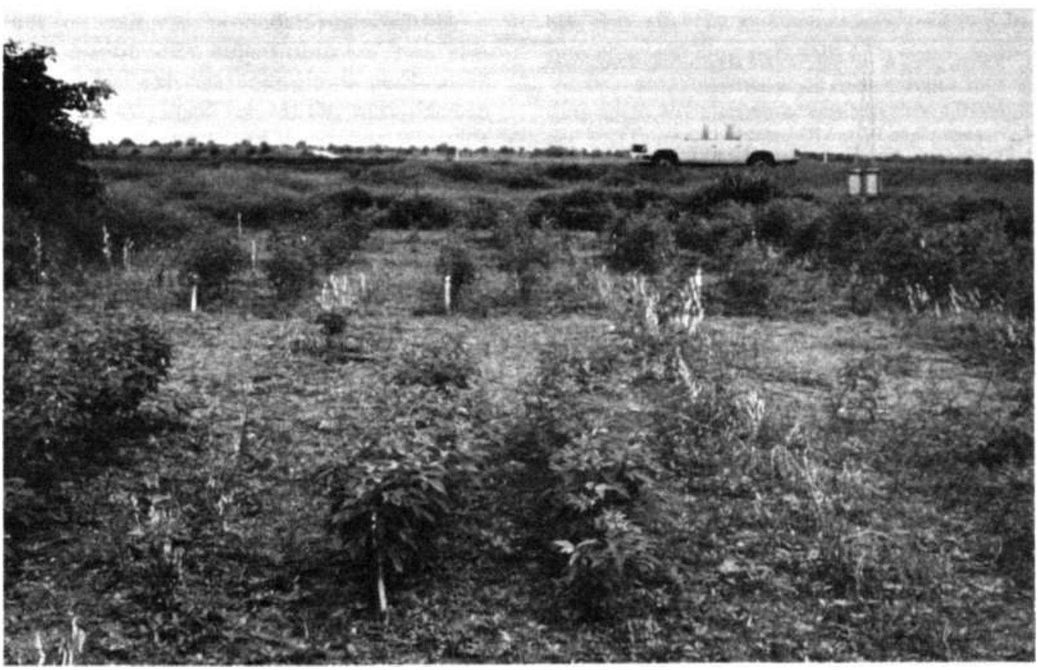


Figure 5. A pigeonpea cultivar showing field resistance to phytophthora blight at ICRISAT Center. Plants in adjacent rows have been killed by the disease.

Table 2. Pigeonpea germplasm accessions, field-resistant (0-10% blight) or tolerant (11-30% blight) to phytophthora blight, ICRISAT Center, rainy seasons 1988 and 1989.

	Mortality due to PB(%)[1]					
	Field test				Pot test (1989)	
	1988/89		1989/90			
Pigeonpea accession	PBN[2]	MDN[3]	PBN	MDN	P2 isolate	P3 isolate
ICP 7200	17(24)	2(5)	44(42)	40(39)	2	71
ICP 7815	16(24)	15(23)	59(50)	22(28)	9	28
ICP 8564	14(21)	8(17)	48(45)	19(26)	2	90
ICP 8610	19(25)	8(16)	24(29)	45(42)	9	70
ICP 8692	22(28)	19(25)	34(35)	14(21)	5	73
ICP 8921	20(27)	30(33)	45(42)	35(36)	4	71
ICP 9046	25(29)	25(30)	42(40)	38(37)	0	83
ICP 9252	28(32)	23(28)	50(45)	30(33)	3	88
KPBR-80-1-4	30(33)	20(22)	52(46)	16(23)	0	73
KPBR-80-2-1	10(18)	20(26)	27(31)	12(21)	0	63
ICP 7119[4]	98(81)	98(83)	100(90)	98(84)	100	100
ICP 2376[5]	96(79)	98(83)	100(90)	95(78)	0	100
SE	(±6.0)	(±3.8)	(±5.2)	(±7.1)		
Mean[6]	48(45)	36(37)	65(57)	47(44)		
CV (%)	(19.0)	(14.5)	(18.0)	(23.0)		

1. Values given in parentheses are angular transformations.
2. PBN = Phytophthora blight nursery.
3. MDN = Multiple disease nursery.
4. Susceptible to P2 and P3 isolates.
5. Resistant to P2 but susceptible to P3 isolate.
6. PBN 1988/89 based on 18 entries; MDN, 1988/89 based on 17 entries; PBN, 1989/90 based on 18 entries; and MDN, 1989/90 based on 23 entries.

era cajani. We multiplied the nematode on a susceptible genotype (ICPL 87). A nematode infestation level of 17 eggs and juveniles cm^{-3} of soil produced reliable screening results. Scoring of root systems for number of white cysts at 30 days after germination was more reliable than scoring at 15 or 45 days after germination.

The white cysts are very small and it is important to train one's eyes to locate them by examining the roots of many infected seedlings before checking the root systems of test genotypes. Cysts are not easily visible when the roots are wet. Air drying of roots to remove surface moisture increases the visibility of cysts but care must be taken to avoid complete drying of the roots.

Screening for Resistance to H. *cajani*

We screened 63 fusarium wilt-resistant pigeonpea germplasm lines, 50 breeding lines, and 60 accessions of wild pigeonpea relatives. Root systems of wild species were scored 45 days after germination because of their slow root growth. The root systems were scored on a 1-9 scale in which 1 = no white cyst (immune) and 9 = more than 30 cysts (highly susceptible). All the fusarium wilt-resistant germplasm lines and advanced breeding lines were susceptible. Accessions of *Atylosia grandifolia (ICPW* 37), *A. scarabaeoides* (ICPW 94, ICPW 111), *Flemingia macrophylla* (ICPW 194), *F.* stricta (ICPW 202), *F. strobilif-*

era (ICPW 203), and *Rhynchosia rothii* (ICPW 257) were resistant.

Viruses

Pigeonpea Sterility Mosaic Disease

We presented data in 1988 to show that a virus or a viroid was probably not involved in the etiology of pigeonpea SM disease (ICRISAT Annual Report 1988, pp. 90-91). Consequently, we explored the possible involvement of a prokaryote. Extracts of SM-infected leaves were subjected to a purification procedure similar to that employed for isolating mycoplasma-like organisms (MLOs). A polyclonal antiserum was produced in rabbits, and a triple antibody sandwich Enzyme-Linked Immunosorbent Assay (ELISA) was standardized. In tests on extracts of SM-infected leaves and comparable healthy pigeonpea leaves, SM extracts consistently gave higher absorption values. This result indicated that the antiserum produced contained agent-specific antibodies. Pellets obtained from SM-infected leaf extracts, following a purification procedure employed for MLOs, were fixed in glutaraldehyde, postfixed in osmium tetroxide and embedded in Spurr® low viscosity medium. Pellets were then subjected to ultra-thin sectioning and the sections were observed under an electron microscope after staining these with uranyl acetate or lead citrate. This revealed the presence of membranous bodies that are found predominantly in infected tissue. We are currently making modifications in the purification procedure with the aim of obtaining larger quantities of these membranous bodies.

Insect Pests

Pest Incidence

In 1988/89, as in all previous years, the pod borer, *Helicoverpa armigera,* was the most damaging pest to SD and MD pigeonpea at ICRISAT Center and throughout southern India. The spotted borer, *Maruca testulalis,* which is usually a pest of SD cultivars common in the northern Indian pigeonpea-growing areas, was also a pest at ICRISAT Center this year on SD material.

Podfly, *Melanagromyza obtusa,* the second most important pigeonpea pest in India, was particularly damaging in MD and LD pigeonpeas grown in central and northern India.

Of the other pests, the blister beetle *(Mylabris pustulata)* was very common from August to late October in southern India. This insect was therefore very damaging to SD pigeonpea grown in small demonstration plots in farmers' fields. Blister beetles congregate on pigeonpea in such plots since the demonstration fields contain the only legumes flowering in the area.

Pod Borer *(Helicoverpa armigera)*

Host-plant Resistance

We evaluated 288 new germplasm accessions in nonreplicated plots in ICRISAT's pesticide-free Vertisol area for damage by *Helicoverpa* at podding stage. We also tested selections from breeders' ESD and SD pigeonpea material with tolerance to *Helicoverpa* damage at ICRISAT Center and at Hisar in replicated, nonprotected trials. At Hisar, ICPLs 8318, 84048-E2, 860016-E2, 269,860026-E2,8327, and ICP 12932-E3 showed less borer damage and higher yields (>2.5 t ha^{-1}) than the susceptible controls. We made some selections of high-yielding, less-susceptible genotypes in the wilt and *Helicoverpa* resistance screening nursery in 1987. We grew these genotypes again during the 1988 rainy season on a highly wilt-sick plot, and made further selections of borer-resistant, high-yielding genotypes for large plot, replicated trials in 1989.

As in the past, we continued testing our promising selections at different locations in India, in collaboration with All India Coordinated Pulses Improvement Project (AICPIP) entomologists. Seeds of borer- and podfly-resistant/tolerant selections in 17 sets of different maturity groups were supplied to nine centers in India for testing under nonsprayed conditions in replicated plots, along with selections from the national program. The performance of these selections in different agroecological zones will be ascertained after obtaining 3-5 years' data. As part of the International Pigeonpea Pest Resistance Nurseries (IPPRN), we supplied seeds of 21 trials with genotypes of different maturities to Indonesia for two seasons' trials at four locations.

So far, we have primarily tested our borer-resistant/ tolerant selections on research stations. We are now expanding our multilocational testing network to include the types of environments our material is ultimately intended for, that is, farmers' fields. This year we grew four of our medium-duration borer-resistant/ tolerant selections in collaboration with the Resource Management Program (RMP) Village level Studies (VLS) group on four farmers' fields in Shirapur (Sholapur district, Maharashtra, India) on 0.1-ha plots without any pesticide application. These selections performed outstandingly well in farmers' fields. We recorded 4-22% borer damage to pods in the samples collected from the test lines compared with 58-60% in the local cultivars grown as controls. Selections ICPL 84060, ICPL 332, and ICP 3328 also yielded more in farmers' fields than the local genotypes.

One of our Helicoverpa-tolerant, high-yielding germplasm selection, ICPL 332, was released as variety "Abhaya" for cultivation in Andhra Pradesh by the Andhra Pradesh State Sub-Committee on Release of Varieties in 1989. This line was tested and promoted jointly by the Andhra Pradesh Agricultural University (APAU) and ICRISAT. We expect that several other pod borer-resistant lines developed at ICRISAT over the last decade will be released in the near future.

Mechanisms of Resistance to *Helicoverpa*

We released laboratory-bred moths and larvae in small plastic cages and in specimen tubes on flowers and green pods of resistant and susceptible pigeonpeas., These tests indicated that in the SD group, flowers of ICPLs 8309, 2, and 269 were less preferred by *Helicoverpa* moths for oviposition than flowers of the control UPAS 120. The green pods of ICPLs 187-1, 2, and 269 had fewer eggs than pods of UPAS 120. In the MD group, flowers and pods of PPE 45-2 and ICP 909 were less preferred for oviposition than those of the control T 21. The flowers of a borer-susceptible genotype, ICP 7203, were most preferred by the ovipositing moths. We carried out antibiosis tests using green pods of ESD, SD, and MD selections and controls. We recorded reduced larval and pupal masses in PPE 45-2 compared with the susceptible control, ICP 7203. Larval mortality was higher in ICP 1903 (83.3%) compared with the control, BDN-1 (70.0%). We also noticed antibiosis to *Helicoverpa* larvae in pods of the borer-resistant line, ICPL 87089.

The Bhabha Atomic Research Centre (BARC), Bombay, has carried out biochemical analysis of the seeds of pest-resistant pigeonpea genotypes. A high level of Trypsin Inhibitor Activity (TIA) was discovered in some of the borer-resistant selections. Further analyses of these genotypes are in progress at BARC.

Drought and Population Dynamics of the Pod Borer

Helicoverpa armigera reproduces throughout the year in southern India. Its populations vary greatly across seasons and among years, but the reasons for these large fluctuations in abundance are not known. In order to better understand the factors determining the pest's population dynamics in and around ICRISAT Center, we interpreted data on pod borer abundance in terms of the recent climatic history of Patancheru.

At and around ICRISAT Center, larvae have been recorded to feed on 98 plant species, including ICRISAT's mandate crops: sorghum, pearl millet, chickpea, pigeonpea, and groundnut. Our Plant Protection Surveillance team records every week the number of *H. armigera* caterpillars on the five mandate crops in all the fields in the areas protected by pesticide. Although the standardized weekly larval counts are not an accurate record of the *total* population present on the crop, they nevertheless provide approximate estimates of the pest's abundance over a wide area. We have used such counts to compare the abundance of *H. armigera* populations across a series of abnormally dry and wet years.

A summary of the data obtained for the years 1983-89 is given in Table 3. The number of *H. armigera* larvae per hectare was significantly lower during the years of high rainfall (June-May 1983/84, 1988/89, and 1989/90) than during the four successive drought years of 1984-87 ($P<0.01$, Kruskall-Wallis one-way analysis of variance by ranks). Moreover, the abundance of the pest's population was compounded from one year to the next during this 4-year period of water deficit. Thus the larval population on ICRISAT's cropped area increased from 218.1 x 10^3 ha^{-1} in 1984 to 638.9 x 10^3 ha^{-1} in 1987. However, in 1987, the moth's migratory activity confounded the direct and indirect effects of drought on the pest's population dynamics. The light and pheromone traps on ICRISAT farm recorded a massive influx of moths from the drought-stricken coastal area of Andhra Pradesh in November-December 1987. This incoming migration contributed to the increase in size of the *Helicoverpalarval* population in 1987/88. The cyclonic winds that carried the migrating moths from coastal Andhra Pradesh to ICRISAT farm were followed by heavy rains in

Table 3. Relationship between drought conditions and the abundance of *Helicoverpa armigera* at ICRISAT Center, 1983-89.

	June-October			June-May		
Year	Rainfall (mm) (±long-term average)[1]	Area surveyed for larval population (ha)	Larval population in 10^3 ha^{-1}	Rainfall (mm) (± long-term annual average)	Area surveyed for larval population (ha)	Larval population[2] in 10^3 ha^{-1}
1983/84	1021.2 (+52.4%)	327.4	45.6	1096.6 (+40.2%)	546.48	132.7
1984/85	591.3 (-11.7%)	333.1	74.7	670.3 (-14.3%)	532.77	218.1
1985/86	477.0 (-28.8%)	320.7	109.3	617.0 (-21.1%)	491.70	296.0
1986/87	538.0 (-19.7%)	235.7	244.6	623.3 (-20.3%)	406.50	379.1
1987/88	595.8 (-11.1%)	319.8	155.3	955.7 (+22.2%)	531.35	638.9
1988/89	900.2 (+34.4%)	420.3	84.7	1019.2 (+30.3%)	648.58	216.9
1989/90	936.7 (+39.8%)	381.7	92.6			

1. Deviations from normal rainfall given in parentheses and were computed from the long-term average for June-October (670 mm). More than 80% of the average annual rainfall occurs during these months at ICRISAT Center. Long-term average rainfall (1974-87): June-October 670 mm, June-May 782 mm.
2. Larval population densities were significantly lower in excess rainfall years than in water-deficient years ($P<0.01$, Kruskall-Wallis one-way analysis of variance by ranks).

November-December 1987, thus explaining the apparent discrepancy in our 1987 88 data for the June-May period (Table 3).

This unique set of results for the semi-arid tropics provides evidence of a positive relationship between drought conditions and outbreaks of *H. armigera.* The reasons for drought favoring high pest population growth are not known. The physical and physiological changes induced by water deficits can make wild and cultivated host plants more vulnerable and acceptable to *H. armigera.* Thus, when subjected to drought stress, all five ICRISAT mandate crops and some of the wild hosts growing on the farm accumulate higher levels of proline, reducing sugars and other metabolites involved in osmotic adjustment. Our laboratory experiments have shown that some of these osmolytes stimulate the larvae's feeding activity and the fecundity of female moths. We hope that further studies will clarify the insect-plant relationship described here and lay a foundation for predicting the likelihood of *H. armigera* outbreaks on a wide-area basis (as opposed to a single crop basis) in the semi-arid tropics.

Podfly *(Melanagromyza obtusa)*

Host-plant Resistance

This year we tested several podfly-resistant selections from the lines bred and advanced for podfly resistance at ICRISAT Center and at Gwalior. The results obtained for the most promising lines grown in large replicated plots are shown in Table 4.

Table 4. Pod damage by podfly *(Melanagromyza obtusa)* on pigeonpea lines, bred for podfly resistance, grown on 5-row plots of 4-m length; in 3 replication-RBD trials at ICRISAT Center and Gwalior, rainy season 1988.

	Mean pod damage (%)	
Pigeonpea lines	ICRISAT Center	Gwalior Cooperative Research Station
ICPX 82111-E4-E1	14.3 (21.9)[1]	8.8 (17.1)
ICPX 82062-E2-E3	29.4 (32.1)	7.7 (15.7)
ICPX 81277-E42-E1	12.5 (20.3)	5.2 (12.9)
ICPX 82056-E4-E1	8.5 (16.8)	9.5 (17.8)
ICPX 82064-E15-E1	12.2 (20.4)	9.3 (17.6)
Controls		
Gwalior 3	22.5 (28.1)	22.8 (28.4)
ICPL 371	33.4 (35.3)	14.2 (21.9)
ICPL 366	25.5 (30.4)	26.2 (30.7)
T 7	30.0 (33.1)	15.0 (22.8)
SE	(±2.28)	(±1.99)
Trial mean	21.7	15.5
(Entries tested)	(16)	(20)

1. Values in parentheses are angular transformations.

Plant Nutrition

A Special Project funded by the Government of Japan, in which the phosphorus nutrition of pigeonpea was examined in detail, has concluded and a workshop on this topic was held. However, a second phase of this Project, to examine aspects of mineral nutrition of pigeonpea, has followed.

Genotypic Differences in Residual Effect

Genotypic differences for nodulation and nitrogen-fixing ability have been observed in pigeonpea, and this may influence the nitrogen available for a succeeding crop. Previous studies indicated that 1CPL 87, an SD genotype with high yield potential in multiple harvests, was low nodulating compared with ICP 1-6, an MD genotype. We therefore investigated whether genotypic differences in nitrogen (N) fixation of ICPL 87 and ICP 1-6 are reflected in their residual effect on a following sorghum crop.

In the 1987 rainy season, the main plot treatments were irrigation and no irrigation and the subplot treatments were ICPL 87 in a multiple harvest system, ICP 1-6, maize and fallow, laid out on an Alfisol and a Vertisol at ICRISAT

Center. In the 1988 rainy season, sorghum (cv ICSH 153 [CSH 11]) with four levels of N fertilizer was grown in sub-subplots.

The results of the Alfisol field alone are presented here as the trial on Vertisol suffered from waterlogging and large soil heterogeneity and is being repeated.

1CP 1-6 had significantly more nodulation (nodule number and dry mass) and acetylene-reducing activity (ARA) than had ICPL 87 in Alfisols (Table 5). The rainfall distribution was such that there was no significant difference in yield and biomass between irrigation treatments given to the 1987 crops. There was little difference between grain yields of ICPL 87 (1.58 t ha^{-1}, total of three harvests) and ICP 1-6 (1.66 t ha^{-1}).

The response of grain yield of sorghum to N fertilizer when the sorghum was grown in the 1988 rainy season indicated a beneficial effect of both pigeonpea genotypes on sorghum yields (Fig. 6). There were large genotypic differences in the residual effect of pigeonpea—the beneficial effect of ICP 1-6 on sorghum grain yield was equivalent to about 30 kg N ha^{-1} and that of ICPL 87 about 5 kg N ha^{-1}, compared to fallow. It is therefore important to select genotypes for both high yield and high nodulation characters in the SD group.

Lack of convergence of the curves at high N levels in Figure 6 indicates beneficial effects of pigeonpea other than just N additions. Detailed studies using ^{15}N isotope techniques would be required to distinguish between inputs of fixed nitrogen and other beneficial effects of pigeonpea. The present study also emphasizes the need for detailed budgeting of nitrogen inputs, particularly of some of the newer plant types being developed, such as ESD pigeonpea, whose nitrogen fixation characteristics are little known.

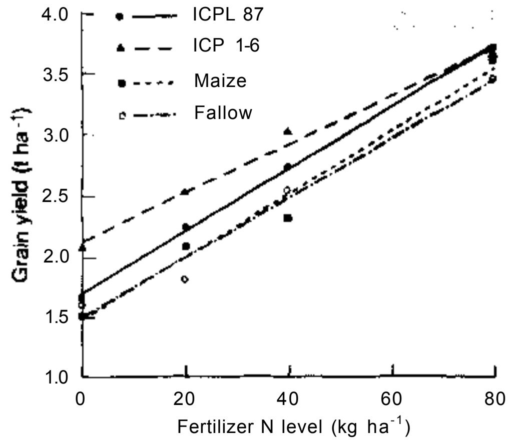


Figure 6. Effect of previous crop treatments on the response of sorghum grain yield to nitrogen fertilizer in an Alfisol, ICRISAT Center, rainy season 1988.

Table 5. Nodulation, acetylene-reducing activity (ARA), and shoot dry mass of pigeonpea genotypes (differing in nodulation), grown on an Alfisol, 35 DAS (A), and 58 DAS (B) at ICRISAT Center, rainy season 1987[1].

	Nodule number $plant^{-1}$		Nodule dry mass (mg $plant^{-1}$)		ARA (µM C_2H_4 $plant^{-1}$ h^{-1})		Shoot dry mass (g $plant^{-1}$)	
Genotypes	A	B	A	B	A	B	A	B
ICPL 87	16	8	30	38	0.73	0.5	0.4	5.1
ICP 1-6	39	20	51	186	1.24	8.0	0.5	7.1
SE	±3.8	±3.7	±3.1	±31.9	±0.163	±1.88	±0.04	±0.61
CV (%)	39	76	21	80	47	125	25	28

1. Means over irrigation levels.

Phosphorus-solubilizing Root Exudates

Last year, we reported identification of components in the anionic fraction of root exudates from pigeonpea, which were not present in root exudates of other crop species, that could solubilize ferric phosphate (ICRISAT Annual Report 1988, pp. 97-98). In collaboration with the Department of Agricultural Chemistry, Hokkaido University, Japan, analysis by gas chromatograph, mass spectrometer, and nuclear magnetic resonance allowed identification of these components as (p-hydroxybenzyl)-tartaric acid and its p-o-methyl derivative (p-methoxybenzyl)-tartaric acid. The former compound is known as piscidic acid.

The configuration of piscidic acid is similar to the family of fukiic acids, which differ by substitution of different hydroxyl and methoxyl groups. By comparing the ability of these different acids to solubilize phosphorus from ferric phosphate, we concluded that the hydroxyl and carboxyl groups on the tartaric portion are the active components in chelating Fe^{3+} and thus releasing phosphorus. Further studies are needed to quantify the release of piscidic acid from roots over time and establish genotypic differences in this regard. This information will be required to determine the extent to which pigeonpea can increase soil available phosphorus in the cropping system by utilizing phosphorus sources of limited availability to other crops.

Grain and Food Quality

Tempeh Quality

Pigeonpea utilization in *tempeh,* a fermented food product, has been reported (ICRISAT Annual Report 1988, p. 99). We studied the organoleptic properties of *tempeh* prepared from whole seeds and dhal samples of 10 cultivars (ICPLs 87, 151, 270, 366, 87051, 87063, 87067, ICP 8863, BDN 2, and C 11). Very little difference was observed in the organoleptic properties and general acceptance of *tempeh* made from these cultivars, as evaluated by eight panel members. We further examined the effect of fermentation on the chemical constituents of pigeonpea dhal. For *tempeh* preparation, soaked and boiled dhal samples of varieties C 11 and Nylon were fermented at 30° C for 24 h using *Rhiiopus oligosporus.* Soaked and boiled dhal samples were used as controls. Fermented and control samples were freeze-dried and analyzed for protein, soluble nitrogen, starch, and soluble sugars. Protein content increased and starch content decreased due to fermentation (Table 6). We also observed remarkable increases in both soluble sugars and soluble nitrogen as a result of fermentation. An increase in soluble sugars after fermentation could have been due to an enzymatic degradation of starch, thus reducing the starch content. The amino acid composition of fermented and control samples was similar.

Table 6. Effect of fermentation with *Rhizopus oligosporus* at 30° C for 24 h on protein and starch contents of C 11 and Nylon, 1CRISAT Center, rainy season 1987[1].

	Protein (%)		Soluble nitrogen[2] (%)		Starch (%)		Sugars (%)	
Cultivar	Control	Fermented	Control	Fermented	Control	Fermented	Control	Fermented
C II	24.8	29.8	2.6	25.6	58.7	51.8	0.6	1.9
Nylon	23.5	26.3	2.9	14.7	57.7	54.3	0.5	1.4
SE	±0.34	±0.30	±0.18	±0.45	±1.02	±0.76	±0.02	±0.03

1. Based on two determinations of freeze-dried sample for each treatment.
2. $g(100g)^{-1}$ protein.

Starch Properties and Noodle Quality

A stable viscosity of hot paste of starch is considered to be a desirable characteristic of legume starch for preparation of noodles. We investigated this property using isolated starches of nine cultivars. A starch solution (8%) was heated at 95° C for 1 h, and initial and final viscosity readings in Brabender units were recorded using the viscoamylograph. There was no breakdown in the viscosity curve during this heating period indicating a stable viscosity of pigeonpea starch. Our earlier studies (ICRISAT Annual Report 1988, p. 98) have shown that starch noodles of pigeonpea dhal were better than those of mungbean dhal, but the starch extraction rate from both the whole seed and dhal samples of mung bean was higher than that of pigeonpea. We extracted the starch from nine cultivars (ICPLs 87, 151, 270, 366, 87051, 87063, 87067, ICPV 1 [ICP 8863], and BDN 2) that were grown at ICRISAT Center in the 1988 rainy season. Starch yield of dhal samples of these cultivars (expressed as percentage of extraction of total starch in the sample) ranged between 64.3% and 82.0%, showing considerable variation. Cultivars yielding higher starch recovery will be further investigated.

New Food Uses

We explored the feasibility of using pigeonpea in various foods items of East Africa. With the help of a trainee from Kenya, three important Kenyan food products namely, *Isyo, Mukimwa,* and *Muthokoyi,* were prepared in which whole pigeonpea seed was used. These food products were prepared by adding other required ingredients such as maize, potatoes, and other vegetables. The organoleptic properties of these three food products were evaluated and found acceptable by the taste panel, which included members from African countries.

Rat Bioassay of Newly Developed Cultivars

Biological value, which serves as an index of protein quality, is lower in pigeonpea than in

Table 7. Biological value (BV), true protein digestibility (TD), net protein utilization (NPU), and utilizable protein (UP) of 10 pigeonpea cultivars, ICRISAT Center, rainy season 1988[1].

Cultivar	Protein (%)	BV (%)	TD (%)	NPU (%)	UP(%)
ICPL 87	23.4	66.0	89.1	58.9	13.8
ICPL151	20.5	68.2	88.3	60.2	12.3
ICPL 270	21.5	64.7	87.6	56.6	12.1
ICPL 366	22.7	70.6	92.4	65.4	14.8
ICPL 87051	23.1	66.7	90.6	60.5	14.0
ICPL 87063	22.7	65.3	87.9	57.4	13.0
ICPL 87067	23.9	61.0	92.8	56.6	13.5
ICPV 1 (ICP 8863)	21.8	67.9	87.6	59.5	13.0
Controls					
BDN 2	22.8	64.8	89.6	58.0	13.3
C11	20.5	69.7	88.8	61.9	12.7
SE	±0.37	±2.35	±1.42	±2.30	±0.52

1. Five rats were used for each cultivar.

other grain legumes, even after cooking. We determined the biological value (BV), true protein digestibility (TD), net protein utilization (NPU), and utilizable protein (UP) by conducting rat-feeding trials on cooked dhal samples of newly developed cultivars. Dhal samples were cooked at 1.05 kg cnr^{2} for 15 min in a pressure cooker. While TD values of these cultivars ranged from 87.6% to 92.8%, BV values ranged from 61.0% to 70.6% (Table 7). Lower BV of cooked dhal samples might have been due to the lower bioavailability of sulphur-containing amino acids.

Chemical Changes in Vegetable Pigeonpea

Keeping in mind the harvesting stages of vegetable pigeonpea, the developing green seeds of two

Table 8. Hundred seed mass, moisture content, and chemical constituents at different stages of seed development of ICP 7035 and T 15-15, ICRISAT Center, rainy season 1988[1].

Days after flowering	100-seed mass (g) Fresh	Dry	Moisture (%)	Protein (%)	Sugars (%)	Starch (%)	Crude fiber (%)	Calcium	Magnesium	Zinc	Iron	Copper
								mg(100g)-1				
						ICP 7035						
24	9.8	1.9	80.3	26.8	21.1	35.0	6.6	59.5	137.6	4 3	3.9	1.0
				(5.0)2	(4.0)	(5.6)	(1.3)					
26	16.2	3.2	80.1	25.8	19.2	39.2	7.4	52.0	135.2	3.7	3.6	0.9
				(8.2)	(6.2)	(12.5)	(2.4)					
28	23.8	5.3	77.6	23.1	15.8	42.7	7.5	50.9	130.7	2.7	3.3	1.1
				(12.3)	(8.4)	(22.8)	(3.9)					
30	27.7	6.6	76.1	23.2	13.7	45.9	7.9	53.9	127.8	2.5	3.0	1.2
				(15.3)	(9.0)	(30.2)	(5.3)					
32	33.8	9.2	72.9	21.4	12.9	50.7	7.8	58.0	123.8	3.1	3.1	1.0
				(19.7)	(11.9)	(46.7)	(7.2)					
SE	±0.29	±0.43	±0.56	±0.53	±0.38	±0.52	±0.09	±2.78	±3.35	±1.02	±0.09	±0.03
				(0.38)	(0.30)	(0.47)	(0.05)					
						T 15-15						
24	9.0	2.1	77.2	29.2	9.8	29.2	10.6	91.8	140.4	2.8	3.9	0.7
				(6.2)2	(2.0)	(6.2)	(2.1)					
26	13.5	3.2	76.3	25.6	8.2	43.6	9.8	80.2	142.8	2.8	3.6	0.8
				(8.2)	(2.6)	(14.0)	(3.2)					
28	13.4	3.3	75.5	25.5	9.5	43.3	9.1	84.3	142.3	2.5	3.7	0.6
				(8.4)	(3.1)	(14.2)	(3.0)					
30	14.8	4.8	67.7	25.7	8.1	45.8	8.9	88.5	145.4	2.8	3.3	0.7
				(12.3)	(3.4)	(22.0)	(4.3)					
32	19.0	6.6	65.2	24.8	6.1	48.0	8.6	87.5	144.1	2.8	2.9	0.7
				(16.2)	(4.0)	(31.7)	(5.7)					
SE	±0.39	±0.20	±0.87	±0.32	±0.08	±0.55	±0.18	±3.89	±4.30	±0.15	±0.14	±0.08
				(0.18)	(0.05)	(0.25)	(0.11)					

1. Means of two determinations on freeze-dried samples. Results are expressed on moisture-free basis.
2. Values in parentheses indicate mg seed^{-1}.

vegetable pigeonpea cultivars, ICP 7035 and T 15-15, were sampled at 24, 26, 28, 30, and 32 days after flowering (DAF). Changes in the chemical constituents including minerals and trace elements, at different DAFs for two cultivars, ICP 7035 and T 15-15 are summarized in Table 8. A large increase in the seed size was noticed between 24 and 28 DAF and it continued to increase up to 32 DAF. The rate of dry matter accumulation in seeds was faster in ICP 7035 than in T 15-15. Soluble sugars and proteins, expressed as percentage of fresh mass and dry mass decreased and starch content increased between 24 and 32 DAF. Green seeds of T 15-15 contained more calcium and magnesium than did seeds of ICP 7035. However, ICP 7035 contained remarkably higher amounts of soluble sugars, at all the stages of seed development, compared to T 15-15, a desirable quality in vegetable pigeonpea.

Plant Improvement

Short-duration Pigeonpea

We continued our emphasis on breeding high-yielding ESD (<100 DAS at Hisar for normal end-of-June sowing) and SD (101 130 DAS) pigeonpeas. We identified two new lines, ICPL 86023 and ICPL 88026, for the AICPIP multilocational trials in 1989. Both are large seeded and outyielded their respective controls in each year. The performance of these lines from 1986-88 is summarized in Table 9.

Table 9. Grain yield and seed mass of ICPL 86023 (indeterminate), ICPL 88026 (determinate), and control cultivars at the ICRISAT Cooperative Research Station at Hisar, rainy seasons 1986-88.

	Grain yield (t ha^{-1})					100-seed
					Superiority	mass (g)
Lines	1986	1987	1988	Mean	over control (%)	(1988)
ICPL 86023	2.77	3.28	2.29	2.78	27.5	13.4
Control						
UPAS 120	2.37	2.86	1.31	2.18		7.2
SE	±0.25	±0.28	±0.23			±0.23
Trial mean	2.23	2.86	1.66			9.24
(Entries)	(14)	(18)	(16)			(18)
CV (%)	23	17	24			4
ICPL 88026	-[1]	4.21	2.82	3.57	46.52	12.0
Controls						
ICPL	-	2.92	1.60	2.44		11.5
ICPL	-	2.74	1.61	2.17		12.0
SE	-	±0.39	±0.23			±0.22
Trial mean	-	2.85	1.92			11.87
(Entries)	-	(16)	(18)			(18)
CV(%)	-	23	20			3

1. - = Data not available.
2. Superiority over ICPL 151.

Table 10. Performance of some newly developed extra-short and short-duration determinate pigeonpea lines at ICRISAT Center and Hisar, rainy season 1988.

Lines	Grain yield ($t\ ha^{-1}$) ICRISAT Center	Grain yield Hisar	Grain yield Mean	At ICRISAT Center: Time to 50% flowering (days)	Time to maturity (days)[1]	100-seed mass (g)	Seed color[2]
Extra-short-duration lines							
ICPL 87094	2.11(1)[3]	1.99(2)	2.05	65	116	8.4	B
ICPL 88001	1.95(2)	2.37(1)	2.16	62	117	9.8	B
ICPL 88009	1.95(3)	0.95 (9)	1.45	64	112	8.9	B
Control							
ICPL 4	1.83(4)	0.91 (10)	1.37	65	108	5.8	B
SE	±0.139	±0.114		±0.7	±1.6	±0.18	
Trial mean (18 entries)	1.55	1.12		55	104	8.9	
CV (%)	15.6	17.5		2.1	2.6	3.6	
Short-duration lines							
ICPL 87101	2.88(3)	2.17(6)	2.53	70	134	12.9	B
ICPL 87104	3.13(1)	1.69(11)	2.41	69	122	12.6	C
ICPL 88020	1.88(15)	3.09(1)	2.49	73	137	10.8	B
ICPL 88023	2.66 (4)	1.88(9)	2.27	71	134	14.1	B
ICPL 88027	2.92 (2)	2.69 (3)	2.81	73	137	11.0	W
Controls							
ICPL 87	2.32 (8)	1.61 (12)	1.97	73	136	10.9	B
ICPL 151	2.44 (5)	1.60(13)	2.02	69	116	11.0	C
SE	±0.279	±0.227		±0.9	±1.5	±0.20	
Trial mean (18 entries)	2.27	1.92		71	130	11.6	
CV(%)	21.3	20.5		2.2	2.0	2.9	

1. Maturity delayed beyond normalcy due to insect damage at ICRISAT Center.
2. B = Brown, C = Cream, W = White.
3. Values in parentheses are ranks at each location.

In ICRISAT's multilocational trials with determinate (DT) lines, on an overall mean basis, a large-seeded line, ICPL 84031, yielded the highest (1.74 $t\ ha^{-1}$) compared to the control, ICPL 151, which was in the fifth position (1.35 $t\ ha^{-1}$). Among 12 locations, at 7 locations it was one of the two high-yielding lines. We identified three new ESD (ICPLs 87094, 88001, and 88009) and four SD (ICPLs 87101, 87104, 88023, and 88027) DT pigeonpea lines yielding higher than the control cultivars, both at ICRISAT Center and at Hisar (Table 10).

We also continued our efforts to develop SD indeterminate (NDT) lines. In ICRISATs multilocational trials with NDT lines, based on overall means, ICPL 87115 yielded the highest

(1.89±0.099 t ha^{-1}) followed by ICPL 84052 (1.63±0.099 t ha^{-1}), and ICPL 85046 (1.61 t ha^{-1}), compared with the 11th rank for the control cultivar, UPAS 120 (1.44 ± 0.099 t ha^{-1}). Of the 13 locations, ICPL 87115 was among the top four entries at eight locations followed by ICPL 84052 at six and ICPL 85046 at five locations compared with the control, UPAS 120, which was among the top four entries only at two locations. In addition to these, we have also identified five new NDT pigeonpea lines (ICPLs 86030, 87113, 87114, 87116, and 88036) with larger seeds and higher grain yields than those of the control cultivars, UPAS 120 and Manak, both at ICRISAT Center and at Hisar (Table 11). Of these, ICPL 86030 yielded the highest at Hisar and ranked 16th at ICRISAT Center, compared with the 15th rank for the control, UPAS 120, and 17th rank for the control, Manak. This indicates that it is more adapted to northern Indian situations.

Comparison Between Determinate and Indeterminate Short-duration Lines

At ICRISAT Center, we give greater emphasis to breeding DT than NDT lines. It is generally believed, however, that DT cultivars are comparatively lower yielders and are more susceptible to pod-borer damage than NDT types. Many replicated yield trials have been conducted with lines of both DT and NDT growth habits at different locations over several years. Data from 115 yield trials, consisting of diverse genotypes of similar maturity, conducted at Hisar, ICRISAT Center, and other locations (multilocational trials) from 1982 to 1988 are summarized in Table 12 to highlight the differences between these groups for yield and insect damage. Grain yield of DT lines was in no way inferior to that of the NDT group. Furthermore, DT lines as a group did not seem to be more susceptible to insect damage.

Table 11. Performance of some newly developed short-duration indeterminate pigeonpea lines at ICRISAT Center and Hisar, rainy season 1988.

	Grain yield (t ha^{-1})			ICRISAT Center			
Lines	ICRISAT Center	Hisar	Mean	Time to 50% flowering (days)	Time to maturity (days)	100-seed mass (g)	Seed color[1]
ICPL 86030	1.54(16)[2]	2.76(1)	2.15	72	124	10.7	B
ICPL 87113	2.49 (2)	2.46 (2)	2.48	65	117	12.1	B
ICPL 87114	2.20(3)	2.19(4)	2.20	64	116	9.4	C
ICPL 87116	1.98(7)	2.04(6)	2.01	68	119	8.8	B
ICPL 88034	2.67(1)	1.36(14)	2.02	68	120	8.9	B
ICPL 88036	1.92(8)	2.07(5)	2.00	71	124	9.0	B
Controls							
UPAS 120	1.69(15)	1.94(7)	1.82	65	120	7.2	B
Manak	1.51(17)	1.73(9)	1.62	61	111	7.0	B
SE	±0.208	±0.203		±1.0	±0.9	±0.21	
Trial mean (18 entries)	1.87	1.65		66	119	9.4	
CV (%)	19.3	21.3		2.5	1.3	3.8	

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

Table 12. Comparative performance of determinate (DT) and indeterminate (NDT) short-duration pigeonpea lines at Hisar and ICRISAT Center, rainy seasons 1982-88.

Parameter	Growth habit	Station trials: Hisar	Station trials: ICRISAT Center	Multilocational trials[1]
Grain yield				
Years	-	1982-88	1984-88	1982-88
Number of trials	DT	38	16	8
	NDT	32	13	8
Total entries tested	DT	821	298	129
	NDT	642	256	119
Mean grain yield ($t\ ha^{-1}$)	DT	2.37	1.72	1.67
	NDT	2.26	1.32	1.59
Mean grain yield of the top five entries in each test ($t\ ha^{-1}$)	DT	3.01	2.10	2.10
	NDT	2.85	1.63	1.96
Insect pest damage[2]				
Years	-	1985-88	1984-88	
Number of trials	DT	6	5	-
	NDT	6	5	-
Total entries tested	DT	120	38	-
	NDT	124	65	-
Hclicoverpa damage (%)	DT	120	38	-
	NDT	31.4	52.8	-
Podfly damage (%)	DT	9.5	4.5	-
	NDT	13.5	3.3	-

1. Data from 69 trials.
2. Data from nonsprayed trials.

Response of Extra-short-duration Pigeonpea to Sowing Date and Plant Population

It has been envisaged that ESD pigeonpea genotypes would benefit double-cropping systems with wheat, as their reduced duration may permit greater flexibility in time of sowing of wheat. However, this should not be at the expense of yield potential of ESD pigeonpeas. Since little is known about optimum agronomic requirements for ESD pigeonpeas, we evaluated their yield potential at different sowings and plant populations. Short-duration pigeonpea genotypes were also included for comparison.

Split-plot experiments were conducted at Gwalior and Hisar with the main plots comprising three sowing dates, subplots including three ESD genotypes and two SD genotypes, and sub-subplots having three plant populations.

At Gwalior, differences among genotypes and their interactions with sowing dates were significant. Extra-short-duration genotypes were more stable across sowing dates than the control, ICPL 151, an SD genotype (Fig. 7a). Although early-sown ESD genotypes were attacked by pod-sucking insects, they were able to flower again, and mature at the same time as SD genotypes. In the latest sowing, in spite of earlier maturity than the SD genotype, the ESD genotype gave up to 28% more yield than ICPL 151.

At Hisar, ESD genotypes matured about 1 month earlier in all the sowings. ICPL 84023, one of the earliest ESD genotypes, grew to only 70% of the height of ICPL 151. Its yield was also low. By contrast, ICPL 85015, another ESD type, had yields similar to or higher than those of ICPL 151 (Fig. 7b), although it matured about a week earlier. The effect of sowing date was not significant at this location. At both locations, ICPL 85045 was generally a good performer compared to all other genotypes.

At both locations, ESD genotypes tended to give higher yields at 30 cm x 10 cm spacing whereas SD genotypes yielded best at 30 cm x 20 cm spacing.

Extending Pigeonpea Adaptation

The present limits to pigeonpea cultivation appear to be 30° latitude and 1000 m altitude. The recently developed ESD lines are relatively photoperiod-insensitive, and it is possible to grow them under nontraditional, relatively cooler environments. Because of their short growth period and relative photoperiod-insensitivity, they can mature before the cold weather begins at higher latitudes and altitudes. An extra-short-duration pigeonpea international trial (EXPIT) was grown at eight locations at latitudes >30° N

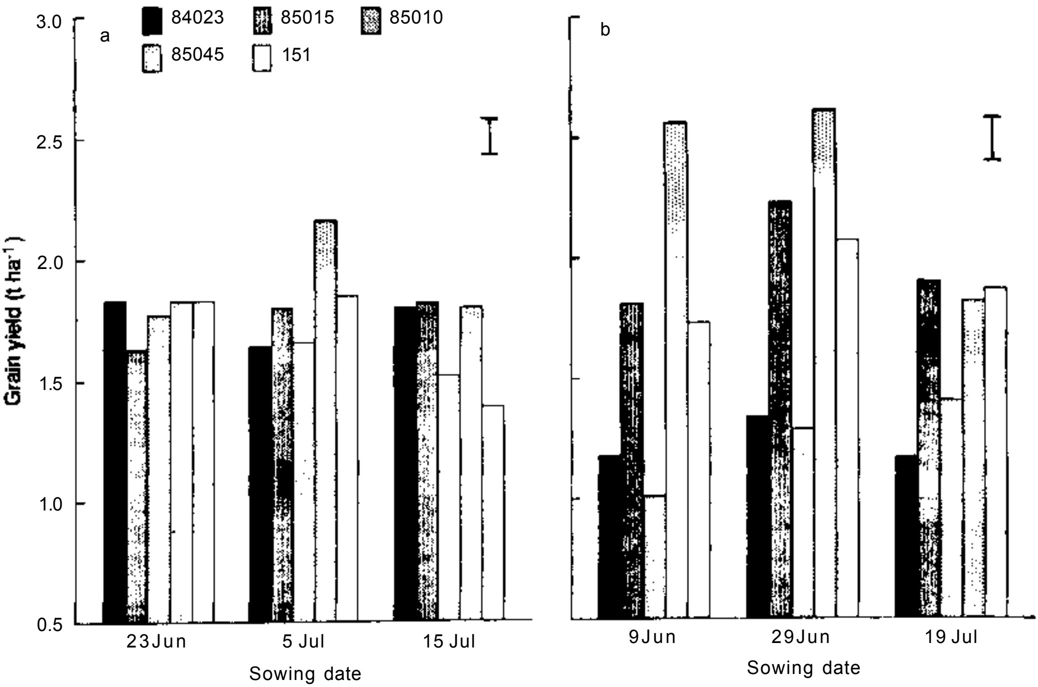


Figure 7. Effect of sowing date on yield of extra-short-duration (ICPLs 84023, 85015, 85010) and short-duration (ICPL 85045 and ICPL 151) pigeonpea genotypes grown at (a) Gwalior and (b) Hisar, India, rainy season 1988/89.

and at six altitudes > 1000 m above sea level (asl). The performance of these lines (Table 13) suggests that the cultivation of newly developed ESD lines can successfully be extended to non-traditional environments.

Incorporating Disease Resistance

In the MD and LD groups, we continued to emphasize stabilizing productivity by incorporating resistance to major diseases. In the MD

Table 13. Summary of the performance of extra-short-duration pigeonpea lines at higher latitudes and altitudes, at different locations, summer 1988.

Location	Latitude	Altitude (m)	Date sown (1988)	High-yielding lines	Grain yield ($t\ ha^{-1}$)
Higher latitudes					
College Station, Texas, USA	32° N	104	13 Jun	ICPL 83015	3.73
				ICPL 83019	3.58
Tifton, Georgia, USA	34° N	-[1]	9 Jun	ICPL 87109	4.97
				ICPL 86029	4.24
Suweon, Republic of Korea	37° N	-	31 May	ICPL 85010	2.42
				ICPL 87100	2.38
Clyde, Central Otago, New Zealand	45° S	150	19 Oct	ICPL 151	1.02
				ICPL 84023	0.91
Pullman, Washington, USA	46° N	-	19 May	ICPL 87097	1.01
				ICPL 86010	0.91
Prosser, Washington, USA	46° N	-	May	ICPL 85031	2.53
				ICPL 85030	2.46
Higher altitudes					
Barapani, Shillong, India	26° N	1000	27 Jun	ICPL 85024	1.83
				ICPL 87095	1.71
Almora, Uttar Pradesh, India	30° N	1250	6 Jun	ICPL 151	1.99
				ICPL 83019	1.76
Srinagar, Jammu and Kashmir, India	33° N	1585	29 May	ICPL 85014	0.89
				ICPL 85031	0.81
Salooni, Himachal Pradesh, India	33° N	1768	6 Jun	ICPL 151	0.42
Alemaya, Ethiopia	10° N	1980	16 Jun	ICPL 86012	0.49
				ICPL 85015	0.39
Ranichauri, Uttar Pradesh, India	30° N	2100	9 Apr	ICPL 85049	0.66
				ICPL 87109	0.65

1. Altitude of the test site not reported.
2. Trials were heavily infected with powdery mildew disease.

group, two fusarium wilt- and SM-disease-resistant lines, ICPL 88046 and ICPL 88047, were tested at six Indian locations in the multilocational Medium-duration Pigeonpea Advanced Yield (MPAY) trial. Yield data are presented in Table 14 and ICPL 88046 and ICPL 88047 have been promoted for evaluation in AICPIP trials for 1989.

We incorporated SM resistance in the adapted variety BDN 1, by backcrossing and evaluated the promising derivatives for yield and other agronomic traits under disease-free conditions at ICRISAT Center. Two lines produced significantly higher yields and had larger seeds than the control cultivar BDN 1 (Table 15). These lines have been identified for the MPAY multilocational trial. We also succeeded in developing a wilt-resistant line, ICPL 88045, through gamma-ray irradiation from a high-yielding but wilt-susceptible cultivar, LRG 30. This line was tested at six Indian locations during the 1988 rainy season and it produced similar average grain yield as the national controls C 11 and BDN 1 (Table 14). In a wilt-sick nursery at ICRISAT Center, ICPL 88045 had 3% wilt compared with 58% in C 11. We plan to evaluate ICPL 88045 in multilocational trials and study its genetics in relation to other wilt resistance sources.

In the LD group, an SM-resistant line, ICPL 87143, produced a significantly higher grain yield of 3.55±0.224 t ha^{-1}, compared with 2.88± 0.224 t ha^{-1} of the control cultivar, Gwalior 3, at Gwalior.

Incorporating *Helicoverpa* Resistance in Medium-duration Pigeonpeas

The yields of the newly released MD *Helicoverpu*-tolerant genotype ICPL 332 (Abhaya) are similar to the controls C 11, BDN 1, and LRG 30 under normal protected conditions but is consistently superior under pesticide-free conditions (Table 16). The value of this line was further proven in 1987 when there was a severe outbreak of *Helicoverpa* pod borer in Andhra Pradesh.

Table 14. Performance of three medium-duration promising lines at six locations in India in the multilocational medium-duration pigeonpea advanced yield (MPAY) trial, rainy season, 1988.

	Grain yield (t ha^{-1})							
Entry	ICRISAT Center	Keonjhar (Orissa)	Badnapur (Maharashtra)	Anand (Gujarat)	Coimbatore (Tamil Nadu)	Vadodara (Gujarat)	Mean	Percentage of wilt in nursery
ICPL 88046	3.18(1)[1]	2.92(4)	0.87 (7)	2.03(1)	0.77 (3)	1.65(9)	1.90(1)	4
ICPL 88047	2.83 (2)	2.94 (3)	0.95 (6)	1.57(6)	0.51 (6)	2.14(3)	1.82(2)	1
ICPL 88045	2.42(5)	2.89(5)	0.76(10)	1.60(5)	0.90 (1)	1.79(6)	1.73(6)	3
Controls								
C 11	2.66 (3)	2.97 (2)	1.06(2)	1.42(9)	0.51 (6)	2.15(2)	1.80(3)	58
BDN1	1.91(11)	2.32(9)	1.00(4)	1.52(7)	0.38(10)	1.97(5)	1.52(10)	57
SE	±0.195	±0.358	±0.127	±0.213	±0.092	±0.211		
Trial mean (12 entries)	2.35	2.67	0.91	1.53	0.57	1.88		
CV (%)	17	20	28	28	32	15		

1. Rank in the trial.

Table 15. Performance of two SM-resistant BDN 1 derived lines grown at ICRISAT Center, rainy season 1988.

Entry	Grain yield (t ha^{-1})	Time to 50% flowering (days)	Time to maturity (days)	100 seed mass (g)	Percentage of SM in nursery 1986	Percentage of SM in nursery 1987
BDN 1 BC3F2-2*-S6*-S3*-SB*-B	2.69	123	205	11.1	0	0
BDN 1 BC3F2-16*-S4*-S5*-SB*-SB	2.61	121	203	13.3	0	0
Control						
BDN J	2.04	120	201	10.3	100	100
SE	±0.130	±1.0	±1.2	±0.15		
Trial mean (12 entries)	2.34	121	203	11.7		
CV (%)	11	2	1	3		

Hybrids

During 1988, new short-duration DT and NDT hybrids were evaluated at Hisar and ICRISAT Center. The performance of some promising hybrids is summarized in Table 17. Among these, an NDT hybrid, IPH 732, maturing in 148 days at Hisar and 129 days at ICRISAT Center, was the most outstanding with a grain yield of over 5 tha^{-1}. We plan to produce large quantities of seed of some of the promising hybrids for multinational testing.

With the close cooperation of ICRISAT pigeonpea breeders, Maharashtra Hybrid Seeds

Table 16. Performance of a Helicoverpa-tolerant line, ICPL 332, and controls, C 11 and BDN 1, in pesticide-free conditions at ICRISAT Center, rainy seasons 1985-88.

Entry	1985 Grain yield (t ha^{-1})	1985 Borer damage[1] (%)	1986 Grain yield (t ha^{-1})	1986 Borer damage (%)	1987 Grain yield (t ha^{-1})	1987 Borer damage (%)	1988 Grain yield (t ha^{-1})	1988 Borer damage (%)	Mean grain yield (t ha^{-1})	Borer damage (mean %)
ICPL 332	1.84	11.6	1.43	22.5	0.30	70.6	1.09	28.8	1.15	35
Controls										
C 11	1.32	21.1	1.05	38.3	0.04	99.6	1.22	34.1	0.89	51
BDN 1	1.44	33.4	-[2]	71.4	0.04	94.2	0.92	43.7	0.78	65
SE	±0.168	±3.34	±0.088	±1.97	±0.087	±7.73	±0.200	±3.01		
Trial mean	1.25	23.2	1.33	24.0	0.27	71.3	0.91	33.1		
(Entries)	(14)	(14)	(16)	(16)	(12)	(12)	(16)	(16)		
CV (%)	23	25	13	16	64	22	38	16		

1. The percentage of borer damage was analyzed after angular transformation.
2. Not measured.

Table 17. Performance of some new short-duration pigeonpea hybrids at Hisar and ICRISAT Center, rainy season 1988.

	Grain yield[1] ($t\ ha^{-1}$)			Time to 50% flowering (days)		Time to maturity (days)	
Entry	Hisar	ICRISAT Center	Mean	Hisar	ICRISAT Center	Hisar	ICRISAT Center
Determinate							
IPH 550	2.36 (2)	5.08 (1)	3.72	69	66	108	110
IPH 565	3.32(1)	3.99 (2)	3.65	68	67	106	109
Controls							
Prabhat	0.78 (9)	1.75(8)	1.27	67	67	105	106
ICPL 151	1.55(4)	0.89(10)	1.22	69	69	114	111
SE	±0.183	±0.585		±0.5	±0.7	±0.9	±1.0
Trial mean (10 entries)	1.49	2.78		66	65	106	108
CV (%)	17	30		1	2	1	1
Indeterminate							
IPH 732	5.51(1)	5.58(1)	5.55	93	86	148	129
IPH 712	4.05 (4)	4.86 (3)	4.46	89	84	146	124
IPH 714	4.46 (2)	4.31 (5)	4.38	88	81	136	126
IPH 721	4.03 (5)	4.23 (8)	4.13	96	91	143	130
Controls							
T21	2.38(15)	2.46(16)	2.27	92	82	143	124
Manak	2.13(17)	1.53(18)	1.83	79	66	130	109
SE	±0.346	±0.679		±0.8	±0.9	±0.8	±1.2
Trial mean (18 entries)	3.34	3.65		89	82	140	124
CV (%)	15	26		1	2	1	1

1. Ranks are given in parentheses.

Company (MAHYCO), Jalna, India, has marketed its first pigeonpea hybrid in nine districts of Maharashtra. Its Research Manager has reported a superiority of 40-60% in the pigeonpea hybrids over the control cultivar C 11, with yield levels of 2.5 3.0 t ha^{-1} under sole crop and 1.7-2.21 ha^{-1} in mixed cropping with cotton. He also informed that MAHYCO's trained contract seed growers have been able to harvest 1.0 1.5 t ha^{-1} of F_1 hybrid seed and their marketing target for the next year is about 20 t.

Genetic Studies

The inheritance of growth habits (DT, semi-determinate [SDT], and NDT) in pigeonpea was studied in F_1, F_2, and backcross generations of 15 complete diallel crosses involving six parents (two of each growth habit). The data revealed that NDT was dominant over both SDT and DT and that SDT was dominant over DT. The segregation pattern in the crosses involving NDT and DT parents indicated that the NDT trait was governed by a single dominant gene. Similarly, crosses between SDT and DT parents showed that the SDT growth habit was controlled by a single dominant gene. The F_2 population of the crosses involving NDT and SDT parents segregated into a dihybrid epistatic ratio of 12 NDT: 3 SDT: 1 DT.

Cooperative Activities

International Pigeonpea Adaptation Trials and Seed Distribution

We continued cooperative testing of newly devel-

Table 18. Performance of some promising pigeonpea genotypes in international trials, 1988. See also data in Table 10.

Country and location	Date sown	Genotype	Yield (t ha[1])	Trial mean (number of entries)	SE	CV (%)
China						
Guangzhou	27 Apr 1988	ICPL 85033	2.03	1.38(17)	±0.17	22
		ICPL 86010	1.98			
Indonesia						
Maros	2 Aug 1988	ICPL 85027	1.09	-[1]	-	23
		ICPL 86005	1.03			
Maros	2 Aug 1988	ICPL 151	1.00	-	-	23
		ICPL 83015	0.74			
Iran						
Keraj	1 Jul 1988	ICPL 86010	2.63	1.76(14)	±0.26	25
		ICFL 86005	2.22			
Niger						
Kolo	17 Jun 1988	ICPL 84032	1.54	0.86(13)	±0.33	66
		ICPL 85012	1.40			
Panama						
Tocumen	24 Oct 1988	ICPL 87	2.21	1.53(16)	±0.24	27
		ICPL 86012	1.95			
Chiriqui	26 Oct 1988	ICPL 85024	2.96	2.46(14)	±0.34	24
		ICPL 87098	2.92			
Sri Lanka						
Aralaganwila	4 Dec 1987	ICPL 151	3.30	2.78(13)	±0.43	27
		ICPL 85021	3.25			
	18 May 1989	ICPL 270	0.88	0.64 (10)	±0.08	26
		ICPV 1 (ICPL 8863)	0.77			
The Philippines						
Ilocos Norte	12 Nov 1987	ICPL 146	4.31	-	-	21
		ICPL 288	4.31			
Ilocos Norte	12 Nov 1987	ICPL 85033	4.17	-	-	20
		ICPL 4	4.0			
Ilocos Norte	12 Nov 1987	ICPL 84037	4.44	-	-	25
		ICPL 151	4.18			
Zimbabwe						
Matopos	24 Nov 1987	ICPL 86005	2.87	1.76(14)	±0.28	28
		ICPL 87046	2.35			
	8 Dec 1988	ICPL 151	1.49	0.84(18)	±0.24	49
		ICPL 84023	1.14			

1. - = Data not reported.

oped pigeonpea genotypes in countries other than India. During 1988, SD yield trials were sent to 20 countries in Asia, Africa, and Central America, and results have so far been received from 12 countries (Table 18). Grain yields ranged from 1.0 to 4A t ha^{-1}. ICPLs 146, 151, 288, 84037, and 85033 produced more than 4 t ha^{-1} grain yield in the Philippines. Similarly, in Sri Lanka, ICPL 151 and ICPL 85021 yielded more than 3 t ha^{-1}.

In response to requests, we supplied 161 sets of trials and 600 seed samples of elite lines to cooperators in 40 countries, that is, Bahrain, Bangladesh, Benin, Bhutan, Bolivia, Cameroon, Canada, Cape Verde, Ethiopia, the Gambia, Guatemala, Guyana, Honduras, India, Indonesia, Japan, Kenya, Mauritius, Myanmar, Nepal, Niger, Nigeria, Oman, Pakistan, Peru, the Philippines, Saudi Arabia, Sri Lanka, Tanzania, Thailand, Togo, Trinidad, USA, USSR, Venezuela, Vietnam, West Germany, Zaire, Zambia, and Zimbabwe.

Cooperation with the Indian Council of Agricultural Research (ICAR)

An ESD line, ICPL 83006, produced an average of 21 % more grain yield than the control cultivar

Table 19. Mean zonal performance of ICPL 83006 and ICPL 84031 in the Extra-early Arhar Coordinated Trial (EXACT) conducted by the All India Coordinated Pulses Improvement Project (AICPIP) tests, rainy seasons 1987-88.

	Grain yield (t ha^{-1})										
	SZ[1]		CZ[1]		NWPZ[1]		NEHZ[1]		Weighted mean		Overall weighted mean
Trials and genotype	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	
Extra-early Arhar Coordinated Trial (EXACT)											
Number of locations	3	3	2	7	4	5	1	-	10	15	-
ICPL 83006	1.88	1.05	1.20	0.90	1.35	2.01	0.92	-	1.42	1.30	1.35
Control											
Prabhat	1.49	(0.87)2	(0.98)[2]	0.87	1.10	1.52	0.83	-	1.16	1.09	1.12
Pooled SE	±0.054	±0.035	±0.042	±0.031	±0.039	±0.062	±0.079				
Superiority over control (%)	26	20	22	3	22	32	11	-	22	19	21
Early Arhar Coordinated Trial (EACT)											
Number of locations	4	2	6	5	-	7	-	1	10	15	-
ICPL 84031	1.74	1.27	1.35	1.02	-	2.10	-	1.77	1.51	1.60	1.57
Control											
UPAS 120	1.34	0.91	1.04	0.98	-	1.59	-	1.15	1.16	1.26	1.22
Pooled SE	±0.048	±0.067	±0.060	±0.050		±0.051		±0.203			
Superiority over control (%)	30	39	30	4	-	32	-	53	30	27	28

1. SZ = South zone; CZ = Central zone; NWPZ = North west plains zone; and NEHZ = North east hills zone.
2. UPAS 120 grain yields are given in parentheses because Prabhat was not included in the trial at locations where data was reported.
3. - = Data not available.

Prabhat, in different zones (Table 19) in the Extra-early Arhar Coordinated Trial (EXACT) conducted by AICPIP. An SD line, ICPL 84031, was on an average 28% superior to the control cultivar, UPAS 120, in the Early Arhar Coordinated Trial (EACT) (Table 19).

ICPH 8, a short-duration NDT hybrid continued to perform well in EACT of AICPIP. In the central zone, it ranked first in multilocational trials in each of the 3 years of testing (Table 20). On an overall basis, ICPH 8 had 46% higher yield than the control cultivar UPAS 120.

In the MD Arhar Coordinated Trial-2 (ACT-2), three ICRISAT lines, ICPLs 87119, 85066, and 85063, occupied the top three ranks for overall performance in the southern zone (Table 21). Besides good average yield potential, ICPL 87119 showed yield stability and has combined resistance to fusarium wilt and SM, whereas ICPL 85066 has resistance to fusarium wilt. Another line, ICPL 85063, has resistance to SM. These lines are likely to provide stability of production in areas where these diseases are endemic.

Scientists from ICRISAT and ICAR identified areas of joint research in pigeonpea, and 3-year projects were developed. Joint projects dealing with exploitation of hybrid vigor, phenological studies, adaptation of SD pigeonpeas, inheritance of SM resistance, drought screening, and exchange of information and materials, and visits were approved.

Table 20. Comparative performance of hybrid ICPH 8 and control cultivar UPAS 120 in Central zone in the Early Arhar Coordinated Trial (EACT) of the All India Coordinated Pulses Improvement Project (AICPIP), rainy seasons 1986-88.

		Yield (t ha^{-1})		
Year	Number of trials	ICPH 8	Control UPAS 120	Pooled SE
1986	3	1.09(1)[1]	0.79(2)	±0.050
1987	4	1.50(1)	1.11(4)	±0.060
1988	6	1.63(1)	1.04(5)	±0.060
Weighted mean		1.46	1.00	

1. Ranks based on means of three trials in 1986, four trials in 1987, and six trials in 1988.

Table 21. Performance of promising lines from ICRISAT in the Arhar Coordinated Trial-2 (ACT-2) of the All India Coordinated Pulses Improvement Project (AICPIP) trials in the southern zone, rainy season 1988.

	Grain yield (t ha^{-1})							In the disease nursery in 1989	
Entry	ICRISAT Center	Gulbarga	Warangal	Palem	Zonal mean	Time to maturity (days)	100-seed mass (g)	Wilt (%)	SM (%)
ICPL 87119	1.75(1)'	1.00(5)	0.66 (4)	0.75 (3)	1.04 (1)	174	9.7	2	5
ICPL 85066	1.74(2)	1.02(4)	0.73 (2)	0.54 (9)	1.01 (2)	174	9.2	9	100
ICPL 85063	1.43(5)	0.89 (7)	0.49(10)	0.91 (1)	0.93 (3)	164	9.8	87	0
Control									
C 11	1.42(6)	0.92 (6)	0.36(13)	0.47(13)	0.79 (9)	168	8.7	32	100
SE	±0.090	±0.124	±0.083	±0.073					
Mean (17 entries)	1.30	0.85	0.52	0.58					
CV (%)	14	25	27	25					

1. Rank in the trial.

Cooperative Hybrid Pigeonpea Network

With the increasing interest of NARS and private and public seed companies in hybrid pigeonpea, the Cooperative Hybrid Pigeonpea Network (ICRISAT Annual Report 1988, p. 103) was strengthened. ICRISAT funded a joint planting plan meeting held at Tamil Nadu Agricultural University (TNAU), Coimbatore (Tamil Nadu, India), to review the progress of the project and to develop research plans for 1989. High-yielding hybrids were identified and a joint plan for developing new hybrids, large-scale testing of promising hybrids, hybrid seed production, and male-sterile conversion was formulated.

A week-long Hybrid Pigeonpea Training Program was conducted in September. This program gave intensive theoretical training and field training in development and testing procedures for pigeonpea hybrids and in procedures for maintenance and transfer of male sterility to elite genotypes. The participants included scientists from Indian agricultural universities, ICAR centers, and private seed industries (Fig. 8).

Impact Studies on Short-duration Pigeonpea

To assess the potential of SD pigeonpea in farmers' field conditions, ICRISAT's breeders, agronomists, and economists collaborated to conduct on-farm adaptation trials at three ICRISAT Village-level Study (VLS) sites during the 1987 and 1988 rainy seasons. Detailed analysis of the results of trials and of farmers' perceptions of SD pigeonpea has produced interesting information.

At Aurepalle, a VLS site in Andhra Pradesh

Figure 8. Some of the participants of the Hybrid Pigeonpea Training Program, identifying male-sterile plants and making pollinations for developing experimental pigeonpea hybrids, ICRISAT Center, September 1989.

characterized by shallow Alfisols (15-45 cm) and low annual rainfall (650 mm) with variable distribution, the outlook for SD pigeonpea appeared more favorable under irrigated conditions. In 1988, profits from SD pigeonpea exceeded those from paddy cultivation. However, under rainfed conditions, insufficient rainfall in 1987 severely limited yield and consequently its adoption potential. In 1988, which was a good rainfall year, the yield potential and returns were high even under rainfed conditions.

At Shirapur, a Vertisol site in Maharashtra, despite favorable yield and economic performance in both 1987 and 1988, there was some reluctance by farmers to adopt SD pigeonpea technology mainly because of the larger investments required and the lack of assurance of adequate return on increased investment. There was a concern about the increased infestation of pod borer. Intensive insecticide use, which is sometimes ineffective or unprofitable, particularly in the low-rainfall years, seems to escalate production costs and increase cost-benefit ratios.

At Kanzara, a deep Vertisol site in Maharashtra, farmers obtained good yield in the first year and therefore formed favorable opinions about SD pigeonpea. They were, however, disappointed in the second year as waterlogging and phytopthora blight decimated crops in 4 of the 9 field tests, again highlighting the element of instability in cultivation of SD pigeonpea.

In all the three villages, utilization of harvested seed depended on yields; high yields encouraged more produce to be used as seed for the succeeding year, and low yields encouraged sale of seed. Initial utilization of seed could therefore be a means of assessing farmers' acceptance of SD pigeonpea technology. The results of these on-farm adaptation trials indicate that, to increase adoption of SD pigeonpea, its stability of production needs to be considerably improved.

Publications

Institute Publications

Information Bulletin

Reed, W., Lateef, S.S., Sithanantham, S., and Pawar, C.S. 1989. Pigeonpea and chickpea insect identification handbook. Information Bulletin no. 26. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 120 pp. ISBN 92-9066-171-2. (IBE 026)

Newsletter

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. International Pigeonpea Newsletter nos. 9 and 10. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0255-786 X. (NPE)

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Linking grain legumes research in Asia: summary proceedings of the Regional Legumes Network Coordinators' Meeting, 15-17 Dec 1988, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 106 pp. ISBN 92-9066-173-9. (CPE 056)

Journal Articles

Faris, D.G. 1989. Leguminosae. *Cajanus cajan* (L.) Millsp. (In De.) Pages 254-255 in Spezieller Pflanzenbau in den Tropen und Subtropen (Rehm, S., ed.). Ludwigsburg, Federal Republic of Germany: Ungeheuer + Ulmer KG GmbH + Co. (JA 275)

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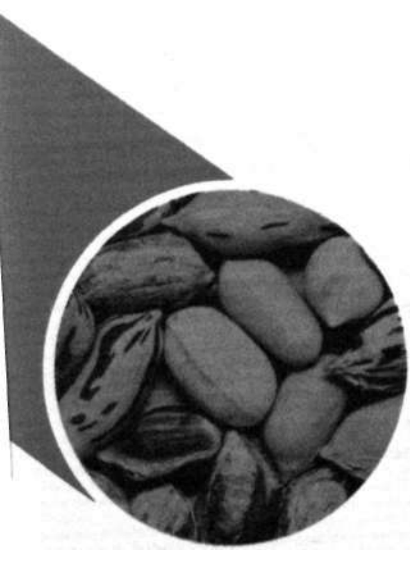
Sharma, S.B., and Nene, Y.L. 1988. Effect of *Heterodera cajani, Rotylenchulus reniformis* and *Hoplolaimus seinhorsti* on pigeonpea biomass. Indian Journal of Nematology 18(2):273-278. (JA 752)

Sharma, S.B., and Nene, Y.L. 1989. Interrelationship between *Heterodera cajani* and *Fusarium udum* in pigeonpea. Nematr6pica 19(1): 21-28. (JA 774)

Conference Papers

Waliyar, F., McDonald, D., Laxman Singh, and Jagdish Kumar. 1989. Recherches sur les legumineuses a graines a l'CRISAT. (In Fr.) Pages 77-96 *in* Les legumineuses a graines: actes du Seminaire, 22- 27 Feb 1988, Madagascar (Demarly, Y., ed.). Stockholm, Sweden: Fondation Internationale pour la Science. (CP 445)

Wallis, E.S., Faris, D.G., Elliott, R., and Byth, D.E. 1986. Varietal improvement of pigeonpea for smallholder livestock production systems. Pages 536-553 *in* Proceedings of the Crop-Livestock Systems Research Workshop, 7 11 July 1986, Khon Kaen, Thailand. Manila, Philippines: International Rice Research Institute. (CP 348)



GROUNDNUT

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

GROUNDNUT

There are three interacting groundnut programs in ICRISAT. The smallest, the Southern African Development Coordination Conference (SADCC)-ICRISAT Regional Groundnut Project for Southern Africa [the SADCC-Malawi (SM) Program] is based at the Chitedze Agricultural Research Station, near Lilongwe, Malawi. It serves the needs of the groundnut researchers in the National Agricultural Research Systems (NARSs) of the eight SADCC countries by organizing workshops and supplying seed. Much of the germplasm supplied has been bred specifically for the region. The stress is on high yield, high quality, and disease resistance.

At the ICRISAT Sahelian Center (ISC), Niger, a slightly larger team, consisting of an Agronomist, Breeder, and Pathologist, aided by a Resource Management Program (RMP) Physiologist, recently transferred from ICRISAPs Groundnut Group, responds to the wide and disparate needs of the West African NARS. The team members have realized that if they can find out why there is so much variability in the size and production of plants growing side by side in a field, they will have defined at least some of the reasons for low yields in the region. The results to date indicate plenty of scope for research by Virologists and Nematologists. The three major foliar diseases are of primary concern throughout the region. The Pathologist is building up a network of field sites and regrouping cooperators to evaluate lines that are known to have resistance to fungal diseases as well as varieties of local significance for adaptation to West African conditions.

At ICRISAT Center, scientists have a global responsibility to carry out research relevant to the needs of groundnut researchers in the semiarid tropics (SAT) and wherever groundnut is grown. Moreover, the Center is also the regional base for Asia.

During 1989 the ICRISAT Groundnut Group spent considerable time and effort reviewing the then current research programs and making plans for the future. In this, it was helped by representatives from the SM Program and ISC and by senior members of the Indian, Indonesian, and Thai NARSs. The links with the Indian Council of Agricultural Research (ICAR) have also been drawn nearer to make it easier for scientists in both Institutions to work together. In 1989, there were visits by several groundnut scientists to and from Bangladesh, the People's Republic of China, Indonesia, Myanmar, Nepal, Taiwan, and Thailand—all of which strengthened the links of ICRISAT's Asian groundnut network.

On the research front, the ICRISAT entomologists have made outstanding progress. Of particular interest is the discovery that several wild *Arachis* spp are resistant to a soil insect (jewel beetle larva, *Sphenoptera* sp) and that a mulch of a common Indian wayside weed can protect drying groundnuts from termite attack. Both these findings show that we may have found leads in solving the refractory problems posed by soil insects.

Groundnut Pathologists at ICRISAT Center screened all the available germplasm for resistance to late leaf spot *(Phaeoisariopsis personata)* (LLS) and rust *(Puccinia arachidis)* and found many resistant lines. This research is helping scientists at ISC, the SM Program, and in the NARSs of Africa and Asia. The Cell Biologists were able to transfer foliar disease resistance from wild *Arachis* species to cultivable genotypes. The Physiologists have increased their understanding of the mechanism of recovery in plants after drought—a key characteristic of certain groundnut varieties. The Breeders have had continuing success on all fronts with the varieties being bred at ICRISAT proving popular. Virologists at ICRISAT Center have found a technique for improving the purification of tomato spotted wilt virus (TSWV). Another common weed host, the groundnut streak necrosis disease (GSND) has been located in Africa. The nematodes and peanut clump virus (PCV) appear to be the cause of the high degree of plant variability in West African groundnut fields.

Physical Stresses

Photoperiod Responses

Selecting for High Harvest Index (HI) under Long Photoperiod

Since a high proportion of groundnut lines selected from material bred for biotic stress resistances was found to be photoperiod sensitive and yielded poorly under long day conditions (ICRISAT Annual Report 1988, p. 116), we initiated a program to select progenies with high pod yields and harvest indices (HIs) in unfavorable photoperiods. During the 1988/89 postrainy season, we grew three segregating early-generation foliar-disease resistant breeding populations under extended daylength (15 h) and selected F_4 individual plants with a range of HIs. We further advanced the F_5 progenies of these selections during the 1989 rainy season under a 17-h daylength. We worked out correlations between F_4 plants and their F_5 progenies for pod yield, biomass, and HI. In all three crosses, correlations were highly significant for HI (r=0.63 - 0.78), indicating that this criterion can be a marker for photoperiod insensitivity (r=0.29 and 0.38). We obtained low, but statistically significant correlations for pod yields in two out of three crosses, indicating that pod yields may also be considered as markers.

Drought

At ICRISAT Center, during the 1988 rainy season, we evaluated 64 genotypes, selected from drought resistance screening experiments for their performance under rainfed conditions at Anantapur, Andhra Pradesh. The crop had adequate rainfall during the vegetative growth phase but experienced a typical end-of-season drought for 4 weeks before harvest. The yields of some genotypes were 30% greater than those of the local control variety TMV 2 (Table 1).

Table 1. Performance of some selected groundnut genotypes under rainfed conditions at Anantapur, rainy season 1988.

Genotype	Pod weight ($t\ ha^{-1}$)	Total dry matter ($t\ ha^{-1}$)
ICGV 86187	3.7	6.7
ICGV 86234	3.5	6.5
ICG 8048	3.5	7.0
ICGV 86124	3.4	5.8
Local control TMV2	2.9	5.4
SE	±0.17	±0.37
Trial mean (64 entries)	2.8	5.6
CV (%)	12	13

During the 1988/89 postrainy season, we screened 391 genotypes for drought tolerance using a line-source sprinkler system and retained genotypes with above-average performances under water deficit conditions.

Drought Physiology

In the 1986/87 postrainy season, we studied the basis of genotypic variability in response to end-of-season drought conditions in 10 selected genotypes in the field. The crop was adequately watered until 82 days after sowing (DAS), after which drought was imposed by withholding irrigation until 112 DAS.

Water used (from a 120-cm soil profile) and total dry matter (TDM) produced by the genotypes during the drought period were measured using a neutron probe and growth analysis techniques. The TDM (vegetative + pod) achieved by genotypes during the drought period ranged from *72 to 150* g m^{-2} and was *closely related to* their water use (Table 2). The genotypic variabil-

Table 2. Total dry matter produced (y), water use (e), water use ratio (q), and partitioning ratio (proportion of total dry matter partitioned into pods) (h) of 10 groundnut genotypes during a period of drought (85-112 DAS), ICRkSAT Center, postrainy season 1986/87.

Genotype	y	e (mm)	q (g kg^{-1})	h (%)
ICG 1697	96	62	1.62	93
ICG 27J6	119	67	1.78	77
ICGV 86707	133	66	2.01	56
ICG 221	107	56	1.90	86
ICGV 86635	150	59	2.50	93
ICGV 86644	126	53	2.38	68
ICG 476	74	48	1.54	97
ICG 2738	99	68	1.44	97
ICG 5305	84	54	1.38	95
ICG 86743	72	50	1.43	65
SE	±11.2	±6.2	±0.18	±1.8

ity was maximum (>70%) for partitioning of dry matter to pods. We also found genotypic variability in the water used and the water-use ratio (dry matter produced per unit amount of water used, Table 2).

We are collaborating with the Australian National University, Canberra, to verify if the C^{13} : C^{12} carbon discrimination technique can be used to quantify water-use ratio of groundnut genotypes grown in the field under drought conditions.

The partitioning of dry matter between vegetative and reproductive components in groundnut is a complex phenomenon. For instance, the timing of drought can also influence the partitioning of dry matter to pods. Earlier studies (ICRISAT Annual Report 1981, p. 189) showed that drought during preflowering phase increased pod yields of Kadiri 3 (Robut 33-1). This yield increased because of a change in the distribution of growth between vegetative and reproductive components following the release of drought.

We have reported that there is significant genotypic variability in the production of pods following the release from midseason drought (ICRISAT Annual Report 1984, p. 200). It is possible that a sudden release from midseason drought may cause a shift in hormonal balance, particularly in endogenous cytokinin levels, thus influencing reproductive growth and development. We examined this possibility in a pot culture experiment using four genotypes with known recovery responses. We grew these genotypes in pots containing an Alfisol + sand mixture (1:1 v/v) with adequate water and nutrient supply. We then imposed midseason drought by withholding water from 40 to 60 DAS, after which we rewatered the plants. We monitored the recovery response in reproductive and vegetative growth by destructive sampling at weekly intervals in the subsequent three weeks. We collected root-pressure exudates for 5 h starting at 0900 after excising stems at the time of sampling for growth analysis. The total cytokinin concentration in the exudates was quantified with a cucumber cotyledonary bioassay.

The concentration of cytokinins in the exudates was significantly higher in the plants during recovery following a midseason drought compared to the control plants which received regular irrigation. A subsequent high pressure liquid chromatography (HPLC) analysis of the exudates revealed seven types of cytokinins of which trans-zeatin riboside, isopentanyladenine, and dihydrozeatin riboside had the highest concentrations.

Out of the four genotypes tested in this experiment, Kadiri 3 had initiated the most pegs 2 weeks after recovery irrigation and EC 76446 (292) the least. The genotypic variation in number of pegs initiated during the recovery period was closely associated (r=0.87) to the concentration of cytokinins in the exudate (Fig. 1).

Drought Research at ISC

We ran two drought simulation trials at ISC in 1989. In the prerainy-season trial, sown on 2 February, we tested 36 groundnut lines under intermittent drought stress. The amount of water applied at each irrigation was calculated by

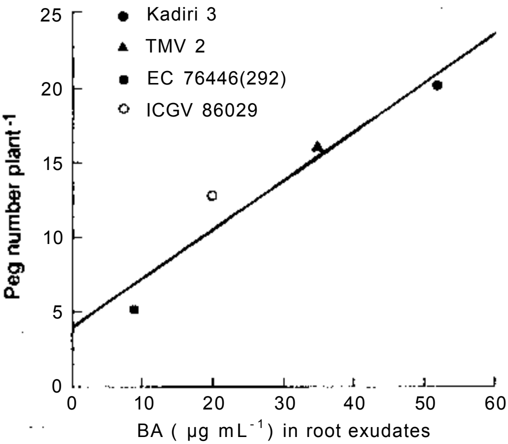


Figure 1. Relationship between concentration of citokinins in root-pressure exudates and peg number, initiated by four groundnut genotypes within 2 weeks after recovery from midseason drought.

determining the daily potential evapotranspiration (PET) using the Penman equation and multiplying this figure by five. In the three irrigation treatments, this calculated quantity was applied once every 5, 10, or 15 days, giving these treatments 100%, 50%, and 33% of the PET. In the second trial, sown on 31 July using 35 of the same 36 groundnut lines, we imposed a terminal drought at the end of the natural rainy season as one treatment and irrigated the other treatment through to maturity. The genotypes ranged, in equal number, from early-, medium-, to late-maturing types.

The mean haulm yields were very much higher in the prerainy-season trial than in the late rainy-season trial, while pod and seed yields were generally much lower in the prerainy-season trial. This effect was due to poor partitioning in the prerainy-season trial, when pod formation and filling were taking place in the longer and increasing daylengths in April and May. We found that the earlier-maturing lines usually gave better pod yields over the drought treatments; out of the medium-maturity lines, ICGV 86015 and ICGV 87123 (ICGS 11) performed particularly well.

We observed that several of the locally adapted early-maturing lines showed above-average partitionings, particularly under stress conditions (Fig. 2). Cultivar 796 partitioned particularly well under extreme stress and cv 55-437 partitioned very well under intermediate stress. ICGV 87123 showed good partitioning under all except the most extreme stress and the early-maturing line ICGV 86047 was uniformly above average. The late-maturing control cv 28-206 showed a below-average partitioning under all the stressed treatments.

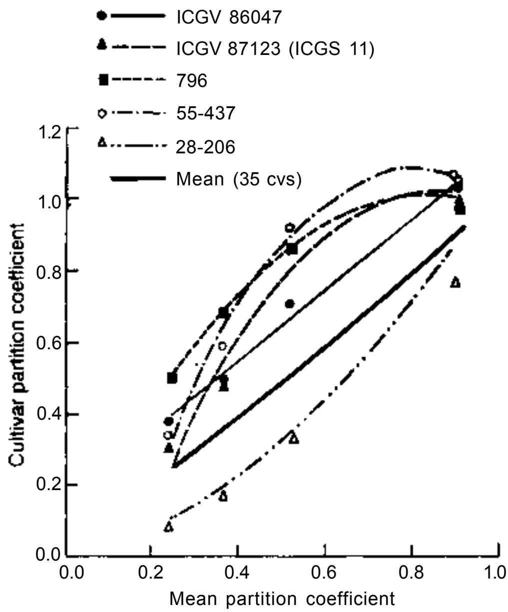


Figure 2. Partitioning of selected groundnut genotypes over five drought environments, ISC, Sadore, Niger, rainy season 1989.

Breeding for Drought Tolerance

We grew 319 F_4-F_8 progenies from 146 crosses under low-input, rainfed conditions during the 1989 rainy season at ICRISAT Center. We made 202 selections from these populations.

Yield Trials

During the 1989 rainy season, we tested 56 advanced breeding lines in three yield trials under low-input, rainfed conditions at ICRISAT Center. The pod yields in these trials ranged from 0.16±0.050 t ha^{-1} to 3.17±0.180 t ha^{-1}. The best entry in these trials, ICGV 86976, gave a 55% higher pod yield than the best drought-tolerant control, ICG (FDRS) 55. At Anantapur, we tested 34 varieties in two replicated yield trials. The pod yields in these trials ranged from 0.42±0.100 t ha'[1] to 1.61 ± 0.089 t ha^{-1}. The best variety, ICGV 86654, gave a 32% higher pod yield than the drought-tolerant control, ICG (FDRS) 55.

Plant Nutrition

An ISC scientist evaluated, in collaboration with the University of Hohenheim, West Germany, the response of groundnut in 1988 and 1989, the response to applications of farmyard manure (FYM), phosphorus (P) with and without micronutrients and carbofuran made at Sadore in 1988. The available P levels of unfertilized soil (Bray P1) were 8.1±0.37 mg P kg^{-1} soil for the top 10 cm and 3.6±0.22 mg P kg^{-1} soil for the 10-30-cm layer. Phosphorus in combination with micronutrients or with FYM enhanced pod and haulm yields more than P alone (Table 3). Analysis of plant tissue at mid-pod fill showed an increased concentration of nitrogen (N) in the leaves and stems in treatments which included micronutrients (Table 3). The same plots were evaluated in 1989 to assess the residual effects of the 1988 treatments. The positive effect of micronutrients on yield were larger in 1989 than in 1988 while the effect of FYM diminished.

We examined the effect of N and molybdenum on N_2 fixation. Seed pelleting with molybdenum at the rate of 100 g ha^{-1} as well as the application of 60 kg N ha^{-1} increased TDM significantly *(P* <0.01 using the Least Significant Difference [LSD] test). Compared to the control, mean pod yield increased by 24% when seed pelleting was used and by 14% when N fertilization was used. Nitrogenase activity (µmol C_2H_2 g^{-1} ha^{-1}) and nodule dry mass were significantly increased by seed pelleting with molybdenum.

Table 3. Effect of carbofuran, phosphorus, micronutrients, and farmyard manure (FYM) on pod and haulm yields of groundnut, Sadore, Niger, rainy seasons 1988 and 1989[1].

	Yield (t ha^{-1})				Nitrogen concentration ($g\ kg^{-1}$ dry mass in 1988)
	1988		1989		
Treatment	Pods	Haulms	Pods	Haulms	
Control	0.88	0.53	0.32	0.32	17.6
Carbofuran[2]	1.91	1.04	1.22	0.72	17.0
18 kg P_2O_5 + Carbofuran	1.76	1.16	1.29	0.80	16.6
36 kg P_2O_5 + Carbofuran	2.15	1.27	1.22	0.73	16.0
36 kg P_2O_5 + Carbofuran + micronutrients	2.61	1.30	2.27	1.08	21.3
36 kg P_2O_s + Carbofuran + FYM	2.88	2.15	1.76	0.91	18.0
SE	±0.162	±0.103	±0.162	±0.093	±0.71
CV (%)	19	20	30	30	10

1. Randomized-block design with six replications, plot size 12 m^2.
2. Carbofuran applied at presowing at 10 kg a.i. ha^{-1}.

We initiated studies to investigate the effect of crop residue, chelate, and P on growth and yield of groundnut. A chelate was used in this study to determine whether the synergistic effects of crop residue and P were caused by a chelating effect of the crop residue rendering the P more available. Phosphorus at the rate of 36 kg of P_2O_5 ha^{-1} with or without chelate significantly increased yield (Fig. 3). Chelate alone had no effect on yield.

In collaboration with the University of Bonn, Federal Republic of Germany, we have been studying the attributes that provide groundnuts with adaptation to low levels of soil calcium. Calcium is taken up directly from the soil by pods, and this inadequate supply results in pods without seeds ("pops"). Runner genotypes disperse their pods more than bunch genotypes, typically providing double the soil volume available for calcium exploitation to pods of bunch genotypes. This year we observed that dispersal of pods resulted in fewer "pops".

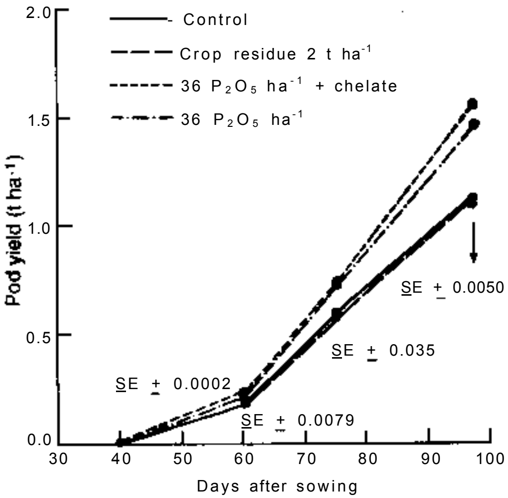


Figure 3. Effect of crop residue, chelate, and phosphorus on pod growth and yield of groundnut cultivar 55-437, ISC, Sadore, Niger, rainy season 1989.

Agronomy

Soil and Water Management

We evaluated the performance of two cultivars, 28-206 and ICGS (E) 30, under three cultivation methods at Sadore and under five levels of phosphogypsum at Sadore and Tara. Cultivation methods had no effect on pod and haulm yields at Tara. Tie ridging resulted in significantly better haulm yields than broadbed or flat cultivation at Sadore. The haulm yields were 1.08 t ha^{-1} for tie ridging, 0.86 t ha^{-1} for broadbeds, and 0.76 for flat cultivation, with an SE of ±0.032. At Sadore, increasing levels of phosphogypsum from 0 to 400 kg ha^{-1} increased pod yield from 0.52 to 0.80 (±0.044) t ha^{-1}, haulm yield from 0.76 to 0.97 (±0.051) t ha^{-1}, and shelling percentage from 62 to 70 (±0.7).

Intercropping

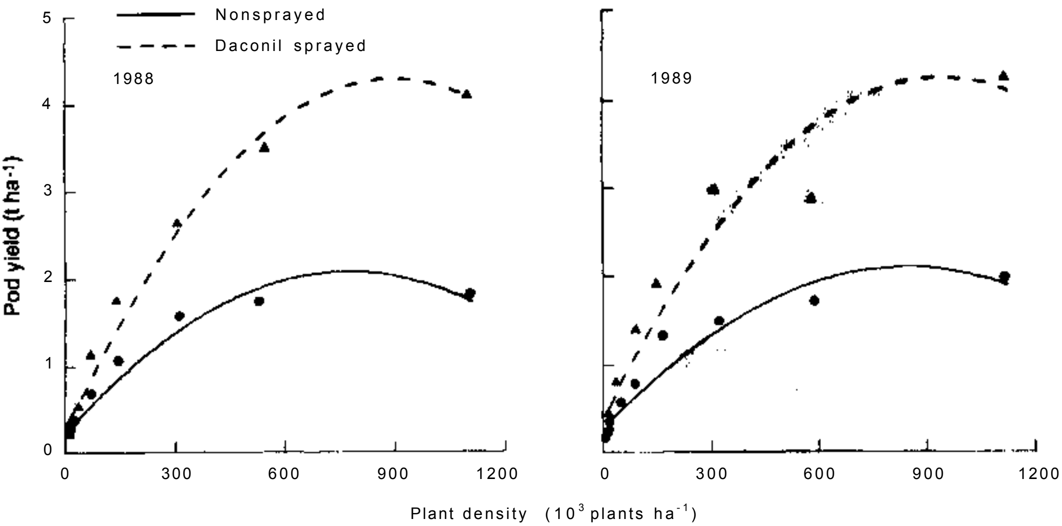
The common practice of intercropping several crops provides the farmer with a variety of returns from land and labor, and this often increases the efficiency with which scarce resources are used and reduces his dependence on a single crop which is susceptible to environmental and economic fluctuations. We continued the intercropping trial initiated in 1988 (ICRISAT Annual Report 1988, p. 145) at Sadore and Tara. As was expected, groundnut pod yields increased as the pearl millet seed decreased with increasing spacing for pearl millet. A similar trend existed for groundnut haulm and pearl millet straw yields. There were no significant differences in the main effect for pod yield between groundnut genotypes, but the variety 47-16 reached a maximum pod yield at 1 m x 2 m pearl millet spacing while 28-206 and ICGS (E) 11 reached their maximum at 1 m x 3 m pearl millet spacing. Variety 47-16 yielded more haulms than 28-206 and ICGS (E) 11.

We grew a trial to evaluate the performance of eight groundnut varieties as a sole crop and as an intercrop with pearl millet (cv CIVT) at Sadore and at the Institut national de recherches agronomiques du Niger (INRAN) stations at Tara and Maradi. There were no significant interactions in pod yield between cropping system and groundnut cultivar at Sadore and Maradi. There was a significant *(P*<0.05) interaction between the groundnut cultivar and cropping system at Tara, but the variance component associated with this interaction was only 13% of the variance component associated with the groundnut cultivar main effect. These results indicate that in a sole crop, it may be possible to select groundnut lines that will perform well as an intercrop.

Influence of Plant Density on Foliar Diseases

Physiologists and Pathologists at ICRISAT Center investigated the interaction of plant density and foliar diseases, and their control, in a disease-susceptible genotype ICGV 87123 during the rainy seasons of 1988 and 1989. Pod and haulm yields, and severity of the foliar diseases were measured in stands of genotype ICGV 87123 grown at eight sowing densities ranging from 14 x 10^3 to 1122 x 10^3 plants ha^{-1}, with and without prophylactic disease control.

Pod yield data typically conformed to a parabolic relationship with plant density (Fig. 4). There were significant interactions between plant density and disease control for pod yield responses and disease severity during both seasons. The seventy of the foliar diseases was higher under high densities. Pod yield response to disease control per unit area was more marked under high than under low densities. This indicates that farmers need to optimize the stand density to maximize their return from fungicide application.



1988	Nonsprayed	$y = 0.204 + 0.0048x\ 3.1 \times 10^{-6} x^2$	$r^2 = 0.96$
	Daconil sprayed	$y = 0.225 + 0.0090x\ 5.0 \times 10^{-6} x^2$	$r^2 = 0.99$
1989	Nonsprayed	$y = 0.261 + 0.0044 \times 2.6 \times 10^{-6} x^2$	$r^2 = 0.92$
	Daconil sprayed	$y = 0.403 + 0.0082x\ 4.3 \times 10^{-6} x^2$	$r^2 = 0.88$

Figure 4. Response of pod yield (t ha^{-1}) of groundnut genotype ICG V 87123 (ICGS 11) to foliar diseases control under different plant densities, ICRISAT Center, rainy seasons 1988 and 1989.

Biotic Stresses

Foliar Fungal Diseases

Disease Surveys

Vietnam

We carried out disease surveys in Vietnam in April 1989 to assess the relative importance of various groundnut diseases. Early leaf spot *(Cercospora arachidicola* Hori.) (ELS) was commonly present throughout Vietnam wherever groundnut was grown and was most destructive in northern Vietnam. Rust *(Puccinia arachidis* Speg.) and late leaf spot *[Phaeoisariopsis personata* (Berk. & Curt.) v. Arx] (LLS) were most severe in southern Vietnam, leading to complete destruction of the foliage towards maturity. The cropping patterns in southern Vietnam, where groundnut is grown most of the year, provide excellent opportunity for the rust pathogen to be perpetuated from season to season.

Preemergence seed and seedling rots (species of *Rhizopus, Fusarium, Aspergillus,* and *Rhi~zoctonia),* damping-off disease *(Pythium* sp), collar rot *(Aspergillus nigervan* Tiegh.), and aflaroot *(Aspergillus flavus* Link, ex Fr.) were commonly observed throughout the country, but their incidence was not high. Aflatoxin contamination is not considered to be a serious problem in Vietnam. Produce from the second crop (April-June) in southern Vietnam usually suffers from slow drying due to frequent rains during harvest, and this may predispose the product to *A. flavus* invasion and aflatoxin contamination. Other diseases observed on groundnut crops during our survey include leaf spot and veinal necrosis *(Alternaria alternata* (Fr.) Keissler), phyllosticta leaf spot, *(Phyllosticta arachidis-hypogaea* Vasant Rao), pepper spot and leaf scorch *(Leptosphaerulina crassiasca* (Sechet) Jackson & Bell), stem rot *(Sclerotium rolfsii* Sacc), pod rots *(Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* (Tassi.) Goid., and *Fusarium* spp), root rot *(Rhizoctonia solani),* botrytis blight *(Botrytis cinerea* Pers. ex Fries), bacterial wilt *(Pseudomonas solanacearum* E.F. Smith), peanut stripe virus (PStV) disease, bud necrosis disease (BND) caused by tomato spotted wilt virus (TSWV), and root-knot nematode *(Meloidogyne* sp).

Guinea

In collaboration with the Institut de recherche agronomique de Guinee (IRAG), we surveyed four agroclimatic zones to identify the constraints to groundnut production in the largest groundnut-growing areas in Guinea. Groundnut is grown throughout the country. A family cultivates an average of 0.2 ha for home use. In Gaoual, Koundara, Dabola, and Dinguiraye, however, groundnut is grown commercially on a large scale.

One of the most important diseases of groundnut in Guinea is ELS, *Cercospora arachidicola.* We found ELS in all groundnut-growing areas. Its incidence was very high in the Dabola region. In a 2-month-old crop there was up to 80% of leaf area damage due to ELS and considerable defoliation. Late leaf spot, *Phaeoisariopsis personata,* was important only in the Kindia region (130 km from Conakry). Rust *(Puccinia arachidis)* was found in Kindia. Its incidence was high only in a few fields. In other regions rust was not observed.

Aspergillus niger was the most common seedling disease and its incidence was very high in some regions. Most of the farmers store their seeds for sowing in the next season. Insects and fungi are the major storage problems in stored seed. We observed some traditional storage facilities and found a very large number of seeds colonized by *A. flavus* and *A. niger.* As seeds are sown by farmers without seed dressing, it is not surprising that seedling diseases are endemic.

Groundnut rosette virus (GRV), both in chlorotic and green forms, was the most important disease and was found in all agroecological zones. It was severe only in the Dabola and Dinguiraye regions. Peanut streak virus was also severe, with up to 70% of plants infected in some fields. Peanut clump virus was found in some areas, however, its incidence was generally low.

Resistance to Rust and Late Leaf Spot

Screening of Germplasm

Sources of resistance to rust and/or LLS diseases identified at ICRISAT Center from 1977 to 1988 were further evaluated for resistance to these diseases in replicated field trials during the 1989 rainy season. A further 800 recently acquired germplasm lines were evaluated for resistance to these diseases. We have now completed the screening of all germplasm lines currently available in the world collection maintained at ICRISAT for resistance to these diseases. We have 124 rust-resistant, and 54 LLS-resistant, and 29 rust- and LLS-resistant germplasm lines available at ICRISAT Center.

Screening of Interspecific Hybrids

We tested four interspecific hybrids (MK 374 x *Arachis* sp PI 276233), derived from tissue cultures by the Cell Biology Unit, for their reactions to rust, ELS, and LLS under monocyclic infection in plant growth chambers using detached leaves. All entries showed a very high degree of resistance to these diseases. These interspecific hybrids will be particularly useful for ELS resistance breeding programs since we do not have adequate levels of resistance to this disease in the cultivated groundnut.

Resistance Breeding

During the 1988/89 postrainy season, we evaluated 89 alternately branching and 35 sequentially branching foliar-disease resistant varieties in five replicated trials both in Alfisol and Vertisol fields at ICRISAT Center. Two of these trials (elite) were also repeated at Bhavanisagar (Tamil Nadu). In the alternately branching group trials, the pod yields ranged from 0.48 ± 0.140 to 5.20±0.320 t ha^{-1}. A preliminary trial entry, ICGV 88281 gave the highest pod yield at ICRISAT Center in the Vertisol field. In the sequentially branching group trials, pod yields ranged from 0.50±0.120 to 4.83±0.150 t ha^{-1}. An elite trial entry, ICGV 87276 gave the highest pod yield, again in the Vertisol field at ICRISAT Center.

During the 1989 rainy season, we evaluated 65 alternately branching and 32 sequentially branching foliar-disease resistant varieties in five replicated trials at ICRISAT Center and in two trials each at Anantapur (Andhra Pradesh), Bhavanisagar (Tamil Nadu), and Hisar (Haryana). For both the groups, trial mean yields were highest at the Hisar Cooperative Research Station. In the alternately branching group trials, the pod yields ranged from 0.71±0.115 to 3.69±0.226 t ha^{1}. An elite trial entry, ICGV 87302 was the best entry that gave the highest pod yield of 3.69 t ha^{-1} at Hisar and outyielded all three controls, C 198, Kadiri 3, and ICGV 87157 [ICG (FDRS) 4] at all locations, except at Anantapur, with the highest mean pod yield of 2.29 t ha^{-1} across the four locations (Table 4). During the 1988 rainy season, ICGV 87302 also outyielded the foliar-disease resistant control variety, ICGV 87157 at six out of seven locations and was moderately resistant to ELS and LLS, iron chlorosis, and jassids (Annual Report 1988, pp. 120-121).

In the sequentially branching group trials, the pod yields ranged from 0.34±0.112 to 3.25±0.212 t ha^{1}. Two foliar-disease resistant varieties, ICGV 87281 and ICGV 83334, outyielded all the three controls, JL 24, ICGV 87157, and ICGV 87128 (ICGS 44) at ICRISAT Center, Bhavanisagar, and Hisar (Table 5). However, it was ICGV 87282 that gave the highest mean pod yield across the four locations and was reasonably stable in its performance.

Effect of Temperature on Urediniospores of *Puccinia arachidis*

We investigated the effect of temperature on urediniospore production in *P. arachidis* under monocyclic infection using detached leaves of the susceptible cultivar TMV 2. Urediniospores produced at different temperatures were also examined for their in vitro germinability. Uredi-

Table 4. Mean pod yields of selected elite foliar-diseases resistant, alternately branching groundnut varieties evaluated at four locations in India, rainy season 1989.

	Location[1] and mean pod yield (t ha^{-1})					Number of locations where entry ranked in:	
Entry	1	2	3	4	Mean	Top 20%	Bottom 20%
ICGV 87302	2.00(2)2	0.80(14)	2.67(7)	3.69(1)	2.29	2	1
ICGV 87304	1.32(12)	1.02(7)	2.90(2)	3.62(2)	2.22	1	0
ICGV 87301	2.01(1)	0.99(8)	2.69(6)	3.11(6)	2.20	2	0
ICGV 87305	1.93(3)	1.02(6)	2.93(1)	2.79(9)	2.17	2	0
ICGV 87319	1.86(4)	0.89(10)	2.79(4)	2.86(8)	2.10	0	0
ICGV 87248	1.35(11)	0.95(9)	2.60(8)	3.48(3)	2.10	1	0
ICGV 87298	1.86(5)	0.82(13)	2.84(3)	2.78(10)	2.08	1	0
Controls							
C 198	1.38(10)	1.05(4)	2.03(14)	3.28(4)	1.93	*4*	*1*
Kadiri 3	0.94(16)	1.17(2)	1.98(15)	3.24(5)	1.83	1	2
ICGV 87157	0.99(15)	1.21(1)	1.97(16)	2.31(13)	1.62	1	2
SE	±0.101	±0.115	±0.182	±0.226			
Trial mean (16 entries)	1.52	0.96	2.45	2.79	1.93		
CV (%)	12	21	13	14			
Efficiency over RBD[3] (%)	100	129	100	131			

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 13.5 m^2 (broadbed and furrows [BBF]).
2 = Anantapur, Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 6.0 m^2 (on flat bed).
3 = Bhavanisagar, Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, research protection, in triple-lattice design, plot size 6.0 m^2 (on flat bed).
4 = Hisar, Entisol, 60 kg P_2O_5 ha^{-1}, supplemental irrigation, no protection, in triple-lattice design, plot size 6.0 m^2 (on flat bed).
2. Numbers in parentheses are rankings of the entries.
3. RBD - Randomized-block design.

niospore production was favorably influenced by temperature levels between 20° and 30° C, the highest production being at 25° C. Temperatures below 20° C or above 30° C were highly detrimental to urediniospore production. There were also marked differences in percentage germination of urediniospores produced at different temperatures, germination being highest at 20° C and decreasing at lower or higher temperatures. The interaction of temperature with urediniospore production and germinability is thus proved to be important in determining the development of groundnut rust epidemics.

Effect of Host Genotype and Temperature on Components of Rust Resistance

We investigated the effects of temperature on incubation period, infection frequency, lesion diameter, leaf area damage, pustule rupture, and sporulation of *P. arachidis* on six groundnut genotypes, representing rust-resistant and -susceptible reactions under monocyclic infection using detached leaves. Rust developed on all genotypes at 10°, 15°, 20°, 25°, and 30° C but did not develop at 35° C and 40°C. Incubation period decreased with increase in temperature, but in susceptible genotypes it again increased at 30° C. There were no marked differences in infection frequency in susceptible genotypes at various temperatures. In resistant genotypes, infection frequency was highest at 30° C. Lesion diameters gradually increased with increase in temperature. In susceptible genotypes, the percentage of leaf area damage was highest at 25° C. Almost all pustules ruptured on susceptible genotypes at all temperatures, releasing masses of urediniospores. In resistant genotypes, the percentage of ruptured pustules was highest at 15° C but with only sparse sporulation. The genotypic differences for some of the components of resistance to groundnut rust could be best studied only at certain temperatures, indicating a strong interaction of temperature and groundnut rust development.

Efficacy of Fungicides for Rust and Late Leaf Spot Control

We compared the efficacy of four fungicides—hexaconazole, chlorothalonil, myclobutanil, and wettable sulphur—for rust and LLS control

Table 5. Mean pod yields of selected elite foliar-diseases resistant, sequentially branching groundnut varieties evaluated at four locations in India, rainy season 1989.

	Location[1] and mean pod yield (t ha^{-1})					Number of locations where entry ranked in:	
Entry	1	2	3	4	Mean	Top 20%	Bottom 20%
ICGV 87282	1.73 (3)[2]	0.78 (5)	2.56 (7)	3.19 (4)	2.07	2	0
ICGV 87259	1.60(9)	0.68(12)	2.52(6)	3.12 (5)	1.98	0	0
ICGV 87281	1.71(4)	0.75(10)	2.01(13)	3.32 (1)	1.95	2	0
ICGV 87206	1.84(2)	0.79 (4)	2.38(9)	2.44(14)	1.86	2	0
ICGV 87276	1.94(1)	0.50(17)	2.54(3)	2.47(13)	1.86	2	1
ICGV 87287	1.51(13)	0.77 (9)	2.53(4)	2.60(10)	1.85	1	0
ICGV 87334	1.60(7)	0.49(18)	2.00(14)	3.30 (2)	1.85	1	1
ICGV 87232	1.52(12)	0.62(14)	2.62(2)	2.51(12)	1.82	1	0
Controls							
ICGV 87157	1.33(17)	0.53(15)	2.00(15)	2.32(17)	1.55	0	2
ICGV 87128 (ICGS 44)	1.19(18)	1.02 (1)	1.16(19)	3.28 (3)	1.66	2	2
JL 24	1.42(15)	0.80 (3)	1.64(17)	2.01(20)	1.47	1	2
SE	±0.068	±0.113	±0.230	±0.206			
Trial mean (20 entries)	1.49	0.68	2.12	2.66			
CV (%)	8	29	19	13			
Efficiency over RBD[3] (%)	113	103	103	118			

1. For locations, see footnote 1 of Table 4.
2. Numbers in parentheses refer to rankings of the entries.
3. RBD = Randomized-block design.

in a replicated field trial at ICRISAT Center using the foliar-disease susceptible cultivar ICGV 87123. Fungicide sprays were given at 10-day-intervals starting 30 DAS. Plots sprayed with tap water served as controls. Hexaconazole and chlorothalonil were the most effective fungicides to control both rust and LLS and to increase the yields of pods and haulms (Table 6). The combined attack of rust and LLS caused 66% loss in pod yield and 52% loss in haulm yield.

Yield Response of Some Breeding Lines to Fungicidal Control of Rust and Leaf Spots

We tested the yield response of 20 high-yielding breeding lines that are susceptible to rust and leaf spots to protective fungicide spray treatments in a replicated field trial during the 1989 rainy season at ICRISAT Center. Pod yields ranged from 0.51 to 1.54 t ha^{-1} (mean yield of 1.07 ± 0.151 t ha^{-1}) in control plots (sprayed with water) and from 1.49 to 2.94 t ha^{-1} (mean yield of 2.33±0.151 t ha^{-1}) in fungicide (chlorothalonil)-sprayed plots. The yield increases due to fungicide treatments ranged from 39 to 192% (a mean of 128%).

Early leaf spot *(Cercospora arachidicola)* research at Chitedze

Screening for Resistance

We screened 25 lines reported to have had resistance to ELS at ICRISAT Center against susceptible controls Malimba and Natal Common, and a Valencia selection ICGMS 55 having tolerance to ELS through good leaf retention. Yields

Table 6. Efficacy of four fungicides for controlling rust and late leaf spot, and the effects on yields of groundnut (cv ICGV 87123) at ICRISAT Center, rainy season 1989.

Spray treatment[2]	Defoliation percentage	Leaf area damage (%)[1] Rust	Leaf area damage (%)[1] Late leaf spot	Yield (t ha^{-1}) Pods	Yield (t ha^{-1}) Haulms	Shelling (%)
Hexaconazole	0(0)3	0.3(3.0)	0.2(2.6)	2.75	2.22	69
Chlorothalonil	0(0)	1.5(6.8)	0.4(3.7)	2.41	2.43	68
Myclobutanil	22(27.6)	4.5(12.2)	5.2(13.1)	1.59	1.83	69
Wettable sulphur	31(34.0)	6.9(15.2)	7.4(15.7)	1.07	1.42	70
Water (control)	62(51.9)	7.0(15.3)	12.6(20.7)	0.93	1.15	72
SE	±1.9 (1.17)	±0.43 (0.61)	±0.82 (0.82)	±0.11	±0.14	±0.8
CV (%)	16 (10)	21 (11)	32 (14)	13	16	2

1. Percentages of leaf area damaged by rust and late leaf spot diseases were assessed on five plants randomly selected from each replicated plot at 100 DAS by comparison with schematic diagrams depicting leaves with known percentages of their affected areas.
2. Hexaconazole (50 mL ha^{-1}), chlorothalonil (1.28 kg ha^{-1}), myclobutanil (96 mL ha^{-1}) and wettable sulphur (800 g ha^{-1}) in 500 L of water ha^{-1}. Plots sprayed with tap water (500 L ha^{-1}) served as controls. Spray treatment was started at 30 DAS and thereafter at intervals of 10 days.
3. Values in parentheses are angular-transformed values.

were poor and results inconclusive. However, a few entries had low levels of resistance, with ELS scores significantly lower than that of ICGMS 55.

We received 3143 germplasm accessions, mainly Spanish types, from ICRISAT Center to screen in observation plots. Few showed promise for ELS resistance but we retained 57 for further observation on yield.

Effect of Timing of Single Fungicide Applications on Yield

The effect of the timing of a single application of chlorothalonil on the yield of Malimba, a susceptible Spanish variety was evaluated. There were two sowing dates. The fungicide was applied at 36, 50, 64, 78, and 92 DAS to the early-sown plots, and at 34, 48, 62, 76, and 90 DAS to the late-sown plots.

There were highly significant yield responses to single applications of fungicide made at 36, 64,78, and 92 DAS on the early- sown Malimba (Table 7). The largest response (122 kg ha^{-1}) was from a spray application at 64 DAS. Sprays applied at 64,78, and 92 DAS resulted in significant increases in seed size but did not affect shelling percentage.

On the late-sown Malimba, single applications at 48, 62, and 76 DAS resulted in significant yield responses (Table 7). The largest response (74 kg ha^{-1}) was from a spray application at 62 DAS. Application at 62, 76, and 92 DAS increased shelling percentage significantly and sprays applied at 62 and 76 DAS resulted in significant increases in seed size also.

In a different experiment we assessed the effects of single applications of chlorothalonil on the ELS-tolerant Virginia selection, 1CGMS 42. Fungicides were applied at 36,49, 63, 77, and 93 DAS. Only the application made at 63 DAS resulted in a significant yield increase (153 kg ha^{-1}) (Table 7). The spray at 92 DAS resulted in a significant decrease in shelling percentage. Seed size was not affected by fungicide application.

Table 7. Responses of two groundnut genotypes to single applications of fungicide made at five dates[1], Chitedze, Malawi, 1988/89.

	Malimba				1CGMS 42	
	Sown 19 Dec 1988		Sown 17 Jan 1989		Sown 20 Dec 1988	
	Application (DAS)	Seed yield (t ha^{-1})	Application (DAS)	Seed yield (t ha^{-1})	Application (DAS)	Seed yield (t ha^{-1})
	36	0.79**	34	0.41	36	1.97
	50	0.75	48	0.44*	49	2.01
	64	0.80**	62	0.40**	63	2.07*
	78	0.80**	76	0.38**	77	1.89
	92	0.77**	90	0.37	93	1.97
	Control	0.74	Control	0.36	Control	1.96
SE		±0.028		±0.012		±0.066
Trial mean (32 treatments)		0.79		0.40		1.98
CV (%)		15		13		13

1. 2^5 factorial experiments in incomplete blocks, 2 replications, plot size 14.4 m^2.

Breeding for Disease Resistance in Malawi

Breeding Material

We sowed 19 F_1 populations from crosses made for ELS tolerance to confirm their hybridity and to advance them to the next generation.

From 1834 F_3 progeny rows we retained 377 and selected 460 plants for further evaluation in progeny rows. Yields were generally low and few retained the leaves under disease pressure. We advanced 87 F_3 populations by single-seed descent.

From 72 F_4 - F_{10} populations, which included disease-resistant material, we retained only five from which we selected 19 plants. Selected interspecific derivatives and other foliar-disease resistant breeding lines retained in 1987/ 88 were reevaluated but most were rejected because of poor yield.

We sowed 23 F_1 populations from crosses made for GRV resistance to confirm their hybridity and to advance them to the next generation. We grew 10 F,s from crosses made for ISC and 10 F_1s from crosses made for the Zimbabwe national program. We advanced 40 F_2 populations by a single-seed descent for screening in F_3. We sowed 697 F_4-F_6 populations arising from GRV-resistant plants and retained 300, from which we made 231 pedigree and 84 bulk selections.

Twelve GRV-resistant breeding lines which entered trials for the first time were included in the GRV screening nursery. All were confirmed resistant.

Research on Foliar Diseases in West Africa

Yield Losses

Foliar fungal diseases are the major constraints to groundnut production in West Africa. Rust, LLS, and ELS are present in all West African groundnut-growing areas, but their severities vary from place to place.

A trial to assess yield losses from foliar diseases was repeated at three locations in Niger (Sadore, Maradi, and Bengou) and grown at three new locations in higher-rainfall areas (Ina and Niaouli, Benin, and Bobo-Dioulasso, Burkina Faso) in collaboration with international and national research organizations: Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD)-Institut de recherches pour les huiles et oleagineux (IRHO), France, Direction Recherche Agronomique (DRA), Benin, Institut national d'etudes et de recherches agricoles (INERA), Burkina Faso, and Institut national d'etudes et de recherches agricoles (INRAN), Niger. Six cultivars were sown in each location (three West African cultivars, 55-437, 28- 206, and 47-16 and three ICRISAT breeding lines, including a high-yielding control, ICGV 87123 and two disease-resistant lines, ICG (FDRS) 4 and ICG (FDRS) 10 (ICGV 87160) in Benin, ICG (FDRS) 2 and ICG (FDRS) 70 in Burkina Faso, and ICG (FDRS) 5 and 1CGMS 55 in Niger. A part of the trial was sprayed with CM (carbendazim and mancozeb) at a rate of 1.5 kg in 500 L water ha^{-1}. The effects of ELS and rust are not taken into consideration because ELS remained at a low level across locations and rust was severe only at Bobo-Dioulasso. Late leaf spot was severe from 65 DAS onwards at all locations except at Sadore and Maradi.

Yield losses varied from one location to another and from one genotype to another. All genotypes yielded better in Benin than in Burkina Faso and Niger. ICGV 87123 was one of the highest-yielding lines in all locations. Average yields with fungicide application were 2.2 t ha^{-1} in Niger (Fig. 5), 3.0 t ha^{-1} in Burkina Faso (Fig. 6), and 4.8 t ha^{-1} in Benin (Fig. 7) while average yields without fungicide application were 1.8 t ha^{-1} in Niger, 2.2 t ha^{-1} in Burkina Faso, and 2.9 t ha^{-1} in Benin. Yield loss in Niger was 49% for cultivar 47-16 and only 6% for ICGMS 55. Yield loss was very high in Burkina Faso with a 56% loss for ICGV 87123 but only 14% for ICG (FDRS) 2. In Benin, a 38% loss was observed in ICGV 87123 and around 20% for the resistant lines ICG (FDRS) 4 and ICG (FDRS) 10. These results show clearly that yield losses were much

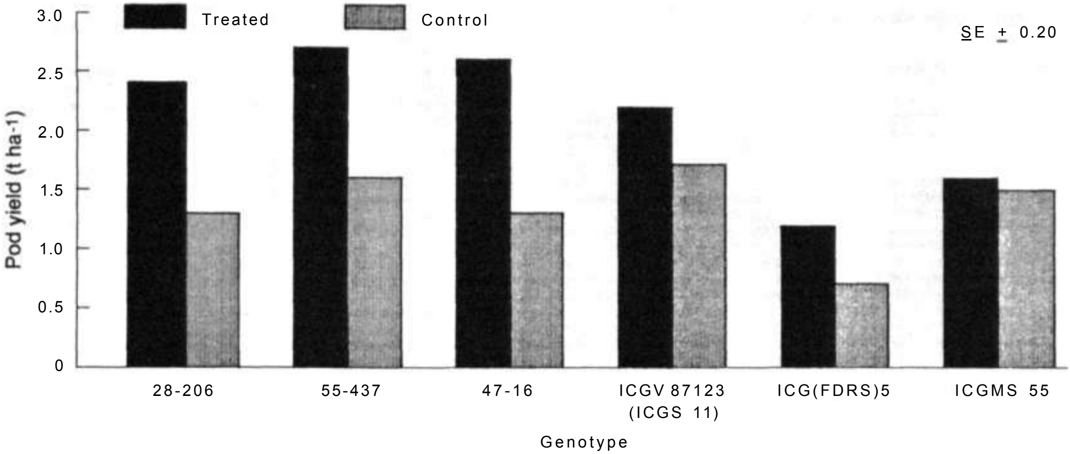


Figure 5. Yield losses from groundnut late leaf spot. Bengou, Niger, rainy season 1989.

lower in lines resistant to foliar diseases than in susceptible lines.

Screening for Resistance to Foliar Diseases

During the 1989 rainy season, we conducted two trials at Bengou to estimate the reaction of some germplasm and breeding lines selected in India, the former for resistance to ELS, and the latter for resistance to LLS. Both ELS and LLS were severe at Bengou. The ELS severity was high from 30 to 65 DAS and LLS was severe from 45 DAS until harvest. The final score for ELS was given at 65 DAS and that for LLS was given at 90 DAS.

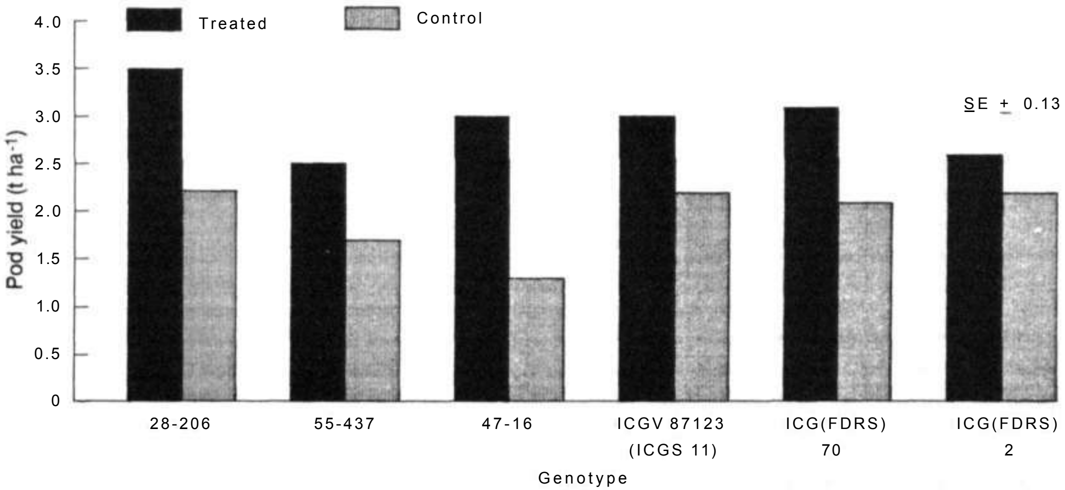


Figure 6. Yield losses from groundnut foliar diseases. Bobo-Dioulasso, Burkina Faso, rainy season 1989.

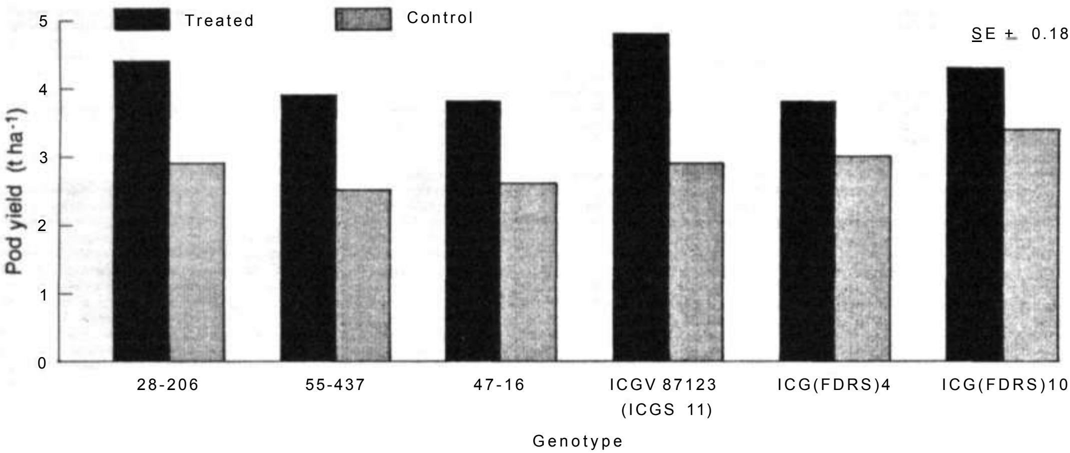


Figure 7. Yield losses from groundnut late leaf spot. Ina, Benin, rainy season 1989.

Early Leaf Spot Resistance Trial

Genotypes which gave ELS scores less than 4.5 or LLS scores less than 3.5 are given in Table 8. Some lines reported to be resistant to ELS in India also showed resistance to ELS in Niger. The best lines were ICG 7878 and ICG 6284. It is interesting to note that ICG 6284 also gave a good pod yield. ICGs 7756, 1710, 2354, and 1707 had resistance to LLS as well as ELS.

Breeding for Yield and Resistance to Foliar Diseases.

The Fourth International Foliar Diseases Resistance Groundnut Varietal Trial (IFDRGVT) was grown at Bengou during the 1989 rainy season. Two lines from the foliar disease resistance breeding program at ICRISAT Center, ICGV 87281 and ICGV 86600, and the susceptible control from ICRISAT Center, ICGV 87123, all significantly outyielded the local control 28-206 (Table 9), but did not show any resistance to ELS or LLS. Only one line, ICGV 86699, showed good levels of resistance to ELS and LLS, but gave a low pod yield. The combination of resistance to the leaf spots and high pod yield has not yet been achieved, but one line, ICGV 87240, had a slightly lower score for LLS than the controls and a reasonable pod yield.

Seed and Seedling Diseases

Yield Losses from Seedling Diseases

Several pathogens cause seed and seedling diseases of groundnut and may severely damage the crop. *Aspergillus niger, A. flavus, Fusarium* spp, *Rhizopus* spp, and *Pythium* sp have been frequently observed in West Africa. Among these, *A. niger* is the most damaging, causing groundnut 'crown rot.'

During the 1989 rainy season we conducted trials at three locations (Sadore, Bengou, and Maradi) in Niger to estimate the yield and plant losses from seedling disease of groundnut, using two fungicides to control seedling diseases. Seeds were treated with Tetramethylthiurum disulphide or CM (carbendazim and mancozeb) at the rate of 3 g kg^{-1} of seed. Figures are only given for the trial at Maradi as the other two locations showed similar results. The percentage of nonprotected plants that died after emergence in the nonfungicide treatment ranged from 19-43% (±3.2) at Maradi (Fig. 8). Seed treated with fungicide produced higher yields than the nontreated con-

Table 8. Disease score and yield of groundnut genotypes selected for resistance to early leaf spot (ELS) and late leaf spot (LLS), Bengou, Niger, rainy season 1989[1].

Entry	ELS[2]	LLS[3]	Pod yield (t ha^{-1})	Entry	ELS	LLS	Pod yield (t ha^{-1})
ICG 7878	3.0(1)[4]	4.6(46)	0.94	ICG 4995	5.6(35)	3.9(21)	1.63
ICG 6284	3.1(2)	6.6(115)	1.61	ICG 6330	5.6(36)	3.3(10)	0.60
ICG 8298	3.4(3)	6.5(110)	1.78	ICG 10756	5.6(37)	3.9(19)	1.41
ICG 2354	3.5(4)	3.0(5)	0.14	ICG 1707	5.7(41)	3.0(4)	1.30
ICG 10900	4.0(5)	5.5(77)	1.06	ICG (FDRS) 6	5.9(52)	3.8(16)	1.16
ICG 10954	4.3(6)	6.6(116)	1.77	ICGV 86643	5.9(54)	3.0(3)	0.63
ICG (FDRS) 272	4.4(7)	4.0(23)	1.12	NC Ac 17506	6.0(59)	3.6(14)	0.54
ICGMS 55	4.4(8)	5.3(68)	1.69	ICG 6340	6.1(63)	3.5(11)	0.67
ICG 6949	4.4(9)	3.8(17)	0.35	ICG 2716	6.1(65)	3.5(12)	0.91
ICG 7756	4.5(10)	2.7(1)	1.35	ICG 7340	6.2(69)	3.9(20)	0.94
ICG 8339	4.5(11)	5.6(79)	0.98	ICG 7885	6.2(71)	3.3(9)	0.77
ICG 4750	4.6(12)	7.2(134)	1.39	ICG 4747	6.4(83)	3.3(8)	1.09
ICG 7741	4.6(13)	6.9(129)	1.53	ICG 10949	6.4(88)	3.7(15)	1.17
ICG 10000	4.9(14)	6.4(108)	1.67	2159	6.8(106)	3.9(22)	0.51
ICG 9402	5.0(15)	4.6(44)	1.39	Controls			
ICG 10960	5.0(16)	5.1(64)	1.11	28-206	7.1(116)	7.1(127)	1.98
ICG 1710	5.0(17)	2.9(2)	1.34	796	7.4(127)	6.2(100)	1.42
2192-4	5.2(18)	3.2(7)	0.81	47-16	7.4(128)	6.0(91)	1.58
USA 63	5.4(28)	3.1(6)	0.99	55-437	7.7(132)	8.9(144)	1.57
ICG 6022	5.4(29)	3.8(18)	1.41	TS 32-1	7.8(135)	8.3(142)	1.94
ICGV 86690	5.4(30)	3.5(13)	0.77	ICGV 87123 (ICGS 11)	8.3(144)	7.8(139)	1.36
SE	±0.68	±0.70	±0.134		±0.68	±0.70	±0.134
Trial mean (144 entries)	6.1	5.4	1.02		6.1	5.4	1.02
CV (%)	19	23	24		19	23	24
Efficiency over RBD[5] (%)	102	103	107		102	103	107

1. 12 x 12 lattice with three replications, plot size 3.75 m^2.
2. Early leaf spot score: 1-9, where 1 = no disease, and 9 = 50-100% foliage destroyed (ranked from lowest to highest).
3. Late leaf spot score: 1 9, where 1 = no disease, and 9 = 50-100% foliage destroyed.
4. Numbers in parentheses are rankings of the entries.
5. RBD = Randomized-block design.

Table 9. Performance of selected lines in the Fourth International Foliar-Diseases Resistance Groundnut Varietal Trial (IFDRGVT), Bengou, Niger, rainy season 1989[1].

Entry	Days to harvest	Early leaf spot score (1-9 scale)	Late leaf spot score (1-9 scale)	Haulm yield (t ha^{-1})	Pod yield (t ha^{-1})	Shelling (%)	100-seed mass (g)
ICGV 87281	94	7.7	7.4	3.54	2.81	70	36
ICGV 86600	94	7.7	8.1	4.03	2.68	73	34
ICGV 86594	94	7.7	7.0	3.78	2.54	75	37
ICGV 87240	94	7.0	6.4	4.80	2.45	73	30
ICGV 87280	94	7.3	7.4	3.43	2.29	71	38
ICGV 86659	94	7.3	5.5	3.83	2.27	66	32
ICGV 86687	94	6.0	4.7	4.88	1.48	65	40
ICGV 86699	93	4.0	3.9	4.63	1.19	59	41
Controls							
ICGV 87123 (ICGS 11)	93	7.7	7.3	2.47	2.66	74	41
28-206	107	6.3	7.0	4.45	2.16	71	39
SE	±17	±0.34	±0.44	±0.492	±0.146	±3.6	±2.2
Trial mean (25 entries)	99	7.1	6.7	4.02	2.14	67	38
CV (%)	5	8	11	21	12	9	10
Efficiency over RBD[2] (%)	105	<100	111	<100	115	102	<100

1. 5 x 5 lattice with three replications, plot size 8 m^2.
2. RBD = Randomized-block design.

trol at Maradi (Fig. 9). Only ICGV 87123 showed a high percentage of plant losses in all three locations in the nontreated plots. There was no significant difference between the two fungicide-treated plots.

Screening for Resistance to *Aspergillus flavus* at ICRISAT Center

In the 1988/89 postrainy season, we tested, for natural seed infection by *A. flavus* and other fungi, 82 germplasm lines that had been subjected to a soil water deficit of approximately 76% during the last 84 -137 days of pod maturation. Levels of *A. flavus* infection in different genotypes ranged from 1.7 to 38.6%. Five lines (ICGs 1859, 1994, 10020, 10094, ICG 10933) had consistently low levels of seed infection (<2%). These will be further tested in the 1989/90 postrainy season to confirm their resistance.

Influence of Soil Type on *A. flavus* Infection of Seeds

In the 1989 rainy season, we again carried out rainfed trials on Alfisols and Vertisols at ICRISAT Center on Alfisols at Anantapur, and on Vertisols at Parbhani (Maharashtra). Levels of

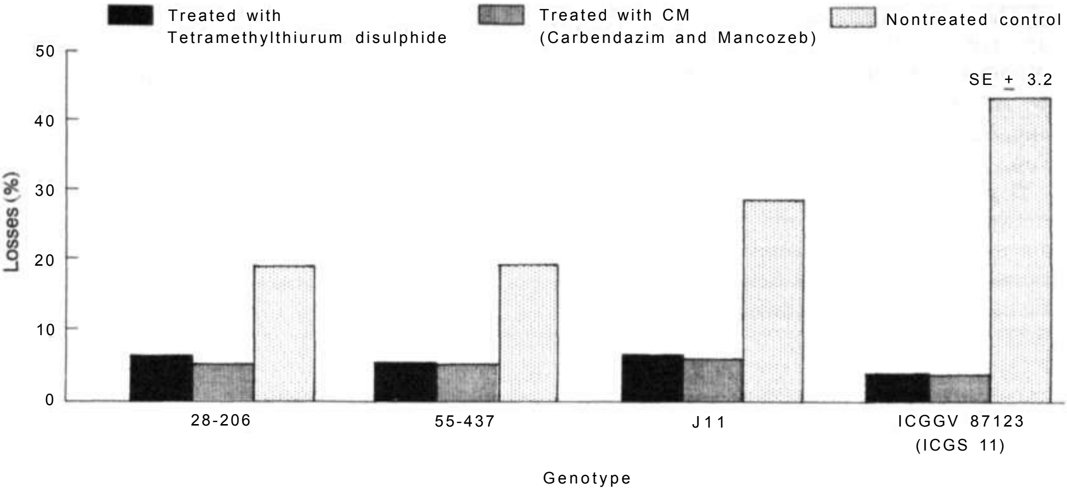


Figure 8. Plant losses from groundnut seedling diseases. Maradi, Niger, rainy season 1989.

A. flavus infection were significantly (*P*= 0.05) higher in seeds from Alfisol fields than in seeds from Vertisol fields. The A *flavus-resistant* genotypes (Ah 7223, J 11, UF 71513, and PI 337394F) had significantly lower levels of seeds infected by *A. flavus* than the susceptible genotypes (TMV 2, JL 24, NC Ac 17090, and EC 76446 [292]) in all trials. However, in general, the levels of seed infection by *A. flavus* were low in all genotypes across all locations and soil types. The low infection levels were attributed to the low-to-moderate drought stress during pod maturation. Aflatoxin contamination (3-8 μg kg^{-1}) was found only in a few samples of NC Ac 17090 and EC 76446 (292) from Alfisol fields at ICRISAT Center.

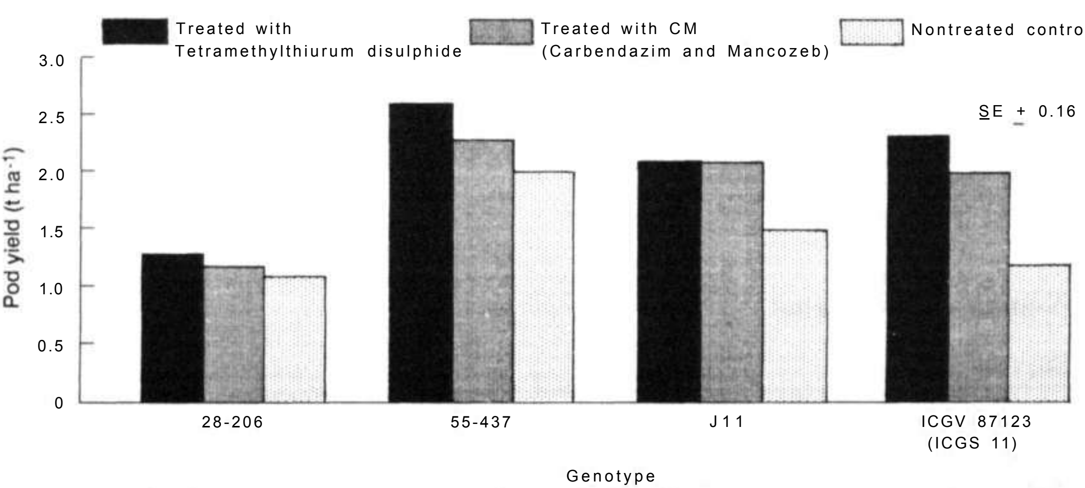


Figure 9. Yield losses from groundnut seedling diseases. Maradi, Niger, rainy season 1989.

There were significant interactions between soil types and genotypes, especially in the *A. favus*-susceptible genotypes, for seed infection by *A. flavus* and such other fungi as *Fusarium* spp, *Macrophomina phaseolina,* and *Penicillium* spp.

Significant differences were also found between soil types for soil populations of *A. flavus,* the numbers of viable propagules being much lower in Vertisol fields than in Alfisol fields throughout the growing season at 1CRI-SAT Center.

Research on Aflatoxin in West Africa

During the 1989 rainy season, we tested 25 lines, including germplasm, advanced *A. flavus-resistant* breeding lines, and some cultivars from West Africa, at three locations (Sadore, Bengou, and Maradi) in Niger. We tested seed collected from field trials in the laboratory to estimate seed contamination by *A. flavus.* We counted more than 50% of seed infected by *A. flavus* at Sadore. Average seed contamination depended on the location (25% at Sadore, 13% at Bengou, and 13% at Maradi) (Table 10). We found significant differences between genotypes. Cultivars 55-437 and J 11 were the least contaminated lines in all locations whereas other lines such as ICGV 87108 showed high infection levels at Sadore and low levels at Maradi. Among the ICRISAT-advanced *A. flavus*-resistant breeding lines, ICGVs 87107, 87094, and 87110 were the least contaminated. Pod yields of all the lines were higher at Maradi than at Bengou and Sadore. Cultivar 55-437 gave a reasonable yield in all the three locations (Table 10).

Nematode Problems

Surveys

We conducted surveys in some groundnut-producing regions of Benin, Burkina Faso, and Nigeria to identify important nematode species associated with the crop. The surveys highlighted the presence of several important crop-damaging nematode species (Table 11). The presence of *Pratylenchus brachyurus* in Benin and Nigeria and of *Scutellonema clathricaudatum* in all three countries indicated the need to map the distribution of these nematodes and to estimate the extent of crop losses caused by them. In another survey in Niger, *Heterodera gambiensis* was found on pearl millet roots in a groundnut-pearl millet intercropped field in Maradi.

Host Range Studies

Host ranges of *Scutellonema clathricaudatum* and *Xiphinema parasetariae* were studied in a nematode-infested field at Sadore, Niger. Sixty DAS of different plant species, populations of *S. clathricaudatum* were found in the roots of pigeonpea *(Cajanus cajan),* groundnut *(Arachis hypogaea),* moth bean (*Vigna aconitifolia),* mung bean (*Vigna radiata),* pearl millet *(Pennisetum glaucum),* bambara groundnut *(Vigna subterranea)* and maize *(Zea mays).* Populations of *X. parasetariae* were higher in the rhizospheres of sesame *(Sesamum indicum),* sunflower (*Helianthus annum),* sorghum *(Sorghum bicolor), Stylosanthes fruticosa,* pigeonpea, and groundnut.

Role of *Scutellonema clathricaudatum* in Crop Growth Variability

A population density of 1.3 individuals of *S. clathricaudatum* cm^{-3} of soil caused stunting and reduced plant growth of groundnut cv 55-437 in pot experiments. In the field, the nematode population was greatest in patches showing poor and stunted plant growth. In some patches soil from around the stunted plants had three times the number of nematodes than did soil from around the apparently healthy plants. Application of carbofuran 5G at 8 kg a.i. ha^{-1} reduced the nematode population and resulted in vigorous and uniform plant growth. Application of carbendazim did not affect the nematode population density.

Table 10. Seed infestation by *Aspergillus flavus in* some groundnut genotypes at Niger, rainy season 1989[1].

	Sadore		Bengou		Maradi	
Entry	Seed infected (%)	Pod yield (t ha^{-1})	Seed infected (%)	Pod yield (tha^{-1})	Seed infected (%)	Pod yield (tha^{-1})
55-437	2.2 (8.6)2	1.51	1.4(6.8)	1.44	0.0 (0.0)	2.39
J 11	4.9(13.0)	1.48	1.8(7.4)	1.34	0.9 (4.4)	2.81
ICGV 87107	6.2(14.1)	1.41	2.2 (8.6)	1.29	4.0 (11.4)	2.10
Ah 7223	7.1 (16.0)	1.22	2.7 (9.0)	1.15	0.9 (4.4)	2.36
ICGV 87094	7.1(15.1)	1.43	10.5(18.8)	1.34	1.8(7.6)	1.52
ICGV 87110	7.1 (15.4)	1.37	4.7 (12.4)	1.30	4.9(12.6)	1.99
U 4-47-7	7.6(15.9)	1.30	2.0 (8.4)	1.10	2.2 (8.5)	2.09
ICGV 87084	10.2(18.5)	1.56	1.5(6.9)	0.95	1.3(6.6)	1.90
UF 71513-1	10.7(19.1)	1.81	1.5(6.9)	1.15	0.9 (4.4)	2.92
ICGV 87109	11.1(19.1)	1.45	5.3(13.0)	1.08	16.0(23.5)	2.07
U 1-2-1	11.1(19.5)	1.18	3.4(10.9)	1.22	8.4(16.8)	2.07
ICGV 87106	12.4(20.1)	1.64	3.3(10.8)	1.13	6.7(14.9)	2.36
ICGV 87089	12.9(20.9)	1.32	6.5 (14.8)	1.46	6.7(14.9)	2.27
ICGV 86174	13.3(21.1)	1.27	7.0(15.2)	1.52	2.2 (8.5)	2.19
ICGV 87095	15.1(22.6)	1.35	3.2 (9.8)	1.78	12.0(20.2)	2.13
ICGV 87112	21.3(27.7)	1.17	4.4(12.2)	1.34	1.3(5.3)	2.47
ICGV 87111	23.6 (29.0)	1.32	5 9(14.0)	0.92	3.1(10.1)	1.91
ICGV 87141 (ICGS 76)	25.8 (30.8)	1.39	13.7(20.4)	1.55	4.4(12.1)	1.71
TS 32-1	26.2(31.1)	1.41	5.7 (13.5)	1.59	6.7 (14.9)	2.14
ICGV 87101	28.0(31.3)	1.54	14.3 (22.2)	1.08	0.9 (4.4)	2.03
Faizpur	28.4 (32.2)	1.44	6.6(14.8)	1.47	6.7(14.9)	2.60
JL 24	33.8 (35.8)	1.20	8.3 (16.7)	1.59	22.7(28.1)	2.75
ICGV 87108	48.9 (44.0)	1.34	9.8(18.2)	1.22	2.2 (8.3)	1.96
28-206	53.3(47.1)	1.53	6.0 (14.3)	1.97	12.9(20.8)	2.02
Var 27	63.6 (53.3)	0.91	14.5 (22.4)	0.95	44.4(41.8)	2.01
SE	(±1.75)	±0.153	(±1.30)	±0.107	(±1.78)	±0.258
Trial mean (25 entries)	19.7 (24.9)	1.38	5.8(13.1)	1.31	6.9 (12.8)	2.19
CV(%)	(12)	19	07)	14	(24)	20
Efficiency over RBD[3] (%)	(103)	127	(103)	123	(<100)	144

1. 5 x 5 lattice with three replications, plot size 8 m^2.
2. Figures in parentheses are arc sine-transformed values.
3. RBD = Randomized-block design.

Table 11. List of some important nematode species found associated with groundnut in different regions of Benin, Burkina Faso, and Nigeria, 1989.

Country/ Region	Nematode species
Benin	
Baou	*Ditylenchus* sp, *Helicotylenchus dihystera*
Bambereka	*Helicotylenchus* sp, *Scutcllonema clathricaudatum, Scutellonema* sp, *Xiphinema parasetariae*
Dadeh	*S. clathricaudatum, Scutellonema* sp
Ina	*Aphelenchoides, Ditylenchus* sp, *Helicotylenchus* sp, *Hoplolaimus pararobustus, Scutellonema* sp, *Pratylenchus* sp
Kandi	*Aphelenchoides, Helicotylenchus* sp, *H. pararobustus, S. clathricaudatum, Scutellonema* sp, *Pratylenchus brachyurus, Pratylenchus* sp, *X. parasetariae*
Malanville	*H. dihystera, X. parasetariae, Pratylenchus* sp
Niaouli	*Criconemoides* sp, *Ditylenchus* sp, *P. brachyurus, Scutellonema* sp, *Xiphinema* sp
Burkina Faso	
Banfora	*H. dihystera, H. pararobustus, S. clathricaudatum, Scutellonema* sp, *Pratylenchus* sp
Dengouindongou	*Ditylenchus* sp, *Helicotylenchus* sp, *Hemicaloosia paradoxa, Hemicycliophora* sp, *Rotylenchulus parvus, S. clathricaudatum, Scutellonema* sp, *Triversus annulatus*
Fada	*Aphelenchoides* sp, *S. clathricaudatum, Scutellonema* sp, *Pratylenchus* sp, *Triversus annulatus*
Hounde	*Aphelenchoides* sp, *Helicotylenchus* sp, *Pratylenchus* sp
Linoghin	*Ditylenchus* sp, *Helicotylenchus* sp, *Hoplolaimus* sp, *Pratylenchus* sp
Nigeria	
Kaduna	*Aphelenchoides* sp, *Helicotylenchus* sp, *Criconemoides,* sp, *Scutellonema* sp, *Tylenchoryhnchus* sp, and *Pratylenchus* sp, *Xiphinema* sp
Katsina	*Aphelenchoides* sp, *Helicotylenchus* sp, *Criconemoides* sp, *Pratylenchus delattrei, P. brachyurus, Scutellonema* sp
Zaria	*Aphelenchoides arachidis, Helicotylenchus* sp, *Criconemoides* sp, *Hoplolaimus* sp, P. *delattrei, P. brachyurus, Tylenchoryhnchus* sp, *Rotylenchulus* sp, *Scutellonema* sp

Virus Diseases

Tomato Spotted Wilt Virus and Bud Necrosis Disease

Although the techniques for purifying TSWV have improved over the years, it has still been necessary to find a way of removing relatively large pieces of cell membrane from the preparations. This was finally done by low speed clarification, concentrations at 14000 g followed by rate, and quasi-equilibrium zonal centrifugation in sucrose solutions (Fig. 10).

We have demonstrated that the Indian TSWV isolate is serologically distinct from isolates obtained from those collected from other Asian countries and USA (ICRISAT Annual Report 1988, p. 123). Antisera from the Netherlands and Australia also failed to react positively with the Indian TSWV isolate in the Enzyme-Linked Immunosorbent Assay (ELISA) tests. Purified TSWV analyzed by polyacrylamide gel electrophoresis was shown to contain five major polypeptides. In the electroblot immunoassay (western blots, utilizing highly sensitive detection methods as described in the section on "Electroblot immunoassay" in this report), all five polypeptides reacted with homologous antiserum, and only one polypeptide reacted with five heterologous antisera.

Among thrips collected from groundnut fields, species reported to be vectors of TSWV (*Frankliniella schultzei, Thrips palmi,* and *Scirtothrips dorsalis*) were present. They are currently being tested for their ability to transmit TSWV.

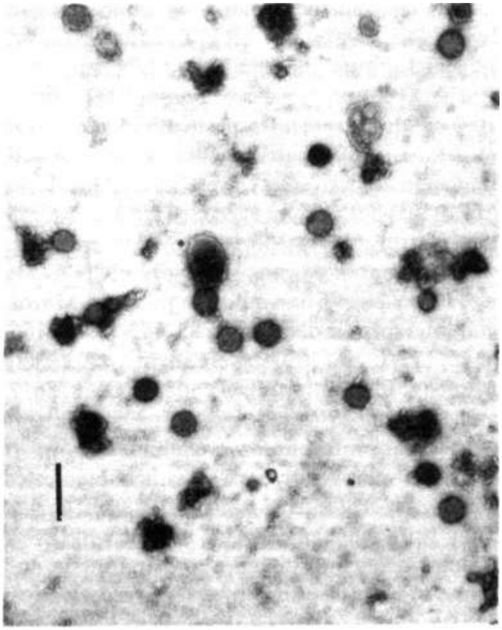


Figure 10. Purified preparation of tomato spotted wilt virus particles (bar represents 150 nm).

Peanut Clump Virus

Purified Indian PCV (I-PCV) was used for extracting ribonucleic acid (RNA). Various clones prepared for RNAs, which can hybridize with RNAs of several PCV isolates, have been identified.

Transmission

We found I-PCV to be seed-transmitted in pearl millet but not in sorghum. We have shown that the plasmodiophoraceous fungus, *Polymyxa graminis,* which is consistently present in roots of infected plants, can transmit 1-PCV. Soakates from roots of infected plants containing resting spores of *P. graminis,* which contain typical zoospores of *P. graminis* (Fig. 11), transmitted the virus; roots containing resting spores of *P. graminis* transmitted the virus when incorporated into sterile soil after storage for 2 years.

Groundnut Rosette Virus

In routine greenhouse inoculations of GRV, we have so far routinely used as the inoculation unit, 5-10 viruliferous apterous aphids (*Aphis craccivora*) reared on GRV-infected plants. We have used, throughout, our standard GRV culture, established from a field infection at Chitedze in 1984.

In routine greenhouse inoculations made before the start of the 1988/89 rainy season, we recorded unexpectedly high numbers of susceptible plants in the resistant varieties RG 1 and RMP 40. To exclude the possibility of a change in virulence in our standard culture, we collected two GRV isolates from the Phalombe and Mulanje districts, over 300 km to the south of Chitedze, and tested resistance in RG 1 against these new cultures. Nine plants out of the 34 inoculated with the Phalombe isolate and 41 out of the 113 inoculated with the Mulanje isolate became infected, indicating that some factor or factors other than GRV virulence were involved.

The recessive genes governing resistance do

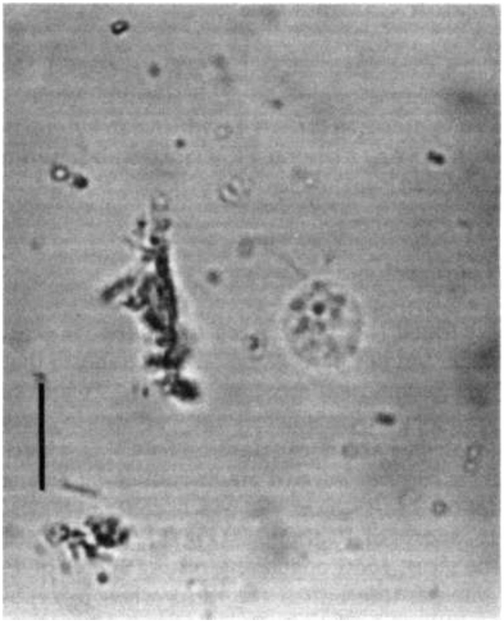


Figure 11. A zoosporangium of Polymyxa graminis. *Note flagella of unequal size (bar represents 11 µm).*

not confer immunity to GRV. Resistant plants grafted to infected susceptible scions develop symptoms of rosette. There are reports of the breakdown of resistance under conditions of high inoculum pressure.

In our 1988/89 GRV screening nursery, we generated an incidence of over 90% in susceptible test lines; only 50 out of 2440 RG 1 plants (2%) exposed to this pressure developed symptoms. In addition to RG 1, we screened 12 advanced F_6 GRV-resistant breeding lines; and only one plant out of the 558 that were exposed became infected. Therefore, there seems to be no marked change in the excellence of the recessive resistance under field conditions, even when inoculum pressure is high.

We are now examining our greenhouse inoculation procedures in relation to numbers of infective aphids used to test each plant and in relation to the possible effects of high greenhouse temperature. Our preliminary results suggest that resistance is overcome by the effects of simultaneous inoculation by comparatively large numbers of aphids.

Peanut Mottle Virus

Resistance Screening

In the 1988/89 postrainy and 1989 rainy seasons, we screened 436 genotypes for resistance to peanut mottle virus (PMV). Thirty-nine wild *Arachis* species, grown in a greenhouse, were tested for resistance to PMV by mechanical sap inoculations. Only 5% of ICGs 8164, 8956, 11562, and 12168 were infected, whereas susceptible genotypes showed more than 90% infection.

Peanut Stripe Virus

In cooperation with the Australian Centre for International Agricultural Research (ACIAR), the Moros Research Institute for Food Crops (MORIF), and the Malang Research Institute for Food Crops (MARIF), Indonesia, we screened groundnut genotypes for resistance to PStV. At Muneng (near Malang), 1352 entries, 10% of which were interspecific derivatives, and at Moros, 1304 entries, 60% of which were interspecific derivatives, were tested. Incidence of PStV at both places exceeded 90% in susceptible control cultivars. The majority of test entries were susceptible. Two genotypes, ICG 11710 and ICGV 88249, had mild symptoms at Moros, and interspecific derivatives 85/165-19, 85/166-4, 85/172-1, and 1093-2 were slightly affected in Muneng. In addition, ICG 4806, ICGV 8786/7, and ICGV 8825/9 had less than 30% infection when adjacent test lines were all infected.

Twenty-nine genotypes were either not infected or were lightly infected in the 1988 test series. They were mechanically inoculated with PStV isolates occurring in India and Indonesia and found to be susceptible. Interspecific derivatives 476-10,478-3,83/147-3-61, and 83/372-5-10 had mild symptoms and will be tested for tolerance to PStV.

Surveys carried out in cooperation with scientists of the National Bureau of Plant Genetic Resources (NBPGR) on groundnut crops raised in various research stations in India revealed that PStV was present in two locations.

Groundnut Streak Necrosis Disease

We identified *Sonchus oleraceus,* a commonly occurring composite weed of disturbed ground, as a further field host of GSND in southern Africa. A second aphid species, tentatively identified as *Myzus persicae,* of which *S. oleraceus* is a field host, may be another vector. Symptoms of the *S. oleraceus* virus in groundnut are dissimilar to those induced by the *Tridax procumbens* virus, suggesting that GSND occurs in at least two strains.

Peanut Chlorotic Mild Mottle Virus (PCMMV)

Leaflets carrying a disease of groundnut characterized by vein-clearing followed by chlorotic mild mottle were collected at several places in North India. The disease was shown to be caused by a whitefly *(Bemisia* tabaci)-transmitted carlavirus called PCMMV. Although the virus is serologically related to cowpea mild mottle virus (CMMV) (ICRISAT Annual Report 1979/80, p. 149), it can be distinguished by its host range and physicochemical properties.

Techniques

Electroblot Immunoassay (Western Blot Technique)

The western blot technique, which involves the separation of polypeptides by polyacrylamide gel electrophoresis and their transfer on to nitrocellulose or nylon membranes by electrophoresis, is now widely used for determining serological relationships among viruses. Polypeptides immobilized on membranes are detected by reaction with specific antibodies utilizing ELISA. We found that an inexpensive dried milk powder "Every Day"® could be used to block sites on membranes, not occupied by polypeptides. Among various substrates used we found Auroprobe BL Plus® and IntenSE BL Immunogold® for alkaline phosphatase and 3, 3, 5, 5 tetramethyl benzidine and H_2O_2 for horseradish peroxidase-detected picogram quantities of viral polypeptides. We have used this technique to determine serological relationships of TSWV and yellow spot viruses.

The Problem of Crop Growth Variability in West Africa

During 1989, our investigations clearly indicated that PCV, among other agents, including nematodes, plays a very important role in causing crop growth variability (1CRISAT Annual Reports 1987 p. 265 and 1988, p. 150) at the ISC Farm at Sadore. In the study of the host range of PCV (in collaboration with the Institut francais de recherche scientifique pour le developpement en cooperation [ORSTOM], IRHO, and ICRISAT Center), we found that PCV has a wide host range. Among those tested, only sunflower did not contain the PCV antigen. This finding may have some implications for the cropping systems and seed distribution in the West African Semi-Arid Tropics (WASAT) as the level of PCV was particularly high in cereals, especially pearl millet.

Screening for Resistance to Crop Growth Variability

Groundnut genotypes that were found to be resistant to crop growth variability in 1987 showed considerable variability in 1988. This is mainly because the possibility of escape is very high in fields showing crop growth variability. An attempt was made to standardize a field screening technique for evaluation of groundnut genotypes for their reaction to the crop growth variability problem in a field infested with plant-parasitic nematodes and PCV. Forty-nine test entries were replicated eight times. Test plots and susceptible controls were arranged in such a way that each small plot (0.5 m^2) of a test entry was surrounded by four control plots.

Test and control plots were visually scored for variability in crop growth. Only three lines showed less than 20% PCV incidence, ICGV 86600 (15%±10%), ICG 10964 (16% ± 10%), and ICG 1697 (18% ± 10%). ICG (FDRS) 41 showed uniform growth and 22%±10% of plants were positive for PCV as against 65%±10% for the control, 55-437. These lines will be further tested to confirm the stability of their tolerance to crop growth variability.

Nematode Population Densities and Growth and Yield of Groundnut

A field at ISC that exhibited severe crop growth variability in 1988 was selected for studying the relationship between the population densities of plant-parasitic nematode, crop growth variability, and growth and yield of groundnut.

Soil samples were collected at the time of sowing, four times during the crop growth period, and at harvest. Root samples were collected three times during the crop-growing period. Irrigation during the summer fallow did not appear to affect the nematode population. The predominant nematode was *S. clathricaudatum* (Table 12). During the crop growth period, nematode population densities were lowest in the carbofuran-treated plots. Stunted plants had up to three times the density of *S. clathricaudatum* in the roots than did healthy plants.

We collected soil samples in bulk from an area of crop showing very stunted growth, and from an area with apparently healthy crop growth and from fields with different densities of *S. clathricaudatum.* Cultivar 55-437 was grown in pots containing these soils and plants were harvested 50 days after germination. The soils were also analyzed for available aluminum, total N, P, organic matter, and for pH. Plant growth was significantly less than the autoclaved control in pots having an infestation level of 1.3 *S. clathricaudatum* cm^3 of soil at sowing time. The plant growth was significantly reduced in pots having a low population of *S. clathricaudatum* (0.1 nematode cm^{-3} of soil) but a higher $Al^{3+} + H^+$ concentration (0.55 meq 100 g^{-1} of soil).

Table 12. Changes in population densities of plant-parasitic nematodes in soil during the crop growth period of groundnut, Sadore, Niger, rainy season 1989[1].

	Nematode population densities 100 cm^{-3} soil			
Sampling dates	SC[2]	XP	T1	TOT
11 Jun 1989	69.2(1.84)3	4.2(0.62)	13.8(1.14)	109.6(2.04)
6 Jul 1989	52.5(1.72)	10.5(1.02)	9.8(0.99)	102.3(2.01)
21 Jul 1989	28.8(1.46)	19.5(1.29)	12.6(1.10)	56.2(1.75)
22 Aug 1989	26.3(1.42)	31.6(1.50)	10.5(1.02)	97.7(1.99)
22 Sep 1989	21.9(1.34)	20.9(1.32)	4.7(0.67)	72.1(1.86)
SE	(±0.08)	(±0.10)	(±0.10)	(±0.07)
CV (%)	(10)	(18)	(28)	(7)

1. Randomized-block design with four replications; plot size 16 m^2; groundnut cultivar 55-437.
2. SC = *Scutellonema clathricaudatum;* XP = *Xiphinema parasctariae,* TI = *Telotylenchus indicus;* TOT = Sum of all parasitic nematode populations.
3. Numbers in parentheses are log (x+1)- transformed values.

Vertical Distribution of Plant Parasitic Nematodes

Scutellonema clathricaudatum, Xiphinema parasetariae, and *T. indicus* were the dominant nematode species present in these fields. *Helicotylenchus* sp and *Pratylenchus* sp were present in low numbers. At the time of sowing, the greatest population densities of all the nematodes were found in the 0-15 cm soil depth. It seems probable that the population of 5. *clathricaudatum* does not migrate downwards very much during the summer fallow but aestivates by-entering a phase of anhydrobiosis.

Insect Pests

Pest Incidence at ICRISAT Center

During the 1988/89 postrainy season, there was a most unusual outbreak of aphids *(Aphis craccivora).* This is regarded as a marked change in the epidemiology of this species. By the first week of March, their density was 15-20 per terminal. This was rapidly reduced by rainfall during the following week but not before their damage caused concern. The thrips (mainly *Frankliniella schultzei)* population was at its peak during the second fortnight of February, with eight thrips per terminal and a resultant mean damage level of 12 leaves per plant. About 8% of the leaflets of susceptible genotypes had jassid *(Empoasca kerri)* damage by the end of March. The groundnut leaf miner (GLM) *(Aproaerema modicella)* population remained low during the whole season (<1 larva $plant^{-1}$) and never approached pest status. *Spodoptera litura* and *Helicoverpa armigera* activity resulted in only 2% defoliation in nonprotected plots, compared with 3% defoliation in plots that had been treated with insecticides.

During the rainy season, a relatively high incidence of GLM during its second generation gave us the opportunity to screen the All India Coordinated Research Project on Oilseeds (AICORPO) entries and other material for resistance to this pest. The second generation was at its peak in the first week of September with 48% damaged leaflets and 31 live larvae per plant in nonresistant lines. The population dwindled to one larva per plant in October. Other insects were of no apparent consequence.

Incidence of Beneficial Insects at ICRISAT Center

General Observations

During the 1988/89 postrainy season, we found that 48% of the GLM larvae were parasitized, mostly by a braconid wasp *(Chelonus* sp). This undoubtedly contributed to the low incidence of GLM during the whole season.

In the rainy season, larval parasitism of GLM was less than 10% on the groundnut plants of the integrated pest managemnt experiment compared to >20% on the soybean infestor rows that were sown between the plots. The groundnut leaf miner prefers soybean *(Glycine max* (L.) Merr.) to groundnut. Although the difference is not that great, it may have been sufficient to concentrate the searching activity of the parasite wasps where their host density was highest. However, there is also the possibility that the parasites are repelled by groundnut plants or attracted by soybean plants. This leads to the suggestion that the effect of intercropping groundnut and soybean on GLM parasitism levels should be investigated.

We have consistently found that there is less leaf damage attributable to defoliators like *Spodoptera litura* and *Helicoverpa armigera* in plots and fields that have not been sprayed with insecticide than in sprayed areas. This observation was followed up in the 1989 rainy season. Adjacent plots in the same field were sampled with DeVac to compare the predator population in areas that had been treated with insecticide with those that had not been treated. The population of spiders and coccinellids, although not high, was denser where insecticides had not been applied (Table 13).

Table 13. Comparison of predator population densities in sprayed and nonsprayed areas at ICRISAT Center, rainy season 1989.

Field condition	Mean spider[1] density	Mean Coccinellid[1] density	Mean defoliator[2] density
Sprayed field	0.3(0.2)	0.22(0.14)	0.23(2.23)
Nonsprayed field	4.6(1.6)	1.0(0.57)	0.93(0.49)
SE	(±0.1)	(±0.17)	(±0.08)

1. The sample unit was a bed of 100 m; there were 10 such samples. The insects were caught with a DeVac collector. Parenthesized data are log (n+1) transformations.
2. Each sample was a 1-m row and a mean of 40 samples.

Special Study of GLM Parasitism and Disease Levels at ICRISAT Center

A 2-year study of GLM, which included a detailed examination of its parasites and diseases, was completed in 1989. Out of the 40 or so parasite species that have been associated with this host, 17 were collected from the ICRISAT Center farm. However, this study made it clear that not all these species are beneficial to farmers because about half are secondary parasites—which means they are parasites of the parasites. In fact, four more secondary parasite species were added to the list in this 2-year period, together with one more primary parasite species. The eulophids *(Stenomesius japonicus* and *Sympiesis dolichogaster)* were the predominant primary parasites. The latter attacked more than 50% of the GLM caterpillars at the start of the 1988 rainy season. The rate of mortality caused by the fungal and viral pathogens increased as the season progressed, accounting for 20-30% of the larvae in the fourth generation. There is scope for further research on the population dynamics of this species because:

- between five and 40% of the mortality that was detected was caused by factors other than parasites and diseases. This presumably included predation and unspecified physical factors, such as desiccation and the failure of caterpillars to establish a feeding site.
- the complexity of the potential interactions between larval density (including the influence of the host genotype), levels of primary and secondary parasitism and the influence of insecticides on the system point to the need for computer simulation studies,
- there may be scope to exploit the pathogens of this species which have not previously been alluded to in scientific literature.

Modeling the Plant-Defoliator (GLM)-Natural Enemy System

The parasite study described above indicates that the life system of GLM is complex. A model of this system that simulates the flow of energy (dry matter) from the plant to the parasites has been constructed. Although further model development and data collection are required, we hope that we shall be able to use it to help solve some of the problems presented by GLM. For instance, although we have measured the quantity of leaf material a GLM caterpillar eats during its development period, this parameter, expanded to simulate the feeding activity of a field population, will not be directly related to the loss in photosynthetic tissue. This is because combined effects of the distortion of the leaves caused by the feeding lesions and the webbing together of leaves have, as yet, an undefined effect on the leaf area index. The model will be applied to define the levels of host-plant resistance needed in cultivars destined for 'hot-spots' and to predict when insecticides need to be applied to optimize farmers' yields.

Host-plant Resistance

Artificial Screening Technique for Groundnut Leaf Miner

So far, screening for resistance to GLM has depended entirely upon natural infestations in field conditions. This procedure can no longer be considered cost-effective. In the last 10 seasons (including the 1989 rainy season), the density of only three generations out of a possible 30-40 generations has been high enough to detect genotypic responses to this insect. Furthermore, genotypes selected for resistance to the third generation (i.e., the plants were near maturity) were susceptible when attacked during the seedling and flowering stage by the first-generation caterpillars. This was discovered four years ago but there has been no opportunity to investigate this observation further because no suitable infestation has since occurred.

Groundnut leaf miner is an important pest throughout Asia, hence we urgently need more information about its interactions with groundnut germplasm. As this information has not been provided by the conventional field screening approach, an alternative method is being developed. In a pilot experiment, we reared GLM on groundnut plants in an insectary and released them on 15-day-old experimental plants growing in pots (six genotypes, 30 plants per genotype) in a neighboring insectary. After 15 days, the plants were brought back to the laboratory for destructive sampling and the examination of the larvae. Although this technique needs standardization in terms of moth load, plant age, etc., Table 14 indicates that we now have the basis of a new routine that makes screening for resistance to this pest more reliable, informative, and independent of seasonal characteristics. For instance, out of the genotypes tested, ICG 221 is likely to be the most susceptible because it promoted the highest rate of larval growth. ICGV 87123 and ICG (FDRS) 10 displayed the lowest larval survival and adult acceptance rates. They are, therefore, less likely to need insecticidal protection from GLM than ICG 221.

Screening for Pest Resistance in the Field

In the 1988/89 postrainy season we found that ICGV 87157 and ICG (FDRS) 10 were resistant to jassid damage, as was the aphid-resistant line

Table 14. Groundnut leaf miner screening under greenhouse conditions using artificial population[1] at ICRISAT Center, rainy season 1989.

Entry[2]	Mean number[3] of total mines	Mean number of active mines	Mean larval mass (mg)	Survival percentage
ICG 221	6.1	2.9	2.93	47.5
ICGS 2271	5.9	2.5	1.87	42.4
ICGV 87123 (ICGS 11)	5.3	1.9	1.86	35.8
ICGV 86011	6.0	2.4	1.91	40.0
ICG (FDRS) 10	5.6	2.1	1.52	37.5
ZMB 2087	8.7	3.5	1.67	40.2
SE	±0.50	±0.24	±0.20	±1.67

1. Moths released 15 days after seedling emergence.
2. Thirty plants per entry.
3. Observations taken 30 days after seedling emergence.

ICG 5240. Two varieties with resistance to defoliators (ICGV 86030 and ICGV 86031) were as resistant to jassids as the resistant control ICG 2271.

During the rainy season, we screened 250 genotypes in three replicated trials at ICRISAT Center for resistance to GLM, in particular. No genotype was outstanding, but in the AICORPO uniform pest nursery, ICGV 87157, ICGV 87160, and ICG 7827 had considerably fewer live mines per plant than the other 37 genotypes.

Insect Resistance in *Arachis* spp

Resistance to defoliating caterpillars and to aphids is uncommon in the germplasm of the cultivated groundnut. Therefore, we are screening wild relatives of groundnut to determine the extent and nature of the insect resistance contained therein. Greenhouse tests have shown that most of the species tested have high levels of resistance to *Aphis craccivora. Arachis cardena-5N, A. otavi, A. kemph-mercadoi, A. khulaminii, A. stenosperma, A. batizocoi, A. duranensis,* and *A. paraguarensis* were as resistant or usually considerably more resistant than the most aphid-resistant *Arachis hypogaea,* ICG 5240. Experiments carried out by the Overseas Development Natural Resources Institute (ODNRI), UK, added *A. correntina, A. chacoense,* and *A. stenophylla* to this list.

Similarly, *Spodoptera litura* feeding tests on detached leaves of *Arachis* spp revealed a wide range of responses — from virtual immunity to susceptibility. *Arachis glabrata, A. major, A. kemph-mercadoi, A. apressipila, A. villosa, A. stenophylla,* and *A. paraguarensis* were the most resistant.

Of great importance was the serendipitous discovery of resistance to a soil insect in the wild species. As our knowledge of above-ground pests of groundnut and our ability to cope with them increased, we realised that our progress in understanding the applied ecology of the soil pests was slow. This is why we were excited to discover an apparent resistance to a natural infestation of the larvae of a soil insect, *Sphenoptera* sp, in the roots of 9 of the 22 wild species growing in a replicated field trial.

Mechanisms of Host-plant Resistance in Cultivated Groundnuts and Wild Relatives

With the hope of devising rapid methods of detecting resistance to sucking and chewing insects, the mechanisms of resistance of several key genotypes are being investigated in order to find chemical and physical markers. This research was conducted at the ODNRI Headquarters, Chatham, UK, Birkbeck College, London, the University of Reading, UK, and at ICRISAT Center.

Paper and HPLC analysis revealed the presence of a compound, concentrated in groundnut stems and petioles, which appeared to be unique to the aphid-resistant genotype ICG 5240. It was an iso-flavonoid but its identity is subject to confirmation. Usually groundnut stems and petioles are the favoured feeding sites of aphid species. This compound is not present in the phloem sap. However, further tests of the phloem sap of ICG 5240 showed that it contained nearly twice the concentration of condensed tannins than the aphid-susceptible control ICG 221. Parallel tests on *Arachis stenophylla* (highly aphid resistant) and *A. duranensis* (aphid susceptible) revealed that there were similar concentrations of these substances in the phloem sap of the aphid-resistant and -susceptible groundnut genotypes and the aphid-resistant and -susceptible wild species.

Despite the high level of resistance to *S. litura* in ICGV 86031 under field conditions, it has not been possible to detect a chemical reason for this. However, when given a choice between this genotype and a susceptible one, newly hatched larvae were more likely to leave the foliage of ICGV 86031. This effect only lasted for a few hours after hatching. The oven-dried biomass of ICGV 86031 per unit leaf area was greater than that of ICG 221. Therefore, larvae feeding on the former consumed a smaller area of leaf than those feeding on that of the latter, but achieved the same body mass. Thus defoliation per larval development was less in the resistant line than in the susceptible, a clear example of tolerance.

We are placing a special emphasis on determining the mechanisms of resistance to aphids and *S. litura* among the wild *Arachis* spp because few sources of resistance have been found in *A. hypogaea.*

Out of the 14 wild species screened for resistance to *S. litura,* all showed various kinds and levels of nonpreference due to physical and chemical factors. In general, *S. litura* larvae developed quicker on pulped leaves of *Arachis* spp than on intact leaves. This indicates that the physical quality of the leaves may be a resistance factor.

A nonprotein amino acid, cis-4-methylene glutamic acid, which is present in susceptible genotypes of *A. hypogaea,* is absent or nearly absent in all resistant *Arachis* spp and in the aphid-resistant ICG 5240. It is possible that this chemical stimulates insects to feed.

Extracts of several species in polar and nonpolar solvents have shown strong antibiotic effects. This indicates that there are more chemical resistance mechanisms in the genus.

The Influence of Drought Stress on Aphids

The unusual appearance of aphids during the postrainy season enabled us to observe aphid distribution across the drought-stress gradient created by the Physiologists' line source overhead irrigation system in their drought resistance screening trial. Figure 12 shows that the aphid density was much higher where most of the irrigation water had been applied. The effect of rain on aphid population density (where one rainfall event decreased their density by 90%) suggests that, although their density was highest near the irrigation source, it had probably been suppressed by the physical effect of the water falling on the plants. The drought stress experienced by the plants farthest from the water source can be considered to be beneficial because these plants supported the lowest density of an important pest and virus vector. The plants that were supported by irrigation during the dry season were exposed to a pest attack that had the potential to reduce their yield significantly.

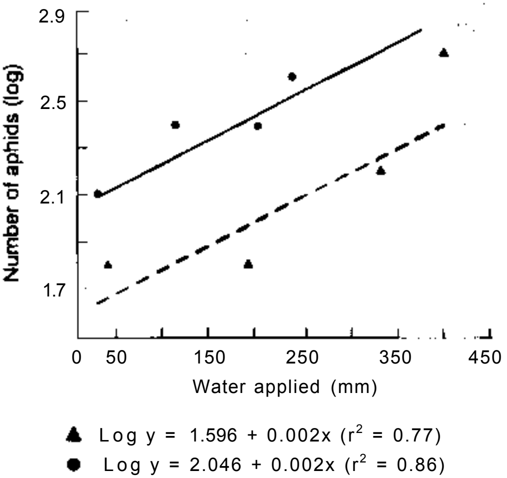


Figure 12. Distribution of aphid populations across a drought stress gradient created by line-source overhead irrigation.

Influence of Cropping System on Soil Insects

The observation that the leaves of a common roadside weed, morning glory bush *(Ipomoaea fistulosa)* are rarely attacked by insect or mammalian defoliators may have lead to a breakthrough in plant protection research. A mulch of the chopped leaves and stems of this plant was as successful at protecting groundnut pods from termite scarification as a neem *(Azadirachta indica)* cake mulch (<10%). A sunn hemp *(Crotalariajuncea)* mulch increased the level of scarification to about 70%, which is considerably higher than the rate that occurred on bare ground (about 35%).

Following the successful demonstration, by the Centro International de Agricultura Tropical (CIAT) scientists working in Colombia, of the ability of sunn hemp to protect cassava *(Manihot esculenta* Crantz) from soil pests we decided to find out if there were any similar benefits to be gained by intercropping sunn hemp with groundnut. The reduction (that we hoped for) in termite activity in the presence of sunn hemp did not occur and, the thrip and jassid densities were lower in the intercrop, presumably because of a barrier effect.

Video Film

The Legumes Entomologists jointly prepared a 30-minute video film entitled "Integrated Pest Management—the ICRISAT Approach" in this year. The film introduces the principles of integrated pest management and the research work entailed in the context of ICRISAT and its environment and objectives. The main pests of the three legume crops are discussed together with demonstrations of the components of integrated pest management.

Breeding for Insect Pest Resistance

Yield Trials

We compared the yields of 30 varieties, including three controls, in an elite insect-pest resistant variety trial at four locations under natural insect infestation during the 1989 rainy season. Four varieties outyielded the recently released ICGV 87141 (ICGS 76) at ICRISAT Center (Table 15). None bettered the highest-yielding controls, JL 24 at Anantapur and ICG 2271 at Bhavanisagar. ICGV 86436 outyielded the recently released ICGV 87141 at Hisar, Anantapur, and Bhavanisagar. ICGV 86522, which had the highest average pod yield of 2.66 t ha^{-1} (control—2.0 t ha^{-1} of average pod yield) appeared to be the best adapted variety for both rainy and postrainy seasons, as it outyielded ICGV 87123 during the 1988/89 postrainy season and also outyielded the national control variety, Kadiri 3, in the 1986/87 postrainy season (ICRISAT Annual Report 1987, p. 243). Several varieties, including those listed in Table 15, showed similar levels of jassid resistance as or higher than the resistant control, ICG 2271.

Plant Improvement

In the crossing program, the emphasis was on the incorporation of multiple resistances into high-yielding, popular cultivars and advanced breeding lines. In the 1988/89 postrainy season, we made 124 crosses (15 030 pollinations) in the field with an average success rate of 19%. In the 1988 rainy season, we made 130 crosses (16 002 pollinations) in the field with an average success rate of 84%. We grew 444 F_1 populations during both seasons, and after confirming their hybridity, we allocated these to various breeding projects. On an average, there were 20.5% selfed plants within the F_1 populations.

Breeding for Adaptation to Specific Environments and Requirements

Early-maturing Group

In the 1988/89 postrainy season, we grew 1147 F_2 - F_{11} populations and made 1031 bulk selections; in the 1989 rainy season, we grew 1172 F_2 - F_8 populations and made 354 bulk selections, based on pod number, maturity, shape and size, and seed maturity in early harvests. During the 1989 rainy season, our selection efficiency was severely impeded by weeds. Most material had to be advanced without selection. We selected 59 new lines in the 1988/89 postrainy season for replicated yield trials in the 1989 rainy season.

Yield Trials

We evaluated 186 varieties in 3 replicated trials, for their pod yield potential in early harvests during the 1988/ 89 postrainy season. In the elite trial, ICGV 87883 produced high pod yields on both the early harvest dates in Alfisol fields at ICRISAT Center: 1.87 ± 0.11 t ha^{-1} in 104 DAS (1260°C day cumulative thermal time [CTT]) and 2.81 ± 0.16 t ha^{-1} in 118 DAS (1494°C day CTT).

During the 1989 rainy season, we evaluated 150 varieties in four replicated trials at ICRISAT Center and 44 at other locations in India. Four varieties outyielded the highest-yielding control in preliminary trials at ICRISAT Center. When compared with the highest-yielding

Table 15. Mean pod yields of some high-yielding jassid *(Empoasca* Krerri)-resistant varieties in the Elite Insect-Pest Resistance Groundnut Varietal Trial (sequentially and alternately branching), rainy season 1989.

	Mean pod yield (t ha^{-1})								Number of locations where entry ranked in:	
Entry	ICRISAT Center[1]	Bhavani-sagar[2]	Ananta-pur[3]	Hisar[2]	Mean	Jassid score[4]	Shell-ing (%)[5]	100-seed mass (g)[5]	Top 20%	Bottom 20%
ICGV 86522	3.50 (1)[6]	2.23 (9)	1.29 (4)	3.61 (3)	2.66	3.2	67	40	3	0
ICGV 86436	2.67(14)	2.34 (6)	1.18(13)	3.98 (1)	2.54	2.9	66	47	2	0
ICGV 87468	2.61(16)	2.19(10)	1.25 (6)	3.23 (9)	2.32	3.9	69	45	1	0
ICGV 86518	2.41(23)	2.06(14)	1.32 (3)	3.37 (6)	2.29	3.6	69	48	2	0
ICGV 86462	2.44(22)	1.89(22)	1.17(14)	3.62 (2)	2.28	2.2	69	33	1	0
ICGV 87453	3.18 (3)	1.84(26)	0.92(24)	3.16(11)	2.28	2.0	67	41	1	1
ICGV 86455	2.67(13)	1.88(23)	1.02(21)	3.48 (4)	2.27	2.2	65	42	1	0
ICGV 86252	2.62(15)	1.78(27)	1.23(10)	3.41 (5)	2.26	1.8	71	48	1	1
ICGV 86351	3.08 (4)	2.04(16)	1.07(19)	2.67(20)	2.21	3.8	68	40	1	0
ICGV 86393	3.15 (3)	1.98(18)	1.11(18)	2.56(22)	2.20	2.5	69	35	1	0
Controls										
JL 24	2.26(28)	2.07(13)	1.51 (1)	2.39(24)	2.06	7.9	69	48	1	1
ICGV 87141 (ICGS 76)	2.41(24)	1.65(30)	0.79(27)	3.12(10)	2.01	5.0[7]	71	52	0 2	
ICG 2271	2.45(19)	2.59 (1)	0.74(29)	2.30(27)	2.02	4.4	62	45	1	2
SE	±0.158	±0.166	±0.088	±0.251	±0.41					
Trial mean (42 entries)	2.65	2.06	1.09	2.89	3.2					
CV (%)	10	14	14	15	22					
Efficiency over RBD[8] (%)	179	168	128	160						

1. Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, no protection against insect pests, protection against foliar diseases, in rectangular lattice design, plot size 13.5 m^2 (BBF).
2. Alfisol (Bhavanisagar) and Entisol (Hisar), 60 kg P_2O_s ha^{-1}, full irrigation, no protection against insect pests, in rectangular lattice design, plot size 4.8 m^2 (on flat bed).
3. Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, no protection against insect pests, in rectangular lattice design, plot size 4.8 m^2 (on flat bed).
4. Average of three seasons' data recorded from ICRISAT Center (rainy seasons 1987, 1988, and 1989). Jassid damage scored on a 1-9 scale under natural insect-pest infestation where 1 = no jassid damage, and 9 = 90 100% jassid damage (leaf yellowing).
5. Average of four locations from the bulk samples.
6. Numbers in parentheses are rankings of the entries.
7. Jassid score from only the 1989 rainy season, ICRISAT Center.
8. RBD = Randomized-block design.

control variety, five varieties in the elite trial outyielded the control in early harvests in mean pod yields at four locations (Table 16). 1CGV 86143 produced the highest pod yields of 2.38 t ha^{-1} in 92 DAS at Hisar and 2.27 t ha"1 in 96 DAS at Bhavanisagar, but the yield was low at ICRISAT Center and Anantapur. Under high-input conditions at ICRISAT Center, ICGMS 32, a variety selected in Malawi, gave the highest pod yield of 1.80 t ha^{-1} in 94 DAS (1494°C day CTT) with 65% shelling percentage and a 100-seed mass of 29 g.

Table 16. Mean pod yield of selected groundnut varieties in the Elite Early Groundnut Varietal Trial, rainy season 1989.

Entry	Mean pod yield (t ha^{-1}) HI(A)[1] (94 DAS)[2]	Anantapur (96 DAS)	Bhavanisagar (96 DAS)	Hisar (92 DAS)	Mean	Number of locations where entry ranked in: Top 20%	Bottom 20%
ICGV 86143	1.51(34)3	0.99(48)	2.27 (1)	2.38 (1)	1.79	2	1
ICGMS 32	1.80 (7)	1.25(31)	2.22 (2)	1.82 (7)	1.77	3	0
ICGM 614	1.76(10)	1.61 (1)	1.92(12)	1.76(10)	1.76	3	0
ICGV 87391	1.78 (9)	1.38(11)	2.06 (4)	1.58(19)	1.70	2	0
ICGMS 23	1.63(19)	1.34(15)	1.90(18)	1.89 (4)	1.69	1	0
Controls							
Chico	1.00(49)	0.61(49)	0.91(49)	1.24(42)	0.94	0	4
JL 24	1.75(12)	1.29(22)	1.91(16)	1.58(20)	1.63	0	0
J 11	1.18(47)	1.23(33)	2.07 (3)	1.26(40)	1.44	1	1
TMV 2	1.29(46)	1.27(26)	1.62(38)	1.31(36)	1.37	0	1
ICGV 87157	1.41(43)	1.06(46)	1.49(41)	1.11(44)	1.27	0	4
SE	±0.103	±0.088	±0.157	±0.161	±0.065		
Trial mean (49 entries)	1.59	1.27	1.77	1.49	1.53		
CV(%)	11.3	12.2	15.4	18.8			
Efficiency over RBD[4] (%)	104	125	123	104			

1. HI(A) = High input (Alfisol), ICRISAT Center, plot sizes are 4.8 m^2 at Anantapur, and 6 m^2 at other locations.
2. DAS = Days after sowing, during the 1989 rainy season, at location HI(A), 94 DAS were equal to 1494 °C day cumulative thermal time (CTT). 1475 °C day CTT gets accumulated at ICRISAT Center in rainy season, on an average, in 90 DAS (based on 14-year weather data and assuming 15 Jun as the sowing date).
3. Numbers in parentheses are rankings of the entries.
4. RBD = Randomized-block design.

Screening for Fresh Seed Dormancy

We tested 26 lines with suspected seed dormancy. Six breeding lines and one germplasm line ICG 7261 (Kanto number 40) had fresh seed dormancy of limited duration.

We took parents with multiple resistance to insect pests (leaf miner and *Spodoptera),* foliar diseases (rust and LLS) and drought, and crossed them with 34 high-yielding, adapted varieties to generate populations with resistance to multiple stresses.

Medium- and Late-maturing Groups

We grew 840 bulk populations (F_2 - F_{12}) during the 1988/89 postrainy and the 1989 rainy seasons and made 371 bulk populations and single-plant selections. We selected 50 phenotypically uniform advanced generation varieties for a preliminary yield trial.

Yield Trials

In the 1988/89 postrainy season, we evaluated 147 sequentially and 98 alternately branching varieties, in eight replicated yield trials. Out of these, 46 varieties were tested at three locations, while the rest were evaluated at ICRISAT Center. The mean pod yields in the sequentially branching group trials at ICRISAT Center ranged from 2.16 ± 0.23 t ha^{-1} to 4.80 ± 0.24 t ha^{-1}. Twenty-one outyielded the national control, J 11, and 10 outyielded the best controls, ICGV 87123 or ICGV 87128.

The mean pod yields in the alternately branching group (ICRISAT Center) ranged from 2.65 t ha^{-1} to 5.51 ± 0.19 t ha^{-1}. Twenty-four varieties gave higher pod yields than the national control, Kadiri 3. In the alternately branching preliminary yield trial, four varieties recorded pod yields in the range of 5.04 - 5.51 t ha^{-1} compared with 4.42 ± 0.19 t ha^{-1} of Kadiri 3.

In the sequentially branching elite variety trial, ICGV 86249 did well again as in previous years. It had outyielded ICGV 87123 during the 1987/88 postrainy season (ICRISAT Annual Report 1988, p. 132) and also showed superiority in pod yield over the national control Kadiri 3, during the 1986/87 postrainy season (ICRISAT Annual Report 1987, p. 243). Therefore, ICGV 86249 appears to be adapted to irrigated Alfisols in the postrainy season.

ICGV 86008, which showed the highest average pod yield of 2.56 t ha^{-1} as against 2.11 t ha^{-1} of ICGV 87123 during the 1988/89 postrainy-season evaluation, also recorded the highest average pod yield of 2.39 t ha^{-1} as against 1.92 t ha^{-1} of ICGV 87123 during the 1988 rainy season (ICRISAT Annual Report 1988, p. 134). Therefore, it appears to be well adapted to the rainy season and irrigated postrainy situation. Other varieties adapted to both seasons are ICGV 86885 and ICGV 86865.

In the 1989 rainy season, we evaluated 98 sequentially branching and 74 alternately branching varieties in four replicated yield trials. Out of these, 36 were tested at four locations and the rest were evaluated only at ICRISAT Center.

Mean pod yields in the sequentially branching group trials at ICRISAT Center ranged from 0.97 to 3.62 ± 16 t ha^{-1}. Fourteen varieties outyielded the national control, JL 24, and 9 outyielded ICGV 87123 and/or ICGV 87128. Three varieties at ICRISAT Center and Bhavanisagar, outyielded the highest-yielding control JL 24, whereas only one variety outyielded JL 24 at Hisar. ICGV 86928, which gave the highest average pod yield (Table 17) of 2.51 t ha^{-1} as against 2.18 t ha^{-1} of JL 24, adapted best to the rainy-season situation. It had also recorded high pod yields in the 1987 rainy season at ICRISAT Center (ICRISAT Annual Report 1987, p. 245).

Mean pod yields in the alternately branching group trials at ICRISAT Center ranged from 1.26±0.11 t ha^{-1} to 3.26 ± 0.17 t ha^{-1}. Sixty-nine varieties tested in different trials had higher pod yields than the national control Kadiri 3. Out of these, twenty-nine outyielded Kadiri 3 and ICGV 87141. Eight varieties at ICRISAT Center outyielded Kadiri 3 and ICGV 87141. At Bhavanisagar, three varieties outyielded Kadiri 3 and ICGV 87141. ICGV 86300, which produced the highest average pod yield of 2.93 t ha^{-1}, as against 2.45 t ha^{-1} of Kadiri 3 (Table 18) adapted best to the rainy season; it also gave the highest average pod yield in the 1988 rainy-season multiloctional trials (ICRISAT Annual Report 1988, p. 135) and highest pod yield in the 1987 rainy-season trial at ICRISAT Center (ICRISAT Annual Report 1987, p. 245).

Confectionery Group

We grew 670 populations (F_2 F_7) in the 1988/89 postrainy and the 1989 rainy seasons and made 325 bulk selections based on pod yield per se, pod and seed size and shape, uniformity, and seed color. We gave most emphasis to selecting two-seeded, elongated, moderately constricted bold pods that resulted in progenies with uniform, large, round or elongated seeds. We selected 92 phenotypically uniform large-seeded varieties for replicated yield trials. We crossed high-yielding confectionery varieties with lines having desirable traits such as resistance to rust and late leaf spot, and short duration.

Yield Trials

During the 1988/89 postrainy season, we evaluated 147 newly developed confectionery groundnut varieties including 48 from North Carolina State University in three replicated preliminary

Table 17. Mean pod yields of some varieties in the Elite Medium- and Late-maturing Groundnut Varietal Trial (sequentially branching), rainy season 1989.

	Mean pod yield (t ha^{-1})							Number of locations where entry ranked in:	
Entry	ICRISAT Center[1]	Bhavani-sagar[2]	Ananta-pur[3]	Hisar[2]	Mean	Shelling (%)[4]	100-seed mass (g)[4]	Top 20%	Bottom 20%
ICGV 86928	2.72 (3)[5]	2.23 (2)	1.63 (8)	3.44 (3)	2.51	63	40	3	0
ICGV 86951	2.00(16)	1.96 (5)	1.79 (5)	4.24 (1)	2.49	73	42	1	1
ICGV 86953	3.05 (1)	1.96 (6)	1.61(10)	3.02 (9)	2.41	63	47	1	0
ICGV 86952	2.42(10)	1.83 (8)	1.90 (2)	3.25 (5)	2.35	74	41	1	0
ICGV 86954	2.45 (9)	1.43(15)	1.66 (7)	3.84 (2)	2.34	71	44	1	1
ICGV 86926	2.53 (8)	2.13 (3)	1.50(14)	3.06 (8)	2.30	67	44	1	1
ICGV 86934	2.54 (6)	2.37 (1)	1.53(13)	2.77(11)	2.30	64	37	1	0
Controls									
JL 24	2.28(13)	1.66(11)	1.81 (3)	2.96(10)	2.18	69	45	1	0
ICGV 87157	2.07(15)	1.65(12)	1.70 (6)	2.62(14)	2.01	65	48	0	2
SE	±0.142	±0.145	±0.091	±0.334					
Trial mean (16 entries)	2.45	1.81	1.65	3.04					
CV (%)	10	14	9	19					
Efficiency over RBD[6] (%)	113	129	119	118					

1. 60 kg P_2O_5 ha^{-1}, full irrigation, full protection against diseases, in triple-lattice design, plot size 13.5 m^2 (BBF).
2. Alfisol (Bhavanisagar) and Entisol (Hisar), 60 kg P_2O_5 ha^{-1}, full irrigation, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
3. Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
4. Average of four locations recorded from bulk samples.
5. Numbers in parentheses are rankings of the entries.
6. RBD = Randomized-block design.

Table 18. Mean pod yields of some varieties in the Elite Medium- and Late-maturing Groundnut Varietal Trial (alternately branching), rainy season 1989.

	Mean pod yield (t ha^{-1})							Number of locations where entry ranked in:	
Entry	ICRISAT Center[1]	Bhavani-sagar[2]	Ananta-pur[3]	Hisar[2]	Mean	Shelling (%)[4]	100-seed mass (g)[4]	Top 20%	Bottom 20%
ICGV 86300	3.26(1)[5]	2.23(4)	1.80(3)	4.44(3)	2.93	63	42	4	0
ICGV 86905	3.04(5)	2.14(6)	1.71(5)	4.54(2)	2.86	67	35	3	0
ICGV 86265	3.03(6)	1.79(12)	1.70(6)	4.86(1)	2.85	69	33	1	0
ICGV 86267	2.79(13)	2.38(3)	1.62(12)	3.94(9)	2.68	69	38	1	0
ICGV 86271	2.93(9)	1.41(25)	1.63(11)	4.34(4)	2.58	67	38	1	1
Controls									
Kadiri 3	2.46(24)	1.51(24)	1.76(4)	4.06(7)	2.45	67	39	1	2
ICGV 87141 (ICGS 76)	2.26(25)	1.76(13)	1.34(22)	3.92(10)	2.32	68	46	0	2
SE	±0.173	±0.174	±0.102	±0.315					
Trial mean (25 entries)	2.81	1.86	1.56	3.49					
CV (%)	11	16	11	16					
Efficiency over RBD[6] (%)	104	113	102	101					

1. Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, full protection against diseases, in triple-lattice design, plot size 13.5 m^2 (BBF).
2. Alfisol (Bhavanisagar) and Entisol (Hisar), 60 kg P_2O_5 ha^{-1}, full irrigation, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
3. Alfisol, 46 kg P_2O_5 ha^{-1}, rainfed, research protection, in triple-lattice design, plot size 4.8 m^2 (on flat bed).
4. Average of four locations recorded from bulk samples.
5. Numbers in parentheses are rankings of the entries.
6. RBD = Randomized-block design.

yield trials at ICRISAT Center. The mean pod yields were 2.12 ± 0.30 t ha^{-1} to 4.67 ± 0.26 t ha^{-1}. In the preliminary trial, six varieties outyielded the Indian confectionery groundnut variety, Chandra, and were also superior in shelling percentage, 100-seed mass, and oil and protein contents. However, only four of these varieties had satisfactory oleic/linoleic acid (O/L) ratios (>1.6).

ICGV 88379, with a pod yield of 4.7 t ha^{-1} outyielded ICGV 87123, which was recently released in India. Out of the 147 varieties evaluated in various trials, thirteen outyielded ICGV 87123. ICGV 88414, with its high protein content (31.1%) and low oil (46.2%), is the most sought after confectionery variety.

In another preliminary trial, none of the introduced varieties outyielded the local control, Chandra. However, ICGVs 88424 (NC Ac 18420), 88429 (NC Ac 18437), and 88438 (GP NC 343 x NC Ac 17367), which had 100-seed masses of 70 g each during the 1988 rainy season (ICRISAT Annual Report 1988, p. 134), also produced high seed masses (>84 g [100 seeds]$^{-1}$) during the 1988/89 postrainy season, indicating stability of seed mass in these varieties. These

Table 19. Mean pod yields of confectionery groundnut varieties in advanced yield trial, ICRISAT Center, rainy season 1989[1].

Entry	Pod yield (t ha^{-1})	Shelling (%)[2]	100-seed mass (g)[3]	Oil (%)[4]	Protein (%)[4]	Oleic/linoleic acid ratio[4]
ICGV 88386	3.00 (2)[5]	64	80	50.7	21.5	1.86
ICGV 88408	3.00 (3)	63	74	51.2	21.4	1.83
ICGV 88390	2.96 (5)	61	73	50.4	20.3	1.91
ICGV 88382	2.93 (7)	63	78	50.6	22.3	1.82
ICGV 88399	2.92 (8)	63	73	49.5	22.4	1.76
ICGV 88365	2.90 (9)	65	73	51.1	24.7	1.91
ICGV 88403	2.88(11)	65	77	50.2	22.3	1.89
ICGV 88367	2.85(12)	68	76	50.6	22.8	1.57
ICGV 88398	2.85(13)	61	73	48.3	23.2	1.71
Controls						
Chandra	2.30(47)	64	70	48.7	21.9	1.96
Chalimbana	2.03(49)	59	69	-[6]	-	-
ICGV 87141 (ICGS 76)	2.38(44)	70	50	-	-	-
SE	±0.130					
Trial mean (49 entries)	2.67					
CV (%)	9					
Efficiency over RBD[7] (%)	133					

1. Alfisol, 60 kg P_2O_5 ha^{-1}, full irrigation, full protection against diseases, in triple-lattice design, plot size 13.5 m^2 (BBF).
2. Recorded from bulk sample of 1 kg of pods.
3. Recorded from bulk sample of randomly selected sound, mature seeds.
4. Average of tests over three seasons at ICRISAT Center (1987/88 postrainy, 1988 rainy, and 1988/89 postrainy).
5. Numbers in parentheses are rankings.
6. - = Data not available.
7. RBD = Randomized-block design.

varieties also had high O/L ratios (1.6-2.3), and are thus potential parents for breeding confectionery varieties.

In the 1989 rainy season, we tested the yield of 90 confectionery varieties with controls, in two advanced yield trials at ICRISAT Center. The mean pod yields ranged from 1.86±0.16 to 3.00±0.13 t ha^{-1}. Thirty-one varieties from various trials outyielded Chandra; however, only 20 outyielded ICGV 87141, which was recently released in India. Also, 41 varieties outyielded Chalimbana, a popular confectionery variety from Malawi. Several varieties, including those mentioned in Table 19, had shown improvement in shelling percentage, 100-seed mass, oil content, and O/L ratio. ICGV 88386 had the highest pod yield of 3 t ha^{-1} compared with 2.38 t ha^{-1} of the best control, ICGV 87141. ICGVs 88367, 88382, 88386, 88403, and 88408 outyielded the highest-yielding control, M 13, during the 1988 rainy-season trial conducted at ICR1SAT Center (ICRISAT Annual Report 1988, p. 136) and also had acceptable traits.

We have 50 confectionery varieties with satisfactory O/L ratios (>1.6) identified during the previous two seasons' evaluation at ICRISAT Center.

Crop Improvement in Southern Africa

Breeding for High Yield and Quality in Malawi

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. We also advanced 10 F_2 populations by single-seed descent.

From 461 F_3 populations, we retained 80 and made 88 pedigree selections. From 270 F_4-F_7 populations we retained 148 and made 118 bulk and 419 pedigree selections. Five will be included in yield trials.

We made several selections for high yield and quality from breeding lines introduced from the Zimbabwe Groundnut Program and 39 of these will be included in a yield trial.

High Yield and Adaptability

We sowed 21 F, populations from crosses involving genotypes showing high yield potential and wide adaptability in the SADCC region to confirm their hybridity and to advance them to the next generation.

We advanced 19 F_2 populations by single-seed advance and made 139 pedigree selections from 12 of these.

Yield Trials

Regional Program Preliminary Yield Trials

We evaluated 20 sequentially branching and 44 alternately branching breeding lines in separate yield trials at Chitedze. Two breeding lines from the 1987 ICRISAT Center preliminary foliar-diseases resistant groundnut variety trial had good yields.

ICR1SAT Center Preliminary Yield Trials

We evaluated 46 early-maturing breeding lines (1987 Preliminary Early Groundnut Varietal Trial 2) at Chitedze. ICGVs 87922 and 87924 performed well in this trial. We also evaluated 28 drought-resistant breeding lines (1987 Preliminary Drought Resistance Groundnut Varietal Trial) for the second season at Ngabu. Although the season was abnormally wet and the results were inconclusive, ICGV 86972 gave satisfactory yields.

ICRISAT Center International Yield Trials

We evaluated 23 early-maturing lines sown on two dates at Chitedze. The early trial was harvested on two dates. The late trial was harvested on one date only, after the same thermal season length as the first harvest in the early trial. Some genotypes performed well even when harvested relatively early and the yield of some entries was not drastically reduced by late sowing.

Regional Program Advanced Yield Yrials

We evaluated 39 sequentially branching and 75 alternately branching test entries along with controls in four trials at Chitedze.

Many sequentially branching entries outyielded the local control, Malimba, and several showed promise for yield potential and large seed size, as measured by 100-seed mass. We selected 14 entries for inclusion in regional yield trials including selections from (J 11 x TG 3 x NC Ac 17090), (USA 20 x TMV 10 x Robut 33-1-10-3), (Robut 33-1-21-11 x Manfredi x M 13), and [(Goldin 1 x Faizpur 1- 5) x (Manfredi x M 13)].

Many alternately branching lines gave higher yields than the local control, but none was higher than ICGV-SM 83708 (ICGMS 42) which gave the highest yield in both the trials. We selected 14 entries for inclusion in the regional yield trials among which are selections from (ICGS 22 x Makulu Red), (ICGS 1 x Makulu Red), (ICGS 18 x TMV 10 x Chico), four GRV-resistant selections (ICGV-SMs 88709, 88710, 88711, and 88734), and introductions from Zambia.

Table 20. Mean seed yields of some entries in the SADCC Regional Groundnut Variety Trials (alternately branching), 1988/89.

Entry	Location[1] and mean seed yield (t ha^{-1})					Mean
	1	2	3	4	5	
ICGV-SM 83708	3.00 (1)[2]	0.61 (7)	1.16 (1)	0.57(16)	0.30(24)	1.13
ICGV-SM 86708	2.82 (2)	0.98 (1)	1.12 (2)	0.36(24)	0.36(21)	1.13
ICGV-SM 86734	2.28(10)	0.46(14)	0.85(10)	0.90 (4)	0.56 (4)	1.01
ICGV-SM 86725	2.67 (3)	0.43(18)	0.99 (4)	0.65(11)	0.30(25)	1.01
ICGV-SM 86720	2.47 (5)	0.48(13)	1.06 (3)	0.53(19)	0.47(10)	1.00
Control P	1.60(25)	0.63 (5)	0.61(19)	0.48(21)	0.45(12)	0.76
Control 2[3]	2.16(16)	0.27(24)	0.74(15)	0.67 (9)	0.72 (2)	0.91
SE	±0.092	±0.088	±0,065	±0.087	±0.096	
Trial mean (25 entries)	2.21	0.51	0.79	0.65	0.46	
CV (%)	8	35	16	28	36	
Efficiency over RBD[4] (%)	100	102	102	104	104	

1. Location 1 = Chitedze Research Station, Malawi, quadruple-lattice design, plot size 21.6 m^2.
   2 = Makoka Research Station, Malawi, quadruple-lattice design, plot size 9.0 m^2.
   3 = Luyengo Campus, Swaziland, quadruple-lattice design, plot size 4.8 m^2.
   4 = Msekera Research Station, Zambia, quadruple-lattice design, plot size 18.0 m^2.
   5 = Chisamba Research Station, Zambia, triple-lattice design, plot size 18.0 m^2.
2. Numbers in parentheses are rankings of the entries.
3. Controls 1 and 2 are Egret and Mani Pintar at location 1; Mawanga and Chitembana at location 2; Egret and Mani Pintar at location 3; MGS2 at location 4, and Makulu Red at location 5.
4. RBD = Randomized-block design.

SADCC Regional Yield Trials

The Virginia trial was sent to nine locations in six countries, the Spanish trial to 11 locations in seven countries, and the Valencia trial to eight locations in six countries.

Of the Virginia cultivars, ICGV-SM 83708 (ICGMS 42) again ranked high at most locations and was superior to local varieties at a number of locations (Table 20). International buyers have indicated recently that ICGMS 42 is acceptable to the confectionery trade. It has large seed of uniform shape and size and acceptable oil stability.

Some other entries were consistently ranked high, notably ICGV-SM 86708, ICGV-SM 86725, both derived from the same cross, ([Robut 33-1 x NC Ac 2821] x [USA 20 x TMV 10]) and ICGV-SM 85737 (ZM 336, an introduction from Zambia). ICGV-SMs 85722, 85726, and 86715 (all interspecific hybrids) were not as good this year as last year. Nine entries have been retained for further evaluation.

Several entries in the Spanish trials gave consistent yields across locations (Table 21). ICGV-SM 85038 [(PI 261911 x PI 262092) x Egret] was again highly ranked. ICGV-SM 83005 and 85048 did poorly at Chitedze but grew well at other locations. Nine entries have been retained for further evaluation.

At most Valencia trial locations, the test entries were superior to the control varieties with

Table 21. Mean seed yields of some entries in the SADCC Regional Groundnut Variety Trials (sequentially branching), 1988/89.

	Location[1] and mean seed yield (t ha^{-1})						
Entry	1	2	3	4	5	6	Mean
ICGV-SM 85038	1.60 (1)[2]	1.26 (8)	1.46 (6)	0.82 (3)	0.73 (6)	1.32 (1)	1.20
ICGV-SM 85045	0.83(16)	1.60 (2)	1.79 (2)	0.75 (4)	0.69(10)	1.09 (4)	1.12
ICGV-SM 83005	0.64(25)	1.84 (1)	1.60 (4)	0.73 (5)	0.85 (2)	1.04 (5)	1.12
ICGV-SM 83011	0.85(14)	1.58 (3)	1.67 (3)	0.83 (2)	0.78 (4)	0.90 (7)	1.10
ICGV-SM 85001	1.16 (4)	1.36 (6)	1.49 (5)	0.90 (1)	0.98 (1)	0.50(23)	1.06
ICGV-SM 86053	1.46 (2)	1.15(11)	1.33 (8)	0.71 (6)	0.71 (8)	0.64(21)	1.00
Control 1[3]	0.72(24)	1.20(10)	0.93(21)	0.40(23)	0.58(18)	0.68(19)	0.75
Control 2[3]	0.74(23)	1.31 (7)	1.25(11)	0.46(20)	0.52(22)	0.84(12)	0.85
SE	±0.055	±0.118	±0.111	±0.077	±0.077	±0.124	
Trial Mean (25 entries)	0.95	1.19	1.22	0.58	0.65	0.82	
CV(%)	12	20	17	27	24	30	
Efficiency over RBD (%)[4]	100	119	122	101	100	118	

1. Location 1 = Chitedze Research Station, Malawi, quadruple-lattice design, plot size 21.6 m^2.
   2 = Nsanje Research Station, Malawi, quadruple-lattice design, plot size 12.0 m^2.
   3 = Lupembe Research Station, Malawi, quadruple-lattice design, plot size 14.4 m^2,
   4 = Luyengo Campus, Swaziland, quadruple-lattice design, plot size 9.6 m^2.
   5 = Masumba Research Station, Zambia, quadruple-lattice design, plot size 18.0 m^2.
   6 = Mochipapa, Zambia, triple-lattice design, plot size 18.0 m^2.
2. Numbers in parentheses are rankings of the entries.
3. Controls 1 and 2 are Malimba and Sellie at locations 1 and 4; Malimba at location 2; and JL 24 at location 3; and at location 5, Comet is used twice as control.
4. RBD = Randomized-block design.

Table 22. Mean seed yields of some entries in the SADCC Regional Groundnut Variety Trials (sequentially branching [Valencia type]), 1988/89.

	Location[1] and mean seed yield (t ha^{-1})				
Entry	1	2	3	4	Mean
ICGM 285	1.05 (3)[2]	1.59 (2)	0.24(12)	1.94 (4)	1.20
ICGM 284	0.88 (7)	1.46 (6)	0.31 (9)	2.15 (1)	1.20
ICGM 189	1.66 (1)	0.97 (9)	0.41 (4)	1.61 (8)	1.16
ICGM 281	0.95 (5)	1.45 (7)	0.34 (5)	1.67 (7)	1.10
ICGM 286	1.00 (4)	1.74 (1)	0.20(14)	1.37(14)	1.08
ICGM 525	1.15 (2)	1.53 (5)	0.28(10)	1.25(15)	1.06
ICGM 550	0.90 (6)	1.58 (3)	0.33 (8)	1.41(11)	1.05
ICGM 554	0.78 (9)	0.96(10)	0.44 (3)	2.00 (2)	1.04
Control 1[3]	0.58(16)	0.92(11)	0.54 (2)	1.38(12)	0.72
Control 2[3]	0.25(15)	1.56 (4)	0.78 (1)	1.19(16)	0.95
SE	±0.155	±0.063	±0.038	±0.163	
Trial Mean (16 entries)	0.77	1.11	0.33	1.62	
CV (%)	42	12	23	20	
Efficiency over RBD (%)[4]	-	100	133	190	

1. Location 1 = Maseru Research Station, Lesotho, randomized-block design, plot size 14.4 m^2.
2 = Chitedze Research Station, Malawi, quadruple-lattice design, plot size 21.6 m^2.
3 = Ngabu Research Station, Malawi, quadruple-lattice design, plot size 12.0 m^2.
4 = Malkerns Research Station, Swaziland, quadruple-lattice design, plot size 6.0 m^2.
2. = Numbers in parentheses are rankings of the entries.
3. = Controls 1 and 2 are MS 8 and MS 7 at location 1; Malimba and Valencia R 2 at location 2; Malimba at location 3; and JL 24 at location 4.
4. RBD = Randomized-block design.

ICGMs 189, 284, 285, and 286 being consistently good (Table 22).

Crop Improvement in West Africa

Cultivar Trials

Advanced Groundnut Cultivar Trial

This trial was grown at eight locations in West Africa in 1989. Results have so far been obtained from six sites in Benin, Gambia, Niger, and Nigeria. Overall, JL 24 was the best yielder and gave the highest pod yields at Yundum and Kadawa, but did not yield so well at the other sites (Table 23). It was closely followed by TS 32-1, which gave the highest yield at Sadore and Maradi and yielded well at all the other sites. ICGV-SM 85045 and ICGV-SM 85038, from the SADCC/ICRISAT program, were ranked next best and yielded reasonably well at all the wetter sites at Yundum, Kadawa, Ina, and Bengou. ICGV 87123 gave good yields at all sites except Yundum, where this line germinated very poorly due to shortage of good quality seed. This line, while slightly later-maturing than JL 24 and TS 32-1, has the advantage of being reasonably dormant for the wetter zones and appears to be

Table 23. Pod yields and yield parameters from the Advanced Groundnut Cultivar Trial, West Africa, rainy season 1989[1].

	Pod yields[2] (t ha⁻¹)							Maradi, Niger		
Entry	Yundum, Gambia	Kadawa, Nigeria	Ina, Benin	Sadoré, Niger	Bengou, Niger	Maradi, Niger	Mean	Days to maturity	Shelling (%)	100-seed mass(g)
ICGV-SM 85045	1.37 (6)[2]	1.47 (5)	3.43 (1)	1.36(14)	2.64 (2)	4.55 (8)	2.47	103	74	46
ICGV-SM 85038	1.47 (3)	1.82 (2)	3.18 (3)	1.42(12)	2.40 (8)	4.43(10)	2.45	112	70	69
ICGV 87141 (ICGS 76)	1.19(11)	1.37 (9)	2.84 (9)	1.62 (6)	2.38 (9)	5.05 (2)	2.41	109	70	57
ICGV 86072	1.13(14)	1.40 (8)	3.14 (4)	1.73 (3)	2.12(13)	4.92 (4)	2.41	106	72	58
ICGV 87123 ICGS 11)	0.38(16)	1.44 (6)	3.19 (2)	1.66 (4)	2.72 (1)	4.93 (3)	2.39	106	73	49
ICGV-SM 85005	1.30 (9)	0.75(14)	3.09 (5)	1.76 (2)	2.52 (4)	4.75 (6)	2.36	109	71	57
ICGV-SM 83708	1.44 (4)	1.63 (3)	2.89 (8)	1.48(10)	2.10(14)	4.08(14)	2.27	123	68	60
ICGV 86028	1.32 (8)	0.73(15)	2.62(11)	1.45(11)	2.25(12)	4.61 (7)	2.16	106	69	58
ICGV 86063	1.16(13)	1.33(10)	2.28(16)	1.35(15)	2.43 (7)	4.29(11)	2.14	99	77	39
ICGV 86047	1.18(12)	1.04(13)	2.35(15)	1.56 (8)	1.96(16)	4.21(13)	2.05	101	74	44
Controls										
JL 24	1.82 (1)	2.18 (1)	3.05 (6)	1.38(13)	2.47 (6)	4.80 (5)	2.62	99	77	55
TS 32-1	1.49 (2)	1.52 (4)	2.99 (7)	1.82 (1)	2.59 (3)	5.25 (1)	2.61	99	76	51
WB-9	1.37 (7)	1.43 (7)	2.35(14)	1.52 (9)	2.36(10)	4.49 (9)	2.25	99	74	40
J 11	1.40 (5)	1.08(12)	2.38(13)	1.64 (5)	2.32(11)	4.26(12)	2.18	99	74	40
55-437	1.24(10)	1.23(11)	2.42(12)	1.61 (7)	2.47 (5)	3.96(15)	2.16	98	77	37
28-206	1.03(15)	0.47(16)	2.70(10)	1.19(16)	2.03(15)	3.60(16)	1.84	123	64	43
SE	±0.094	±0.117	±0.122	±0.101	±0.143	±0.167	±0.052	±1.5	±1.4	±2.0
Trial mean (16 entries)	1.27	1.30	2.81	1.54	2.36	4.51	2.30	106	72	50
CV (%)	17	20	10	15	14	8		3	4	9
Efficiency over RBD[3] (%)	107	132	146	141	127	113		105	<100	<100

1. 4 × 4 balanced lattice square with 5 replications, plot size 8 m².
2. Numbers in parentheses are rankings of the entries.
3. RBD = Randomized-block design.

one of the most widely adaptable ICRISAT breeding lines.

Intermediate Groundnut Cultivar Trial

This trial was made up from breeding and germplasm lines that had yielded well in previous seasons. We grew the trial at three sites in Niger during the 1989 rainy season. ICGV 86015 gave the highest pod yield overall and was ranked in the top 12 at all three sites (Table 24). ICG 8361 (Lonyun 6101 from Thailand) ranked second overall, followed by ICGVs 86529, 87123, 86756, ICGV-SM 86725 (a Virginia line from the SADCC/ICRISAT program) and TS 32-1 ranked the best control.

Germplasm Evaluation Trials

We grew 45 groundnut lines selected in 1988 from observation plots of recent germplasm collections made in Chad and South America in a trial at ISC, Sadore and the INRAN station at Bengou, with four control cultivars. One of the lines collected in Chad, PS 87-500, gave a significantly higher pod yield (2.69 ± 0.177 t ha^{-1}) than the best control cultivar, 28-206 (2.00±0.177 t ha^{-1}), at Sadore and its yield was not significantly different from the best control cultivar, TS 32-1, at Bengou.

Groundnut Cultivar Trials from Other ICRISAT Programs

We grew three preliminary confectionery trials from ICRISAT Center with a total of 132 test lines at Bengou in the 1989 rainy season. None of the test lines with acceptable shelling percentage and well-filled grain outyielded the best control, TS 32-1 (a variety intended for oil extraction, but is also used locally for confectionery purposes). However, some of the test lines had yields comparable with that of TS 32-1 and much bolder grain, notably ICGVs 88390, 88396, 88434, and 88435 with 100-seed masses of 87±4.7, 64±4.7, 64±4.7, and 63±4.7 g, when compared with 40±4.7 g for TS 32-1.

In the SADCC/ICRISAT regional Virginia cultivar trial, the line ICGV-SM 87707 gave a significantly higher pod yield (2.96 ± 0.114 t ha^{-1}) than all other lines except ICGV-SM 85764. Four other lines, ICGV-SM 85764 (2.66±0.114 t ha^{-1}), ICGV-SM 83708 (2.45 ± 0.114 t ha^{-1}), ICGV-SM 86725 (2.40 ± 0.114 t ha^{-1}) and ICGM 336 (2.37±0.114 t ha^{-1}) also significantly outyielded the best control, 28-206, (2.01±0.114 t ha^{-1}).

Partitioning Response to Humidity

In collaboration with the Departement de recherche agronomique of Benin, we compared the growth and development of four genotypes for their response to the humidity of environments prevailing at Ina (Benin) and at Sadore (Niger). The dwarf line MH2 did not have the rank stem growth that normal genotypes show at Ina. This dwarf attribute should provide higher yield potentials (through high partitioning) for groundnuts grown in the humid regions of the world.

Utilization of Wild *Arachis* Species

Fertile progenies from crosses of *A. hypogaea* with *A.* sp 30085 and of *A. hypogaea* with *A. chacoense,* both wild species resistant to ELS, were selfed or backcrossed to advanced breeding lines adapted to conditions in Malawi. Progenies have been sent to the ICRISAT Regional Center, Malawi, for screening for ELS.

In order to transfer genes from species in section Erectoides, hybrids have been produced with diploid species in section Arachis using in vitro culture to rescue embryos that would have aborted if left on the plant. Hybrids of *A. batizocoi* with both *A.* sp 30003 and *A.* sp 30126 have produced flowers, but univalents are observed at meiosis and their pollen fertility is very low. A tetraploid plant of *A. batizocoi x A.* sp 30003 has been produced. Resistance of these hybrids

Table 24. Pod yields of selected lines in the Intermediate Groundnut Cultivar Trial, Niger, rainy season 1989[1].

	Pod yields ($t\ ha^{-1}$)				Number of sites[2]		Maradi		
Entry	Bengou	Sadoré	Maradi	Mean	Top 20%	Bottom 20%	Days to maturity	Shelling (%)	100-seed mass (g)
ICGV 86015	2.59(12)[3]	1.59 (9)	5.51 (1)	3.23	2	0	109	72	50
ICG 8361	2.37(25)	1.43(22)	5.20 (2)	3.00	1	0	110	74	49
ICGV 86529	2.47(19)	1.69 (1)	4.76 (4)	2.97	2	0	109	67	54
ICGV 87123 (ICGS 11)	2.55(15)	1.59 (6)	4.72 (5)	2.95	2	0	108	73	46
ICGV 86756	2.44(20)	1.64 (3)	4.71 (6)	2.93	2	0	108	72	45
ICGV-SM 86725	2.61(10)	1.59 (8)	4.57 (9)	2.92	3	0	113	72	60
Controls									
TS 32-1	2.58(13)	1.46(15)	4.68 (7)	2.91	1	0	98	76	48
55-437	2.10(41)	1.50(13)	3.89(30)	2.50	0	1	99	72	35
28-206	2.06(45)	1.43(21)	3.29(44)	2.26	0	2	121	69	39
SE	±0.161	±0.107	±0.223	±0.102			±2.4	±2.5	±3.1
Trial mean (49 entries)	2.32	1.28	3.92	2.56			110	68	49
CV (%)	12	14	10				4	6	11
Efficiency over RBD (%)[4]		142	205	<100			112	106	<100

1. 7 × 7 lattice with three replications, plot size 8 m^2.
2. Number of sites where entries ranked in top 20% and bottom 20%.
3. Numbers in parentheses are rankings of the entries.
4. RBD = Randomized-block design.

to ELS has been confirmed by detached leaf screening technique.

Many intersectional hybrids have been produced between species in section Erectoides, and fertility of the hybrids varies between species combinations. Hybrids have been treated with colchicine to produce tetraploids that will facilitate gene transfer to *A. hypogaea.*

Oil Quality

We determined various oil quality characteristics of cultivars ICGSs 1, 5, 11, 21, and 44, and compared them with the controls Kadiri 3 and J 11. The percentage of free fatty acids, expressed as acid value, is a measure of the extent of hydrolysis that has occurred in a fat. Acid values in these cultivars, including the controls, ranged from 0.10 to 0.15% (SE ±0.007) and were well within the reported range of 0.02-0.6% for groundnut oil. The saponification value (mg KOH g^{-1} of oil) is inversely proportional to the mean molecular weight of the glycerides of fat. The saponification values ranged between 175 and 184 (SE ±1.8) in the five cultivars and it was 173 for Kadiri 3, and 185 for J 11. These values were lower than the range of 188-195 reported for groundnut oil. This indicated that the mean molecular weight of the glycerides in the cultivars in this study was slightly higher than the reported values.

Groundnut oil as an unsaturated lipid is susceptible to oxidation. This was also indicated by the relatively high iodine values (g iodine absorbed $[100\ g]^{-1}$ oil) in the five cultivars, which ranged from 91 to 99 (SE ± 1.2). They were within the reported range of 82-106. The controls Kadiri 3 and J 11 had the lowest iodine value (91), indicating a relatively low concentration of unsaturated fatty acids.

Oxidative rancidity in oil can be measured by the peroxide value. It is important, especially in an oil having high concentrations of unsaturated fatty acids like oleic and linoleic acids, as they are particularly susceptible to oxidation. The peroxide values of the five cultivars ranged from 6.5 to 9.4 meq kg^{-1} (SE ± 0.59) oil while it was 6.1 meq kg^{-1} for Kadiri 3 and 4.4 meq kg^{-1} for J 11. These values were below the maximum recommended value of 10 meq kg^{1} of oil.

Fatty Acid Composition

The fatty acid composition of these cultivars and that of the controls was somewhat variable for the oleic acid (37.1-44.7%) and linoleic acid

Table 25. Fatty acid composition and oleic/linoleic (O/L) ratio of hexane extracts of groundnut seeds, ICRISAT Center, rainy season 1988[1].

Fatty acid (%)	ICGS 1	ICGS 5	ICGV 87123 (ICGS 11)	ICGS 21	ICGV 87128 (ICGS 44)	Controls Kadiri 3	Controls J 11	SE
Palmitic (16:0)	12.8	12.5	12.5	11.6	12.5	14.2	12.4	±0.30
Stearic (18:0)	2.2	2.2	2.1	2.7	2.2	2.3	5.6	±0.48
Oleic (18:1)	37.1	37.2	37.2	44.7	37.5	37.1	40.4	±1.09
Linoleic (18:2)	39.0	39.2	39.4	33.7	39.0	38.7	32.5	±1.11
Arachidic (20:0)	1.4	1.4	1.4	1.4	1.4	1.4	2.4	±0.14
Eicosenoic (20:1)	1.4	1.4	1.4	1.3	1.4	1.4	0.9	±0.08
Behenic (22:0)	3.2	3.3	3.2	2.9	3.3	3.2	4.0	±0.12
Lignoceric (24:0)	1.8	1.8	1.7	1.3	1.8	1.7	1.4	±0.08
O/L ratio	0.96	0.95	0.95	1.35	0.96	0.96	1.25	±0.064

1. Means of three replications.

(32.5-39.4%) concentrations (Table 25). It may be noted that the concentrations of oleic and linoleic acids were the lowest in controls Kadiri 3 and J 11, similar to the data obtained on the iodine values of these cultivars. The 0/ L ratio is important in influencing the stability or shelf life of an oil. A minimum ratio of 1.6 has been recommended for groundnut but none of the cultivars nor the two controls attained this minimum. ICGS 21 had the maximum O/L ratio of 1.35 which was significantly higher than the remaining cultivars (*P* <0.05 based on Duncans Multiple Range Test). Apart from oleic and linoleic acids, the other predominant fatty acid in groundnut is palmitic acid and these three together accounted for more than 85% (range 85.2-90.1%) of total fatty acids. Stearic acid was unusually high in J 11, while palmitic acid was the highest in Kadiri 3, among the seven cultivars. The concentration of fatty acids having 20 *or more* carbon *atoms* (shown within parentheses in Table 25) was generally low in all the groundnut cultivars and did not show appreciable variation except in the case of J 11.

Minerals and Trace Elements

Although groundnut is usually associated with the supply of oil and protein in the human diet, it is also a reasonably good source of minerals and trace elements, especially phosphorus and magnesium (Table 26). It is noteworthy that, among the seven cultivars, Kadiri 3 contained the highest amount of phosphorus, potassium, zinc, and copper.

Cooperative Activities

Cooperation with AICORPO and Other Programs in India

Yield Trials

At ICRISAT *Center,* we conducted four AICORPO trials composed of 47 entries during the 1988/89 postrainy season and seven trials of 106 entries during the 1989 rainy season. The

Table 26. Minerals and trace element composition of groundnut seeds (mg [100 g]$^{-1}$), ICRISAT Center, rainy season 1988[1].

Cultivar	Phosphorus	Potassium	Calcium	Magnesium	Zinc	Copper	Iron	Manganese
ICGS 1	345	512	62	197	3.16	0.77	4.30	1.12
ICGS 5	352	530	53	211	3.02	0.77	4.72	1.23
ICGV 87123 (ICGS 11)	357	525	74	202	3.06	0.80	3.83	1.11
ICGS 21	366	514	52	201	3.19	0.80	4.37	1.26
ICGV 87128 (ICGV 44)	345	513	63	195	2.86	0.70	5.05	1.31
Controls								
Kadiri 3	550	600	58	189	3.52	0.91	4.10	1.26
J 11	370	538	67	206	3.20	0.77	3.61	1.02
Recommended allowance[2]	800	-	800	350	15	2-3	10	2.5-5
SE	±25.1	±17.9	±2.9	3-4.4	±0.077	±0.024	±0.188	±0.040

1. Means of three replications.
2. Recommended daily dietary allowance for an adult male, National Academy of Sciences, USA (1980).

pod yields in the postrainy-season trials ranged from 1.37±0.13 to 3.23±0.18 t ha^{-1}, whereas the pod yields in the rainy season ranged from 2.40±0.17 to 0.46 ± 0.09 t ha^{-1}.

Currently, we have 29 ICRISAT varieties in the rainy-season AICORPO trials and 11 ICRISAT varieties in the postrainy-season trials. Varieties in the final stages of evaluation during rainy season are ICGV 86015 in the northern zone, and ICGVs 86010, 86005, 86699, 87780, and 87184 in the peninsular zone. Similarly, ICGV 86309 and ICGV 87189 are in the final stages of testing in the 1989/90 postrainy-season trials.

Release and Seed Supply of ICRISAT Material

During the year, the Central Sub-Committee on Release of Varieties of the Government of India formally notified the release of variety ICGV 87141 for rainy-season cultivation in southern Maharashtra, Andhra Pradesh (except north coastal districts), Karnataka, Tamil Nadu, and Kerala.

We supplied large quantities of breeders' seed of eight released and prerelease varieties to nine seed multiplication agencies in India. In addition, 983 samples of advanced breeding lines went to 78 locations, and 286 segregating populations to 17 locations in India.

International Trials and Observation Nurseries

We continued to supply sets of various international trials of both the third and fourth series in 1989. During the year, we supplied a total of 37 sets of trials to 15 countries. These include 10 sets of International Early-maturing Groundnut Varietal Trial (IEGVT), seven sets of International Foliar Diseases Resistance Groundnut Varietal Trial (IFDRGVT), six sets each of International Medium- and Late-maturing Groundnut Varietal Trial (IMLGVT) and International Confectionery Groundnut Varietal Trial (ICGVT), five sets of International Insect Pest Resistance Groundnut Varietal Trial (IIPRGVT), and three sets of (International Drought Resistance Groundnut Varietal Trial (IDRGVT).

In addition, we supplied 723 advanced breeding lines to cooperators in 20 countries and 67 segregating populations to Thailand and Myanmar. During the year we received data for 21 trials.

Early-maturing Groundnut Varietal Trial

Several selected early-maturing lines outyielded the local control varieties in different countries. Among them, ICGV 86015 outyielded the local varieties in Bangladesh, Benin, Gabon, Malawi, Nepal, Philippines, Thailand, and Vietnam. In addition to this variety, ICGVs 86056, 86072, and 86061 were identified as widely adapted early-maturing parental lines for the next cycle of hybridization activity at ICRISAT Center.

Results received during 1989 on the IEGVT from Vietnam indicated that 14 varieties outyielded the local variety, Sen Nighe An. ICGV 86055 was the highest-yielding variety with 2.91 ±0.03 t ha^{-1} of dry pods with a shelling percentage of 78, while Sen Nighe An produced 2.22 t ha^{-1}.

Medium- and Late-maturing Groundnut Varietal Trial

In the Sudan, ICGV 87141 gave the highest pod yield of 5.59±0.47 t ha^{-1} with 74% shelling percentage whereas the local control, Ashford, produced 4.77 t ha^{1} with 61% shelling percentage. ICGV 87141 may soon be released in the Sudan. It has also done well in Niger.

In Myanmar, 15 varieties at Yezin and three varieties at Magwe, outyielded the local controls. ICGV 87129 at Magwe produced the highest pod yield of 1.95 compared to 1.02 ± 0.25 t ha^{-1} of Sinpadetha.

Six varieties in Vietnam recorded pod yields in the range of 3.34 to 3.51±0.13 t ha^{-1}, similar to the highest-yielding local control Tram-Xuyen which produced 3.28 t ha^{-1}. Compared to Tram-Xuyen, ICGV 86008, which recorded the highest pod yield of 3.51 t ha^{-1}, had the highest shelling percentage and 100-seed mass and was tolerant to 'brown spot' disease.

In Malaysia, the pod yields of ICGV 87122 (3.87 t ha^{-1}) and ICGV 87123 (3.01 t ha^{-1}) were better than that of the highest-yielding local control, Bandau Trio (2.36±0.129 t ha^{-1}).

Insect Pest Resistance Groundnut Varietal Trial

In the trial conducted at Agricultural Research Institute, Yezin, Myanmar, ICGV 86029 produced a 60% higher pod yield than the local control, Sinpadetha.

In the Philippines, ICGV 86527 produced a pod yield of 4.29 t ha^{-1} which was higher than that of the highest-yielding control, BPI Pn-6 (3.74 ± 0.480 t ha^{-1}).

Confectionery Groundnut Varietal Trial

In the Sudan, ICGV 86552 had higher pod yield of 6.26 t ha-^{1} than the 5.71±0.44 t ha"^{1} of the highest-yielding control, Kiriz. It had a 100-seed mass similar to that of Kiriz.

ICGV 86028 has done well in Niger for the last 2 years. Several confectionery varieties in Vietnam recorded pod yields in the range of 2.5-3.2 t ha^{-1} and 100-seed masses of 60-80 g.

In Cyprus, ICGV 86553 produced on average, 9.6% more seed than the local control in 5 years of testing and it may be released soon. Several new confectionery varieties in a preliminary confectionery groundnut nursery in Cyprus had high seed yields in the range of 6.04-7.90 t ha^{-1} and 100-seed masses between 102-127 g compared with an average seed yield of 5.07 t ha^{-1} of the local variety with a 100-seed mass of 92 g.

In Malaysia, ICGV 86564 (71 g) and ICGV 86577 (77 g) recorded better 100-seed masses as against 56 g of the local variety, China I, and gave similar seed yields as that of local control.

Foliar Diseases Resistance Groundnut Varietal Trial

At Bengou, Niger, six foliar-disease resistant varieties, ICGVs 87185, 87183, 87156, 87160, 87172, and 87157, outyielded the local susceptible cultivar.

In Vietnam, six foliar-disease resistant varieties gave higher pod yields than the local cultivar, Tram Xuyen. The best entry, ICGV 87158, gave 1.70 t ha^{1} pod yield compared with 1.40 t ha^{-1} of the control.

In the Philippines, ICG (FDRS) 11 has been promoted to the advanced yield trial at the Institute of Plant Breeding. In the Third IFDRGVT, six foliar-disease resistant varieties outyielded the local control, BPI Pn-9. ICGV 87184 gave the highest pod yield of 3.06 t ha^{-1} compared with 1.45±0.40 t ha^{-1} of BPI Pn-9.

At Yezin, Myanmar, eight varieties outyielded the local control variety, 'Small Japanese'. The highest-yielding variety was ICGV 87183 with 223% more pod yield than Small Japanese. At Magwe, another location in Myanmar, 12 varieties outyielded the same local control. The best variety, ICGV 87175, outyielded Small Japanese by 130%.

In the Sudan, ICGV 87182 produced 4.84±0.37 t ha^{-1}, whereas the local control variety, Kiriz, gave 4.4 t ha^{-1} and the shelling percentage was also higher in ICGV 87182 (62.5%) compared with Kiriz (57.5%).

In the Third IFDRGVT conducted in Malaysia, ICGV 87161 gave a pod yield of 3.0+0.13 compared with 1.94 t ha^{-1} for the best control variety, Tainung 1.

Adoption of ICRISAT Material

Pakistan has released 'BARD 699', a composite of two ICRISAT groundnut varieties, ICGV 87187 (ICGS 37) and ICGV 87128, for rainfed cultivation.

The Republic of Korea has released a selection from ICRISAT groundnut variety, ICGV 87127 (ICGS 35) as Jinpungtangkong. It has high oil (52.3%) and protein (23.2%) contents and a low

O/ L ratio (1.07) and has outyielded the two local controls, Saedletangkong by 9% and Yeoungho-tangkong by 23%.

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RESOURCE MANAGEMENT

Contents

The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

RESOURCE MANAGEMENT

For the Resource Management Program (RMP), 1989 was notable for the amount of effort devoted to assessing progress, agreeing on research tactics for the immediate future, and developing a strategy for the next decade.

In November 1989, the Program held a Global In-house Review, which differed from earlier reviews because themes rather than projects were chosen for presentation and discussion. The review was 'global' in the sense that it was attended by staff from the ICRISAT Sahelian Center (ISC), Sadore, Niger, and from Mali, as well as from ICRISAT Center.

Resource Management Program staff have contributed during the year to the Institute's Strategic Plan and especially to sections concerned with the allocation of research resources and priorities for 'environment' research on our mandate crops.

Since the Program was formed in 1985 (by an amalgamation of Farming Systems and Economics Programs), several shifts in emphasis have occurred: from soil-centered research to crop-centered research in which we treat plants as systems adapted to capturing resources from both soil and atmosphere; from the development of technological packages based on empirical evidence to the examination of processes and mechanisms that allow components of technology to be tailored more precisely to specified environments; and from site-specific statistical relations between treatments and yields to computer models simulating the interaction of physiological processes with environmental controls. We have moved away from continuous monitoring of farm and household activity in individual villages to periodic updating of records from benchmark sites to document the adoption or rejection of ICRISAT technology along with changes in productivity and income; from on-site analysis of production constraints to village-level diagnostic surveys and plots; from research whose applications are limited by a narrow disciplinary base to more difficult but more rewarding efforts by interdisciplinary teams; and finally, more dispersion of Resource Management activities to the National Agricultural Research System (NARS) in Asia (as our contribution to the work of the Asian Grain Legumes Network [AGLN]) and to eastern and southern Africa to strengthen existing ICRISAT work on cereals and legumes there. Some of these changes in emphasis are apparent in the report that follows. The impact of others will appear by degrees in the subsequent years.

Characterization of Resources

Climate Change and Implications to Agriculture in Niger

In countries such as Niger, with a predominantly agrarian economy, economic development can be hampered by the impact of climatic constraints on agriculture production. Previous analysis of the Sahelian rainfall shows a sharp contrast before and after 1950. While some analysts predicted a continued downward trend in rainfall, others have argued that there is no indication of a climatic change. Most of these studies were based on monthly rainfall totals.

In assessing the impact of rainfall changes on agriculture production, we recognized that one month is too long to index crop responses accurately. Hence we obtained daily long-term rainfall data from 21 stations in Niger to determine possible changes in the Sahelian rainfall and their effects on crop production.

Five-year moving averages were calculated to determine changes in annual and monthly rainfall patterns. Rainfall timing (dates of onset and end of rains) and growing-season length were computed using a procedure described earlier (ICRISAT Annual Report 1986, p. 264). Statistics, such as the average interval between rainy days, were computed using the RAINSTAT computer program developed at ISC.

Rainfall in Niger is monomodal with over 80% of the annual rainfall in July, August, and September. Moving averages were plotted to establish the relationship between rainfall in these three months and annual rainfall. Data from Filongue (long-term average annual rainfall 460 mm) show a pronounced decline in annual rainfall from mid-fifties to the present (Fig. 1). The August rainfall patterns closely follow annual trends, but the September rainfall increased from 1981 to 1985.

In view of the importance of the August rainfall in crop production, 16 stations in Niger with compatible records for 1944-88 were selected and moving averages plotted. At 12 of the 16 locations, rainfall decreased over the 1965-88 period (Fig. 2). However, at the remaining four locations (Niamey, Dosso, Say, and Gaya) rainfall increased after 1984.

In view of the observed decline in rainfall at 12 stations after 1964, the data were divided into two periods (1945-64 and 1965-88). Variations in the average dates of onset and end of rains and the growing-season length were computed. For selected locations in Niger after 1964, the onset of rains was delayed at all but four sites (Agadez, Birni N'Konni, Gaya, and Tanout). Further, after 1964, the rains stopped sooner at all locations except at Zinder. At most locations the delayed onset and early end of rains after 1964 resulted in a shortening of the growing season from 5 to 20 days.

To quantify this change, total rainfall, number of rainy days, amount of rain per rainy day, and the average duration between rainy days were compared for the two periods.

After 1964, rains became less frequent and the volume of rain per storm decreased. These changes are more pronounced in August when soil moisture is critical for crop growth and production. For pearl millet (*Pennisetum glaucum* [L.] R. Br.) sown in early to mid-June, less rainfall in August will impose stress when the plants flower and their grain initiation begins.

We examined the effect of reduced rainfall in August on pearl millet by plotting initial relative

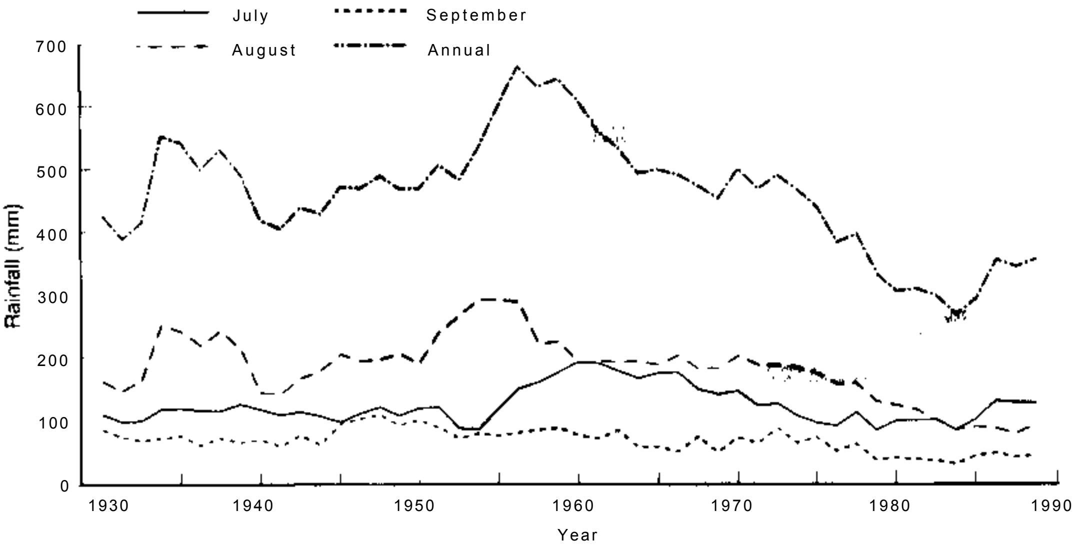


Figure 1. Moving monthly (July, August, September) and annual values of mean rainfall for 1938-90 measured at Filingue, Niger.

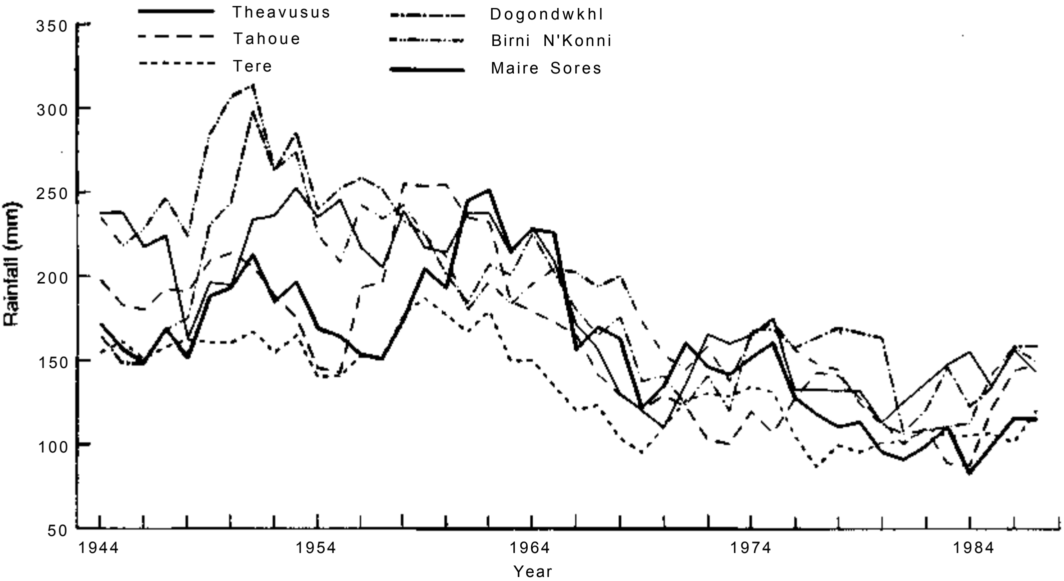


Figure 2. Moving mean August rainfall values measured at Theavusus, Tahoue, Dogondwkhl, Birni N'Konni, and Maire Sores in Niger from 1944 to 1984.

growth rates (RGR) during two seasons with similar rainfall amounts up to the end of July but different rainfall amounts in August. At Dosso, Niger, with 57 mm of rainfall in August 1984 (227 mm long-term mean), the reduced RGR was less than that in 1986 when rainfall was 183 mm (Fig. 3). These results support studies at ICRISAT Center which showed that when stress of 10-20 days continues after flowering, yield is severely reduced. If this stress ends at the time of or before flowering, yield loss is usually small.

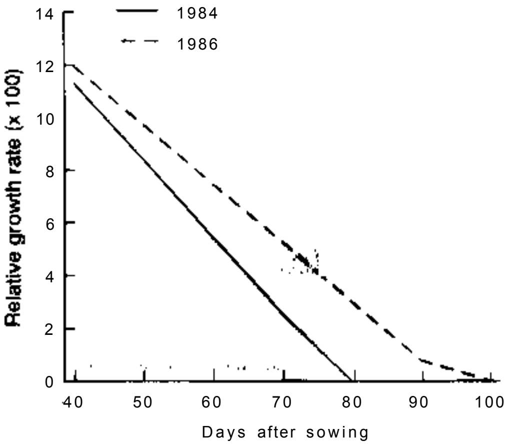


Figure 3. Relationship between relative growth rate (RGR) of pearl millet and days after sowing in 1984 and 1986 at Dosso, Niger.

Bare Soil and Fallow Bushland Net Radiation and Evaporation

Widespread degradation of savannah vegetation in some areas of semi-arid Africa has now reached a point where large areas of bare soil appear between vegetation. The proportion of bare soil is a measure of the degree of degradation. Models of the Sahel indicate that removing vegetation may modify the climate such that rainfall would get reduced. However, models suffer from a lack of data for calibration; and more accurate information is needed on the energy and water balance of vegetated and bare soil surfaces.

In collaboration with the Institute of Hydrology, UK, we conducted experiments on fallow bushland and on soil containing pearl millet stubble. The fallow bushland consisted of a mixed community of leguminous and grass species, woody shrubs, and occasional trees. Evaporation was measured using a 'Hydra' (version MK2). Net radiation was measured using dome net radiometers. Changes in reflection from a bare sandy soil were measured every hour, using albedometers, over three days in the dry season (May) after initial soil saturation.

When the soil surface was dry, net radiation over the bushland was about 20% more than that over bare soil. Immediately following rainfall of 39 mm on one occasion, net radiation over the bushland was found to be only 12% more than that over dry soil (Fig. 4).

Total daily actual and potential evaporations for a sequence of 6 days indicate a greater potential evaporation for the bushland because of its higher net radiation (Fig. 5). During the first three days, actual evaporation from both soil and bushland decreased despite increasing potential evaporation.

Following rain, evaporation from the soil increased even though potential evaporation decreased. The ratio of actual to potential evaporation was very similar for both sites on all days, except for the one immediately following a rainstorm.

Differences in net radiation can result from changes in albedo and/or surface temperature. Over fully wetted bare soil, the albedo was 0.24 (Fig. 6), rising over a 3-day period to about 0.38 as the soil dried. The albedo of savannah vegetation in northern Nigeria has been reported approximately as 0.19. These values could explain differences in net radiation observed in this study. Further, daytime surface temperatures of bare soil are expected to be greater than those of the bushland.

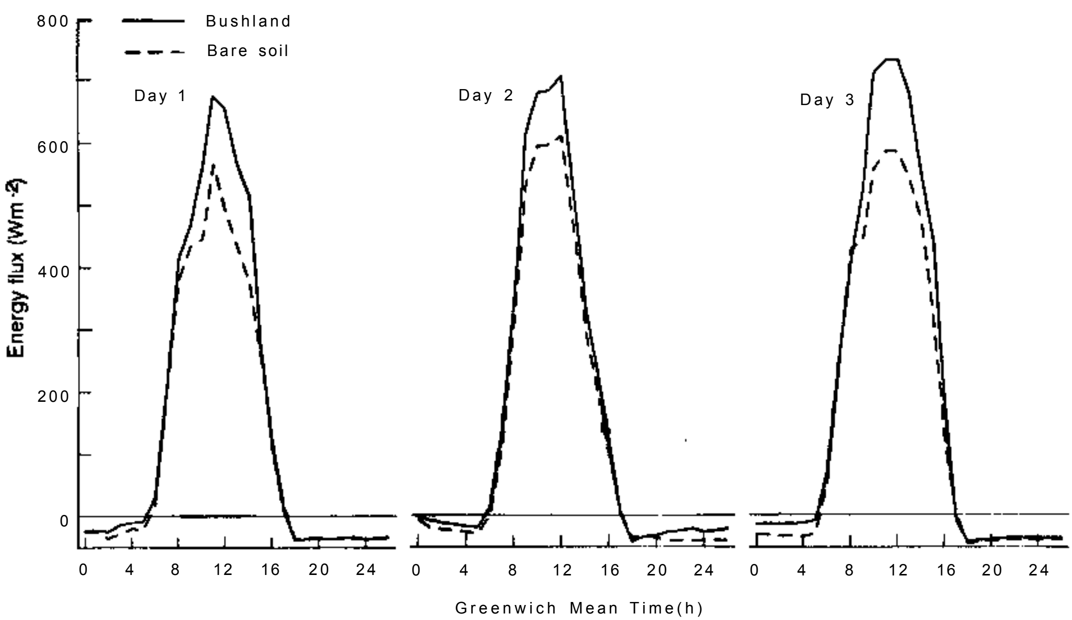


Figure 4. Comparison of net radiation measured over fallow bushland and bare soil on three days in 1989 at ISC, Sadore, Niger.

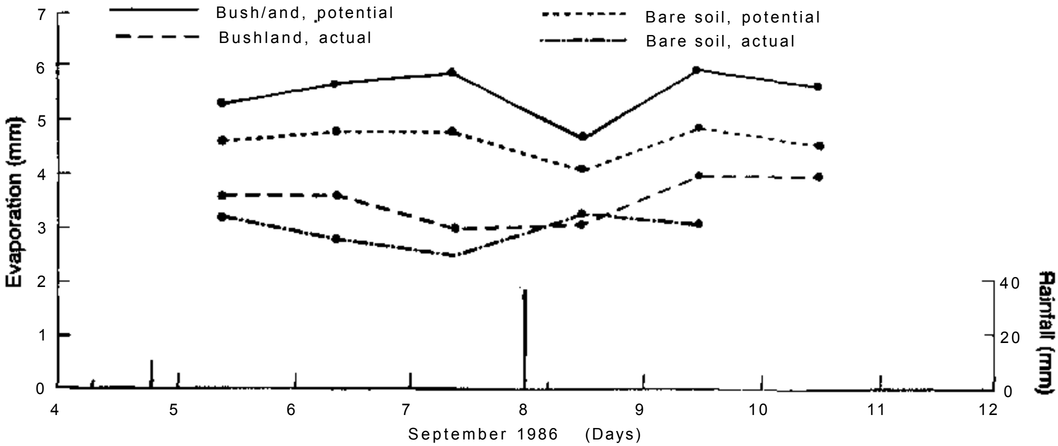


Figure 5. Actual and potential evaporation from fallow bushland and bare soil before and after rainfall in September 1986 at ISC, Sadore, Niger.

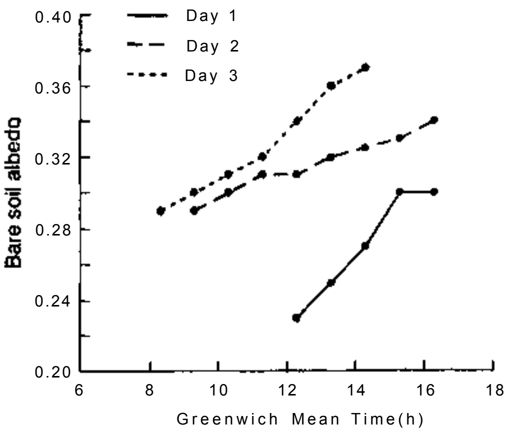


Figure 6. Change in bare soil albedo measured in 1989 for 3 days following an initial soil wetting and soil volumetric moisture content (VMC) in the top 25 and 15 mm soil layers at ISC, Sadore, Niger.

Crop Rotations in Dryland Farming Systems in the SAT

Based on field-specific cropping histories covering 10 years from 1975-1985, we analyzed farmers' crop rotation practices in three agroclimatic regions of India's semi-arid tropics (SAT). Farmers in the study areas are fully aware of the advantages of crop rotations and try to practice them (Table 1). Agronomic considerations, which guide them in crop rotation decisions include maintenance of soil fertility, control of soilborne diseases, beneficial residual effects of certain crops, and protection of soil by periodic fallowing. Balancing food and cash supplies and protecting subsistence needs over time are other primary considerations.

A strict sequencing of crop rotations to satisfy these requirements is normally not possible. For instance, farmers in the Sholapur region believe in the beneficial effects of a cereal-legume rotation but succeed in putting that belief into practice only in 1 out of 4 years (Table 1).

Differences in the amount and distribution of rainfall, especially during sowing, prevent adoption of a strict rotation. More recently, a number of other factors have emerged that militate against traditional land-extensive crop rotations. Increasing land pressure makes it more difficult to rest or fallow land before cropping. Increased exposure to market forces has induced farmers to pay greater attention to price signals in their cropping decisions than to crop rotation require-

Table 1. Percentage of farmers following cropping patterns in three agroclimatic zones of India.

Particulars	Farmers (%)		
	Agroclimatic zone		
	Mahboobnagar	Sholapur	Akola
Cropping events[1] (number)	753	973	1016
Proportion of cropping events where:			
Cereals follow			
Cereals (%)	33	58	11
Legumes (%)	3	14	4
Oilseeds/cotton (%)	23	2	24
Legumes follow			
Cereals (%)	1	12	2
Legumes (%)	1	3	3
Oilseeds/cotton (%)	1	1	4
Oilseeds/cotton follow			
Cereals (%)	9	1	18
Legumes (%)	25	2	23
Oilseeds/cotton (%)	2	1	3

1. The events include only cases where crops were sown as sole crops and/ or base crops of the intercropping systems.

merits. Occasional institutional interventions, such as administered prices, levies imposed on producers, and monopoly procurement of produce by the state, also induce frequent changes in cropping decisions, which are often inconsistent with crop rotation needs.

In brief, cropping decisions are a dynamic mixture of deliberate efforts to rotate crops and adjustments forced by weather and other circumstances. Technological improvements in crop rotations therefore need to be sensitive to the above factors in order to maximize their adoption potential.

Village-level Studies, Mali

Understanding production behavior and resource utilization patterns of smallholder farmers in West African Semi-Arid Tropics (WASAT) is central to developing technologies to suit their production environment. We started a village-level study (VLS) program in the West African Sorghum Improvement Program (WASIP) (Mali) designed to: (1) characterize production patterns in Mali and identify the productivities of resources in different cropping systems practiced by farmers; and (2) diagnose constraints to increased productivity with farmers' resource endowments, technical feasibility under on-farm stress conditions, and economic profitability under farmers' management. A total of four villages, one located in the sudano-sahelian zone, two in the Sudanian zone, and one in the northern Guinea zone, was selected. Eighty farmers (20 per village stratified by level of animal traction [AT] use [manual tillage and oxen tillage]) were selected for monitoring.

Cropping intensities were determined across zones to understand changes in production patterns. In the Sudanian zone, cropping intensity in relation to total cultivated areas was 50% for sorghum *(Sorghum bicolor* [L.] Moench), 24% for pearl millet, 5% for rice *(Oryza sativa* L.), and 1% for maize *(Zea mays* L.). Rice and maize, however, gain importance with the transition into the northern Guinea zone, where rice accounts for 26% and maize for 6% of cultivated area. Sorghum intensities were also high in the northern Guinea zone. However, pearl millet cropping intensity diminishes from 24% of total cultivated area in the Sudanian zone to 4% in the northern Guinea zone. Although the area sown to maize increased in the northern Guinea zone, maize remains a minor crop, contrary to the widely held view that it is displacing sorghum in the transition and northern Guinea zones. While major production gains have been made (maize yields are 2-3 times greater than sorghum yields) sorghum remains the major crop for agricultural households in both the Sudanian and the northern Guinea zones. The reasons for this are: (1)

the local taste preference for sorghum '*to',* and (2) better relative adaptation of sorghum to water stress and low soil fertility. However, because maize is early maturing, it is preferred, to cover food needs in the 'hungry season' before the harvests of sorghum and millet.

Differences in soil fertility by field location determined yield on farmers' fields (Table 2). Maize sole crop yield averaged 2.08 t ha^{-1} on compound fields, compared with 1.12 t ha^{-1} on bush fields. Sorghum yields in sorghum/cowpea *{Vigna unguiculata* [L.] Walp.) intercropping systems (the most prevalent intercrop in the study zone) averaged 1.26 t ha^{-1} on compound fields, compared with 0.74 t ha^{-1} on bush fields.

Lower yields on the bush fields have implications on the development and introduction of technical interventions. Existing compound fields are more fertile but highly fragmented, due to increasing human population and the breakdown of large households into nuclear family units. Therefore most cereal cultivation occurs on less fertile bush fields. To avoid increasing degradation and soil fertility loss in the bush fields, and to ensure higher productivities on these fields for the enhancement of household food security, measures are to be taken to improve the fertility of bush fields. Such measures would include: either (1) more use of manure or organic matter reincorporation, or (2) investment in soil and water conservation. These measures are central to sustaining cereal productivities on a long-term basis on the already infertile bushlands.

Table 2. Average cereal yields (t ha^{-1}) under alternative cropping systems by field spatial location and toposequence position, WASIP/Mali Economics study villages, 1989 rainy season[1].

	Field location		
	Compound land (plateau)	Bushland (plateau)	Bushland (valley)
Cropping systems	Average cereal yields (t ha^{-1})		
Maize			
Sole crop	2.80 (0.83)[2]	1.12 (0.82)	-
Maize/sorghum	1.90 (0.58)	-	-
Sorghum			
Sorghum/ cowpeas	1.26 (0.78)	0.74 (0.47)	-
Pearl millet			
Sole crop	-	0.64 (0.39)	0.51 (0.28)
Pearl millet/cowpeas	1.05 (0.48)	-	-

1. Averages are across three villages, Nankilabougou, Kayo, and Ngalamadibi. Compound fields are located 0-800 m from the village and bush fields are located 800 m-4000 m from the village.
2. Values in parentheses are standard deviations of corresponding yields. Yields vary widely between individual farmers, because of differential soil fertility and crop management practices.
3. - = Data not measured.

Measurement and Management of Constraints

Residual Effects of Legumes in Crop Rotations on Alfisols

Previous research at ICRISAT Center shows good residual effects of legumes on subsequent cereal yields. In an 8-year experiment on a loamy Alfisol, soil nitrogen (N) status was maintained at 0.049% (Annual Report 1987, p. 318) and sorghum yields at 2.6 t ha^{-1} by the input of N from legumes in a 2-year crop rotation of pearl millet-groundnut (*Arachis hypogaea* L.) alternating with sorghum-pigeonpea *(Cajanus cajan* [L.] Millsp.). On a sandy loam Alfisol, the yield of an unfertilized sorghum crop was increased from 1.1 to 2.7 t ha^{-1} by rotating with sole pigeonpea instead of continuous sorghum crops. Legume input was sufficient to ensure that the soil could provide most of the N requirement to sorghum; fertilizer N increased yields to 2.9 and 3.4 t ha^{-1} for these two treatments (Annual Report 1983, p. 262). Encouraged by these results, we initiated experiments in 1985 to assess the beneficial residual effects of legumes on a light-textured sandy Alfisol.

In one study, residual effects of pigeonpea and pearl millet on a subsequent sorghum crop (Figs. 7 and 8), and residual effects of groundnut and sorghum on a subsequent pearl millet crop (Figs. 9 and 10) were compared. Data from three years indicate that sorghum benefited from a preceding pigeonpea crop only in 1988 (Figs. 7 and 8); but pearl millet consistently benefited from the preceding groundnut crops (Figs. 9 and 10). The residual effects shown by increased pearl millet yields were substantial in 1986 and 1987, when seasonal rainfalls were normal (418 and 369 mm) and well distributed. We attribute these effects to increased available N because pearl millet yield-response curves converge with increasing levels of applied N. However, when there was excessive seasonal rainfall (736 mm in 1988), the benefits

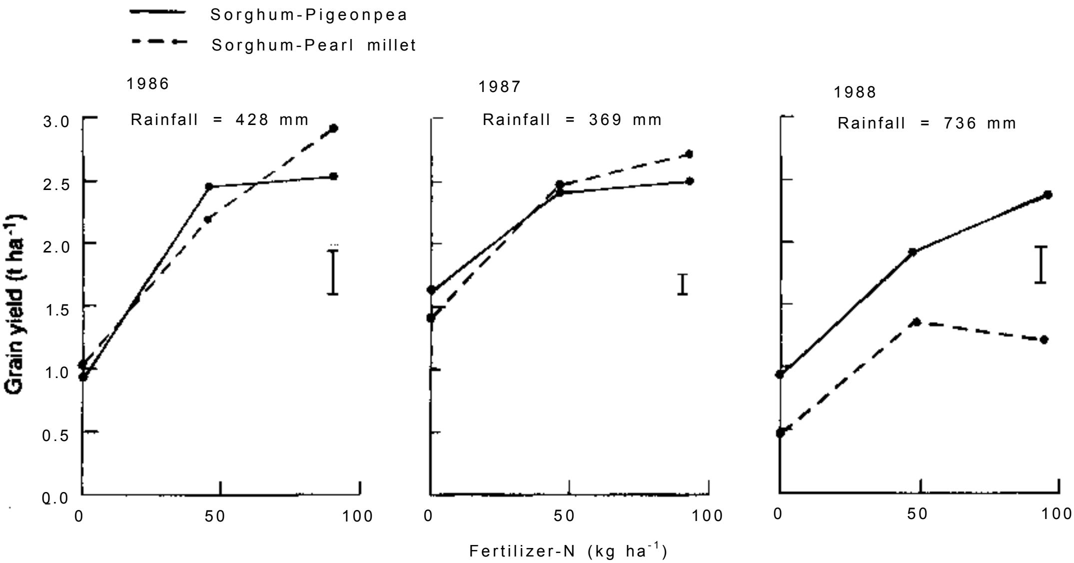


Figure 7. Effect of pigeonpea and pearl millet on the response of sorghum grain yield to fertilizer-N during the 1986, 1987, and 1988 rainy seasons at ICRISAT Center.

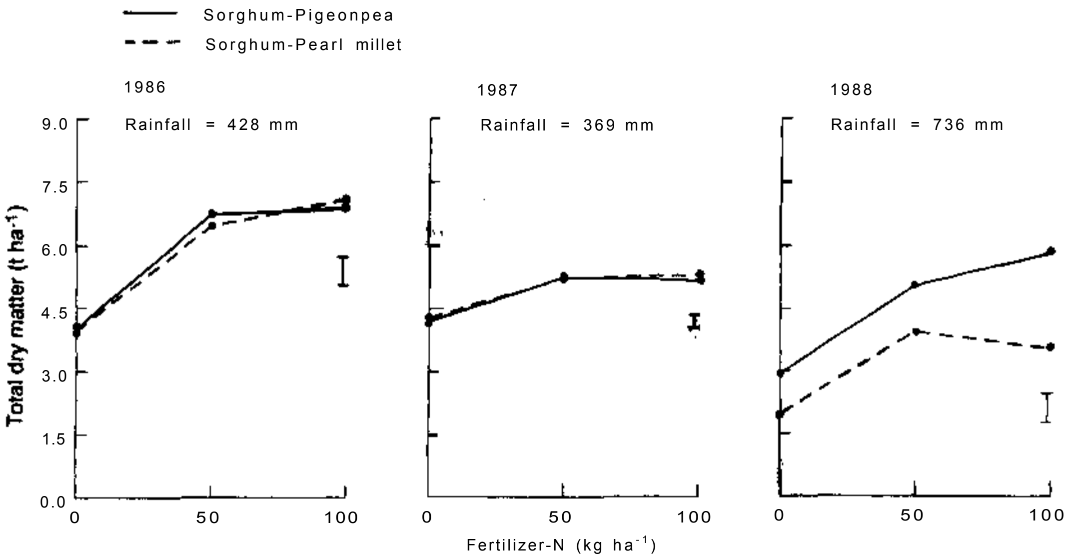


Figure 8. Effect of pigeonpea and pearl millet on the response of sorghum total dry matter production to fertilizer-N during the 1986, 1987, and 1988 rainy seasons at ICRISAT Center.

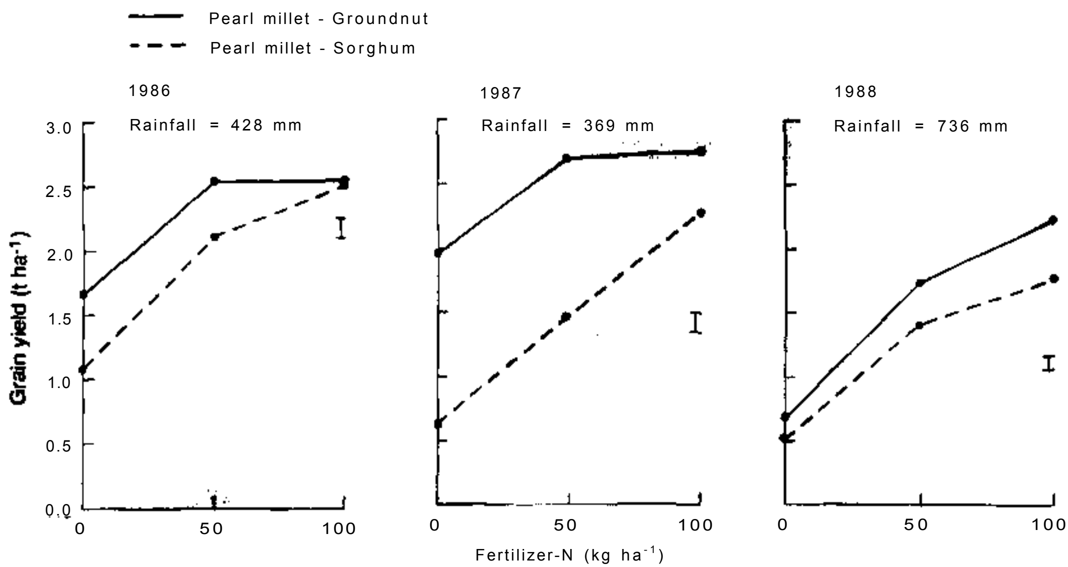


Figure 9. Effect of groundnut and sorghum on the response of pearl millet grain yield to fertilizer-N during the 1986, 1987, and 1988 rainy seasons at ICRISAT center.

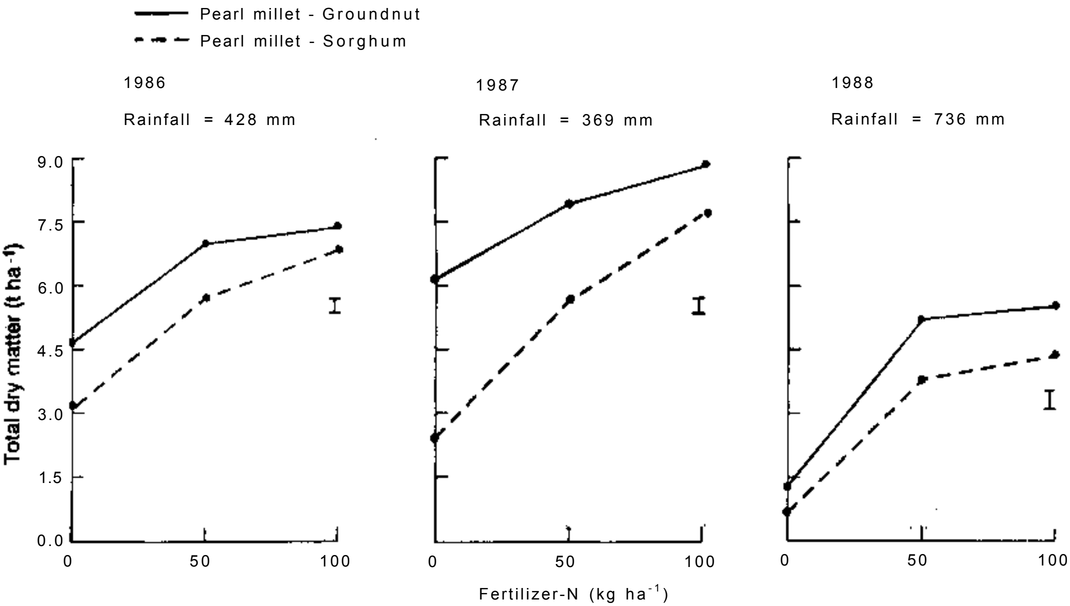


Figure 10. Effect of groundnut and sorghum on the response of pearl millet total dry matter production to fertilizer-N during the 1986, 1987, and 1988 rainy seasons at ICRISAT Center.

of legume N were small and the shape of the response curves was different from that of the two previous years. From this, we suspect that there was an appreciable leaching of nitrates beyond the root zone.

The second experiment was part of a collaborative project with the Central Research Institute for Dryland Agriculture (CRIDA), which conducted a similar experiment on its Hayatnagar Farm in Andhra Pradesh. Effects of sole sorghum, sorghum/pigeonpea, and groundnut/pigeonpea intercrops on a subsequent castor *(Ricinus communis* L.) crop were studied for 4 years (these crop rotations are typical for sandy Alfisols in southern India). Results for 3 years showed that the inclusion of legumes as preceding crops (sorghum/pigeonpea or groundnut/pigeonpea intercrops) reduced castor pod and stalk yields (Table 3), presumably because of root-rot diseases. On these residual-legume treatments, plant populations were lower and the incidence of root rot higher.

Table 3. Castor pod and stalk yield affected by previous cropping systems and years at ICRISAT Center.

	Castor yield ($t\ ha^{-1}$)	
Cropping systems and years	Pod	Stalk
Cropping system before castor:		
Sorghum	0.75	0.83
Sorghum/ pigeonpea	0.46	0.48
Groundnut/ pigeonpea	0.43	0.53
SE	±0.057	±0.071
Year in which castor was cropped:		
1986	0.47	0.49
1988	0.63	0.73
SE	±0.031	±0.047
CV (%)	51.0	56.8

Table 4. Pearl millet grain and stalk yield following different cropping systems at ICRISAT Center, rainy season 1989.

	Pearl millet yield (t ha^{-1})	
Cropping system	Grain	Stalk
Sorghum	0.68	1.00
Sorghum/ pigeonpea	1.00	1.22
Groundnut/ pigeonpea	1.24	1.52
SE	±0.056	±0.091
CV (%)	9.9	12.7

In the fifth year we replaced castor with pearl millet. In contrast to castor, pearl millet yields increased when preceded by a legume (Table 4). We attribute these results to the type of root systems (tap root vs fibrous root) as well as the growth pattern (slow vs fast) of castor and pearl millet. Pearl millet's fast-growing root system could take up nitrates faster (thus minimizing leaching losses) than the slower-growing and less-extensive castor root system.

In conclusion, these experiments showed that legume residual effects are variable on Alfisols: two important features contributing to the variability are soil texture and the type of beneficiary crop. Maintaining or improving N availability to nonlegumes in rainfed Alfisols through the use of legumes is proven to be possible.

Soil Management of a Shallow Alfisol

Management of Alfisols by manipulating tillage depth, by applying organic amendments or by maintaining pasture leas conserves water and soil in such ways that yields are increased. High runoff rates have been measured under traditional management systems, and several hydraulic throttles occur in the profile: surface crusts, the argillic B horizon, and the cemented, gravelly *morrum* layer. Poor soil physical characteristics include hard setting, high bulk density, and the cemented *morrum,* and these may limit crop establishment and root growth. However, the mechanisms functioning on a field scale and the impact of management on these mechanisms have not been quantified. Intensive tillage, often recommended for Alfisols, may degrade soil chemical and physical properties. In 1988, ICRISAT Center started an experiment to compare tillage options with alternate soil managements. Soil amendments were used to protect the soil surface and to encourage biological activity in the soil. Perennial crops were planted to provide root penetration into the *morrum* layer and to improve soil structure, at depth, in the profile.

Responses to tillage (nil, tynes at 10 cm or 20 cm depth) and amendment (nil, 15 t ha^{-1} farmyard manure [FYM], 5 t ha^{-1} rice straw) were compared in a factorial experiment. In addition, six combinations of perennial crops (perennial pigeonpea, *Stylosanthes hamata, Cenchrus ciliaris)* provided a range of surface protection and dry matter production. The tillage-plus-amendment treatments were cropped annually while perennial crops were maintained. There were three replicated plots of 5 * 28 m.

Measurements include runoff (by tipping buckets logged every minute), soil loss (bed load and suspended sediment), soil structure and stability, soil strength and water content, bulk density and porosity, soil hydraulic properties, projected cover (straw and crop), nutrient and sand distribution in the 0-10 cm depth, and soil fauna (earthworms, termites, macro and micro arthropods, fungi, and bacteria). Runoff records are used to calculate infiltration parameters.

In 1988, pearl millet was not sown till 27 July because of delays in installing equipment. In 1989, tilled plots received a shallow tillage followed by tillage to the treatment depth a week later. Sowing of sorghum (19 July) followed one week later.

Runoff records from 1988-89 indicate large treatment responses among the tillage plus amendment treatments (Table 5). Data from the perennial crop treatments are not listed because this was the establishment period. There was a significant effect of amendment throughout the season because of decreased runoff from plots with rice straw. Farmyard manure had little or

Table 5. Runoff (mm) during the cropping season (5 Aug-5 Oct) in 1988 and during the period before treatments were reimposed (1 Mar-29 Jun) in 1989, in response to tillage and amendments[1].

	Runoff (mm)					
	5 Aug-5 Oct 1988			1 Mar-29 June 1989		
Treatment	Bare	FYM[2]	Straw	Bare	FYM[2]	Straw
Zero tillage	108	95	48	53	48	26
10 cm tillage	104	99	56	67	57	30
20 cm tillage	91	75	58	34	51	33
SE		±10.5			±5.1	
CV (%)		17			20	

1. Associated rainfall was 330 mm in 1988 and 226 mm in 1989.
2. Farmyard manure.

no effect. A significant response to tillage was measured at the first three runoff events after the treatments were imposed (5-17 August, 1988). During this period, tillage at 20 cm produced the least runoff and bare treatments the most. Initial tillage effects were large but diminished rapidly and this decline was not affected by the amendments. Seasonal effects of tillage were not significant (Table 5). Reduced runoff following straw application in August 1988 was still apparent in May-June 1989 (Table 5) even after much of the straw had decomposed. Generally runoff was substantial for all treatments and occurred on bare plots receiving as little as 6 mm rainfall. These data underline the need to reduce runoff in Alfisols and the potential for soil management to increase infiltration and reduce crop water stress.

Soil loss measurements followed expected trends of either decreasing soil loss with increasing cover, or of increased soil loss following tillage and seasonal changes. However, total soil loss was small (>2 t ha^{-1}) and the quantification of treatment responses will require more data.

Soil Factors Affecting Root Development in a Vertic Inceptisol

Vertic Inceptisols are often stony or gravelly, and have low available water-holding capacity (AWHC) and a coarse subsoil inhibiting root penetration. Castor is grown extensively on these soils. An experiment was conducted to study the effects of soil factors on the development of the castor root system.

Soil around four 'large' and four 'small' plants of mature castor (cv Aruna) was drenched with water for 12 h and then drained. The soil was immediately excavated, root systems sketched, physical and chemical properties of three soil horizons measured. The horizons were: (1) a surface Vertic layer, the lower boundary of which ranged from 15 to 45 cm (referred to as the A horizon); (2) a calcareous layer of strongly weathered parent material, often with gravel and stones, with a lower boundary ranging from 40-70 cm (C_1 horizon); and (3) a less calcareous layer of weathered parent material (C_2 horizon).

There were significant differences ($P < 0.01$ based on LSD test) between the A and C_1 horizons in bulk density, water content, shear strength, penetration resistance, and gravel, coarse sand, and clay percentages, pH, electrical conductivity, and carbonate (Table 6). Properties of the C_1 and C_2 horizons were similar except for cation exchange capacity (CEC) which was significantly higher in C_2 ($P < 0.05$ based on LSD test) than in C_1.

The root/ shoot ratio was not significantly different for large and small plants (Table 7). Root

Table 6. Properties of soil horizons found during excavation of castor root systems on a Vertic Inceptisol, ICRISAT Center, March 1987.

Properties (mean values)	Horizon A	Horizon C_1	Horizon C_2	SE
Bulk density (gm cm^{-3})	1.37	1.54	1.54	±0.02
Water (% by weight)	22.9	16.7	18.7	±0.7
Shear strength (kPa)	10.8	26.3	23.1	±1.8
Penetrometer resistance (MPa)	0.91	2.65	2.33	±0.18
Gravel >2 mm (%)	23.7	36.9	30.6	±1.8
Coarse sand (%)	24.4	38.5	32.2	±1.8
Fine sand (%)	23.8	19.6	25.7	±1.37
Silt (%)	16.5	15.2	17.1	±0.69
Clay(%)	35.3	26.7	25.0	±1.5
pH	8.1	8.4	8.4	±0.1
Electrical conductivity (ds cm^{-1})	0.151	0.114	0.113	±0.005
Carbonate $CaC0_3$ (%)	3.4	17.4	11.5	±1.9
CEO (meq) (%)	22.4	20.9	25.9	±1.0

1. CEC = Cation exchange capacity.

length per unit root mass and per unit shoot mass was significantly higher ($P<0.05$) for small plants. This suggests that small plants used relatively more assimilate to increase root length rather than root diameter.

Our observations of root morphology in relation to soil depth showed that: (1) near or in the surface of the C, horizon or near stones associated with it, many roots ended, branched, changed direction abruptly (including growing horizontally), were either constricted, pitted, or deformed; (2) most roots penetrating the C_1 horizon to 50 cm grew deeper than 100 cm. Although bigger plants had longer roots, they were not necessarily associated with a deeper A horizon.

These observations indicate that impediments in or near the surface of the C_1 horizon restrict root growth. We suspect that penetration to the C, horizon is restricted by the number of root-sized pores and by the mechanical impedance caused by bridging between gravel particles. Further work is needed to develop a better understanding of root restriction mechanisms at the upper layer of the C_1 horizon of this soil and to alleviate them.

Table 7. Above-ground and below-ground components for large and small mature castor plants on a Vertic Inceptisol, 1CRISAT Center, March 1987.

Plant components (mean values)	Large plants	Small plants
Plant height (m)	2.98 (±0.27)[1]	1.83 (±0.23)
Shoot mass[2] (g)	921 (±162)	115 (±26)
Root length[3] (m)	11.9 (±0.5)	0.55 (±0.24)
Root mass (g)	201 (±2.8)	27.7 (±4.0)
Root mass/shoot mass	0.22 (±0.009)	0.23 (±0.049)
Root length/root mass (cm g^{-1})	5.92 (±1.00)	22.51 (±5.3)
Root length/shoot mass (cm g^{-1})	1.29 (±0.28)	4.74 (±3.24)

1. Figures in parentheses are standard errors.
2. Oven dried.
3. Roots of diameter >2 mm.

Wind Erosion

In the Sudano-sahelian zone of West Africa, wind has a significant effect on productivity. In the past two decades, the use of marginal lands, overgrazing, and removal of trees and shrubs in this zone have accentuated wind erosion. The rainy season is generally preceded by dust storms with winds that can exceed 100 Km h^{-1}. This contributes to erosion and can damage young

owing to complete loss of seedlings, farmers need to resow their fields.

In 1986, pearl millet was sown between strips of *Andropogon gayanus,* a perennial native to the Sahel. *A. gayanus* was selected because it does not require weeding and its stover is used in construction and for making mats. We conducted an experiment consisting of two treatments: protected and nonprotected 10 x 20 m pearl millet plots with four replications. The protection was 5-m wide strips of *A. gayanus* sown perpendicular to the prevailing wind direction. Nonprotected plots had strips of pearl millet sown instead of *A. gayanus* and Were continuous with the pearl millet crop area, Wind speed was monitored throughout the cropping season with anemometers placed 50 cm above ground level at the center of each plot. Pearl millet was sown on 23 May 1986, 8 July 1987, 15 June 1988, and on 19 June 1989. Harvesting was completed between mid-September and mid October depending on sowing dates.

In 1986, *Andropogon* emergence and establishment were very poor. Filling the gaps was completed in early August using slips from existing plants. Establishment and growth of slips were much best than seed sowings. and were used subsequently.

From 1987 onward *Andropogon* barriers significantly reduced wind speed in pearl millet plots (Table 8) between 1 July and 1 August. After 1 August pearl millet plants surrounding the nonprotected plot reduced wind speed as effectively as the *Andropogon* strip-

In September 1989, a survey of soil accumulation in *Andropogon* and cropped zones was completed. These data (Fig. 11) show a difference in soil surface elevation of 15 cm between these two zones. Using a bulk density of 1.5 g cm^{3}, we found that over 3 years, a 5 x 100-m long *Andropogon* strip trapped 112 t of sand. We also concluded that wind strips effectively protected seedlings in the beginning of the rainy season.

Table 8. Wind speed (average and maximum) ($m\ s^{-1}$) in pearl millet protected and nonprotected plots 182-222 DAS at 0.5 m above ground level, ISC, Sadore, Niger, rainy season 1987.

Day	Treatment[1]	Average	Maximum
1 July	PMA	3.09	4.63
	PM	3.65	5.52
11 July	PMA	2.88	5.77
	PM	3.70	6.53
21 July	PMA	3.20	4.29
	PM	3.45	5.17
31 July	PMA	2.15	3.26
	PM	2.33	3.65
10 August	PMA	3.56	4.49
	PM	3.63	4.76
SE		±0.10	±0.07
CV (%)		17	19

1. PMA = Pearl millet with *Andropogon;* PM = Pearl millet.

Treatments did not significantly reduce grain yield (Table 9). Some competition between the grass and cereal is indicated. Pearl millet plots protected by *Andropogon* used more water than nonprotected plots. This was most evident in 1987 when water use for protected plots was 326 mm against 307 mm (±4.3) for nonprotected plots. Rainfall was abundant and well distributed in 1988 and 1989. In 1988, water use was 384 mm for protected and 409 mm for nonprotected plots (±9.4), and in 1989, it was 379 mm for protected and 392 mm for nonprotected plots (±13.6). *Andropogon gayanus* straw yields increased continuously from 1986 to 1989. Stover value (market at Say, Niger) in October 1989 was 32 CFA kg^{-1} compared to 16 CFA kg^{-1} for pearl

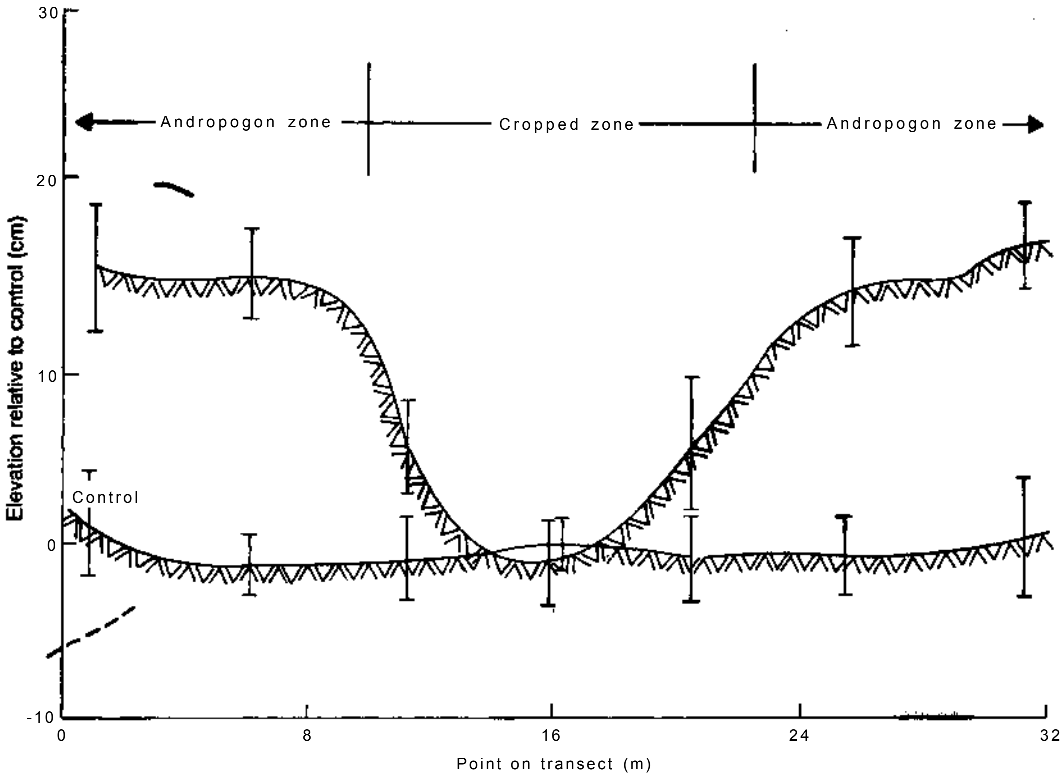


Figure 11. Height of sand trapped by a 10-m wide strip of Andropogon gayanus *over a 3-year (1986-1989) period in a pearl millet field at ISC, Sadore, Niger.*

millet straw and 56 CFA kg^{-1} for pearl millet grain. These returns, coupled with low requirements for labor, should make this system attractive to farmers.

Competition and Microclimatic Effects of Neem Windbreaks

We earlier reported on competition between neem (*Azadirachta indica)* windbreaks and pearl millet in an off-season, irrigated experiment at ISC (1CRISAT Annual Report 1988, p. 190). In 1988, we began a collaborative program with the University of Edinburgh to study further the nature of this competition and to determine windbreak effects on microenvironment in a developing pearl millet crop. Trials were established using a 7-year-old neem windbreak oriented north-south and averaging 6 m in height. Pearl millet (cv Sadore local) was established at 2 hills nr^2. Instrumentation was set up at 1, 3, 6, and 10 times windbreak height (h) to monitor net radiation, air humidity, wind speed, leaf and air temperatures, boundary layer, and stomatal conductances.

Maximum grain and biomass yields in 1988 and 1989 were measured 15-36 m from the windbreak (Figs. 12 and 13). Although analysis of micrometeorological data is still in progress, initial interpretation points to a favorable sheltering effect from windbreaks. Air and leaf

Table 9. Grain (G) and stover (S) yields (t ha^{-1}) of pearl millet protected by wind strips of *Andropogon gayanus* and nonprotected pearl millet stover yields (t ha^{-1}), ISC, Sadore, Niger, rainy season 1986-89.

	1986		1987		1988		1989	
Treatment	G	S	G	S	G	S	G	S
Protected								
Pearl millet (Center)	0.96	3.38	0.52	1.44	0.70	2.57	0.41	2.32
A. gayanus (West)		0.22		2.31		5.14		9.22
A. gayanus (East)		0.36		2.28		6.18		12.93
Nonprotected								
Pearl millet (Center)	0.92	3.50	0.61	1.54	0.94	2.42	0.67	2.39
Pearl millet (West)[1]	.2	-	0.55	1.57	0.67	2.20	0.51	1.81
Pearl millet (East)	-	-	0.54	1.52	0.73	1.96	0.49	1.53
SE (Pearl millet)	±0.08	±0.30	±0.09	±0.23	±0.08	±0.33	±0.09	±0.33
SE *(A. gayanus)*		±0.10		±0.29		±0.7		±0.46
CV (%) (Pearl millet)	16	17	34	32	21	29	34	31
CV (%) *(A. gayanus)*		16		25		25		8

1. Pearl millet (West) and (East) are portions of nonprotected field corresponding to *A. gayanus* (West) and (East) strips in protected fields.
2. - = Data not available.

temperatures were found to increase slightly in the lee of the windbreak with the effect decreasing towards the field center (Fig. 14). Air/leaf temperature differences, related to the degree of air mixing, were least at 3 m from the windbreak. The shelter effect disappeared beyond 10 m.

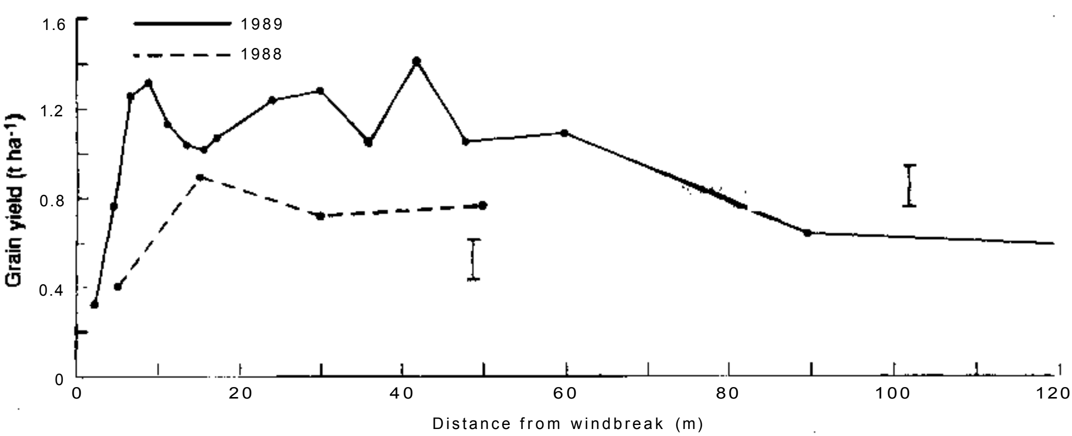


Figure 12. Pearl millet grain yield and distance behind an Azadirachta indica *windbreak at ISC, Sadore, Niger, in 1988 and 1989.*

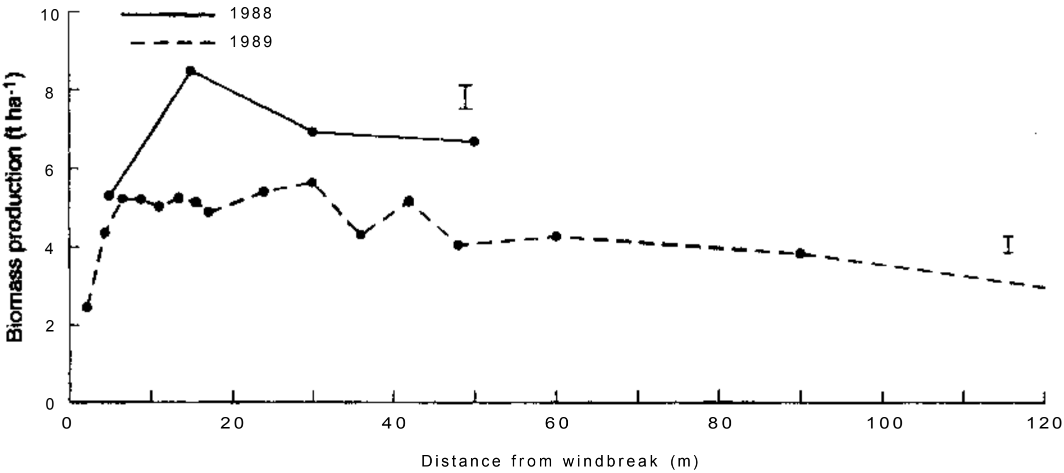


Figure 13. Pearl millet biomass production and distance behind an Azadirachta indica *windbreak at ISC, Sadore, Niger, in 1988 and 1989.*

In another study conducted in 1989, we compared plots with polyethylene sheet barriers (installed at a depth of 1.2 m to separate neem and pearl millet roots) and plots without root barriers. In plots without barriers, at a distance of 3 m from the windbreaks, we found a 69% reduction in grain and 45% reduction in biomass yields compared to yields of millet 15 m from the neem windbreak (Fig. 15). Plots with root barriers had reductions of 43% (in grain) and 21% (in

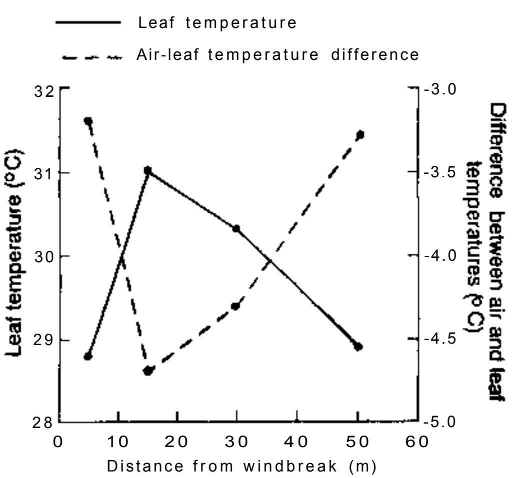


Figure 14. Measured leaf temperature (°C) and the difference between leaf and air temperatures (°C) moving away from an Azadirachta indica *windbreak on 21 August 1988 at ISC, Sadorb, Niger.*

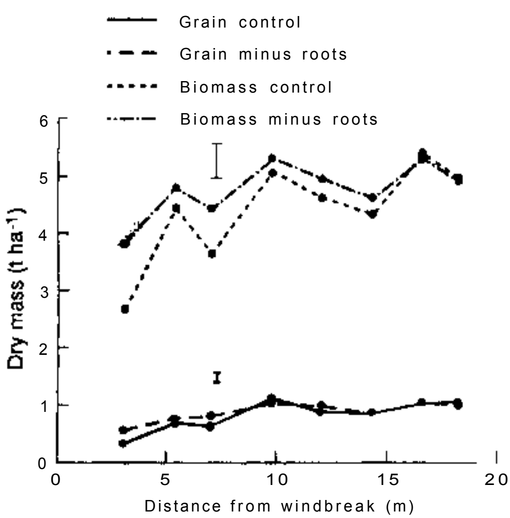


Figure 15. Effect of neem windbreaks on pearl millet grain and biomass yields with and without root barriers measured during the 1989 rainy season, at Sadore, Niger.

biomass) over the same zone. These figures imply that although there is a component of underground competition in this windbreak system, a considerable amount of competition occurs above ground and is probably linked to shading.

Weed Management Effects on Crop Yield and Weed Populations

In the traditional millet production systems of West Africa almost all weeding is done by hand. Although the quality of hand weeding is potentially high, availability of labor can be a serious constraint. Mechanized weeding using AT is one solution, but the effectiveness of mechanized weeding can be less than hand weeding when weeds between the rows are not removed and those in the row are left untouched. We therefore investigated the effectiveness of different weeding operations to suppress weed growth and to increase crop yields.

In 1987, the following weeding treatments were implemented on land previously under bush-fallow: (1) no weeding, WO; (2) two mechanical interrow weedings, W l ; (3) same as Wl but with additional within-row hand weedings, W2; and (4) two full hand weedings, W3. An additional comparison was made between pre-sowing, direct ridging, and flat cultivation using one local millet cultivar (cv Sadore) and one improved cultivar (cv CIVT). A 4 x 2 x 2 factorial design was used with weeding method x tillage x cultivar confounded in blocks. Treatments were permanently assigned to plots. Weed samples were taken from between rows and within rows at four dates to assess treatment effects in terms of dry matter production. Phosphorus was applied annually (SSP, single superphosphate with Boron®) at 17 kg ha^{-1} before primary tillage. Pearl millet was hill-sown by machine in 0.75-m spaced rows with 0.67-m spacing between hills. Alternate hills were removed after establishment resulting in a final population of 1 hill nr^2 and a wider within-row spacing than between-row spacing.

Ridging increased plant populations. There was a significant interaction between ridging and seeding method which, in treatment W1, reduced the growth of weeds throughout the season. Pearl millet grain and stover yields were significantly effected by the weeding method, tillage, and cultivar (Fig. 16). There was a significant effect of season on pearl millet grain and stover yields, with the 1989 yields being lowest. Weed populations did not differ significantly between years.

With adequate rain, the local cultivar significantly outyielded the improved cultivar regardless of weed numbers at harvest. Mechanical

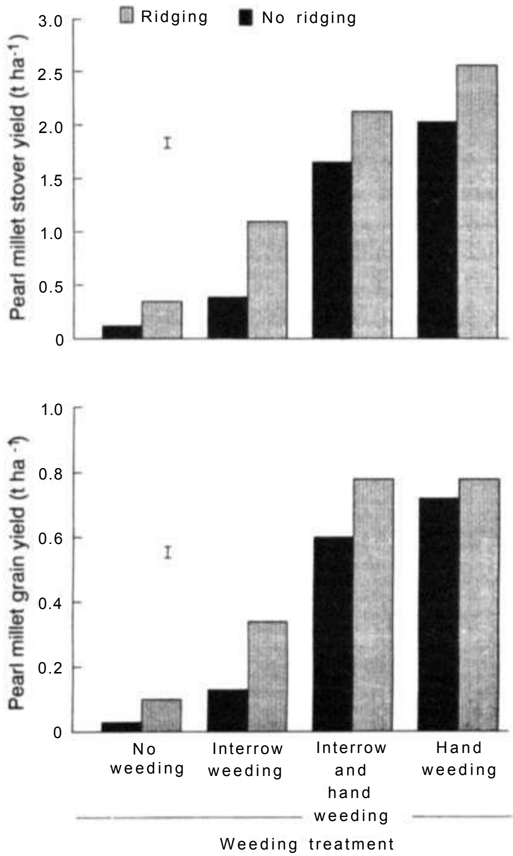


Figure 16. Interaction effect of ridging and weeding on pearl millet grain and stover yield. A verage of two cultivars over three years (1986- 1988), at ISC, Sadore, Niger.

weeding alone resulted in unacceptably low grain yields (mean 0.23 t $ha^{-1)}$ Additional within-row hand weeding increased yields to 0.69 t ha^{-1}. Hand weeding the whole field suppressed weeds most effectively with a resulting crop yield of 0.75 t ha^{-1}. Ridging decreased numbers of weeds at harvest and increased crop dry matter production from 1.04 t ha^{-1} to 1.46 t ha^{-1} (SE ± 0.05) when averaged over other factors.

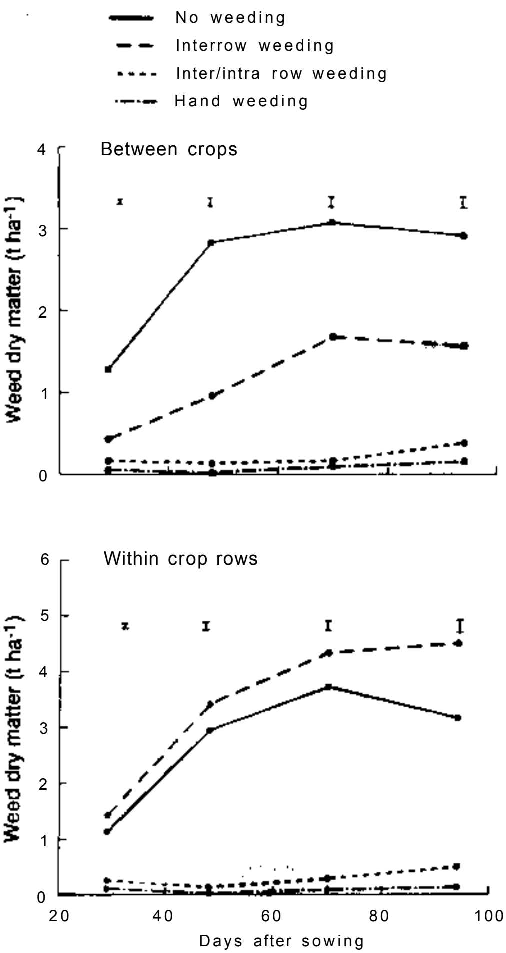


Figure 17. Effect of weed management on weed dry matter production between and within pearl millet ro ws for a crop gro wn in the 1989 rainy season a t ISC, Sadore, Niger.

Total dry matter production (crop plus weed dry matter) remained constant at 3.3 t ha^{-1} for all treatments, indicating a stable competitive relationship between crop and weeds. With interrow cultivation (with W1), within-row weed growth exceeded that of weed growth in nonweeded plots (Fig. 17), indicating that within-row weed growth increased to compensate for weeds removed from between rows. This is possibly why there was little effect of interrow cultivation on reducing weed numbers resulting in low crop yields. These observations suggest that insufficient weed control from mechanical weeding could be compensated for by ridging which reduced total weed dry matter at harvest by 50%.

Composition of weed species as a percentage of total weed number depends on tillage and weeding methods. As the season progressed, leguminous species increased in nonweeded plots (Fig. 18). Weeding created a shift from graminaceous species to leguminous species. Similar trends were found during the 1989 cropping season, except for the complete disappearance of leguminous species. Tillage effects on weed composition were similar to those for weeding. Untilled plots had about twice the number of graminaceous species.

Mechanization of weeding in combination with supplemental within-row hand weeding gives the most satisfactory weed control and crop yields. Tillage promotes weed control within rows and increases crop yields, particularly with low weeding levels.

Weed Control in Sorghum/ Legume Intercrops

At Samanko, Mali, we studied the infestation of weeds and their manual control in different cropping systems. Through the rapid covering of soil surface, intercrops, sorghum/cowpea in particular, reduced weed emergence between 0 and 70 days after sowing (DAS). Mean fresh weights of weeds were 1.18 t ha^{-1} in sorghum and 2.33 t ha^{-1} in groundnut sole crops compared to 1.47 t ha^{-1} in sorghum/groundnut and 1.10 t ha^{-1} in

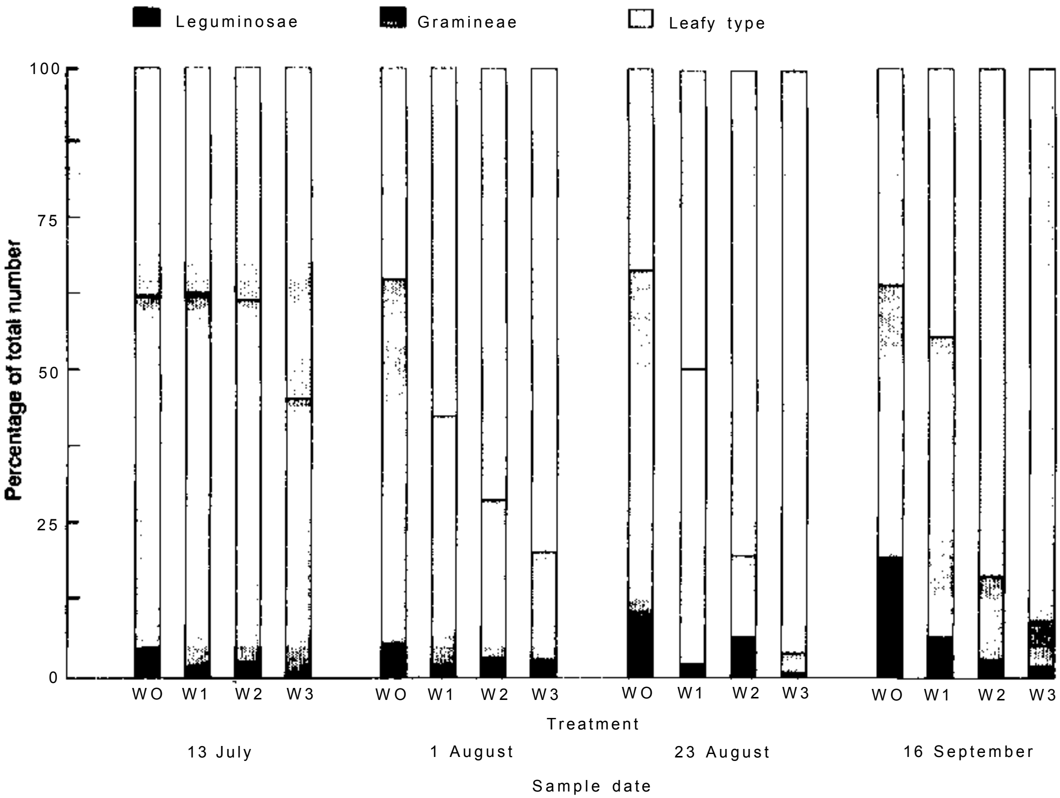


Figure 18. Effect of weed management on weed species in a pearl millet crop grown in the 1989 rainy season at ISC, Sadore, Niger.

sorghum/cowpea intercrops (SE ±0.24). Consequently, only two weedings were required in intercrops (at 20 and 40 DAS). Total weeding labor was 396 h ha^{-1} for sorghum sole crop, 412 h ha^{-1} for groundnut sole crop, 368 h ha^{-1} for sorghum/groundnut intercrop and 312 h ha^{-1} for sorghum/cowpea intercrop, (SE ±17). The conclusion is that intercropping saved about 10% of labor.

Wetness Requirements for Groundnut Rust Infection

Rust occurs on groundnut in virtually all parts of the world where the crop is grown. Reduction of yield by the disease may exceed 50%, and greater losses have been reported when rust and leaf spot diseases occur together.

Urediniospores of groundnut rust are effectively dispersed by air and are commonly deposited on the surface of dry leaves. However, liquid water is thought to be necessary for the spores to germinate and infect. The water leaches an inhibitor from the spores and is needed for the growth of germ tube.

Sources of leaf wetness in field crops are dew, rain, and irrigation and the period that leaves remain wet is critical to the infection process. We conducted experiments at different temperatures to quantify the relation between the duration of leaf wetness and rust infection.

We inoculated leaves attached to potted plants with a suspension of rust spores (50 000 mL^{-1}) and placed the plants in a dark dew chamber for different periods. After removal, we dried the leaves in front of a fan before transferring the plants to a greenhouse where we observed them for symptoms. We counted the number of lesions per unit leaf area every day and recorded the maximum number for each inoculated leaf. We repeated the experiments several times at each temperature, and normalized lesion densities to combine data from all the experiments (for each set of data, values were divided by the asymptote; the asymptote was taken as the average value of points for periods beyond which there was no further increase in lesion density).

We were able to identify a minimum period for infection to occur and a maximum period beyond which there is no further increase in disease. Both periods were affected by temperature (Fig. 19) although results from replicate experiments at 15°C were less consistent than at 25° C. The minimum periods for infection were 3.4 h at 25° C and 6.4 h at 15° C. With wetness for 12 h, the lesion density was close to the maximum at 25° C, but around 50% of the maximum at 15°C.

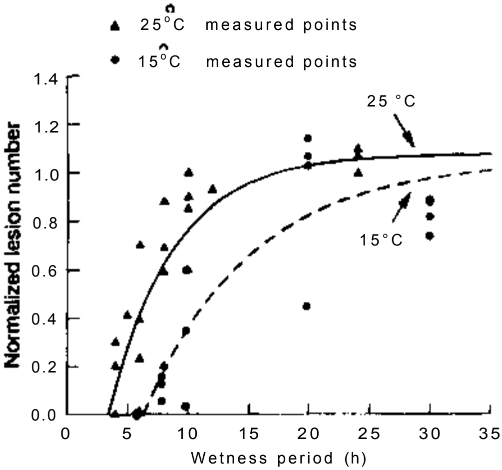


Figure 19. Relationship between wetness and normalized lesion number of groundnut. Points are from experiment environments. Equations of the dotted lines are at 15°C, T= 1.05 (l-exp (-0.114) (x-6.44)), r^2 =0.85 and at 25 °C, T=1.08 (1-exp (-0.188 (x-3.39)), r^2 = 0.74 where T = normalized lesion number.

In the field, periods of wetness at night are important for rust since infection is inhibited by light. Wetness from dew, or rain late in the day, may persist for about 12 h. This would be ideal for rust infection at 25°C and, if wetness persisted for more than 8 h, substantial infection would be expected. However, for a night temperature of 15°C, infection would be much less and would be negligible if the period of wetness was less than 8 h.

These findings will help to identify periods when the weather favors rapid rust development, and could form the basis of a scheme to optimize the timing of control measures.

Modeling of Constraints

A Resource Capture Model (RESCAP) for Sorghum and Chickpea

A simple model based on the concept of resource capture was developed to simulate the growth and yield of sorghum. The distinguishing features of the RESCAP model are: (1) emphasis on the use of conservative quantities, (2) parameters and variables kept to a minimum, (3) all quantities have clear physical or physiological meaning, (4) all parameters are measurable in the field, (5) components are readily expanded or replaced, and (6) the model is easily adapted to different crop types.

Two assumptions, well supported by field evidence, are central to the RESCAP model:

1. the amount of dry matter produced per unit of radiation intercepted by foliage is effectively constant during vegetative growth when water is not limiting; and
2. the amount of dry matter produced per unit of water transpired is inversely proportional to

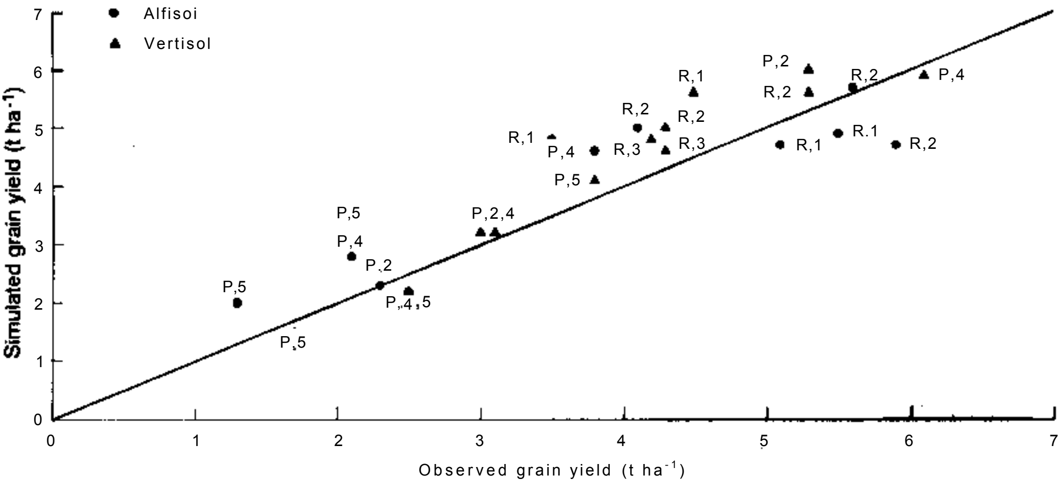
the mean saturation deficit of air whether water is limiting or not.

The model, therefore, places equal emphasis on the role of leaves in relation to the interception of light, and to the role of roots in relation to the uptake of water.

Climatic data used in the model include daily values of rainfall, dry- and wet-bulb temperatures, solar radiation, and open-pan evaporation. Soil data include the initial soil moisture deficit, the maximum AWHC of the rooted profile, and a depth-dependent response time for water extraction. Cultivar-specific parameters are: initial seed mass, durations of growth stages in photothermal units, specific leaf area, a light extinction coefficient for foliage, initial values of root length per unit volume of soil, specific root mass, maximum root front velocity, fraction of dry matter allotted to roots until that velocity is achieved, and harvest index (HI).

The procedure on each day evaluates: (1) current weather, (2) stage of development, (3) dry matter production and therefore water loss on the basis of solar radiation and leaf area, (4) water uptake and therefore dry matter production on the basis of soil water content and root length density. The choice between light-limited and water-limited growths is determined by current soil water status and weather. Dry matter produced is allocated to leaves, roots, grain, etc., according to the developmental stage with a consequent increase of leaf area, root length, root front depth, and a change of soil water distribution. The model repeats this cycle on a daily basis till physiological maturity (a fuller description and a flow chart were published in Research Bulletin no. 12).

The model was calibrated using records from 24 field trials in which five cultivars of sorghum were grown at 1CRISAT Center in 1979 and 1980 on two soils (Alfisol and Vertisol), and in two seasons (rainy and postrainy). The regression of simulated yields against observed yields (Fig. 20) shows that the model simulated the range in grain yield well (r^2=0.82). Moreover, the



$y = (0.73 \pm 0.36) + (0.88 \pm 0.09)x$, $r^2 = 0.82$,
PR < 0.01, rse = 0.60.

Figure 20. Comparison ofobserved and simulated grain yield (n = 24) for five sorghum cultivars (1 = CSH 1,2 = CSH 6,3 = SPV 351, 4 = CSH 8,5 = M 35-1) grown on two soils (Alfisol Vertisol) in rainy (R) and postrainy (P) seasons of 1980 at ICRISAT Center.

regression line intercept was not significantly different from zero and the slope was not significantly different from unity.

The sensitivity of the model to changes in the standard value of six parameters was tested in terms of differences in above-ground dry matter (W) of sorghum cultivar (CSH 6) grown on a Vertisol at ICRISAT Center in 1980 (Table 10). Parameters such as fraction of dry mass below ground (Xr) and maximum root front velocity (u_m) needed to calculate root growth and thus water capture, are difficult to measure. The standard value of Xr used in the model was 0.30 (held constant from emergence to the day when the root front velocity reached its maximum value). The standard value of u_m was 0.035 m day^{1}. The standard value of specific leaf area (B) needed for leaf growth and light capture was 40 m^2 kg^{-1} from emergence to the day when root growth reached its value of u_m, and then 25 m^2 kg^{-1} for the rainy season, and 22 m^2 kg^{-1} for the postrainy season.

The other three parameters examined were water use efficiency (qD), light use efficiency (e), and initial seed mass (W_0). The standard value of qD was 10.8 g kg^{-1} kPa; e was 1.8 g MJ^{-1} from emergence to anthesis and then onward 1.1 g MJ^{-1}; W_0 was 24 x 10^{-6} kg $seed^{-1}$. These parameters were adjusted one at a time by increasing and decreasing the standard value used in the simulation of the field data in steps of $\sqrt{2}$. The percentage change in W, as a result of assuming different values for each parameter was compared for rainy and postrainy seasons (Fig. 21). The most sensitive parameters are those responsible for crop establishment and dry matter accumulation. For example, crop growth in the postrainy season was dependent on water uptake; whereas a decrease in Xr in the postrainy season decreased W almost linearly, a further increase in Xr from the standard value did not alter W. In the rainy season when crops received intermittent rain, changes in Xr did not affect W, until it reached 0.9 and caused a serious imbalance between leaf and root growth. Changes in u_m did not affect W in the rainy season, but reduced W somewhat by reducing u_m. W did not increase with an increase in B, but decreased with a decrease in B implying that the standard value of B was close to optimal for light interception. There was a strong interaction between seasons and soils for e and qD. During the rainy season with more light-limiting days, W was sensitive to e but during the postrainy season with more water-limiting days, W responded to changes in qD. Changes in W_0 had essentially very little or no effect on W. This analysis draws attention to the need to obtain better estimates of some of the parameters.

Table 10. Conditions under which sorghum cultivar (CSH 6) was grown, for use in sensitivity analysis, on a Vertisol during the 1980 rainy and postrainy seasons at ICRISAT Center.

	Rainy	Postrainy
Date of emergence	5 Jul	1 Dec
Available soil water at sowing (mm)	102	202
Irrigation (mm)	0	206
Rainfall (mm)	557	57
Days from emergence to maturity	84	96
Above-ground dry matter (t ha^{-1})	11.3	11.1

The RESCAP model, originally developed for sorghum, has been adopted for millet, groundnut, and chickpea (*Cicer arietinum* L.). An account of progress with the chickpea model follows.

Crop-specific coefficients and parameters for sorghum crop were replaced by those of chickpea crop. We assumed (1) that when water was not limiting and that the light use efficiency (e) was 0.67 g of dry matter produced MJ^{-1} of intercepted solar radiation; and (2) that when water was limiting, the normalized water use efficiency (qD) was 4.8 g kg^{-1} kPa. Maximum extension of the root front was taken as 0.015 m day^{-1}, reached in chickpea about 20 days after emergence (DAE). Other components of soil water balance are estimated in the same fashion as for RESCAP-sorghum.

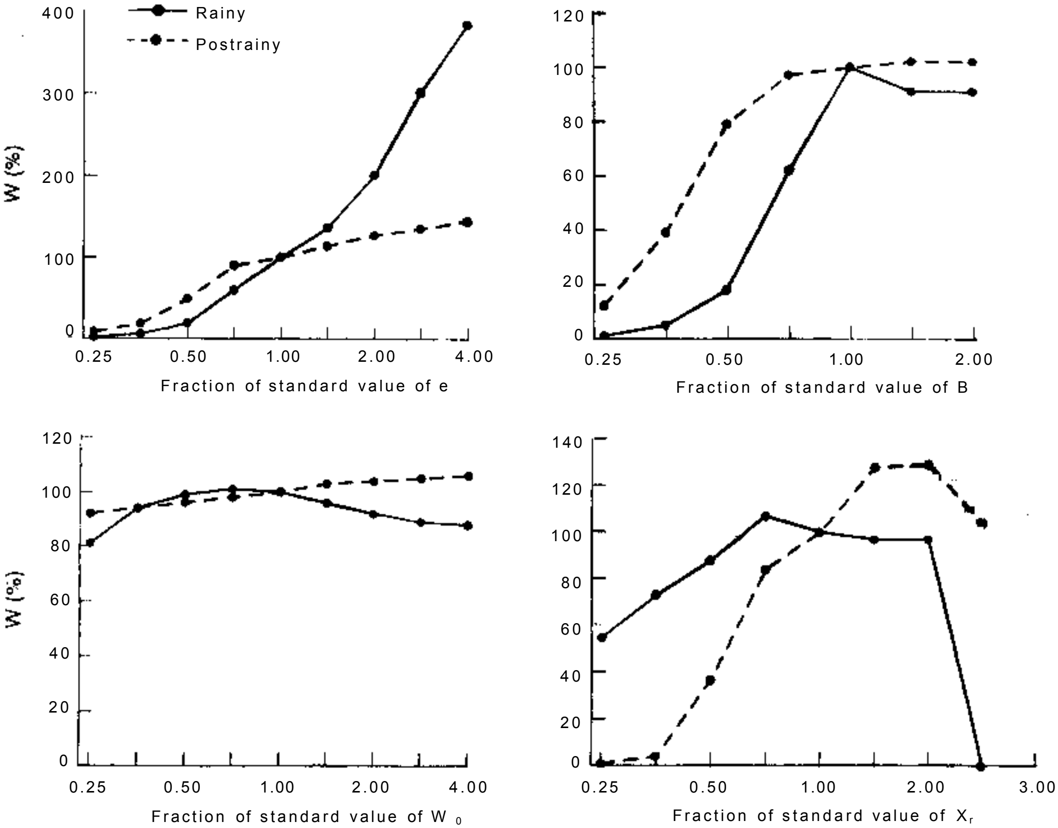
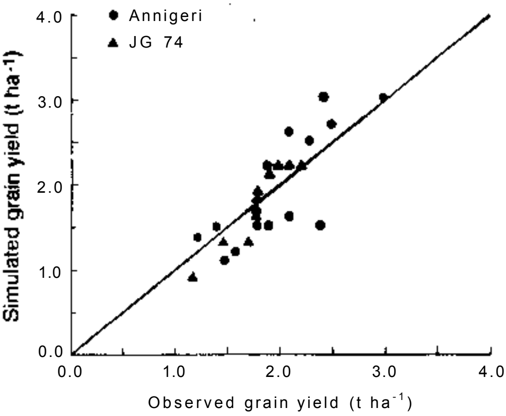


Figure 21. Percentage of above-ground dry matter (W) at maturity (W, using standard value of each parameter) as a function of fraction of standard values of X_r, W_0, B and e parameters for sorghum cultivar CSH 6 grown in rainy and postrainy seasons of 1980 on a Vertisol at ICRISAT Center.

Chickpea development is determined by temperature, photoperiod, and water deficits. Considering the changes in dry matter allocation with development, growth can be divided into three phases: emergence to flowering (GS1), flowering to pod initiation (GS2), and pod initiation to physiological maturity (GS3). The duration of GS1 was computed from photoperiod and thermal time, and those of GS2 and GS3 from thermal time. The durations of all phases were further adjusted to account for the rise of foliage temperature when the crop was short of water.

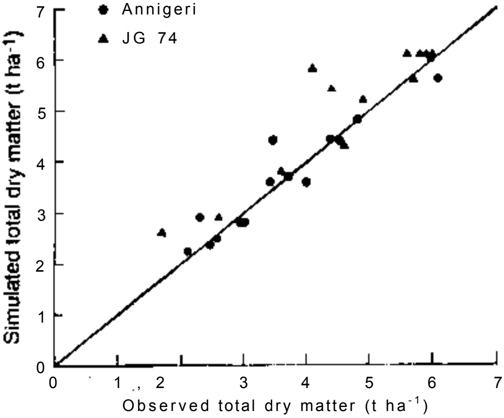
The fraction of above-ground dry matter (W) was divided between leaves, stems, pods, ana seeds in proportions which changed with plant age. From emergence to pod initiation, 50% of the above-ground dry matter (W) was allocated to leaves and the remaining 50% to stems including branches. After pod initiation, the fraction allocated to pods (pod wall + seed) was increased at a constant rate from 0 to 1.1 to allow up to 10% translocation to pods from leaves. Similarly, at the beginning of pod fill, the fraction allocated to seeds was increased from 0 to 1.1 with crop age. If the plant experienced water stress, vegetative growth was suppressed and proportionately more assimilate was allocated to leaves by factors determined by cultivar calibration. After pod initiation, the allocation to stems decreased exponentially from 0.5 to a minimum value determined by the time after pod initiation. After assimilates were allocated to pods and stems, the remaining fraction was allocated to leaves.

The model was calibrated with measurements of Annigeri taken in 1985 and JG 74 in 1987, and then used to predict biomass, seed yield, and evapotranspiration (ET) for other seasons. A total of 27 independent data sets for seasons from 1978 to 1986 was available for testing. Simulated total dry matter was strongly correlated (r^2=0.86, P<0.01) with observed total dry matter yields (Fig. 22). Similarly simulated seed yields and ET were well correlated with observations (r^2=0.71 for seed yield and r^2=0.85 for ET) (Figs. 23 and 24). These correlations suggest that the model could be used more widely to assess water requirements and the associated biomass and seed yields of chickpea in response to soil water availability and supplemental irrigation.



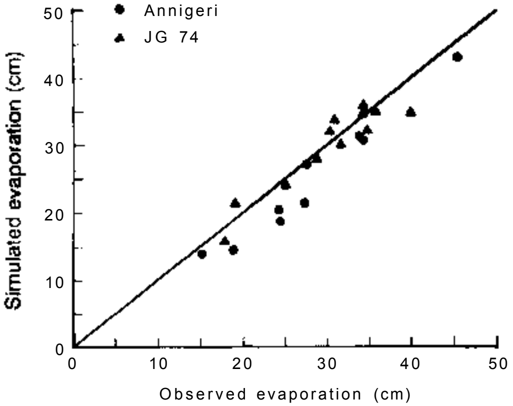
$y = (-0.25 \pm 0.27) + (1.11 \pm 0.14)\,x$, $r^2 = 0.72$, PR < 0.01, rse = 0.33.

Figure 23. Comparison of observed and simulated grain yields of chickpea cultivars, Annigeri (1978, 1979, and 1980 postrainy seasons) and JG 74 (1986 postrainy season) grown on a Vertisol at ICRISAT Center.



$y = (0.41 \pm 0.31) + (0.94 \pm 0.07)x$, $r^2 = 0.87$, PR < 0.01, rse = 0.49.

Figure 22. Comparison of observed and simulated total dry matter yield of chickpea cultivars, Annigeri (1978, 1979, and 1980 postrainy seasons) and JG 74 (1986 postrainy season), grown on a Vertisol at ICRISAT Center.



$y = (-1.44 \pm 2.17) + (0.99 \pm 0.07)x$, $r^2 = 0.91$, PR < 0.01, rse = 2.48.

Figure 24. Comparison of observed and simulated evaporation for chickpea cultivars, Annigeri (1978, 1979, and 1980 postrainy seasons) and JG 74 (1986 postrainy season) grown on a Vertisol at ICRISAT Center.

Careful studies are needed on the influence of the environment, and general management on growth and extension of root system of chickpea and allocation of assimilates to different plant parts. To extend the use of the model to other environments and cultivars, information needs to be generated on base temperature, ceiling temperature, and photoperiod sensitivity of other chickpea cultivars.

Water Interacting with Nitrogen Experiment (WINE)

In parts of India where sorghum is grown on Vertisols during the postrainy season, yields are limited by the inefficient uptake of N from the soil near the surface, which is rapidly dried by roots and rarely rewetted by rain throughout the season. Fertilizer management is based almost entirely on results from field trials which are specific to sites and seasons. Modeling, as a basis for developing better systems of management, has made little progress because the interaction of water and N with root systems is little understood. Information is needed to relate rates of water and N uptake to the growth of roots which provide a 'supply' to the rest of the plant and to the growth of shoots which determine the 'demand'. A multidisciplinary experiment to obtain this information had these objectives: (1) to study the growth and activity of sorghum root systems and of foliage in relation to water and N availability; (2) to parameterize the uptake of water and N by roots to extend a comprehensive RESCAP model described earlier.

Sorghum genotype SPH 280 was grown on a Vertisol during the 1988/1989 postrainy season. The experiment consisted of two water regimes, the main plot treatments, and six N levels applied to subplots, with three replications. The moisture regimes were: (1) no irrigation after emergence, (2) irrigation in the 1st, 3rd, 5th, and 8th week after emergence giving a total of 150 mm of water. The six N levels were 0, 30, 60, 90, 120, and 150 kg N ha^{-1}, applied with a basal application of P and Zn immediately before sowing. The entire experimental area was irrigated on 30 October 1988 to bring the soil to field capacity; the crop emerged on 4 November 1988 and was harvested on 22 February 1989.

Crop growth and nutrient uptake were monitored by removing samples weekly from a 1 m^2 area. Root samples and soil samples (for inorganic N) were taken every 2 weeks. A 0.6 x 0.8-m area including eight plants was excavated down to 0.6 m and deeper soil was removed by coring down 2.0 m. Soil moisture was measured every week to a depth of 1.65 m, by the neutron scattering method. Microclimatic characteristics were monitored continuously. The interception of total solar radiation was measured using tube solarimeters and that of quanta was measured using quantum sensors, installed under the canopy in all treatments.

Root mass increased up to the dough stage (93 DAE) and then leveled off or declined under both irrigated and nonirrigated conditions (Fig. 25). The root-shoot ratio reached a maximum between 0.21 and 0.34 depending on N application rate and irrigation level around panicle initiation (31 DAE), and then declined to a minimum of about 0.10 at harvest, almost independent of N and irrigation. Around panicle initiation, differences in root-shoot ratios between N levels were larger than those during other growth stages, and the treatments with less N and no irrigation had slightly higher root-shoot ratios. These responses suggest that the partition of photosynthate is influenced by available soil N during early growth and that the root system serves as a strong sink when N or water is in short supply.

Irrespective of water treatment, total root length increased steadily from 19 DAE to 45 DAE and then decreased until 75 DAE. It then increased up to dough stage (93 DAE) and finally declined (Fig. 26). At 93 DAE, root length density per unit volume across all N levels was significantly larger at a depth of 180 cm, and was larger below a depth of 165 cm without irrigation (Fig. 26).

The root systems seemed to possess the ability to find and exploit wetter soil by extending roots when the crop was short of water. The sharp increase in total root length density between 74

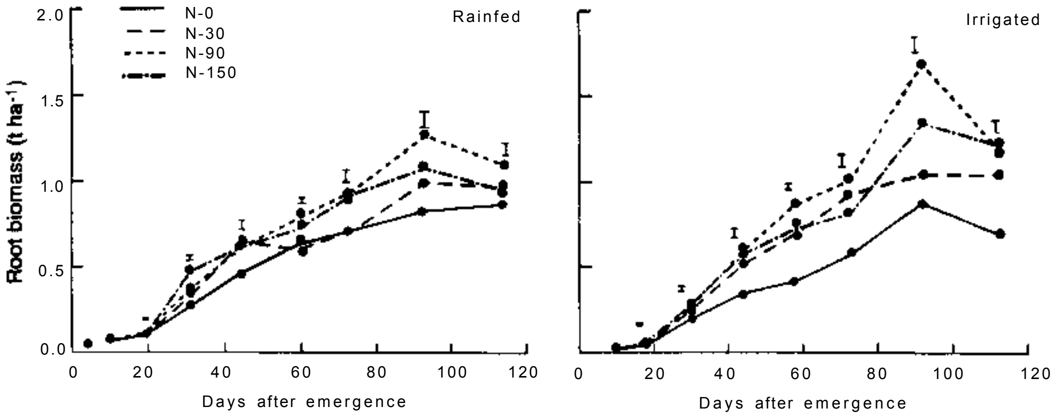


Figure 25. Root biomass of irrigated and rainfed treatments and four N application rates in a sorghum (SPH 280) sowing at ICRISAT Center during 1989.

and 93 DAE (late flowering to dough stage) (Fig. 27) resulted from further branching and elongation, apparently stimulated by a demand for water.

Leaf area responded to N over most of the growing season and to water from the 8th week. Interaction between water and N became evident from the 10th week. Without irrigation, leaf area increased with the application of about 60 kg N ha^{-1} but there was little response at higher levels of N. With irrigation, the N response was extended to 120 kg N ha^{-1}. Measurements of quantum interception (Fig. 28) show that the canopy closed about 8 weeks after emergence when water was supplied but was not maintained on plots receiving less than 90 kg N ha^{-1}. With irrigation, less light was intercepted at all levels of N (except zero) compared with nonirrigated treatments. The anomaly for the zero N treatment may have been a result of leaching.

During grain filling, leaf area declined faster on the irrigated plots than on the nonirrigated

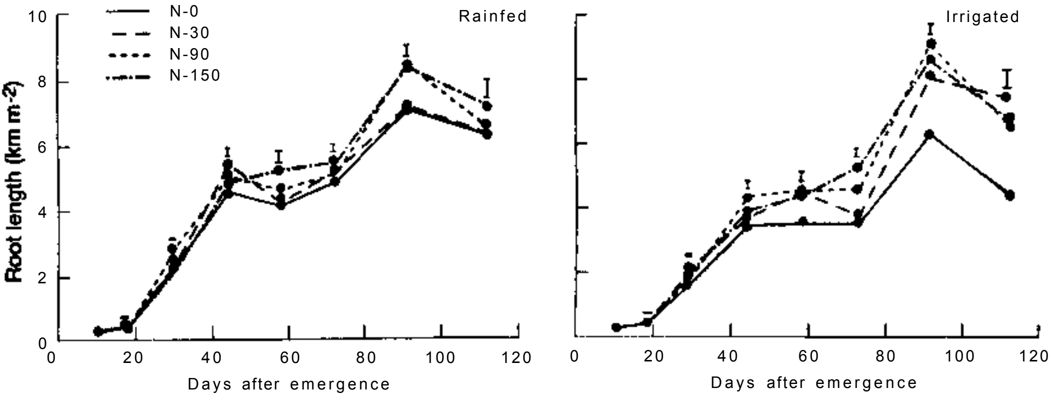


Figure 26. Root length in irrigated and rainfed treatments and four N application rates in a sorghum (SPH 280) sowing at ICRISAT Center during 1989.

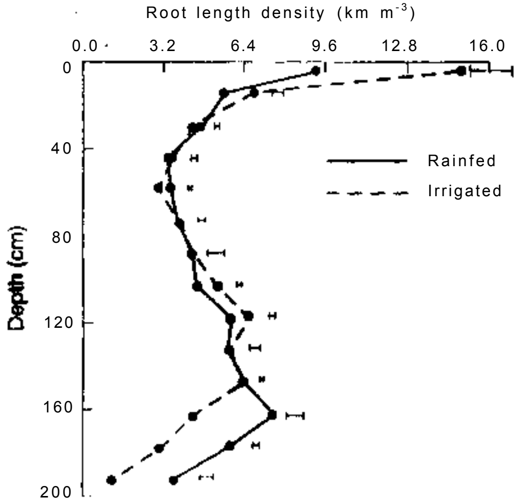


Figure 27. Root length density and rooting depth in irrigated and rainfed sorghum (SPH 280) grown at ICRISAT Center during the 1989 post rainy season.

plots, possibly because there was more remobilization of assimilates to panicles and/or more water stress because of faster rates of evaporation during vegetative growth.

The response of shoot dry matter production to N and water was less pronounced than the response of leaf area, and the interaction between water and N was barely significant. However, irrigation did increase the rate of dry matter production at all levels of N. Under irrigation, the total dry matter at maturity increased, with N up to 90 kg ha^{-1}, while without irrigation the limit was 60 kg N ha^{-1} (Fig. 29). The response of grain yield was similar. When no water was applied, the efficiency with which intercepted radiation was stored as dry matter was almost independent of N application at about 1.10 g MJ^{-1} (Fig. 30). With irrigation, the efficiency increased sharply when N increased from 0 to 30 kg ha^{-1} and then more gradually to a maximum of about 1.5 g MJ^{-1} at 150 kg N ha^{-1}.

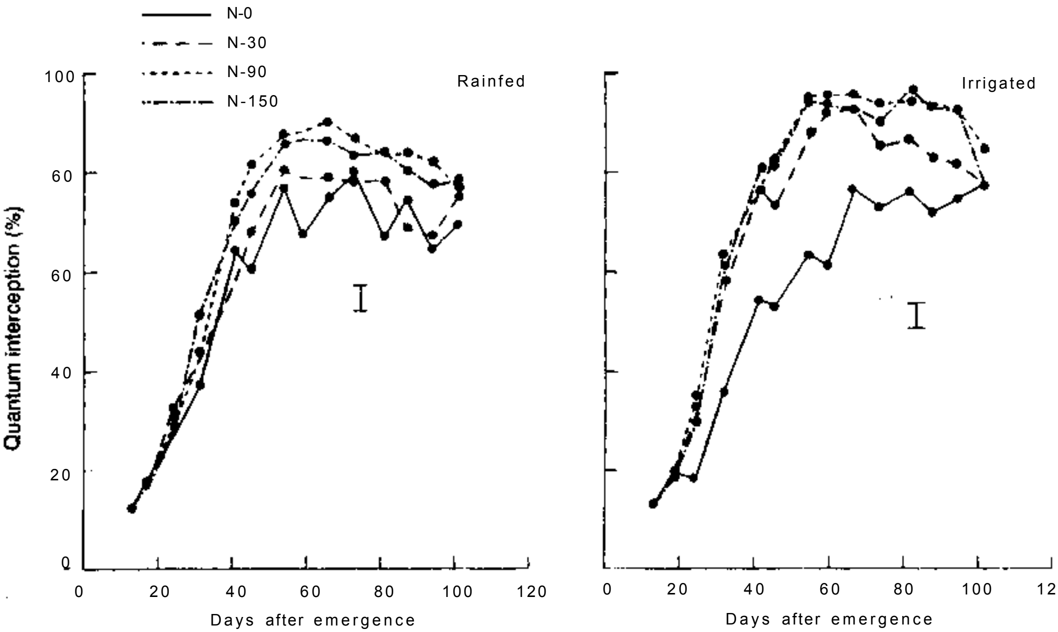


Figure 28. Quantum interception for irrigated and rainfed treatments and four N rates in a sorghum (SPH 280) crop grown at ICRISAT Center during the 1989 postrainy season.

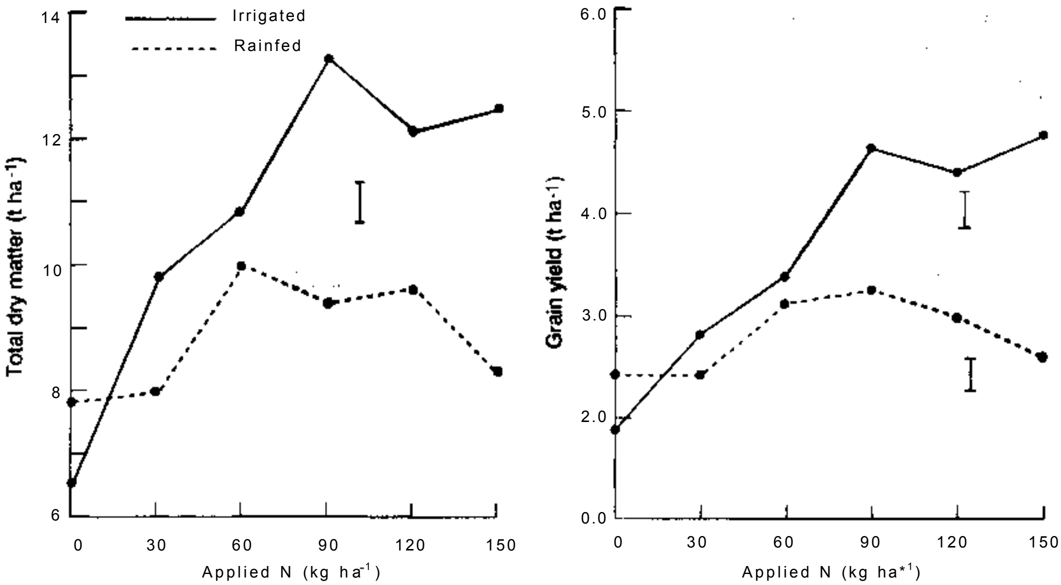


Figure 29. Relationship between total dry matter production and applied N for irrigated and rainfed treatments in a sorghum crop grown at 1CRISA T Center during the 1989 postrainy season.

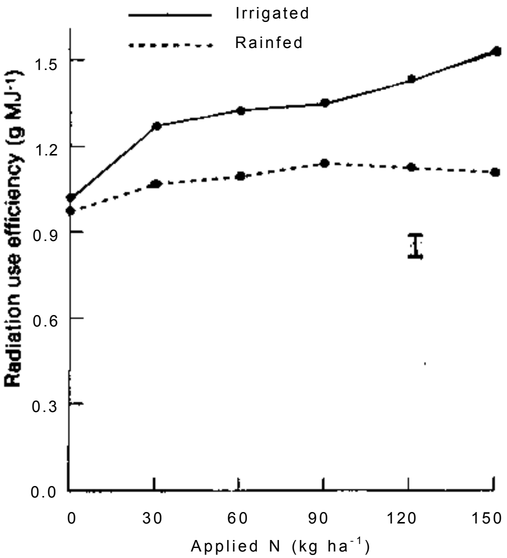


Figure 30. Relationship between radiation use efficiency and applied N for rainfed and irrigated treatments in a sorghum crop grown at ICRISAT Center during the 1989 postrainy season.

Improvement of Production Systems

Perennial Pigeonpea for Agroforestry Uses

A major objective of agroforestry research at ICRISAT Center is to produce fodder during the dry season (January-June) without sacrificing crop yield during the rainy season (June-October). Earlier investigations at ICRISAT Center and CRIDA have consistently shown that alley cropping with *Leucaena leucocephaJa* is not acceptable because yields of many dryland crops are greatly reduced. We have therefore turned our attention to perennial pigeonpea which has an appropriate phenology for intercropping, that is, slow growth during the rainy season and a deep rooting habit which facilitates utilization of residual soil moisture in the dry season.

Previous perennial pigeonpea studies (ICRISAT Annual Report 1987, p. 309) identified varieties with resistance to wilt and sterility mosaic disease and with a high potential for grain and fuelwood production. Varieties like ICPL-8094 have produced up to 2.0 t ha^{-1} of grain at populations of 1.5-9.5 plants m^{-2} implying that there is considerable scope for intercropping without reducing grain yield. In the first 18 months following sowing, 21-24 t ha^{-1} of fuelwood were produced by a sole stand of ICPL-8094 grown on Alfisols. In 1987 and 1988, we examined the suitability of ICPL-8094 for intercropping with sorghum and groundnut which are commonly intercropped with annual pigeonpea in peninsular India. Traditionally, farmers in peninsular India sow 6-20 rows of sorghum or groundnut alternately with one or two pigeonpea rows, although research at ICRISAT Center and elsewhere showed that either a 2:1 row arrangement of sorghum and pigeonpea or a 4:1 row arrangement of groundnut and pigeonpea is more productive and profitable.

In 1988, ICPL-8094 (sole crop) was compared with a medium-duration pigeonpea variety (ICP 1-6) in a 2:1 row arrangement of sorghum (CSH-6) and pigeonpea on a Vertisol and a 4:1 arrangement of groundnut and pigeonpea on an Alfisol at ICRISAT Center. Plant spacing on the Vertisol site was 45 x 10 cm for sorghum and 75 * 22 cm for pigeonpea; on the Alfisol site it was 30 x 10 cm for groundnut and 60 x 20 cm for pigeonpea. At both sites, ICPL-8094 was nearly as productive as ICP 1-6 in terms of grain yield but produced more biomass at the Vertisol site (Table 11). Furthermore, companion crop yields were similar in both intercrops resulting in combined land equivalent ratios (LERs) of 1.3 to 1.6 over both grain and biomass on the Vertisol and 1.52 to 1.75 on the Alfisol. Land equivalent ratio of ICPL-8094 was consistently lower than that of ICP 1-6 largely because ICPL-8094 performed relatively better in a sole cropping. Thus, ICPL-8094 can be used in conventional rainy-season intercropping systems without significantly reducing companion crop yields.

Table 11. Comparison of grain yield, biomass, and land equivalent ratio (LER) of pigeonpea cultivars ICPL-8094 and ICP 1-6 intercropped with sorghum on a Vertisol and with groundnut on an Alfisol, ICRISAT Center, rainy season 1988.

Crops/cultivars	Grain yield (t ha^{-1})		Biomass (t ha^{-1})		Total LER	
Sorghum/ pigeonpea	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Grain	Biomass
ICPL-8094	2.64	0.77	5.80	3.63	1.41	1.31
ICP 1-6	2.63	0.99	5.47	3.69	1.60	1.43
SE	±0.17	±0.07	±0.47	±0.10	-	-
CV (%)	11.0	13.6	14.4	4.6		
Crops/cultivars	Grain yield (t ha^{-1})		Biomass (t ha^{-1})		Total LER	
Groundnut/ pigeonpea	Groundnut	Pigeonpea	Groundnut	Pigeonpea	Grain	Biomass
ICPL-8094	1.22	0.94	3.98	3.91	1.61	1.52
ICP 1-6	1.30	1.00	3.58	2.90	1.75	1.60
SE	±0.05	±0.05	±0.30	±0.09		
CV(%)	7.1	8.2	13.8	4.7		

During the dry season, pigeonpea was cut twice to 0.5 m for fodder production in both soils. On the Alfisol, ICP 1-6 flowered within weeks of cutting, but fresh fodder production was lower than the 3 t ha^{-1} produced by ICPL-8094. Dry-season fodder production on the Alfisol was similar to that reported for leucaena on a similar Alfisol (ICRISAT Annual Report 1988, p. 185). On the Vertisol, only ICPL-8094 survived till the end of the dry season and produced very little fodder. This was surprising since an adjacent trial with ICPL-8094 at 1 x 1-m spacing produced 5.5 -5.7 t ha^{-1} of fresh fodder during the same period. Soil analysis indicated no nutrient disorders or soil pathogens. These observations highlight the importance of spacing for the survival and productivity of perennial pigeonpea.

In a separate trial we examined the interaction between perennial pigeonpea and crops during the rainy and postrainy seasons on a shallow Vertisol. ICPL-8094 was sown in June 1987 at 1 * 1-m spacing in blocks (32 rows x 36 m) or in strips (4 rows x 36 m) with 9 m of crops between the strips. In the first year, sorghum was sown between pigeonpea strips during the rainy season followed by chickpea in the postrainy season. In February 1988, the pigeonpea was cut to 1.0 m. Detailed measurements began in 1988 when sunflower *(Helianthus annuus* L.) (cv Morden) was sown in June and chickpea (cv Annigeri) in October. In the second year, pigeonpea produced 3.7 ±0.4 t ha^{-1} of grain and 22.3 ±3.2 t ha^{-1} of biomass in the strip spacing treatment compared to 2.04±0.23 t ha^{-1} of grain and 15.3 ±2.20 t ha^{-1} of biomass in the block spacing treatment. These yields are substantially greater than those from a medium-duration pigeonpea, which produced 1.0±0.14 t ha^{-1} of grain and 2.4±0.05 t ha^{-1} of biomass in a nearby field. By June 1989, plant mortality was 44% in block spacing treatment and 18% in strip spacing treatment. These observations are consistent with previous findings that low plant populations are necessary for greater plant survival and higher productivity in perennial pigeonpea.

Rainy-season sunflower growth was reduced by about 50% with 0.5-m row spacings of pigeonpea but this was more than compensated for by increases of 150% in grain yield of neighboring pigeonpea (Fig. 31). During the postrainy season, chickpea establishment was severely affected at 0.5-2.5 m distance from pigeonpea. It would be better to have a lower perennial pigeonpea population to reduce competition; or to avoid sowing a postrainy crop, dispersing pigeonpea more evenly as a single row at 2-4-m spacing to optimize uptake of residual soil moisture.

Although the rainy-season crop yield of chickpea was little affected by perennial pigeonpea in the first year, the vegetative growth of pigeonpea was excessive with many branches failing to produce grain. Two pruning treatments were imposed on the block and strip treatments in August 1988 to remove: (1) all branches at 1.0 m or (2) 50% of the branches. Removal of all branches resulted in 90% plant mortality and a fresh fodder yield of 20.2±3.3 t ha^{-1}. The 50% pruning did not result in plant mortality and produced 1.5 t ha^{-1} of grain (24% less than the unpruned control) and 8.5 t ha^{-1} of fresh fodder.

Following a late grain harvest in January 1989, perennial pigeonpea was cut to 1 m and three treatments were imposed to determine the best pruning regimes for dry-season fodder production. Treatments consisted of pruning in: (1) March, April, and May; (2) April and May; and (3) a single cut in May. Three prunings produced 5.5 t ha^{-1} and two prunings produced 5.7 t ha^{-1} of fresh fodder while the single cutting produced only 3.4 t ha^{1}. With 2-3 prunings, plants remained vegetative and were more productive whereas with a single cutting, they flowered.

We conclude that perennial pigeonpea should be managed as a tree after the second year of growth, but unlike *Leucaena leucocephaJa,* it is not able to recover from complete pruning during the rainy season. The advantages of perennial pigeonpea as an agroforestry species are: absence of strong competition with intercrops, ease of plant establishment, good economic returns from grain production within the first year, and high fodder production during the dry season compared to leucaena (ICRISAT Annual Report 1988, p. 185). However, like annual

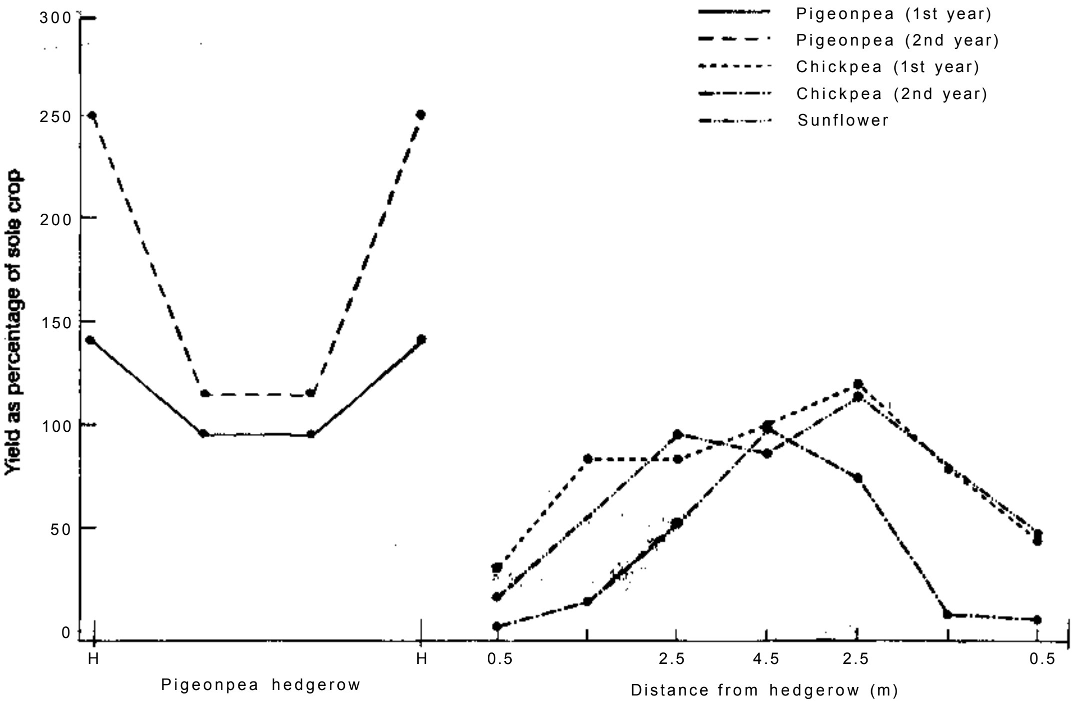


Figure 31. Relationship between pigeonpea sole crop yield (2 years), chickpea grain yield (2 years), and sunflower grain yield, and distance from pigeonpea hedgero w for so wings made at ICRISAT during the 1987 and 1988 rainy seasons.

pigeonpea, perennial pigeonpea is also susceptible to damage by pests such as *Helicoverpa armigera,* and therefore timely spraying is necessary.

Evaluation of Legumes for Cereal/ Legume Cropping Systems

Pearl millet/cowpea cropping systems are prevalent in the Sahel. Forage legume accessions were tested in pure stands beginning in 1985 with the objective of diversifying this system. Eight out of 34 accessions obtained from Centro Internacional de Agricultura Tropical (CIAT, Columbia) and Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia) were retained after preliminary trials in 1985 including *Stylosanthes* spp, and *Ccntrosems brasilianum.* A local *S. fruticosa* was also included.

Sowings at 4 kg ha^{-1} were done on 5 May 1986, 6 July 1986, and 11 June 1987. A fertilizer application of 13 kg P ha^{-1} was given at sowing. The plants were harvested at a height of 10 cm in October 1986, in November 1987, and in November 1988.

In 1987, three accessions *(Stylosanthes guianensis, S. sympodialis,* and C. *brasilianum)* did not survive the 1986/87 dry season and were discontinued. Two new cultivars of *S. viscosa* were added to the remaining six *Stylosanthes* accessions. In all three years, growth of annual *Stylosanthes* spp sowings and annual regrowth

Table 12. Dry matter forage yields (t ha^{-1}) of *Stylosanthes* fodder species, Sadore, Niger, rainy seasons 1986-1988[1].

Stylosanthes accession	1986 sowing	1987 regrowth	1988 regrowth	1987 sowing	1988 regrowth
S. capitata (CIAT 1315)	0.10[2]	0.0[3]	0.0[3]	0.26	9.70
S. capitata (CIAT 1019)	0.0[3]	0.0[3]	0.0[3]	0.45	11.35
S. macrocephala (CIAT 1643)	0.54	0.21	0.0[3]	0.65	5.63
S. hamata (cv Verano)				1.21	6.55
5. capitata (CIAT 10280)	0.59	0.0[3]	1.40	1.04	18.48
5. *hamata* (Badikaha CI)				1.80	10.15
5. hamata (CIAT 147)	5.30	0.86	2.80	2.51	16.68
S. fruticosa (local)	0.74	1.97	1.70	0.84	7.75
SE	±0.47	±0.235	±0.444	±0.093	±1.231
CV (%)	40	46	45	17	23

1. Randomized-block design with four replications; plot size 25 m^2.
2. These values are not included in the statistical analysis.
3. No harvestable yield and not included in statistical analysis.

of *A. hamata* cv 147 and 5. *fruticosa* sown in 1986 were measured. Regrowth of other species was poor.

S. hamata CIAT 147 and *S. fruticosa* produced acceptable yields in a dry year (1987) and outstanding yields in a good rainfall year (1988) (Table 12). *S. hamata* (all cultivars) exhibited biennial growth behavior and dropped leaves in drought. *S. fruticosa* performed better than *S. hamata,* retaining its leaves when dry and has a perennial growth habit. We have begun evaluating these two species in pearl millet intercropping systems. Ten accessions of moth bean (*Vigna aconitifolia* [Jacq.] Marechal) from Rajasthan, India, were evaluated during the 1987 rainy season and seven were retained for further studies. These selections were sown on 7 July 1988 and 6 June 1989. A basal application of 30 kg P ha^{-1} was made at sowing. In both years harvesting was completed by mid-September.

Grain yields for most accessions were relatively high in 1988 with three entries yielding more than 0.5 t ha^{-1} (Table 13). The 1989 sowing

Table 13. Grain yields (t ha^{-1}) and plant densities (plants m^{-2}) of moth bean accessions, Sadore, Niger, rainy seasons 1988-1989.

	1988[1]		1989	
Moth bean accessions	Grain yield	Density on 20 Aug	Density on 21 Jul	Density on 21 Aug
JMM 259A	0.42	10.5	14.0	10.9
Balashwar 12A	0.84	12.0	11.9	6.9
IPCMO 131	0.59	13.8	13.3	8.7
IPCM0 912A	0.40	12.0	18.7	7.6
Badami 12B	0.21	11.0	12.3	6.7
Balashwar 12B	0.62	10.4	12.9	5.6
JMM 259B	0.21	9.6	11.0	8.8
SE	±0.20	±1.0	±2.7	±1.4
CV (%)	83	18	40	37

1. Grain yields were lower than 0.03 t ha^{-1}, densities are given before and after a storm event.

was severely affected by a 3-week drought at the end of July and a heavy rainstorm (120 mm) in August. Plant stands and yields were severely reduced with grain yields between 0.01 and 0 03 t ha^{-1} (Table 14). Moth bean does not tolerate extreme conditions of drought and waterlogging commonly found in the Sahel.

We compared, at wide spacings (1 x 2 m), the growth and development of local cowpea, runner and bunch groundnut, bambara groundnut (*Vigna subterranea* [L.] Verdi.), pigeonpea, moth bean, and guar (*Cyamposis tetragonolobus* [L.] Taub.). Moth bean failed. Canopy development was most rapid with cowpeas but the determinate nature of grain varieties resulted in early leaf senescence and a reduced biomass. Local cowpea cultivars produced most biomass and achieved maximum interception of light by 60 DAS when most other species had reached only 25% interception. Given the wide plant spacings found in farming systems throughout the Sahel, the value of a spreading growth habit was well demonstrated. Harvest index was greatest in pigeonpeas and bambara groundnut (>0.4). Guar proved to be worthy of further research, since yields comparable with other crops were possible with this multipurpose crop.

Extending Cowpea Adaptation

The climate of the Sahel is harsh with a short rainy season (<90 days) from June to September. There is increasing interest in irrigated cowpea production during the noncereal season. Between November and March, night temperatures below 20°C are common and are known to reduce cowpea growth. On the other hand, night and day temperatures between March and June are extremely high, hence they reduce cowpea growth.

In 1984/85, 295 cowpea cultivars were evaluated during the cool months. The objective of this trial was to evaluate plant emergence of introduced and local cultivars. Soil temperatures during the trial period were between 14°C and 20°C, low enough to delay emergence in some lines up to 15 DAS.

In 1985/86, these studies were extended to

Table 14. Yield ($t ha^{-1}$) of cowpea cultivars during the cool season at ISC, 1985-1988[1].

	1985/86		1986/87		1987/88[2]		Mean	
Cultivars	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder
IT84E-1-108	0.76(4)3	0.99(8)	0.45(8)	0.62(8)	0.33(8)	0.45(6)	0.51(7)	0.85(5)
IT83D 237	0.18(9)	0.58(9)	0.35(9)	0.65(7)	0.17(9)	0.32(9)	0.23(9)	0.52(9)
B99 2-1	0.79(3)	1.62(5)	0.73(5)	0.68(6)	0.66(1)	0.71(2)	0.73(3)	0.81(6)
A73-1-2	0.61(6)	2.03(1)	0.77(3)	0.70(4)	0.55(3)	0.49(5)	0.64(4)	0.86(4)
A18-1-l	0.93(2)	1.84(3)	0.75(4)	1.05(2)	0.65(2)	0.91(1)	0.78(1)	1.26(1)
TN27-80	1.12(1)	1.81(4)	0.79(2)	0.69(5)	0.42(7)	0.37(8)	0.78(1)	1.13(3)
TN88-63	0.54(7)	1.90(2)	0.88(1)	1.16(1)	0.51(4)	0.67(3)	0.64(4)	1.18(2)
TN2-78	0.49(8)	1.09(7)	0.52(7)	0.48(9)	0.47(6)	0.43(7)	0.49(8)	0.67(8)
TN5-78	0.72(5)	1.33(6)	0.70(6)	0.83(3)	0.48(5)	0.56(4)	0.63(6)	0.78(7)
SE	±0.09	±0.19	±0.08	±0.10	±0.05	±0.06		
Mean	0.64	1.46	0.66	0.81	0.48	0.54		
CV(%)	29	26	23	24	23	24		

1. Randomized complete block design with four replications, plot size 18 m^2.
2. Five replications used.
3. Values in parentheses are ranks.

evaluate the effects of low night temperature during the reproductive period. A set of 254 introduced and local cultivars was grouped into sets of 20 entries each and sown on 5 November into single-row plots of 4 m length. Two replicates were sown. The phenological stages recorded were: emergence, flower bud formation, first flower, first ripe pod, and physiological maturity. Lower temperatures extended the period of vegetative growth. In some lines, flower abscission was very common and pods were poorly filled. As a group, medium-maturing lines (70-85 days) were most sensitive to cool temperatures.

In 1986/87, 100 promising lines were evaluated. These were sown in single-row plots replicated three times in a randomized complete block design. Phenology and production of total biomass, pods, and seed were measured. Considerable variation between lines for most measured characters was noted.

In addition to our mass screening program, 10 entries were evaluated for their potential 'off-season' performance. Growth of nine cowpea cultivars (Table 14) was comparable with the one obtained during the regular season. We therefore concluded that irrigated cowpea can be grown during the cool dry season.

In order to determine an optimum sowing date for the cool season, three cowpea cultivars were used in a date-of-sowing study. Four fortnightly sowings began in late November. Yield declined with later sowing dates because of excessive flower drop brought about by rising temperatures in February and March. These results indicate that sowing in November was appropriate.

Drought and heat stresses are common in the Sahel. Most local varieties are of long duration with reproductive periods which coincide with the end of the rainy season. The timing of flowering and grain filling in many traditional cultivars coincides with higher temperatures and increased risk of moisture stress. High temperatures are reported to delay or inhibit flower bud development, to increase floral abscission, male sterility, and embryo abortions; all these processes decrease seed-set and grain yield. A set of lines was tested for their ability to produce flowers and pods under temperatures greater than 35°C (March-April).

Significant differences were found between cultivars in their ability to flower and produce pods and grain (Table 15). Introduced cultivars IT84EI-108, IT82D 716, and TVX 3236 were low yielding in both years. The highest-yielding cultivars (SUVITA 2, TN 88-63, and Tera Local) are local cultivars whereas KVX 100-2, KVX 183-1, and KVX 30-309-6G are derived from SUVITA 2. The Sahelian cultivars and their derived lines appear relatively tolerant to high temperatures.

Intercropping Legumes with Upland Rice

Upland rice is a subsistence crop of poor farmers. In a global total of 141 million ha sown to rice, about 19 million ha, or nearly 12%, is sown to upland rice. Its distribution is mainly in Asia (11 million ha), Africa (2 million ha), and Latin America (6 million ha). About 75% of the rice area in Latin America and 50% in Africa are under upland rice.

Productivity of upland rice has remained low (about 0.6 t ha^{-1}) because of climatic stresses of which rainfall is the most variable and least predictable. Recently developed upland rice cultivars maturing in 75-100 days and yielding well (2-4 t ha^{-1}) have increased the prospects for crop diversification in upland sowings. Crop diversification, in terms of both intercropping and sequential cropping, can stabilize productivity in such systems. The most important criterion for intercropping upland rice is to maintain rice yield while obtaining additional yield from grain legumes.

We initiated trials on a Vertisol site at ICRISAT Center during the 1988 rainy season to:

1. develop better agronomic practices for inter- or sequential cropping with upland rice;
2. evaluate the comparative performance of different rice genotypes and grain legumes; and
3. assess the most remunerative and stable

Table 15. Yield (t ha^{-1}) of cowpea cultivars grown under high temperature conditions, ISC, Sadore, Niger, postrainy season 1987-1988[1].

	1987		1988	
Cultivars	Grain	Fodder	Grain	Fodder
IT84E1-108	0.22(12)2	0.62(13)	0.11(13)	0.55(13)
IT82D 716	0.18(13)	0.91(10)	0.50(10)	0.70(11)
B99-2-1	0.67(3)	0.90(12)	0.50(10)	1.45(2)
TVX3236	0.52(9)	1.59(5)	0.33(12)	0.63(12)
KVX268-K03-3	0.54(8)	1.02(8)	0.67(6)	1.07(7)
KVX61-74	0.39(11)	1.74(4)	0.60(8)	1.33(3)
KVX 183-1	0.62(5)	1.02(8)	0.85(2)	1.20(5)
KVX 30-309-6G	0.64(4)	2.14(1)	0.54(9)	1.07(7)
KVX 100-2	0.76(2)	1.16(7)	0.73(5)	1.07(7)
TN88-63	0.55(7)	1.84(3)	0.88(1)	1.22(4)
TN27-80	0.56(6)	0.91(10)	0.75(4)	0.90(10)
SUVITA 2	0.52(9)	1.98(2)	0.80(3)	1.08(6)
Tera Local	0.85(1)	1.59(5)	0.16(7)	1.78(1)
SE	±0.06	±0.12	±0.07	±0.14
Trial mean	0.55	1.35	0.61	1.05
CV (%)	22	18	23	26

1. Randomized complete block design with four replications, plot size 15 cm^2.
2. Values in parentheses are ranks.

cropping systems under different moisture regimes.

Two varieties of each crop, i.e., pigeonpea (ICPL 87 [Pragati] and Hy-3C), groundnut (ICGV 87123 [ICGS 11] and ICG [FDRS] 4), and cowpea (Russian giant and EC - 6216) were intercropped with upland rice (IET-7613 and 7564). Two sowing dates were used—simultaneous sowing of rice and legumes or sowing of legumes a month after sowing of rice. Delayed sowing of legumes was used to maximize rice yield.

Total intercropping yields were greater than those for sole cropping (Fig. 32). Among intercrops, pigeonpea and cowpea were more compatible companion crops with upland rice than groundnut. Pigeonpea intercropping resulted in a yield advantage of 59-100%. Both pigeonpea cultivars were suitable for intercropping because of their ability to withstand wet conditions. Pigeonpea cultivar ICPL 87 was able to avoid terminal drought by early maturity while later-maturing HY-3C utilized residual soil moisture better. Cowpea cultivar EC-6216 was less competitive than Russian giant because of its upright growth character and early maturity. Russian giant smothered the rice with excessive vegetative growth. Cowpea intercropping resulted in a 17% reduction of rice yields but had itself an overall yield advantage of 24-48 %. Although groundnut had no adverse effect on rice yields, LER values for this combination increased only to 1.24-1.26 due to poor groundnut yields.

The intercropping trial was modified and repeated during the 1989 rainy season. Ground-

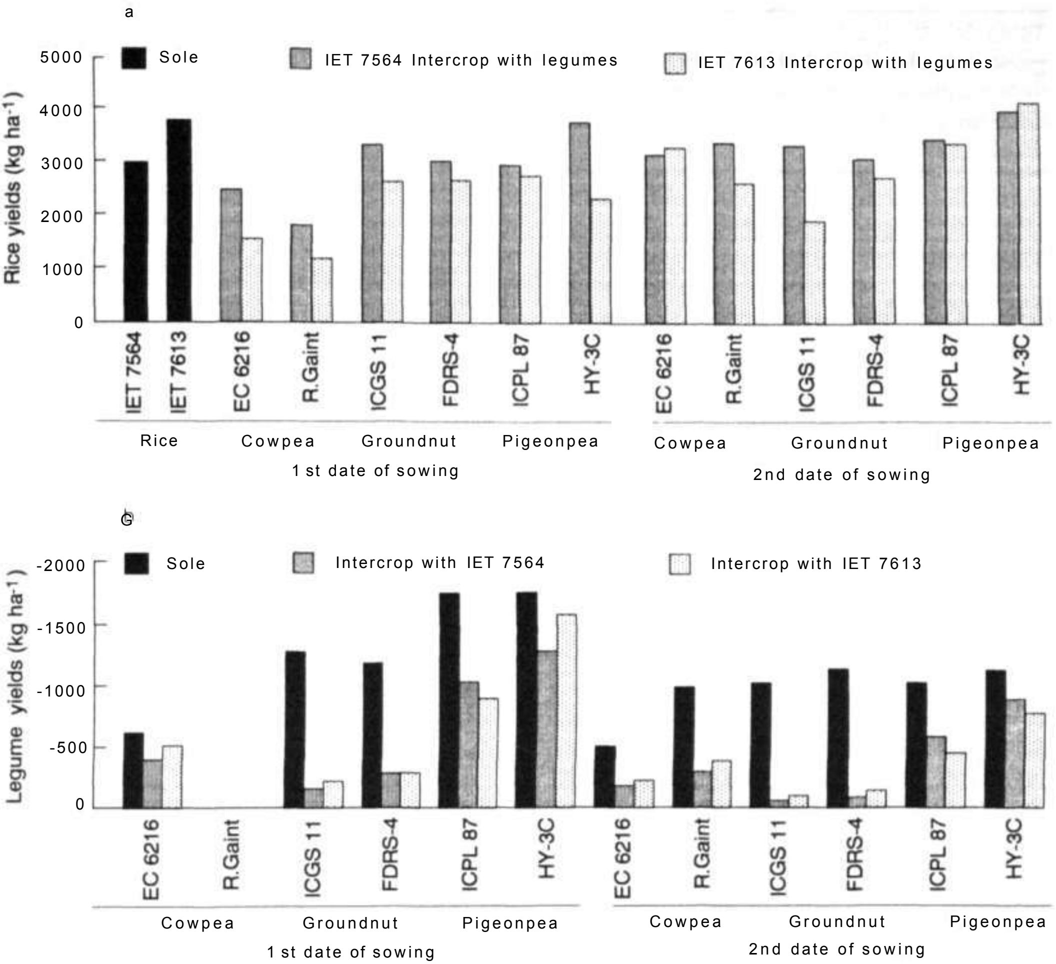


Figure 32. Rice (a) and legume (b) grain yields as influenced by sowing date and cropping system for rainy season sowings made at ICRISAT Center during 1989.

nut was omitted because of low LER values and cowpea cv Russian giant replaced with GC-2, which had upright growth, minimum branching, and early maturity. All crops were sown simultaneously with rice. In addition, work on rice/ pigeonpea intercropping systems was expanded in response to favorable results on biomass production and economic returns in the 1988 studies. Pigeonpea genotypes of medium, early, and extra-early maturity were selected for tolerance to waterlogging. Results indicated that extra-early-maturing and early-maturing pigeonpea genotypes are suitable for intercropping with rice while medium-maturing genotypes are too competitive (Table 16). Extra-early-maturing pigeonpea genotypes were sensitive to competition from rice and matured too early to take full advantage of residual soil moisture after the rice harvest.

Results of the pigeonpea/ rice systems for both years confirmed that high LER and economic returns were possible using early-maturing pi-

Table 16. Comparison of grain yields of rice grown as a sole crop and as an intercrop with different pigeonpea cultivars, influenced by their different maturities, ICRISAT Center, rainy season 1989.

Treatments	Duration	Grain yield (t ha^{-1})
Sole rice (IET-7564)		4.11
Rice + pigeonpea		
ICPL 83015	Extra early	3.36
ICPL 84023	Extra early	3.58
ICPL 87 (Pragati)	Early	3.69
HY-3C	Medium	1.90
ICPL-8357	Medium	1.09
ICPL-84071	Medium	1.26
ICPL-8744	Medium	1.32
SE		±0.144
CV(%)		9.8

geonpea genotypes such as ICPL 87. Medium-duration pigeonpea genotypes were more competitive with rice in 1989 than in 1988 largely because the rainfall distribution in 1989 was more favorable for pigeonpea growth. In sharp contrast, a long period of waterlogging in 1988 promoted rice growth while suppressing pigeonpea growth. Our findings highlight the importance of rainfall quantity and intensity on the interaction between intercropped pigeonpea and upland rice.

Economic Evaluations

Productivity in Intercropping Systems

Drawing on the concept of production possibility curves, an analytical procedure was developed for evaluating trade-offs in biological productivity in intercropping experiments. Yield trade-offs between species were evaluated by plotting the yields of the two competing crops on a graph. The shape of the curve passing through the scatter of mean yield observations in Figure 33 indicates the nature of the relationship between the crops: complementary if the curve is convex, or competitive if concave, and independent if the estimated relationship is a straight line. A 'global index' of biological productivity (or Yield Advantage Index [YAI]) was defined as the ratio of the area under the curve to the area under the straight line joining the sole crop yields.

To estimate statistically the curve that fits best a scatter of points, it is necessary to assume that the curve takes a certain mathematical form. This form should be flexible enough to capture the range of crop enterprise interactions described in Figure 33 but also compact enough to summarize the relationship with as few parameters as possible.

Several functional forms were tried. The one that best satisfied the flexibility and compactness conditions was the Constant Elasticity of Substitution/Constant Elasticity of Transfor-

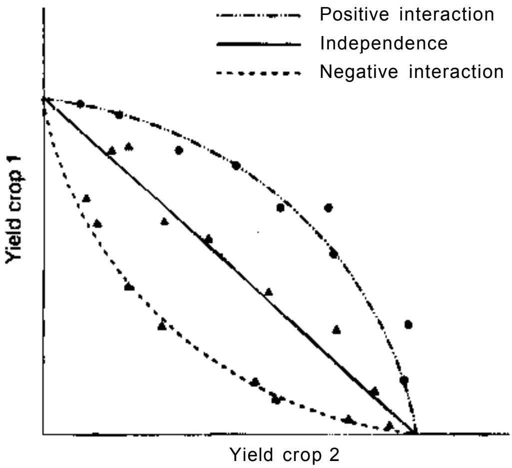


Figure 33. Theoretical basis for interactions between two species in intercropping experiments.

mation (CES/CET) functional form. The equation of the CES/CET is:

$$b = [aY_1^c + (1-a)\ Y_2^C]^{(1/C)}$$

where Y_1 and Y_2 are yields of the component crops; a, b, and c are parameters to be estimated. For ease in computation, the equation was rewritten as

$$b^* + aY_1^c + (1-a)\ Y_2^C = 1, \text{ where } b^* = l-b^c\ .$$

The parameters estimated are b*, a, and c. When c = 1, the equation is that of a straight line; if c > 1 the curve is concave; if c <1 the curve is convex. Thus one parameter, 'c,' in the CES/ GET functional form directly provides information on the nature of species interactions. The other two parameters position the curve: increasing 'b' pushes the curve from the origin perpendicular to the 45° axis, while modifying 'a' rotates the curve, lengthening one axis and shortening the other.

Data were obtained from intercropping experiments at ICRISAT Center, India. The experiments were selected to determine how well the CES/CET functional form stood up to the range of experience of potential intercropping interactions conveyed in Figure 33.

The estimated coefficients are presented in Table 17. For the three data sets, the fit is satisfactory, and the estimated shape of the curve corresponds well with prior agronomic knowledge about the relationship between the crops. The sorghum/ pigeonpea intercrop, for instance, is known to display strong temporal complementarity. For the agroforestry data set, the relationship is marked by competition. Leucaena roots were found near the soil surface competing with the annual crops for soil moisture (Annual Report 1986). Pigeonpea was highly susceptible to competition from leucaena.

Table 17. Estimated parameters of the CES/ CET function and the Yield Advantage Index (YAI).

	Estimated parameters			
System	b*	a	c	YAI
Sorghum/ pigeonpea 1978-1981	-0.15	0.59	3.28	1.79
Pearl millet/groundnut 1980-82	-0.19	0.52	1.18	1.16
Leucaena/ sorghum/ pigeonpea 1986-87	-0.24	0.41	0.76	0.73

Turning to the economic interpretation of the three data sets, for almost all price ratios of pigeonpea to sorghum, farmers would choose an intercrop over sole crops of either species. The estimated curve is consistent with the recommendation to invest agricultural research and extension resources in the sorghum/pigeonpea intercrop because of its superior relative yield performance. Such investment could take the form of cultivar screening in intercropping conditions or of demonstrations assigning priority to the sorghum/pigeonpea intercrop vis-a-vis sole crops of sorghum or pigeonpea.

On the basis of biological productivity, the case for the pearl millet/groundnut intercrop is much weaker. The small intercropping yield advantage does not appear to warrant favoring pearl millet/ groundnut intercrop over sole cropping alternatives in decisions on research and extension resource allocation. The choice of sole cropping or intercropping depends largely on the price ratio of groundnut to pearl millet. Positive yield interactions are not large enough to offset the importance of economic considerations in the choice of cropping systems. Highly negative yield interactions swamp economic considerations in each year of the agroforestry trial. For all output prices, hedgerow intercropping with leucaena is economically inferior to producing leucaena in sole stands.

On-station Operational-scale Trials

Operational-scale trials at ISC from 1986 to 1988 evaluated combinations of improved varieties of pearl millet and cowpea, the use of AT for ridging and weeding, and an improved technology package consisting of new varieties, higher sowing densities, rotations, intercrops, and 13 kg ha^{-1} of phosphorus (ICRISAT Annual Report 1988, pp. 195-197).

A comparative economic analysis of data from 13 treatments showed that manual cultivation of a pearl millet/cowpea rotation or intercrop plus the improved package may be the best combination to recommend to farmers. This is particularly appropriate for farmers who have little experience with AT, who cannot afford the expense, or who cultivate less than 4.5 ha. Incremental value-to-cost ratios were greater than 4 for either manually cultivated pearl millet-cowpea rotation or intercrop, while the same ratios were scarcely greater than 2 for any of the other treatments. The pearl millet-cowpea rotation or intercrop also produced returns to land, labor, and capital that were superior to returns to similar factors of production used in the other treatments.

The choice between a pearl millet/cowpea rotation or intercrop depends on the availability of household labor and on the true opportunity costs of farm household resources. For pearl millet to obtain the maximum benefit from the N fixed by a preceding cowpea crop, careful rotation of sowing sites may be necessary. Moreover, in view of the need to manage sowing dates and densities so that neither crop in the intercrop is disadvantaged, pearl millet-cowpea rotation seems to be more attractive to farmers. In such rotations, the farmer can allocate portions of his land to cowpea and pearl millet each year, conforming with his household's goals for food security and income.

Table 18 shows that the beneficial effects of crop rotation were larger than those by using AT for ridging and weeding. With the inclusion of a cowpea rotation instead of sole continuous pearl millet under improved conditions, returns from all factors of production increased substantially. The inclusion of a cereal/ legume intercrop greatly enhances benefits derived from the use of new varieties, phosphorus fertilizer, and high populations. Returns from the use of animal traction for 2 ha were less than returns from manual cultivation. However, improved returns from land and household labor were achieved when AT was used for 4.5 ha. The analysis therefore showed that economies of size in the use of AT were necessary for this technology to be relatively profitable compared to the use of manual cultivation.

Pigeonpea Production in Northeast Thailand

In collaboration with the Ministry of Agriculture in Thailand and the Australian Centre for International Agricultural Research (ACIAR), we assessed the economic feasibility of pigeonpea production in northeast Thailand. Collaborative research by Thai institutions and ACIAR conducted earlier indicated that, although pigeonpea is not grown as a field crop in Thailand, it is well suited to the environment in the northeast. Further, pigeonpea could, within limits, replace imported soybean *(Glycine max* [L.] Merr.) meal in broiler diets. We approached the assessment as an attempt to identify economically viable production and utilization of niches and to indicate which niches may be amenable to expansion through research.

From maps of land use potential and rainfall probability profiles from meteorological stations in the northeast, we identified Khon Kaen and Chayaphum provinces as target areas for a survey of 58 farms. In addition, the researcher-managed, on-farm pigeonpea production trials were conducted on six farms, two each from the Khon Kaen, Ubon Ratchathani, and Rayong provinces. Records from the survey and the production trials enabled us to construct a synthetic pigeonpea budget and an assessment of the profitability of pigeonpea production when this crop has to compete for land with crops already grown in the area.

The main conclusions from the study are as follows:

- There are no obvious technical, institutional, or agronomic constraints to prevent farmers in the northeast Thailand from growing pigeonpea. However, pigeonpea is unlikely to

Table 18. Percentage changes in returns due to specific improved practice(s) and operational-scale research (OPSCAR) trials at Sadore, Niger, 1986-1988.

Effect of:	Comparisons	Land area (ha)	Increments in increased returns[1]					
			Land		Labor		Capital	
			CR[2]	PMCR[3]	CR	PMCR	CR	PMCR
Rotation[4]								
Manual	PM, C, PM vs PM, PM, PM	2.0	130	80	24	17	55	37
Traction	PM, C, PM vs PM, PM, PM	2.0		39	33	-5	10	7
		4.5	46	18	-3	-16	12	4
Animal traction[5]								
(PM/C,C,PM/C)	Traction vs manual	2.0	-14	-11	-3	-1	-50	-55
		4.5	53	37	25	-17	-17	-24
Improved inputs[6] (manual)								
	Improved vs traditional[7] (PM/C,PM/C,PM/C)	2.0	489	320	62	66	94	62
	Improved vs traditional[7] (PM,PM,PM)	2.0	129	66	30	43	25	15
Rotation plus	PM/C,PM,PM/C	2.0	426	198	61	67	94	58

1. Labor opportunity cost; 65 CFA h^{-1}
2. CR = Crop values including cowpea hay.
3. PMCR = Crop values including cowpea and pearl millet residues.
4. Rotation: PM = pearl millet, C = cowpea.
5. Animal traction is used for ridging and weeding.
6. Improved inputs: improved varieties, phosphorus applications, increased plant densities.
7. Traditional inputs: traditional varieties, no fertilizer, low plant densities.

be adopted if adoption diminishes the production of rice for home consumption.

- Pigeonpea production is unlikely to be profitable when its yield levels are around 11 ha^{-1} or less and when its value as broiler feed is 3 Baht kg^{-1} or less.
- Effective and cheap insect pest management will be decisive for the profitability of pigeonpea production.
- Kenaf (*Hibiscus cannabinus L.*) is the weakest competitor for pigeonpea in the northeast, but cassava (*Manihot esculenta* Crantz) could compete with pigeonpea only if cassava prices collapsed.
- Current efforts to increase soybean production in Thailand will reduce pigeonpea's attractiveness as a substitute for soybean in broiler diets, and an increase in its value above 3 Baht kg^{-1} is unlikely.

Time Preference

Trade-offs between consumption today and consumption tomorrow reflect the rate at which a farmer prefers the present or discounts the future. A farmer with a high positive rate-of-time preference is 'impatient' and prefers consumption in the present to an equivalent level of consumption in the future. Such a farmer is not likely to save or invest significantly unless the returns he expects from his investment are large enough to outweigh his preference for current consumption. Information about the rate of time preference can therefore be useful in understanding investment and credit market behavior. Moreover, the prospects for adoption of new agricultural technologies and their structural impacts are partially determined by the way farmers behave with respect to time.

Through experimental games and hypothetical questions, we elicited information on discount rates from heads of rural households in SAT India. Participating in the study were households in two ICRISAT study villages, Aurepalle and Dokur, in the Mahboobnagar district of Andhra Pradesh. Forty-eight respondents were selected from each village. Six experimental games and five hypothetical questions were used to estimate participants' rate-of-time preference under various control conditions. The control variables were: (a) size and timeframe of game (3 combinations); (b) order of games (3); and (c) reference point (2).

Although the mean levels of estimated discount rates were not significantly different between the experimental game and hypothetical question methods, the patterns and behavior of responses were fundamentally different for the two methods. Village credit market conditions served as reference or anchoring points for responses to the hypothetical questions. In contrast, respondents were more deliberate in choosing rewards in the experimental games. Their choices seemed to reflect a 'purer' consumption rate-of-time preference which appeared to be influenced by their assessment of current ability to meet consumption requirements relative to future ability. Because of these differences, the responses to the experimental games showed considerably more variation across households than did the answers to comparable hypothetical questions.

Both methods of measurement gave one clear and similar result: the estimated discount rates were high. The mean annual discount rates for the five hypothetical questions ranged from 0.33 to 0.55. In each experimental game, the estimated discount rate exceeded 0.40 for two-thirds of the participants. In general, the estimated discount rates were considerably higher than subsidized annual interest rates of 9-11 % for institutional credit or even 2-3% per month for medium-term loans offered to good clients in the village informal credit market. Given a mean per caput income of about US $ 200, high rates of discount were anticipated. A mean discount rate of 0.45 stiffly penalizes technologies that generate benefits in the future relative to the present. For example, a discount factor of 0.45 implies that benefits received 4 years from now are only worth about 30% of benefits received now.

With economic growth and development, economic theory suggests that the strong preference for the present will secularly decline. Preliminary empirical evidence on the effect of wealth on discount rate also supports this prediction. Wealth was inversely and significantly related to the discount rate in several of the experimental games and hypothetical questions. A proportional 10% rise in net wealth was accompanied by a 3-7% fall in the discount rate. Without economic growth and development, environmental concerns about the future will continue to be divorced from the reality of high rates of positive time preference shown by decision-makers at present.

Collaborative Work

CRIDA-Agroforestry

We continued our collaboration with CRIDA at the Hayatnagar Farm to determine the mechanisms responsible for the apparent absence of competition between two N-fixing trees, *Faidherbia albida* (earlier *Acacia albida)* and *Albizia lebbek,* and dryland crops (ICRISAT Annual Report 1988, p. 188). Both species are deciduous but *A. lebbek* sheds its leaves during the dry season and *F. albida* sheds its leaves during the onset of the rainy season. At low densities, *A. Jebbek* was reported to have increased the yield of *Panicum maximum* and spear grass in northern Australia.

This study is part of a wider effort by both CRIDA and ICRISAT scientists to investigate the long-term consequences of four N-fixing trees on soil properties. The other species—*Leucaena leucocephala* and *Prosopis cineraria* have not been included because leucaena is too competitive and *P. cineraria* too slow growing. Trees were planted at 4 x 4-m spacings in June 1985 on a shallow gravelly Alfisol as described previously (ICRISAT Annual Report 1988, p. 188). Measurements included growth, transpiration, and canopy development of the trees, and the yield of understory sorghum and castor.

Figures 34 and 35 illustrate the growth in height and diameter of all four tree species and show that leucaena was clearly the fastest-growing species, reaching a height of 7.8 m followed by *A. lebbek* and *F. albida* at 3.5-4.0 m and lastly by *P. cineraria* at 1.5 m. After the second year, *A. lebbek* had a larger diameter than *F. albida* but yield of understory crops was greatly reduced by *A. lebbek* in 1988. Leucaena was even more competitive than *A. lebbek,* resulting in complete failure of castor crop in both years.

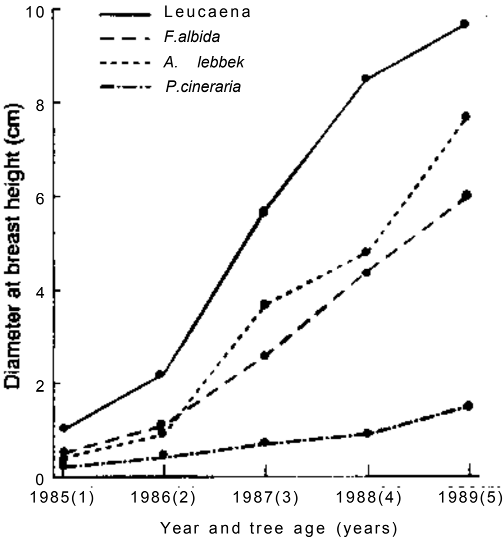


Figure 35. Diameter at breast height and age of four tree species grown at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India.

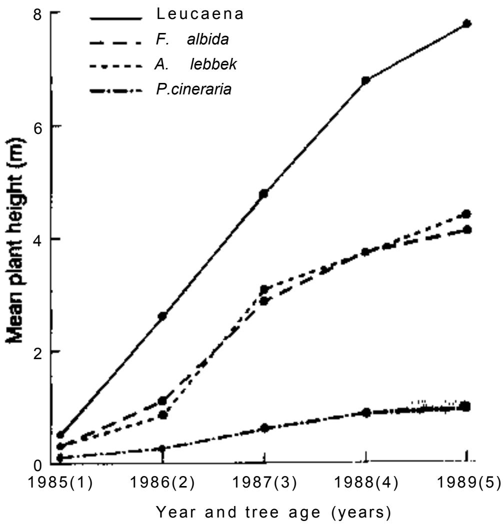


Figure 34. Mean plant height (m) and age of four tree species grown at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India.

The general trend in canopy cover as measured by fisheye technique, showed that during the dry season from October 1988 through July 1989, *A. lebbek* had a much more extensive canopy than *F. albida* even when leaf shedding was greatest in *A. lebbek* in April 1989 and before the onset of rain in mid-June 1989 (Fig. 36). *F. albida* commenced rapid canopy development in mid-August when the sorghum was 50-days-old and when *A. lebbek* had reached 30% canopy cover.

The trend in transpiration of *F. albida* is consistent with the canopy measurement which showed a rapid increase from mid-August to early October at the time when transpiration of *A. lebbek* was steadily declining (Fig. 37). These results imply that the late canopy development of *F. albida* allows the roots of sorghum to

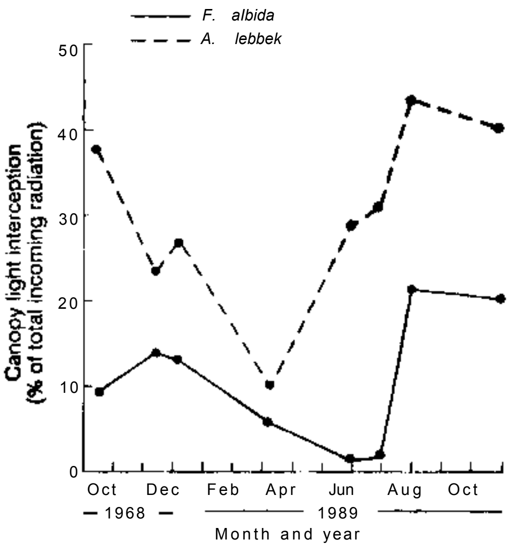


Figure 36. Canopy light interception of total incoming radiation for two tree species between October 1988 and 1989 at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India.

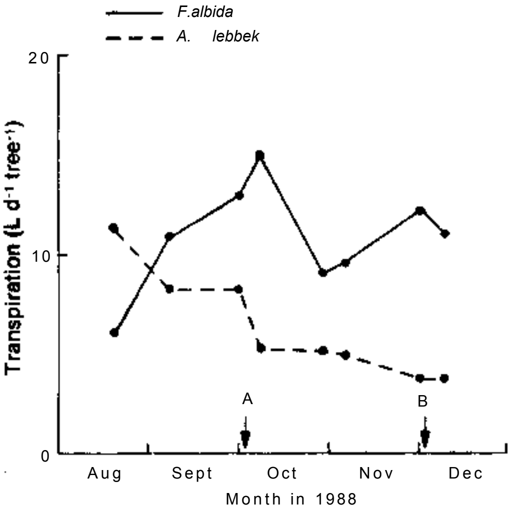


Figure 37. Transpiration (L d^{-1} $tree^{-1}$) for two tree species between August and December 1988 at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India.

explore the moisture in the upper soil profile so that the roots of *F. albida* had to extract deeper moisture. In marked contrast, the early and greater canopy development of *A. lebbek* was associated with a 40% reduction in the grain yield of sorghum and a 45% reduction in castor in 1988 (Table 19). It is doubtful whether the present population of *A. lebbek* will be suitable for understory crops in the future unless it is pruned further during the early part of the growing season.

Table 19. Grain yield (kg ha^{-1}) of crops grown under N-fixing trees at the Hayatnagar farm in 1987 and 1988.

	1987		1988	
Crops	Sorghum	Castor	Sorghum	Castor
Faidherbia albida	587	635	1730	525
Albizia lebbek	467	507	1020	294
Prosopis cineraria	520	534	1710	539
Leucaena leucocephala	73	0	780	0
Sole crops	577	576	1720	542
Grain mean	445	450	1392	380
SE	±32	±20	±106	±28
Rainfall (mm) (Jul-Nov)	320		470	

Operational-scale Research at Birni N'Konni (Niger) with INRAN

In 1987, the Institut national de recherches agronomiques du Niger (INRAN) and ICRI-

SAT began collaborating on an operational-scale experiment at the INRAN substation located at Birni N'Konni, 340 km east of Niamey, Niger. Soils in this area are characterized by a slightly higher clay content than the sandy soils at ISC, Sadore. For this experiment, INRAN and ICRISAT identified components of research that had consistently shown promising results.

We compared combinations of innovative technologies including application of P-fertilizer (13 kg ha^{-1}), improved varieties of pearl millet (C1VT) and cowpea (TN 5-78) in pure crop systems, rotation of pure crops, and AT for presowing ridging and weeding. Each component was expected to contribute significantly to increased productivity, making adoption rather more flexible than in the case of a complete package. These components were combined in seven treatments (Table 20). We used a factorial experimental design with four replications, and a plot size of 500 m^2. The experiment was conducted during the 1987, 1988, and 1989 rainy seasons.

During the first year, we experienced a 5-week delay in the onset of rains. In addition, total rainfall was only 248 mm, putting the systems under severe drought stress. The other years had normal onsets of the rainy season with well distributed total rainfalls of 534 mm in 1988 and 448 mm in 1989.

The positive effect of modest doses of P-fertilizer on crop yields was significant in all years particularly in 1987 which was a highly rainfall-deficient year. In the same year, presowing ridging increased average pearl millet grain yield by 0.16 t ha^{-1} and stover by 1.55 t ha^{-1}. The other improved component, that is, crop rotation, could be analyzed only from 1988 onwards.

The rotation of pearl millet with cowpea has had a consistently positive effect on pearl millet yields during the two years analyzed. Pearl millet grain yield was less in 1989 than in 1988 and there was no year by treatment interaction for pearl millet grain or stover. Rotation almost doubled pearl millet grain yield from 0.97 t ha^{-1} to 1.73 t ha^{-1} (SE ± 0.04) and stover yield from 1.56 t ha^{-1} to 2.81 t ha^{-1} (SE ± 0.07) (Fig. 38).

Grain yields of the improved pure cowpea systems (after two sprayings to control insects) proved very stable, did not differ because of rotation or ridging, and were on average 1.34 t ha^{-1} in 1988 and 1989. However, ridging increased hay yields significantly on average by 0.68 t ha^{-1}. In the dry year of 1987, ridging boosted hay yields by 0.34 t ha^{-1}.

Table 20. Treatment combinations under eval-uation in operational-scale research (OPSCAR) during 1987, 1988, and 1989 in INRAN/ICRISAT, Birni N' Konni, Niger.

Treatments	Cropping system[1]
Traditional[2]	With PM/C, PM/C, PM/C
Improved[3], ridging[4]	With PM, PM, PM
Improved, ridging	With C, PM, C
Improved, ridging	With C, PM, C
Improved, ridging	With PM, C, PM
Improved, manual[5]	With C, PM, C
Improved, manual	With PM, C, PM

1. PM = pearl millet (sole) at 1.5 x 0.75 m spacing.
   C = cowpea (sole) at 0.75 x 0.36 m spacing.
   PM/C = pearl millet/cowpea intercrop; traditional varieties with PM at 1.5 x 1.5 m and C at 1.5 x 3 m hill spacings.
2. Two manual weedings, no chemical or fertilizer inputs.
3. P-fertilizer at 13 kg ha^{-1}, insecticide on cowpea, parallel rows with pearl millet and cowpea, and cowpea thinning.
4. Presowing ridging without primary tillage, animal power per ridging without primary tillage, animal power per ridging and weeding with manual intrarow weeding.
5. No preparatory tillage, all weeding by hand.

In the first year when procedures for labor time measurements were being standardized, labor times of some operations were much higher and more variable than those measured in the following years. Therefore labor time measurements were presented for 1988 and 1989 only (Table 21).

Animal traction reduced the overall time spent on weeding by 17 man-hour ha^{-1} for improved pearl millet and 19 man-hour ha^{-1} for improved cowpea. The time saved is modest, but it is accrued at a critical time whereby arduous

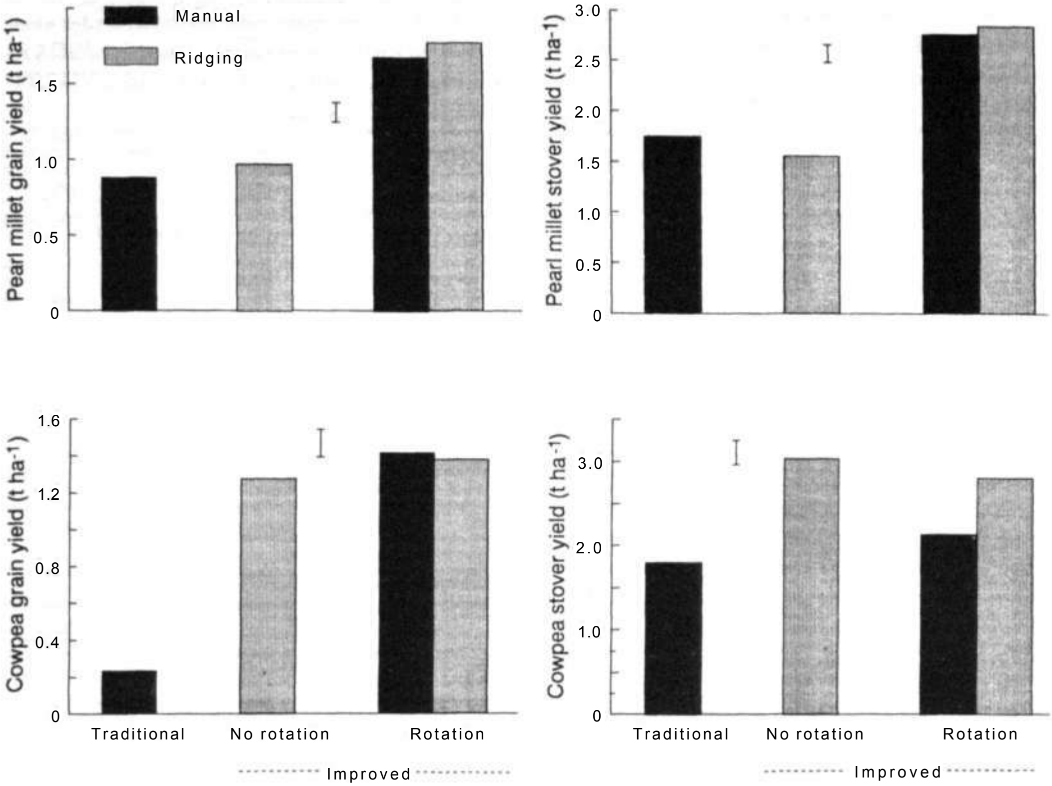


Figure 38. Impact of crop rotation and animal traction on grain and stover yield, Birni N'Konni, Niger, average of the 1988 and 1989 rainy seasons.

hand weeding is avoided. It is apparent that the grain harvest of the improved pure cowpeas is a tremendous bottleneck of labor. In 1988 and 1989, when cowpea grain yields were more than double of those in the dry year of 1987, the time needed for hand picking the cowpea pods, which was already considerable, was also doubled. Farmers who visited the site were impressed by the tillage and weeding using AT, and by the use of improved varieties.

Results obtained so far are promising. The effects of phosphorus and the legume-cereal rotation are very clear. Labor returns in output h^{-1} of work are considerably higher for improved pearl millet-based production systems, because less labor time is needed to produce higher yields. Omitting ridging would save additional 10 man-hours ha^{-1}, but would detract time from weed control. On the other hand, ridging resulted in increases of stover or hay production. Another untested option of animal-powered mechanization such as sowing does not seem relevant to the widely spaced pocket-sown pearl millet. It might, however, save time in the case of the more densely sown cowpea. We believe that AT should be used to intensify crop production, combined with the use of P and higher sowing densities. If not, it will result in increasing the land under cultivation but will not contribute to the sustainability of the production systems.

Table 21. Labor time requirements (man-hours ha^{-1}) of field operations for five millet-based cropping systems. INRAN/ICRISAT collaborative operational-scale research (OPSCAR) experiment, INRAN Research Station, Birni N'Konni, averages of rainy seasons of 1988 and 1989.

Treatment	Ferti-lizer	Ridg-ing[2]	Sow-ing	Thin-ning	1st weed-ing[3]	2nd weed-ing[3]	Harvest[1]: Spray-ing cowpea[4]	Harvest[1]: Grain	Harvest[1]: Dry matter	Total man-hours
Traditional	-	-	11.2	-	57.2	28.4	-	51.6	51.9	200
Improved										
Pearl millet, manual	3.5	-	14.4	26.1	41.0	26.0	-	42.1	18.0	173
Pearl millet, ridging	3.1	10.5	15.0	25.9	26.0	23.8	-	39.6	19.2	162
Cowpea, manual	3.7	-	31.4	11.9	37.0	36.2	4.8	354	44.6	524
Cowpea, ridging	3.8	10.4	28.7	14.5	26.8	27.4	4.7	355	45.9	518
SE	±0.33	±0.29	±0.87	±0.89	±1.40	±1.06	±0.17	±12.5[5] ±2.48[6]	±2.69	±11.49
CV (%)	26	8	12	17	12	11	7	10[5] 18[6]	22	10

1. Cowpea beans picked and bagged, pearl millet heads cut and bundled, pearl millet and cowpea stover cut and bundled.
2. Two operators, one pair of bullocks.
3. Supplemental intrarow hand weeding where mechanized cultivation was used.
4. Two sprayings with ULV sprayer.
5. Cowpea beans.
6. Pearl millet heads.

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TECHNOLOGY TRANSFER

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The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

TECHNOLOGY TRANSFER

Human Resource Development

During 1989, National Ministries of Agriculture, Universities, and semi-arid tropics (SAT) research or development programs nominated more than 400 scientists or technicians for training. ICRISAT Center accepted 258 nominees (Tables 1 and 2). There were 116 participants in the regional and national human resource development activities (Tables 3 and 4) in addition to those participating in degree programs. The Postdoctoral Fellows, In-service Fellows, Research Scholars (MSc or PhD), National Scientists, In-service Trainees, and Apprentices were coordinated by the Training Officers and Research Scientists through the Training Advisory Committee.

Table 1. Participants in long-term training programs, ICRISAT Center, 1989.

Category	Number	Weeks	Countries
Postdoctoral Fellows	12+7[1]	536	11
In-service Fellows	66+6	398	27
Research Scholars	15+15	752	10
In-service trainees (6 months)	99	2563	33
National Scientists	18	84	11
Apprentices	17+3	242	9
Total	227+31	4575	51[2]

1. Number continuing into 1990.
2. Different countries.

Table 2. Participants by region, country, and category in training, ICRISAT Center, 1989.

Region/country	PDF[1]	1SF	RSC	IS	NSC	App	Total
Eastern Africa							
Burundi				1	1		2
Ethiopia		5+2[2]		8	2		15+2
Kenya		4		1	2		7
Rwanda					2		2
Somalia	1	0+1	1+3	4	3		9+4
Sudan		4		5	2		11
Uganda	0+1	2		3	1		6+1
Southern Africa							
Botswana				1			1
Malawi		1		4			5
Mozambique				4			4
Swaziland				4			4
Tanzania		1	1	2	2		6
Zambia				5			5
Zimbabwe		3	1	5			9

Continued

Table 2. *Continued*

Region/country	PDF[1]	ISF	RSC	IS	NSC	App	Total
Western Africa							
Benin		1		2			3
Burkina Faso		2		3			5
Cameroon		1					1
Chad				2			2
Cote d'Ivoire				2			2
Ghana	1	2					3
Guinea				3			3
Mali		1		4			5
Mauritania		1		1			2
Niger		1		1	i		3
Nigeria		2+1		2			4+1
The Gambia				3			3
Togo		1					1
Asia							
Afghanistan				2			2
Bangladesh		2					2
India	4+2	20	7+8			1	32+10
Indonesia		1					1
Nepal		2		2			4
Pakistan		0+1		2			2+1
People's Republic of China			1	3			4
Sri Lanka	1	1		4	1		7
Thailand		3		5			8
The Philippines		3+1		5	1		9+1
Vietnam			1	4			5
Yemen, Arab Republic		1		1			2
Latin America and the Caribbean							
Argentina	0+1						0+1
Honduras				1			1
Mexico		1				1	2
Trinidad	1						1
Others							
Australia						2	2
Denmark						1	t
Federal Republic of Germany	1		2+1			2+1	5+2
France	0+2						0+2
Japan	1		0+1			3	4+1
The Netherlands						2+1	2+1

Continued

Table 2. *Continued.*

Region/country	PDF[1]	ISF	RSC	IS	NSC	App	Total
UK			0+1			5	5+1
USA	2+1		1+1			0+1	3+3
Total	12+7	66+6	15+15	99	18	17+3	227+31

1. PDF = Postdoctoral Fellows, ISF = In-service Fellows, RSC = Research Scholars, IS = In-service Trainees (6 months), NSC = National Scientists, App = Apprentices

2. Number continuing into 1990.

Table 3. International and regional special training activities, 1989.

Activity (sponsors/leadership)	Location	Participants	Country and participants
Cereal pathology for eastern Africa technicians (SAFGRAD, EARSAM, ICRISAT)	India	12	Burundi, Kenya (2), Rwanda (2), Somalia (2), Sudan (2), Tanzania (2), Uganda
Detection and identification of legume viruses (ICRISAT)	India	8	Bangladesh, India, Nepal (2), Sri Lanka, Thailand, the Philippines, Uganda
Vertisol; soil management technology (IBSRAM, ICRISAT)	India	20	Benin, Burkina Faso (2), Cameroon, Ethiopia (3), Ghana (2), Kenya (2), Malawi, Mali, Nigeria (2), Sudan, Tanzania, Togo, Zimbabwe (2)
Legume pathology (ICRISAT)	India	9	Ethiopia, India (3), Indonesia, Kenya, Niger, Thailand, Uganda
Cereal entomology (KARI, SADCC, EARCAL, ICIPE, ICRISAT)	Kenya	17	Burundi, Ethiopia (2), Kenya (6), Rwanda (2), Somalia (2), Sudan (2), Uganda (2)

In-service Training Programs at ICRISAT Center

The intensive 8-week course in scientific English comprehension and usage was attended by 28 research scientists and technicians from 15 countries: Benin (2), Burkina Faso (3), Chad (2), Cote d'Ivoire (2), Guinea (3), Mali (4), Mozambique (4), Somalia (2), Honduras, Mauritania, Niger, Sudan, Thailand, and Yemen Arab Republic.

There were nine employees from seven countries who completed the chickpea, pigeonpea, and groundnut postrainy-season improvement programs in March. Eighty-four nominees from

In-service trainee emasculating pigeonpea florets.

Table 4. In-country training activities, 1989.

Location	Activity (sponsors/leadership)	Partici-pants
India	Hybrid pigeonpea production (ICRISAT)	10
Bangladesh	Legume breeding, management, and production (BARI, AVDRC, ICARDA, Indian NRS, AGLN/ ICRISAT)	30
Nigeria	Sorghum hybrid seed production (WASIP/ICRISAT)	10

30 countries (Table 5) participated in rainy-season practical field training and conducted 60 sorghum, 22 pearl millet, 40 groundnut, 18 pigeonpea, 22 intercropping, and 2 maize experiments, as well as 19 sorghum, 8 pearl millet, 5 groundnut, and 3 pigeonpea international trials. Production agronomy participants, interested in extension methods, conducted two pearl millet field demonstrations (Table 6).

National scientists from Ethiopia (2) undertook selected training (17 weeks) in soil and plant analysis techniques. Climatology studies (2 weeks) were completed by a scientist from Sri Lanka. Germplasm collection and evaluation techniques were studied (12 weeks) by a Somalian scientist. Research workers from Niger and the Philippines studied millet pathology (5 weeks)

Table 5. Six-month in-service training participants in 1989.

Study group	Country and participants	Total number of participants
Postrainy-season programs	(Continued from 1988)	
Legumes Improvement	Afghanistan (2), Malawi, Pakistan (2), the Philippines, Sri Lanka, Sudan, Zambia	9
Rainy-season programs		
Cereals Improvement	Burkina Faso (2), Chad, China, Cote d'Ivoire, Ethiopia (2), the Gambia, Mali, Mauritania, Mozambique, the Philippines, Somalia (3), Sudan, Swaziland (2), Uganda (2), Vietnam (2), Zambia (2), Zimbabwe (2)	27
Legumes Improvement	Benin, Burkina Faso, People's Republic of China, Ethiopia, Guinea, Malawi (3), Mali, Mozambique (2), Nepal, Sri Lanka (2), Sudan, Swaziland, Thailand (2), Vietnam (2)	20
Production Agronomy	Benin, Botswana, Burundi, People's Republic of China, Cote d'Ivoire, Ethiopia, Guinea, Mali, Nepal, Nigeria (2), the Philippines, Somalia, Sri Lanka, Swaziland, Tanzania (2), Thailand (2), Uganda, Yemen Arab Republic, Zambia, Zimbabwe (2)	24
Resource Management	Chad, the Gambia (2), Guinea, Honduras, Mali, Mozambique, Niger, the Philippines (2), Sudan, Thailand, Zambia	13

Table 6. Experiments, trials, and demonstrations planned and conducted by rainy-season 6-month in-service trainees , ICRISAT Center, 1989.

	Crop					
Experiment or trial involving	Sorghum	Pearl millet	Groundnut	Pigeonpea	Inter-cropping	Total
Varieties	17	3	24	12		56
Hybrids	4					4
Fertilizer	15	4	5	2	1	27
Weed control	1	2				3
Plant density	8	3	5	4		20
Pathology	10	10	3			23
Entomology	4					4
Intercropping trials					21	21
B-line evaluation	1					
International trials	19	8	5	3		35
Demonstrations		2				
Crossing blocks			3			
Total	79	32	45	21	22	199

A trainee sowing seeds as part of his field experiment.

and legume agronomy (7 weeks) with our research program scientists.

In-service Regional and National Activities

Mexico

Scientists from Mexico (3), and El Salvador, and a technician from Columbia completed 3-month programs in sorghum improvement and production at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) with Latin American Sorghum Improvement Program (LASIP) staff.

Zimbabwe

The Southern African Development Coordination Conference (SADCC/ICRISAT staff provided a 12-week training program for four Somalian technicians in sorghum breeding, entomology, pathology, and agronomy.

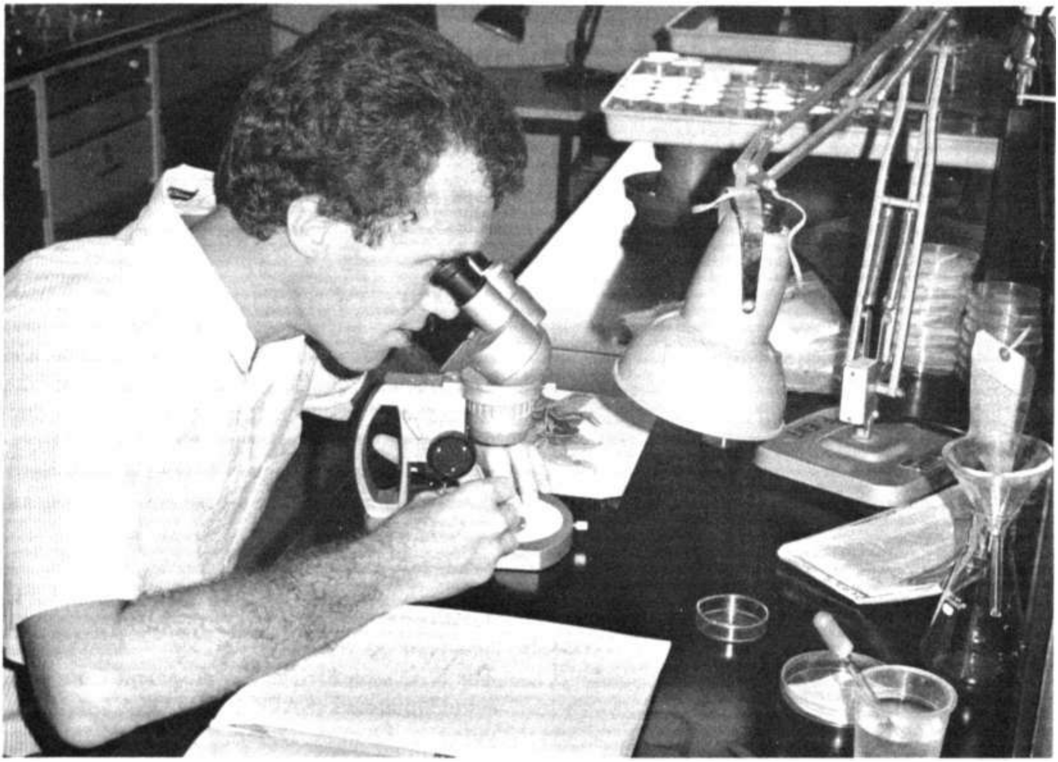
A 6-week research station development and management training program involved station managers from Lesotho (2), Malawi (2), Swaziland (2), Tanzania (4), Zambia, and Zimbabwe (4). Faculty for the program were from SADCC/ICRISAT, ICRISAT Center, and the International Fertilizer Development Center (IFDC).

An intensive 4-day entomology and pathology course was conducted by SADCC/ICRISAT staff (3) for technicians from Botswana (2), Lesotho (2), Malawi (2), Swaziland (2), Tanzania (3), Zambia, and Zimbabwe (3).

Special National Scientist Skill Development Activities

Two scientists from El Salvador studied for 1 week each, and two scientists from Guatemala

National Scientist evaluating food quality.



Postdoctoral Fellow identifying insect parasites.

studied for 2 and 5 weeks, sorghum improvement techniques with the LASIP staff.

An 8-day food preparation and quality evaluation course was provided by SADCC/ICRISAT staff in Zimbabwe to a research assistant and nutritionist from Lesotho. Eight months of training was given in quality assessment and in the use of microbiological techniques in food processing to a participant from Bulawayo Polytechnical College. The SADCC/ICRISAT economist trained two Bulawayo Polytechnical College students in practical microcomputer utilization for research for 7 weeks.

Postdoctoral Fellowships

Cereals Program

Postdoctoral Fellows from Japan, Somalia, and Federal Republic of Germany completed studies related to sorghum head bug management, *Striga* control (part-time assignment in Niger), and pearl millet improvement by selection. A Tanzanian Fellow continued research on millet improvement with the pearl millet breeder at SADCC/ICRISAT.

Legumes Program

Fellows from India (3) completed their research on chickpea dry root rot, the use of anther cultures for haploid production in groundnut, and the use of attractants in *Helicoverpa armigera,* while Fellows from Trinidad and United States (2) completed studies related to waterlogging effects on pigeonpea, the influences of cropping systems on insect levels, and the characterization of the causal agent of pigeonpea sterility mosaic disease.

Resource Management Program

A Ghana Fellow studied the physical properties associated with soil water management in Alfisols. A Fellow from Sri Lanka completed his agroforestry research on perennial pigeonpea and leucaena trees.

Genetic Resources

Studies evaluating the wild species of *Pennisetum* for pearl millet improvement were completed by an Indian Fellow.

In-service Fellowships

Scientists with MSc or PhD degrees came from 27 countries to participate in individualized study programs to improve specific research skills (Table 7).

Research Scholar Regional and National Activities

Mali

The ICRISAT-Mali scientists guided six Katibougou Agricultural College BSc students in their final year field research studies and reports. Three students are continuing their degree studies in soil fertility, plant breeding, and agronomy and one is studying plant breeding at the University of Dschang, Cameroon.

Niger

An Institut national de recherches agronomiques du Niger (INRAN) Millet Breeder conducted field experiments for his PhD thesis for a U.S. university. A Swiss doctoral student initiated his thesis research studies in agronomy. A student from the Institut pratique de developpement rural (IPDR), Kolo, studied for 3 months on a postflowering drought screening technique. Students from the Departement de formation en protection des vegetaux of the Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (CILSS) studied the effects of N on stem borer populations and the reaction of wild

Table 7. In-service Fellow study programs, ICRISAT Center, 1989.

Program / discipline	Country	Number of weeks
Cereals Program		
Millet physiology	Bangladesh	4
Sorghum breeding	Mexico, the Philippines, Thailand	33
Sorghum pathology	Ethiopia, India, Kenya, Sudan	53
Sorghum entomology	Sudan, Yemen Arab Republic	12
Legumes Program		
Chickpea breeding	India	41
Electron microscopy	Zimbabwe	4
Groundnut agronomy	Pakistan, the Philippines, Sudan	37
Groundnut virology	Nepal, Sri Lanka	9
Legume microbiology	India	2
Legume pathology	Ethiopia (2), India (3), Indonesia, Kenya, Niger, Thailand, Uganda	36
Legume virology	Bangladesh, India (2), Nepal, the Philippines, Thailand, Uganda	21
Pigeonpea agronomy	The Philippines	12
Pigeonpea breeding	India (11)	8
Pigeonpea entomology	India	1
Resource Management		
Agroclimatology	Ethiopia, India, Nigeria	61
Land and water management	Benin, Burkina Faso (2), Cameroon, Ethiopia (3), Ghana (2), Kenya (2), Malawi, Mali, Nigeria (2), Sudan, Tanzania, Togo, Zimbabwe (2)	44
Genetic Resources		
Germplasm conservation	Mauritania, Somalia	24

millets to smut and ergot. Four University of Hohenheim students completed their field studies in agroforestry, soil physics, plant nutrition, and soil chemistry.

Three students from the university of Niamey conducted 2-month field studies in resource management and groundnut improvement. Millet pathology training was given to two participants from the Centre regional de formation et duplication en agrometeorologie et hydrologie operationnelle (AGRHYMET). There were 10 participants from various institutions in Niger who completed 1- to 3-month practical studies guided by research, administration, physical plant operations, and farm operations staff.

Zimbabwe

The SADCC/ICRISAT staff assisted 23 University of Zimbabwe students (BSc) in 3- to 4-month sorghum and millet improvement projects on plant breeding, pathology, entomology, agronomy, economics, food technology, and research farm operations for final year study papers.

BSc, MSc, and PhD degrees (37 candidates from nine countries) are being sponsored in some U.S. and Brazilian universities by the SADCC/ICRISAT/USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL) program. A student from Lesotho completed a PhD degree in adult education. MSc studies were completed by students from Tanzania (Entomology), Malawi (Plant breeding), Botswana (Statistics), Zambia (Plant breeding), Zambia (Grain science), and Lesotho (Agronomy). A student from Botswana completed a BSc degree in plant breeding. Five PhD degree research scholars conducted their theses research under the supervision of research scientists in plant breeding (Botswana and Zimbabwe), entomology (Botswana and Zimbabwe), and economics (Federal Republic of Germany). An MSc degree student from Botswana was guided in agricultural economics thesis research.

Apprentice Activities

A 4-month pathology study was completed at Matopos, Zimbabwe, by a student from the Netherlands.

Self-supported undergraduate and unemployed students from Australia (2), Denmark, the Netherlands (3), India, Japan (3), Mexico, UK (5), USA, and Federal Republic of Germany (3) conducted work-study and special-report activities (1-10 months) in agronomy, climatology, cytogenetics, economics, pathology, physiology, plant breeding, soil science, and other related research programs. Their contributions represent more than 242 weeks of field experience in semi-arid agricultural research.

Networks

A major channel for transferring technology to National Agricultural Research Systems (NARS) is through research networks. ICRISAT has eight research networks: separate ones for sorghum and pearl millet for West Africa; a sorghum, pearl millet, and pigeonpea network for eastern Africa; a sorghum network for Central America; a sorghum and millets network for southern Africa; a kabuli chickpea network for western Asia and northern Africa; a global cereals network; and an Asian grain legumes network. These networks assist national scientists in research, enhance their participation in cooperative research, and transfer ICRISAT technology directly to individual NARS.

Asian Grain Legumes Network (AGLN)

Since 1986, the AGLN has assisted in the exchange of plant material, technology, and information of groundnut, chickpea, and pigeonpea among the network members in the Asian region. The AGLN Coordination Unit at ICRISAT Center acts as the Secretariat to facilitate these exchanges, training and visits for the members, and organizes monitoring tours, disease and pest surveys, meetings, and workshops. By the end of December 1989, there were 650 members in the AGLN Cooperators' Directory. At present 11 countries of south and southeast Asia (Bangladesh, People's Republic of China, India, Indonesia, Myanmar, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, and Vietnam) are formally involved in AGLN through country-ICRISAT Memoranda of Understanding (MOU) and workplans. Other Asian countries participate on a more informal basis.

During the year, AGLN collaborated effectively with other regional and international organizations in organizing the cooperative network activities. Notable among these were the joint National Grain Legumes Improvement Programme (NGLIP)-Asian Rice Farming Systems Network (ARFSN)-AGLN Workshop in Nepal; the Consultants' Meeting on Legume Uses at ICRISAT Center, the Second Peanut Stripe Virus Coordinators' Meeting at ICRISAT Center, and the Second National Pulses Workshop, and In-country Legume Training Course in Bangladesh (details are given later in the section under Conferences/Workshops/Meetings).

Memorandum of Understanding

An MOU between ICRISAT and the Ministry of Agriculture and Food Industry (MAFI), Government of Vietnam, was signed in Hanoi on 25 September 1989. The MOU envisages collaborative research on the ICRISAT mandate crops for dryland agriculture in Vietnam. This will provide the necessary framework for strengthening ICR1SAT and AGLN activities in Vietnam.

Workplans

The MOUs with the countries form the basis for developing a detailed workplan of collaborative activities between each country and AGLN/ICR1SAT. These workplans list the activities agreed for implementation. In September 1989, ICRISAT's Director General signed in Beijing a 3-year (1989-91) workplan with the Vice President of the Chinese Academy of Agricultural Sciences (CAAS).

In other countries, Review and Planning Meetings were held to review the progress of the previous workplan, and to prepare a new one for the next year or two. These meetings were held in Bangladesh, Myanmar, Nepal, and Sri Lanka. AGLN activities in these four countries are supported by a special grant from the Asian Development Bank (ADB). The National Agricultural Research System (NARS) scientists have shown interest in these workplans because the latter relate directly to national needs and priorities and include reviews of the national program's trials and experiments.

In collaboration with the Australian Centre for International Agricultural Research (AC1-AR), workplans were prepared for pigeonpea research in Thailand and Indonesia and groundnut research in Indonesia. An overall policy workplan was developed with the Philippine Council for Agriculture Research and Resource Development (PCARRD) for cooperation with the AGLN for grain legume research in that country.

Consultancy and Visiting Scientists

An ICRISAT breeder was posted in Nepal for 3 weeks to assist NGLIP in selection, evaluation, and harvest of chickpea breeding material and trials.

A visiting scientist from NGLIP with support from ICRISAT and IDRC spent 4 months at NGLIP, Rampur, and ICRISAT Center to produce a Germplasm Catalog of Legumes in Nepal. Another scientist from Nepal spent a month at ICRISAT Center to analyze the data and write a report on chickpea and pigeonpea trials in Nepal.

An Agroclimatologist from ICRISAT Center visited Myanmar to assist scientists there to prepare a report on agroclimatic zones, constraints to production, and potential production areas for chickpea, pigeonpea, and groundnut for publication in an Information Bulletin.

Two scientists from the Agriculture Research Institute, Yezin, Myanmar, and a scientist from the Regional Agricultural Research Centre, Bandarawela, Sri Lanka, spent a week at ICRISAT Center visiting different legumes research programs and discussing cooperative research activities with ICRISAT scientists.

Agroclimatic Zonation

Delineation of agroecological zones in a spatial mode allows for a rapid identification of farmers* production problems and it helps researchers to find solutions expeditiously.

A methodology for agroclimatic zoning based on the principles of Geographic Information System (GIS) has been established. It includes the preparation of country/regional maps showing area and distribution of crops/cropping systems. The abiotic (e.g., length of growing period, soil type) and biotic (e.g., diseases, pests) stress maps are then superimposed. The outcome is a well defined agroclimatic zonation which can be used to facilitate technology development and its transfer.

ICRISAT is now working with the Asian NARS to map agroclimatic zones in the AGLN countries. Mapping work for Bangladesh, People's Republic of China, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, the Philippines, Sri Lanka, and Thailand has been completed recently.

Legumes On-Farm Testing and Nursery (LEGOFTEN) Unit

The LEGOFTEN unit continued to cooperate with agricultural scientists and extension workers in several states of India to compare the ICRISAT practices for groundnut and pulses production with the state-recommended and farmers' practices.

Groundnut

In the 1988/89 postrainy season, 11 groundnut yield maximization trials in Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Orissa, and Tamil Nadu were closely monitored. The yield trends were similar to those reported earlier (Table 1). However, the cost of cultivation was lower than in the trials laid out during the previous postrainy season. (ICRISAT Annual Report 1988, p. 223).

The higher yields of groundnut from 1CR1-SAT-recommended cultivation practices came from improved varieties which responded to inputs and to changed agronomic practices which included the raised bed and furrow system. We observed better root growth and nodulation in plants grown on raised beds and furrows than in those grown on flat land. Other agronomic practices included a reduced dose of nitrogen, use of single superphosphate (SSP) fertilizer in place of diammonium phosphate in order to alleviate sulfur and calcium deficiency, use of gypsum and micronutrients ($ZnSO_4$ as a

Table 1. Average[1] pod yield[2], shelling percentage, seed mass, oil content, haulm mass, and cost of cultivation of groundnut crops according to ICRISAT and state practices under irrigated conditions, postrainy season 1988/89.

	Cultivation practice			
	ICRISAT		State	
Parameters	ICRISAT cultivar	State cultivar	ICRISAT cultivar	State cultivar
Dry pod mass (t ha^{-1})	2.98	2.02	2.37	1.72
(range)	(1.98-3.70)	(0.92-3.03)	(1.24-3.44)	(1.09-2.60)
Shelling percentage	74	76	74	75
(range)	(70.3-78.1)	(72.4-81.2)	(65.7-82.5)	(73.5-78.5)
100-seed mass (g)	548	476	525	437
(range)	(436-629)	(368-476)	(370-520)	(364-458)
Oil content (%)	47.3	47.4	46.6	47.2
(range)	(44.07-52.14)	(45.12-51.49)	(44.34-48.87)	(44.03-50.45)
Haulm mass (t ha^{-1})	5.6	6.5	7.2	5.8
(range)	(2.90-10.75)	(3.43-11.25)	(4.69-12.25)	(3.85-10.75)
Cost of cultivation (Rs '000 ha^{-1})[3]	8.9	8.7	7.6	7.7
(range)	(5.2-14.2)	(5.2-14.2)	(5.5-12.5)	(4.8-12.5)

1. Average of 11 trials in six states : one each in Andhra Pradesh, Gujarat, Karnataka, and Orissa; three in Maharashtra, and four in Tamil Nadu.
2. Plot size 0.2 ha.
3. U.S. $ 1 = Rs 17.

basal dose and $FeSO_4$ as a foliar spray), controlled irrigation, and proper plant protection measures. On-farm trials conducted by extension workers and experiments conducted by scientists using these recommended practices consistently gave higher groundnut yields than experiments in which recommended practices were not used.

Pigeonpea

Short-duration cultivars. A total of 44 trials was planned in 11 states of India (ICRISAT Annual Report 1988, p. 225). Of these trials, 12 were chosen for close monitoring. Later, three more trials were included because of their easy accessibility (Table 2).

Table 2. Grain yield of short-duration pigeonpea ICPL 87 in southern India and ICPL 151 in central and northern India grown under rainfed conditions, rainy season 1988.

	Yield ($t\ ha^{-1}$)					
	ICRISAT practice		State practice			
State and locations	ICRISAT variety	State variety	ICRISAT variety	State variety	Number of harvests of ICRISAT varieties	District average yield ($t\ ha^{-1}$)[1]
Andhra Pradesh						
Tangadencha	1.32	-[2]	-	0.12	2	0.11
Gujarat						
Hathrol	0.78	-	-	0.61	1	0.33
Karnataka						
Devihosur	1.31	-	-	-	2	0.57
Gangavati	2.37	-	-	-	2	0.24
Guladhalli	1.59	-	-	-	1	0.24
Madhya Pradesh						
Narsinghpur	1.62	-	-	-	1	1.71
Bhikengaon	1.77	-	-	-	1	0.50
Maharashtra						
Amraoti	2.03	-	-	-	2	0.82
Latur	1.34	-	-	-	3	0.19
Shirla	3.48	-	1.60	-	3	0.68
Orissa						
Sukinda	0.57	-	-	-	1	0.54
Phulbani	2.42	-	-	1.43	2	0.66
Rajasthan						
Bharatpur	0.70	-	-	0.30	1	0.33
Tamil Nadu						
Danishpet	1.62	-	0.46	-	1	0.72
Athyanthal	1.27	-	0.52	-	1	0.64
Mean	1.61		0.86	0.61		0.55

1. Source: Agriculture situation in India, 1988.
2. Practice or variety not tested.

The pigeonpea cultivars ICPL 87 ('Pragati' used in southern India) and ICPL 151 ('Jagriti' used in central and northern India) were grown at these sites using three different options: (1) ICRISAT variety with ICR1SAT practice, (2) ICRISAT variety with ICRISAT practice and ICRISAT variety with state practice, and (3) ICRISAT variety with ICRISAT practice and state variety with state practice. These varieties gave substantially higher yields than other common cultivars—BDN 2 grown in Gujarat, LRG 30 grown in Andhra Pradesh, and UPAS 20 grown in Rajasthan and Orissa (Table 2). Because of its ability to produce three flushes of flowers, ICPL 87 performed well even when the first flush was destroyed by heavy rains at Amraoti and by insects at Tangadencha. Under good management—close spacing, proper drainage, and protection from pests—ICPL 87 gave high yields.

Extra-short-duration lines. A set of extra-short-duration (ESD) pigeonpea cultivars was tested in seven states (Table 3) to study their perfor-

Table 3. Grain yield of extra-short-duration pigeonpea crops at 14 locations in seven states of India, postrainy season 1988/89.

		Yield (t ha^{-1})				
State and locations	Sowing date	ICPL 85014	ICPL 85030	ICPL 84023	ICPL 85010	ICPL 151 (Jagriti)
Andhra Pradesh						
Tangadencha	13 Jan	0.74	-[1]	-	-	-
Gujarat						
Nadiad	18 Jan	0.80	-	-	-	-
Karnataka						
Devihosur	23 Jan	0.52	-	-	-	-
Tamil Nadu						
Shivalingapatti	24 Dec	0.98	-	-	-	-
Kottur	18 Jan	0.94	0.85	-	-	-
Rajadani	29 Dec	0.95	1.03	-	-	-
Tappakundi	3 Jan	0.96	0.77	-	-	-
Kamatchipuram	19 Jan	0.64	0.60	-	-	-
Maharashtra						
Parbhani	22 Dec	0.60	-	-	-	0.67
Ridaj	20 Jan	1.00	-	1.00	1.33	1.05
Niwali	6 Feb	0.65	-	-	-	-
Bhogaon	29 Jan	0.60	-	-	-	-
Orissa						
Sakhigopal	10 Jan	0.63	-	0.92	0.63	0.48
Madhya Pradesh						
Bhikengaon	8 Jan	-	-	0.58	0.28	0.33
Mean		0.77	0.81	0.83	0.75	0.63

1. - = Varieties not tested.

mance in the off-season, (December-February) sowings with irrigation. The cultivars tested were ICPLs 151, 84023, 85010, 85014, and 85030. These cultivars matured in about 90-100 days after sowing (DAS) and performed well at several locations (Table 3). However, at a few locations where they were sown early while temperatures were still low, they did not grow or yield well (Parbhani in peninsular India and Bhikengaon in north central India). The optimum date for sowing off-season pigeonpea appears to be during second to third week of January in peninsular India and the fourth week of January in north central India. In Andhra Pradesh, Gujarat, and Orissa the ESD pigeonpea cultivars also performed well in the January sowing. In Tamil Nadu (southern India), where temperatures are higher, they did well at all sowing dates from 25 Dec to 19 Jan.

Chickpea

Out of a total of 43 irrigated and 33 nonirrigated on-farm trials during the 1988/89 postrainy season, 19 irrigated and eight nonirrigated trials were closely monitored by LEGOFTEN and Department of Agriculture. Both improved (desi ICCC 37, ICCC 42; kabuli ICCV 6, ICCV 5 or ICCV 2) and common (Annigeri, ICCC 4, Ujjain 21, JG 315, Chafa, BDN 9-3, Phule G-5, H 208, C 235, K 850) chickpea varieties showed a high yield potential of up to 3.7 t ha^{-1} with good management and irrigation (Table 4). The only ESD kabuli variety ICCV 2, grown on residual moisture, yielded up to 1.7 t ha^{-1} (Table 5). Its yield was about 30% higher than those of the common long-duration varieties grown under similar situations. ICCV 2 matured in about 70 days in Tamil Nadu. However, it required 92-110 days to mature in Madhya Pradesh, Orissa, and Uttar Pradesh. These maturity periods were still shorter by 11-30 days than those of commonly grown cultivars.

Technology Transfer

As a result of conducting adaptive research and on-farm trials, important constraints to the adoption of technology by farmers such as the difficulty of preparing raised beds and furrows were understood. Finding solutions to these constraints coupled with systematic efforts by government agencies and farmers to carry out large-scale multiplication and distribution of seed of improved varieties and to demonstrate the effectiveness of new components of the technology has resulted in rapid adoption of this improved technology in many areas. The activities of the Department of Agriculture, Parbhani district (Maharashtra), in the transfer of groundnut technology during the past 3 years are listed in Table 6.

Table 4. Grain yield and cost of cultivation of the ICRISAT/Department of Agriculture-monitored, irrigated chickpea trials at different locations in India, postrainy season 1988/89.

	ICRISAT package				State package			
	ICRISAT variety		State variety		ICRISAT variety		State variety	
State/locations	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})
Andhra Pradesh								
Tangadencha	1.55	7.2	1.28	7.5	1.09	6.2	1.09	6.0

Continued

Table 4. *Continued.*

State/locations	ICRISAT package				State package			
	ICRISAT variety		State variety		ICRISAT variety		State variety	
	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs' 000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})	Yield (t ha^{-1})	Cost (Rs '000 ha^{-1})
Gujarat								
Hathrol	1.43	3.8	1.70	3.7	1.22	3.5	1.44	3.3
Karnataka								
Gangavati	0.92	4.2	1.27	4.2	1.27	4.3	1.46	4.3
Madhya Pradesh								
Bhikengaon	0.81	6.0	0.86	5.1	0.78	4.1	0.80	3.8
Narsinghpur	1.61	4.6	1.71	4.7	1.34	3.8	1.27	3.9
Maharashtra								
Chakur	1.36	4.7	1.77	4.7	1.45	3.6	2.32	3.6
Parbhani	1.75	9.3	1.70	9.3	1.68	7.7	1.66	7.7
Pokharni	1.62	4.4	1.25	4.4	1.20	3.9	1.08	3.9
Bori	2.95	4.7	2.81	4.7	2.20	4.2	2.95	4.2
Niwali I	0.85	4.0	0.78	4.0	0.76	3.6	0.70	3.6
Niwali II	3.70	4.7	3.60	4.7	2.96	3.6	3.11	3.6
Niwali III	2.50	4.7	2.41	4.7	2.31	4.2	2.04	4.2
Jintur	2.95	4.1	2.46	4.1	2.37	3.5	1.86	3.5
Ridaj	3.50	6.0	2.80	6.0	2.24	4.4	1.40	4.4
Gangakhed	2.85	4.5	2.50	4.5	2.50	3.5	2.42	3.5
Hingoli	1.50	7.0	1.21	7.0	1.10	5.2	0.73	5.2
Orissa								
Keonjhar	1.73	5.9	1.11	5.9	0.99	5.1	0.45	5.1
Rajasthan[1]								
Ajmer	0.44	-[2]	0.23	-	0.11	-	0.11	-
Uttar Pradesh								
Amarokh	1.59	3.9	1.51	3.7	1.59	2.6	137	2.4
Mean	1.87	5.2	1.73	5.2	1.53	4.3	1.49	4.2

Two-way comparison of average yields (t ha^{-1}):

Variety	Cultivation package: ICRISAT	Cultivation package: State	Mean	Increase due to variety (%)
ICRISAT	1.87	1.53	1.70	5.8
State	1.73	1.49	1.61	
Mean yield	1.80	1.51		
Increase due to package (%)	19.4			

1. Damaged by frost.
2. Data not received.

Table 5. Grain yield and cost of cultivation in the ICRISAT/Department of Agriculture-monitored, nonirrigated chickpea trials at different locations in India, postrainy season 1988/89.

State/ locations	ICRISAT package				State package			
	ICRISAT variety		State variety		ICRISAT variety		State variety	
	Yield ($t\ ha^{-1}$)	Cost (Rs '000 ha^{-1})	Yield ($t\ ha^{-1}$)	Cost (Rs '000 ha^{-1})	Yield ($t\ ha^{-1}$)	Cost (Rs '000 ha^{-1})	Yield ($t\ ha^{-1}$)	Cost (Rs '000 ha^{-1})
Andhra Pradesh								
Tangadencha	0.82	5.1	0.20	4.9	1.62	5.1	0.76	4.3
Karnataka								
Gangavati	1.31	3.7	1.36	3.7	1.26	3.7	0.62	3.7
Madhya Pradesh								
Bhikengaon	1.38	3.9	0.95	3.7	1.19	3.2	0.84	3.2
Narsinghpur	1.62	3.5	1.52	3.5	1.02	3.4	1.19	3.5
Maharashtra								
Chakur	0.91	4.9	1.03	4.9	0.48	3.5	0.75	3.5
Sawarkhed	1.04	3.6	0.95	3.6	0.73	3.2	0.86	3.2
Orissa								
Keonjhar	1.01	5.5	0.73	5.5	0.82	4.8	0.58	4.8
Uttar Pradesh								
Amarokh	1.75	2.3	0.87	2.6	1.38	2.5	0.82	2.3
Mean	1.23	4.1	0.95	4.0	1.06	3.7	0.80	3.6

Two-way comparison of average yields ($t\ ha^{-1}$):

Variety	Cultivation package		Mean	Increase due to variety (%)
	ICRISAT	State		
ICRISAT	1.23	1.06	1.15	30.5
State	0.95	0.80	0.88	
Mean yield	1.09	0.93		
Increase due to package (%)	17.1			

Cooperative Cereals Research Network (CCRN)

The CCRN was started at ICRISAT Center to work towards providing support to national programs. Through this network we organize international sorghum trials and nurseries to provide the NARSs in Asia, Africa, and Central America access to improved cultivars in the world for their use in breeding programs and the ultimate transfer to farmers. We also evaluate elite material originating from the NARSs over a wide range of agroclimatic conditions.

At present in Asia, the activities involve exchange of genetic material, scientific visits, joint evaluation of trials and nurseries, and training. We shall further intensify the ongoing activ-

Table 6. Activities of the Department of Agriculture in the transfer of groundnut technology in Parbhani district, Maharashtra, India, 1987-1989[1].

Activity	Target group	Method	1987/88	1988/89	1989/90
Training	Extension workers	Classroom lectures	44	36	8
		Practicals	11	23	26
	Farmers	Training classes	3	-[2]	.
		Field days and group discussions	7	22	19
Extension	Farmers	Exhibitions	1	3	1
		Radio talks	-	2	-
		TV	-	1	-
		Slide and video casettes	-	2	2
		Pamphlets	5000	10 000	-
		Newsletters and popular articles	19	11	-
Demonstrations			7	24	15
Pilot projects			-	22	25

1. Source: Department of Agriculture, Training and Visit System, Parbhani district.
2. - = Activities not considered necessary seeing the automatic technology adoption.

ity through better identification of sorghum production constraints in different nations, joint research programs among institutions, intercountry interaction through workshops, and organizing monitoring tours of field experiments.

During 1989, we sent international sorghum trials and nurseries to 38 locations in Asia, Africa, and Central America. We jointly evaluated, with the NARSs scientists, a number of these trials and nurseries. In Asia, most of the test entries were unsuitable because they were tall and late.

We plan to characterize sorghum test locations environment in Asia, Africa, and Central America to improve the effectiveness of international trials and nurseries. We also plan to send useful test material to Asian countries.

West and Central African Millet Research Network

During the Regional Pearl Millet Improvement Workshop held at ISC, Sadore, from 4 to 7 September, the participants (47 participants from 11 national programs, INSAH, CILSS, SAFGRAD, and ICRISAT) formalized the West and Central African Millet Research Network. A steering committee, consisting of six representatives of the NARS (elected by the participants), a coordinator from ICRISAT, and three observers (from ICRISAT, SAFGRAD, and INSAH/CILSS) was established.

The participants outlined the objectives of the network, and responsibilities of the steering committee. The first meeting of the committee was held at ISC from 12 to 15 December. The committee worked on the preparation of the document, a detailed questionnaire to elicit information on constraints to production, staff, and facilities available for millet improvement research in the member countries.

Eastern Africa Regional Cereals and Legumes (EARCAL) Program

ICRISAT placed a pigeonpea agronomist/ breeder in its EARCAL Program in Nairobi, Kenya, in order to strengthen the National Agricultural Research System (NARS) and the regional efforts of pigeonpea improvement and development for food, fodder, and fuelwood production.

In association with Kenya Agricultural Research Institute (KARI), we studied the production systems in major pigeonpea-growing districts of eastern and coastal provinces of Kenya at the end of September. We visited 21 farmers and their fields where pigeonpea had matured and was being harvested. We collected mature pod samples for assessment of pest damage. Except in two cases, the crop was not sprayed with insecticides. All farmers expressed the opinion that insect pests (pod-sucking bugs, podfly and pod borers) and moisture stress (intermittent and terminal) were the major constraints and that marketing was not a constraint. All indicated interest in short-duration (5-6 months maturity, compared with local landraces of 10-month duration) pigeonpea but were concerned about enhanced pest damage. In the pod samples collected from landraces, we observed seed damage of 15-50%, predominantly by pod-sucking bugs, followed by podfly. In the local system, pigeonpea is sown in October-November in furrows opened by oxen-drawn plows and is grown as an intercrop with maize, beans, cowpea, mung bean, and in some cases, cassava, sorghum, and millets. Large-podded and white-seeded long-duration landraces are commonly grown in Machakos district, whereas white seeds with brown mottling are common in Embu and Meru districts. Even though there are some dhal mills (to make split peas) in Nairobi, the bulk of pigeonpea is consumed as a green vegetable and cooked as dry whole grain. Dry stalks are used as fuelwood and thatch material.

In November, a scientist from KARI was trained at ICRISAT Center for 6 weeks, in processing methods and preparing new pigeonpea dishes.

Meetings with NARS scientists in Kenya, Ethiopia, and Sudan were held to identify areas of collaborative research and training needs. Inter-Center collaboration was developed with the International Livestock Centre for Africa (ILCA).

Regional Sorghum and Millets Improvement Program for Southern Africa

Workplans and Collaborative Activities

Workplans giving details of the SADCC/1CRISAT regional program activities were discussed and agreed upon during the annual regional workshop by all participants. Among workplans approved for the 1989-90 season are:

1. To establish basic Sorghum and Millets Improvement Program (SMIP) trials to evaluate introductions, segregating materials and advance-generation breeding stock, and to collect and characterize germplasm.
2. To set up collaborative nurseries and trials including entries identified and submitted by both national and regional programs. There will not be more than 30 entries which will be in advance or elite stages while provisions of nurseries would be provided as requested by national programs. The nature and possibilities for specific collaborative projects and activities with individual countries are included.
3. To set up nurseries and trials to evaluate resistance to leaf and head diseases, and shoot pests of sorghum and millets, that have been found important in the region.
4. To develop the ability to produce nationally and regionally developed hybrids in relation to seed-set and ergot incidence.
5. To conduct market analysis research examining factors influencing decisions to grow alternative course grains and to utilize sorghum and millet both on the farm and by agricultural industries. This includes an analysis of pricing problems underlying the build-up of sorghum and millet stocks.
6. To develop technical and laboratory support and backup services for sorghum utilization projects in specific countries (Botswana and Zambia) in the region.
7. To assess progress made and to develop future plans for training.

8. To plan monitoring tours and workshops during 1990.

In 1989, we participated in national crop planning meetings in several countries including Botswana, Tanzania, Zambia, and Zimbabwe.

During the year, SADCC/ ICRISAT regional program scientists traveled with the national scientists in nine countries at different times to monitor, evaluate, select, and appraise national and regional collaborative activities. Future course of action in each case was discussed.

Appraisal of Processing and Utilization of Sorghum and Millets in SADCC

The SADCC/ICRISAT Economics Program is pursuing a series of collaborative investigations with scientists throughout the SADCC region. These include support for a national reconnaissance of sorghum and millet marketing and utilization constraints in Tanzania. This is being used to define a joint program of research with the Sokoine University of Agriculture examining options to expand sorghum and millet trade and industrial use. In Lesotho, we are working with the Marketing and Research Divisions of the Ministry of Agriculture on an investigation of factors explaining the dominance of maize in the semi-arid regions and the potential demand for a sorghum dehuller. In Zambia, we worked with the National Commission of Development Planning, National Council for Scientific Research and University of Zambia on a study of options to expand sorghum and millet use in baking, brewing, and stockfeed industries. A similar study is underway with the Ministry of Agriculture in Zimbabwe. This broadly examines the dynamic comparative advantage of sorghum and millet.

Finally, the Economics program is collaborating with the University of Zimbabwe on a study of alternative means to expand course grain trade as a means to improve food security in the country's semi-arid regions. The cumulative results from such collaboration will be presented at a series of future regional conferences.

Conferences/Workshops/ Meetings

International Workshops

Workshop on Chickpea in the Nineties

The second International Workshop on Chickpea Improvement was held at ICRISAT Center, from 4 to 8 December. The Workshop, called Chickpea in the Nineties, was organized by the International Center for Agricultural Research in the Dry Areas (ICARDA) and ICRISAT.

The Workshop's objectives were to summarize the present status of chickpea production and utilization; to review progress since the previous workshop held in 1979; to project goals for production and use of chickpea; to identify constraints, and research needed to overcome these constraints; to recommend and develop collaborative research proposals based on these priorities; and to suggest the resources and training required to effect these proposals.

Contributions from 142 delegates from 29 countries generated lively discussions on a wide variety of research topics. The delegates agreed on the approaches needed to bring about a sustained and substantial increase in chickpea production in the world and provided valuable guidance to ICRISAT and ICARDA for their future chickpea programs. It was agreed that chickpea production was likely to move from traditional areas of low productivity to areas of higher potential where farmers were willing to adopt modern technologies and use higher levels of management skills.

Second Peanut Stripe Virus Coordinators' Meeting

Thirty-nine plant virologists gathered at ICRISAT Center from 1 to 4 August to discuss viruses that attack the groundnut crop. These specialists came from Australia, Canada, France, India, Indonesia, Japan, the People's Republic of China, the Philippines, Thailand, UK, and USA.

The main objective of the meeting was to discuss research on peanut stripe virus (PStV), the most economically damaging virus of groundnut in south and southeast Asia. A major concern of the participants was to minimize the risk of spread of this and other viruses of groundnut from countries known to harbor these viruses, into others where they are not yet established.

Vigilant checks on germplasm exchange are essential. Therefore plant quarantine officials of the National Board of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR) also participated in the meeting.

Aspects discussed included identification of isolates of PStV, production of specific antibodies to identify PStV isolates, screening of germplasm for resistance, tolerance, and non-seed transmission, and further refinements to the estimation of yield losses due to PStV. It was also decided that germplasm screening, currently being carried out in Indonesia with financial assistance from the Australian Centre for International Agricultural Research (ACIAR) and 1CRISAT, will be continued.

The meeting recommended procedures to investigate epidemiology and those to be followed for maintenance and distribution of germplasm free from seedborne groundnut viruses. Participants also recommended extensive screening of wild *Arachis* species and interspecific derivatives to locate resistance to the virus and identification of genotypes that do not transmit PStV through the seed.

The meeting was cosponsored by ACIAR, Peanut Collaborative Research Support Program (Peanut CRSP) of USA, the Food and Agricultural Organization of the United Nations (FAO), and ICRISAT.

Meeting to Explore Diversifying Uses of Grain Legumes

A Consultants' Meeting on "Uses of Grain Legumes" was held at ICRISAT Center, during 27-30 March to discuss the current production trends and end uses of the grains of chickpea, pigeonpea and groundnut, and to explore diversification of end uses.

The meeting reviewed existing knowledge on the uses of these grain legumes, identified areas that require further research and development, and formulated immediate and long-term plans to improve their end uses. With those objectives in view, areas for collaborative research and training needs were also identified.

Regional Workshops/Meetings

Asia

International Workshop on Varietal Improvement of Chickpea, Pigeonpea, and Other Upland Crops in Rice-based and Other Cropping Systems

This workshop, held in Katmandu, Nepal, 19-22 March was cosponsored by the National Grain Legume Improvement Programme (NGLIP), Nepal; Asian Rice Farming Systems Network (ARFSN), International Rice Research Institute (IRRI), and the AGLN, ICRISAT. There were 60 participants from 13 countries and from the Asian Development Bank (ADB), Asian Vegetable Research and Development Center (AVRDC), Cowpea-Bean CRSP, FAO, Ford Foundation, ICARDA, International Development Research Center (IDRC), International Institute of Tropical Agriculture (IITA), ARFSN-IRRI, ICRISAT, and Winrock International. This was a unique meeting as it provided an opportunity for interaction and exchange of information among the members of the two networks (AGLN and ARFSN) working in Asia. The participants discussed aspects relating to moisture stress, need for early-maturing varieties, soil constraints, and disease and insect pest problems of upland crops in general and chickpea and pigeonpea in particular. More specifically, they recommended that AGLN should consider including other legumes important in Asia under its umbrella, there should be more emphasis on coordinated efforts on acid soil tolerance of all crops, and on insect pest management of pigeonpea, and that more use be made of the comparative advantages of AGLN and ARFSN for cooperative endeavors in the Asian region.

Second National Workshop on Pulses

The AGLN, in collaboration with the Bangladesh Agricultural Research Institute (BARI), Joydebpur, and the IDRC organized the Second National Workshop on Pulses, 6-8 June at Joydebpur, Bangladesh. About 50 scientists from research and extension departments of Bangladesh, and scientists from India, Myanmar, Nepal, and ICRISAT participated in the workshop. The workshop reviewed the progress in pulses research in Bangladesh since the first workshop in 1981, and made plans for future research that includes on-farm testing of available technology, and increased collaboration among different research groups within Bangladesh.

Asian Grain Legumes Outreach (AGLO) Research Planning Meeting

The AGLO meeting was held at ICRISAT Center, 20-24 November. Three representatives from each of five countries (Indonesia, Myanmar, Nepal, Sri Lanka, and Vietnam) formed the Project Country Group. Legume scientists from India, Pakistan, the Philippines, CGPRT Centre, and ARFSN-1RR1 formed the Consultants' Group. These two groups and the concerned ICRISAT scientists reviewed the constraints to production of groundnut, pigeonpea, and chickpea in each country, examined the methodologies for on-farm research and technology transfer, and prepared draft proposals for technology transfer projects in the project countries. The participants visited the LEGOFTEN technology transfer activities in the Parbhani district of Maharashtra, India, from 25-27 November.

ICAR/ICRISAT Workplan Meetings

Discussions were held 25-26 August at ICRISAT Center between senior scientists and officials of ICAR and ICRISAT to develop formal workplans for 1989-91.

Over 80 ongoing and new collaborative projects relating to the improvement of ICRISAT's mandate crops in India were approved by the two organizations during these deliberations. This collaboration involves active participation of several ICAR institutions and agricultural universities throughout the arid and semi-arid tropics of India, extending from Rajasthan Agricultural University in the north to Tamil Nadu Agricultural University in the south. Collaborations with other national institutes, such as the Indian Institute of Management in Ahmedabad and the National Remote Sensing Agency (NRSA) in Hyderabad, are also being developed.

Other collaborative efforts agreed include projects in crop pathology, entomology, physiology, breeding, and modeling; managing soil resources and agroforestry; demonstrating, comparing, and testing improved varieties and technologies; and collecting and evaluating germplasm of ICRISAT's mandate crops.

West Africa

In-country Workshop on Improving the Productivity of Malian Soils

An in-country workshop on improving the productivity of Malian soils was held at Cinzana, Mali, 11-13 September, in collaboration with the Institut d'economie rurale (IER), Mali. It was attended by 30 agronomists representing different research and extension organizations. The workshop discussed problems associated with the Malian soils and prospects of alleviating them to improve their productivity. The participants discussed in depth the physics, chemistry, and biology of Malian soils and developed a set of recommendations on future research priorities and actions for development.

West African Regional Pearl Millet Improvement Workshop

The annual regional pearl millet workshop was held at ISC, Sadore, from 4-7 September. Forty-seven participants representing 11 national programs, Institut du Sahel (INSAH)/Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (CILSS), Semi-Arid Food Grain Research and Development (SAFGRAD), and ICRISAT participated. Sixteen technical papers were presented and the participants also visited the fields where they saw the ongoing research.

Participants of this workshop formalized the West and Central African Millet Research Network. A steering committee, consisting of six representatives of the NARS (elected by the participants), a coordinator provided by ICRISAT, and three observers (of ICRISAT, SAFGRAD, and INSAH/CILSS) was established.

The participants outlined the objectives of the network, and the responsibilities of the steering committee. The first meeting of the committee was held at ISC from 12 to 15 December. The committee worked on the preparation of the document, a detailed questionnaire to elicit information on constraints to production, staff, and on facilities available for millet improvement research in the member countries.

Industrial Utilization of Sorghum in Nigeria

Fifty-one delegates participated in a symposium on Industrial Utilization of Sorghum held from 4 to 6 December at Kano, Nigeria. The symposium was jointly organized by Nigeria's Institute for Agricultural Research (IAR) and ICRISAT.

The meeting brought together scientists and administrators from the national agricultural research system of Nigeria, as well as industrialists and policymakers. The industrial uses of sorghum are of considerable significance in Nigeria because imports of wheat, barley, and maize were recently banned in that country.

The event focused on the need for ICRISAT's West African Sorghum Improvement Program (WASIP) based at Kano, Nigeria, to work towards improving the malting, brewing, and milling qualities of sorghum; identification of suitable cultivars for forage and feed; and cooperation with national agricultural research systems and industry to achieve these goals.

Industrial uses of sorghum such as brewing, feed and flour milling, and baby food and beverage manufacturing in Nigeria are gaining considerable importance. Attention is also being given to sorghum end products such as raw grain, grits (coarsely ground hulled grain), and malted material. Some forecasters project that sorghum will eventually replace maize as the energy source in the Nigerian food industry. The symposium recommended identification of hard-grained sorghum having low fat and polyphenol content with adequate protein content for grits, and medium- to soft-grained sorghum for malting.

Recommendations of the symposium included development of small-scale milling machinery, production of fine sorghum flour for bakery products, and identification of sorghum varieties suitable for baked composite-flour products. The symposium recommended development of grain sorghum processing technology for use in poultry and cattle feed.

Meeting in Kano to strengthen NARS Collaboration

This meeting, held 25-26 September, was organized by WASIP—Nigeria, in Kano. Two representatives each from Benin, Cameroon, Ghana, Niger, and Nigeria and one from Chad attended the meeting. The objective was to strengthen collaboration with the NARS in these countries and to provide opportunities for selection of genetic material for utilization in the national programs.

Human Resources Workshop Conducted in Mali for West and Central Africa

A training workshop was conducted in Mali from 19 to 30 September by the West and Central African Sorghum Research Network (WCASRN) on Agronomic Research and On-farm Testing for nine participants from Cote d'Ivoire, the Gambia, Ghana, Guinea-Bissau, Mauritania, Niger, Nigeria, Senegal, and Sierra Leone.

Providing instructions on several subjects were resource personnel from ICRISAT's WASIP, Mali's IER, ILCA, the United States Agency for International Development (USAID), ISC and the Institut national de recherches agronomiques du Niger (INRAN). The participants saw various on-farm experiments at Sotuba, Cinzana, and Samanko, and *Striga* trials in Koulikoro village.

Southern Africa

Annual Workshop on Sorghum and Millet Improvement

The sixth annual Regional Workshop of the Sorghum and Millets Improvement Program (SMIP) for Southern Africa was held at Bulawayo, Zimbabwe from 18 to 22 September. The workshop was a reporting and planning meeting and gave an opportunity to gain a better perspective of sorghum and millet production, processing, and utilization problems. Participants included 57 national scientists from nine Southern African Development Cooperation Conference (SADCC) countries, 12 scientists from the regional program, two each from ICRISAT Center and EARCAL network, Nairobi, and one from USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), USA. Representatives from the USAID, Canadian International Development Agency (CIDA), and Deutsche Gesselschaft fur Technische Zusammenarbeit (GTZ) also participated. The 5-day deliberations were focused on sorghum and millet improvement, food technology, livestock feed, economics, and station development and management.

Second Regional Workshop on Crop Utilization

This workshop was held at Matopos, 21-22 November, and was attended by 15 invited participants and 10 principal staff members from SADCC/ICRISAT. The theme of the meeting was Market Quality Grades and Standards for Sorghum, and the objective of the meeting was to provide a forum for all relevant sectors such as breeders, food technologists, and members of the industry and marketing sectors to examine issues of grain quality currently affecting utilization. Countries represented were Botswana, Zambia, and Zimbabwe, where quality problems are being experienced.

SADCC/ICRISAT Technical Advisory Panel Meeting

The fifth meeting of the Technical Advisory Panel for the SADCC/ ICRISAT Regional Sorghum and Millets Improvement Program took place in Bulawayo, Zimbabwe, on 16-17 March. The eight panel members, with the Director of SACCAR as Chairman, together with five directors or their representatives from the SADCC countries, and three donor representatives from USAID, GTZ, and CIDA met with 13 staff members (including the Executive Director) of the regional program and the INTSORMIL Associate Program Director. The participants reviewed and evaluated progress being made in the regional program for sorghum and millet improvement in 1988-89, including human resource development, and made recommendations for the next season's course of activities.

Second SADCC-ICRISAT Regional Groundnut Breeders' and Agronomists'Meeting

Eighteen groundnut scientists from Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe, and from ICR1SAT Center and ISC attended this meeting, held 12 16 March at Lilongwe, Malawi.

This meeting gave an opportunity for the SADCC national program scientists to review progress made by their regional program and to view germplasm in the fields.

The recommendations arising from the meeting provide valuable guidelines for regional project activities. Of special note is the recommendation relating to regional screening of late leaf spot and rust diseases. This work is to be undertaken by the Swaziland national program on behalf of all national programs and will be funded by the regional project.

Regional Tours

Chickpea and Pigeonpea Monitoring Tour

The monitoring tour of chickpea and pigeonpea growing on experiment stations and farmers' fields in the Terai region of Nepal was organized 12-17 March prior to the NGLIP-IRRI-ICRISAT Workshop. Thirty-two participants from 10 AGLN countries, ICRISAT, and NGLIP participated. The observations from the monitoring tour formed the basis for discussions at the workshop.

Sorghum Research Monitoring Tour Conducted by WCASRN

The West and Central African Sorghum Research Network (WCASRN) organized a research monitoring tour from 9 to 18 October for seven scientists from Benin, Burkina Faso, Cameroon, Chad, Guinea, Mali, and Togo.

During the tour the scientists visited national, regional, and international trials and nurseries at Sotuba, Samanko, and Cinzana in Mali; Farako-Ba and Saria in Burkina Faso; and Lossa, Tillabery, and Maradi in Niger. These visits gave the touring scientists an opportunity to evaluate and select breeding materials for use in their respective programs.

The participants exchanged views during periodic group discussions and evaluated the entries in regional trials, and were able to appreciate the interaction between genotype and location.

Sorghum Monitoring/Evaluation Tour

This was held from 6 to 19 May at the SADCC Regional Sorghum and Millets Improvement Program, Bulawayo, with visits to the sorghum fields at the regional headquarters at Matopos for 3 days and to the national and collaborative sorghum research and demonstration fields in Tanzania, the largest sorghum producer and consumer in the region, for 11 days. Seventeen national scientists including agronomists, breeders, entomologists, pathologists, soil scientists, and food nutrition researchers from seven of the nine SADCC countries participated. A multidisciplinary team of six scientists from the regional program at Matopos, and a plant breeder from EARCAL joined the national program scientists. The objectives of the tour included evaluation of national and regional collaborative nurseries, trials, and demonstrations in a multidisciplinary manner, with interaction and exchange of ideas among the scientists.

Forage Traveling Workshop

A Forage Traveling Workshop was held, 23 January to 7 February, at the SADCC Regional Sorghum and Millets Improvement Program, Bulawayo. The group of 16 scientists from six SADCC countries and from regional programs visited forage research areas in Zimbabwe, Botswana, Lesotho, Mozambique, and Swaziland.

Field Days

Pearl Millet Field Day

ICRISAT's biennial International Pearl Millet Field Day was held on 12-13 September at ICRISAT Center. Forty participants from India, Kenya, the Republic of Korea, Mali, Niger, Pakistan, Tanzania, Zambia, and Zimbabwe took part. Participants were informed about recent developments in the pathology, breeding, physiology, and agronomy of pearl millet. A major objective was to strengthen collaborative links between ICRISAT and national agricultural research systems. Opportunities were provided for the participants to select or request genetic material for utilization by their national programs.

Field Days by ICRISAT/Mali

ICRISAT/Mali organized field days for Mali agricultural research scientists during August at Sotuba, Cinzana, and Koporo Research Stations where ICRISAT had collaborative agronomic and breeding trials with IER.

Pigeonpea Field Days in Venezuela

Venezuela's Fondo Nacional de Investigaciones Agropecuaria (FONIAP), in collaboration with ICRISAT, held two pigeonpea field days in January, at Quibor (Lara province) and Yaritagua (Yayacuy province) to demonstrate the results of the ICRISAT/FONIAP pigeonpea germplasm evaluations. Each field day was sponsored by the respective FONIAP experiment station. The field visits were preceded by a seminar and followed by detailed discussions of the experiments.

Visitors agreed that utilization of elite pigeonpea lines with proper production techniques would result in yields three times the present yields. Several farmers expressed enthusiasm for cultivating pigeonpea and requested seed for their farms, which are usually 100-200 ha. The Government of Venezuela is now planning to substantially increase pigeonpea production using improved lines and technology. Better pigeonpea production could reduce the strain on the nation's economy aggravated by large soybean imports for poultry and animal feed.

Information Services

ICRISAT Center

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 1989, the Editorial Committee handled the review of 176 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 those issued in the following categories: Germplasm Catalogs, Plant Material Descriptions, Books, Research Bulletins, Information Bulletins, Conference/Workshop Proceedings, Bibliographies, General Audience Publications, and Audiovisual (AV) Materials.

In 1989, we published 43 items within these categories and 38 semiformal documents. We responded to requests from librarians in SAT countries and from a range of partners who collaborate with the Institute in various ways by dispatching some 95% of priced publications (37 784) 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 more than 1400 pieces of artwork directly and indirectly connected with this publishing work, our photographic staff handled 1700 assignments and processing jobs, our compositors created and processed 5390 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. The percentage of ICRISAT's major publications that have foreign-language (French, Spanish, and/or Portuguese) editions as well as English editions and abstracts in those languages remained at about 25.

During the year, experimental work in the production of videos and tape-slide programs about aspects of the Institute's work was initiated in collaboration with a local AV agency. The objective was to explore the potential for AV communication by building on experience gained from a member of staffs sabbatical project in 1988, in which a video on "Living with Drought", including aspects of ICRISAT's work in Niger, was coproduced with the BBC's Open University Production Centre in the UK. At the end of this year we drafted modalities for undertaking a planned series of AV productions, based on the production of two AV aids about the work of ICRISAT's legumes entomologists.

In handling distribution of publications, the combined invoicing and stock recording system has been computerized, and the turn-around period in handling sales and requests has accordingly been reduced from 1 week to about 1 day.

In order to maintain quality and cost-effectiveness in our book production work, it was decided in 1989 to employ consultants to assess the level of the Division's productivity, in relation to a known and anticipated increase in printing demand of 10% per annum. Their report has resulted in the placement of orders for electronic software and hardware, to be installed in 1990, that will considerably enhance the throughput of work by the editors, graphic artists, and compositors.

Care has been taken to ensure that key national program research organizations in the 50 SAT countries have continuing access to ICRISAT publications, and respondents to a questionnaire addressed in 1989 to 2000 selected national program research staff showed that there is a preference for ICRISAT 'quality' publications: the Annual Report, Research Highlights, Conference Proceedings, Books, Research Bulletins, etc. But questionnaire respondents also expressed an increasing interest in AV aids—a new demand the division is now ready to meet.

ICRISAT Sahelian Center

The activities of the Information Unit at ISC are mainly related to translation, publication , and public relations. We offer to the management and scientists, translation services into French, which are mainly used for conference papers, journal articles, and correspondence. During this year, the Unit provided active support for the Annual Report 1988 and translated this publication into French. The Unit is responsible for all ICRISAT publications in French, including books, Information Bulletins, sections of Workshop Proceedings, Progress Reports, and general audience publications. We have also published, with the Institut d'economie rurale, Mali, proceedings of two national workshops, one on intercropping and the other on sorghum and millet. We published the biannual newsletter, Nouvelles de l'ICRISAT.

Scientific translation is a problem faced by all the institutes of the Consultative Group on International Agricultural Research (CGIAR). To standardize terms, style, and presentation in French, we have prepared—in collaboration with the Centre de cooperation international en recherche agronomique pour le developpement (CIRAD) and a senior proofreader/writer from Le Monde—a French Agronomic Style Manual, which will be published by CIRAD. In addition, we plan to publish internally, a bilingual lexicon on the terminology used by ICRISAT (this was accomplished by a senior staff member during his sabbatical leave).

We receive officials and journalists (from the press, radio, and television). A TV program in French and local languages was prepared for the inauguration of ISC. We provided displays on ICRISAT's activities during the World Food Day and other agricultural fairs held in Niamey,

Library and Documentation Services

Acquisitions

During 1989, we added 1507 documents to our collection (Table 1).

Table 1. Status of acquisitions in the ICRISAT Library during 1989.

Documents	Additions during 1989	Total holdings as on 31 Dec 1989
Books	466	23 325
Bound volumes of periodicals	395	14593
Annual Reports	155	1836
Pamphlets	482	5814
Microforms	9	835

Database Development

During 1989, the library's database on the Institute's VAX-11/780 grew by 8542 records. The database is being built with machine-readable data received from two international databases: CAB International (CABI), and the FAO's International Information System for Agricultural Sciences and Technology (AGRIS). To these sources is added data pertaining to books and other documents procured by the library.

A breakup of contributing sources to the database is given in Table 2.

Table 2. Sources contributing to the database during 1989.

Source	Number of records
CABI[1]	3822
AGRIS[2]	1758
Local input	1346
Data from retrospective sorghum and millet bibliographies	1014
Retrospective library catalog data	602
Total	8542

1. CABI — CAB International.
2. AGRIS International Information System for Agricultural Sciences and Technology.

Documentation Services

Semi-Arid Tropical Crops Information Service (SATCRIS)

The SATCRIS, a project funded in part by the International Development Research Centre (IDRC) in 1986 to succeed the Sorghum and Millets Information Center (SM1C), 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 automated SDI service, commenced in March 1988, added 95 new recipients to the service. Of these, 40 are from 14 countries of Africa, 41 from 4 countries in Asia, 7 from 4 countries in the Middle East, and 7 from North and South America. The countrywise breakup of new entrants to the SDI service is given in Table 3. The service now reaches 297 users in 43 countries of the world. A countrywise breakup of the recipients of the SDI service is given in Table 4.

Literature Search Services

During the year, we conducted 314 on-demand literature searches for users all over the SAT.

Table 3. Countrywise breakup of new recipients of the SDI service.

Country	Number of recipients
Africa	
Botswana	1
Burkina Faso	1
Ethiopia	10
Kenya	9
Malawi	1
Mali	1
Niger	1
Nigeria	2
Somalia	1
Sudan	2
Tanzania	2
Uganda	1
Zambia	5
Zimbabwe	3
Americas	
Mexico	5
USA	2
Asia	
China	2
India	35
Iran	1
Nepal	3
Syria	1
Thailand	1
Turkey	4
Yemen	1
Total	95

Table 4. Countrywise breakup of recipients of the SDI Service.

Country		Number of recipients
Africa	98	
Benin		1
Botswana		2
Burkina Faso		7
Cameroon		1
C6te d'Ivoire		1
Ethiopia		21
Kenya		14
Malawi		1
Mali		4
Niger		11
Nigeria		6
Senegal		2
Somalia		8
Sudan		3
Tanzania		2
Uganda		1
Zambia		8
Zimbabwe		5
Americas	15	
Mexico		8
Nicaragua		1
Peru		1
USA		5
Asia	180	
Bangladesh		1
China		9
India		147
ICRISAT	40	
Other institutions	107	
Indonesia		2
Iran		1
Iraq		1
Japan		1
Nepal		3
Pakistan		4
Syria		2
Thailand		1
Turkey		4
Vietnam		1
Yemen, Arab Republic		1
Yemen, People's Democratic Republic		2
Europe	4	
Federal Republic of Germany		1
Netherlands		1
UK		1
Yugoslavia		1
Total		297

Continued

Table 4. *Continued.*

This is more than double the number of search requests responded to in 1988 and includes 11 on-line searches.

The search services reached users in 21 countries including 11 countries of Africa. The countrywise distribution of search services is given in Table 5.

Specialist Abstracts Services

Three abstracts services, Sorghum and Millets Abstracts, Chickpea and Pigeonpea Prompts, and Groundnut Prompts, were produced by CABI in collaboration with ICRISAT under the SATCRIS project. The three services were provided free of charge to 761 individuals or institutions in over 45 countries of the SAT.

Document Delivery

Copies of documents found useful in the SDI, literature searches, and abstracts services are requested by recipients of these services. During 1989, more than 6000 requests for copies of doc-

Table 5. Countrywise distribution of search services.

	Type of search				
Country of user	CD-ROM[1]	SATCRIS	On-line	Manual	Total
India					
ICRISAT	97	28	9	4	138
Others	87	10	1	-	98
Africa					
Burkina Faso	2	-	-	-	2
Ethiopia	2	-	-	-	2
Kenya	1	-	-	-	1
Mali	2	2	1	1	6
Niger	5	3	-	1	9
Nigeria	4	3	-	-	7
Sudan	2	-	-	-	2
Tanzania	4	-	-	-	4
Uganda	1	1	-	-	2
Zambia	3	1	-	-	4
Zimbabwe	13	7	-	-	20
Other countries					
Belgium	1	-	-	-	1
China	1	1	-	-	2
El Salvador	1	-	-	-	1
Indonesia	4	1	-	-	5
Mauritius	2	2	-	-	4
Mexico	1	1	-	-	2
Pakistan	2	-	-	-	2
Trinidad and Tobago	1	-	-	-	1
Yemen, Arab Republic	1	-	-	-	1
Total	237	60	11	6	314

1. CD-ROM = Compact Disk-Read Only Memory.

uments were entertained. Of these, the SDI service alone has provided copies of 4100 papers totaling to about 32 000 pages.

SATCRIS Workshops in Southern Africa

Two staff members from SATCRIS traveled to 5 countries of southern Africa in September-October 1989 to conduct user-oriented workshops. The workshops aimed at improving the awareness of potential end-users in different institutions in southern Africa to the resources and services of SATCRIS, at identifying gaps in accessibility to information on ICRISAT's five mandate crops, at building contacts with libraries and documentation centers in the region, and at identifying sources of conventional and nonconventional literature.

One hundred and sixty-nine participants from 33 institutions in Botswana, Malawi, Tanzania, Zambia, and Zimbabwe participated in these workshops.

Input to the AGRIS Database

Items of ICRISAT-generated conventional and nonconventional literature, totaling 289, were input to the AGRIS database.

CGIAR Documentation and Information Services Meeting

ICRISAT hosted the second Consultative Group on International Agricultural Research (CGIAR) Documentation and Information Services meeting at ICRISAT Center in January 1989. The meeting was attended by 35 participants from other CGIAR and non-CGIAR centers, National Agricultural Research Systems (NARS) institutions in Asia, Africa, and Latin America, the database producers, and donors. The meeting made several recommendations and designated specific centers to coordinate or lead action in implementing the recommendations. Several steps have since been taken by centers to implement the recommendations.

Union Catalog of Serials Holdings in IARCs

One of the recommendations of the CGIAR Meeting on Documentation and Information Services was that the library at ICRISAT should develop a machine-readable database of serials held by Center libraries, and produce a hard copy of the Union Catalog of Serials held by the participating International Agricultural Research Centers (IARCs). Work on this project began by upgrading the Serials data system software that the library had already developed in 1987-88. During 1989, 2800 records were added to the Union Catalog of Serials database with data received from 14 IARCs. Further, the library was able to provide camera-ready copy of the Catalogs of Serials to libraries at Asian Vegetable Research and Development Center (AVRDC), International Center for Agricultural Research in the Dry Areas (ICARDA), and Centro Internacional de la Papa (CIP) during 1989. ICARDA has since offset-produced its Catalog for wide distribution in its region. Programs were also written to make the database available as a Micro CDS/ ISIS and a BASIS application. The Micro CDS/ISIS database will be offered as a product to the NARS libraries in addition to a hard copy version of the Union Catalog of Serials which is to be printed in 1990. It is envisaged that the availability of this Catalog would enable the NARS and IARC libraries to make better use of the rich serial resources of IARCs in document delivery to end users.

ISC Activities

The ICRISAT Sahelian Center (ISC) Library, like the other services, has moved into the new buildings at Sadore, in March 1989. This section, with the Information Services, caters to the information needs of scientists as well as other users.

Established in 1984, this Library subscribes to 57 periodicals covering a wide range of topics and branches in the world of science. We have around 5000 specialized books, annual reports, progress reports, conference proceedings, bound volumes of periodicals and theses.

Acquisitions

The status of acquisitions at the ISC library during 1989 is riven in Table 6.

Table 6. Status of acquisitions in the ICRISAT Sahelian Center Library during 1989.

Documents	Additions during 1989
Books and Reports	316
Bound volumes of periodicals	160
Annual reports	32
Pamphlets	46

Documentation

From March 1989, a weekly bulletin of contents pages of journals was distributed to our scientists at Sadore and in West African Sorghum Improvement Program (WASIP) in Mali and Nigeria. So far we have distributed more than 14 000 copies of articles from different journals, which indicates the usefulness of this bulletin.

We have established very good contacts with the other information centers and libraries in Niger: Institut national de recherches agronomiques du Niger (INRAN), Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM), Centre d'information et de documentation pour le developpment rural (CIDR), faculty of Agronomy, Centre regional de formation et d'aplication en agrometeorologie et hydrologie operationnelle (AGRHYMET), in the subregion ODESSA (Cote d'Ivoire), Semi-Arid Food Grain Research and Development (SAFGRAD), Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (CILSS) (Burkina Faso), Centre de cooperation Internationale en recherche agronomique pour le developpement (CIRAD), International Service for National Agricultural Research (ISNAR), etc., based on an exchange basis.

Publications

Institute Publications

Annual Progress Reports

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Annual report 1988. Patancheru, A.P. 502 324, India: ICRISAT. 306 pp. ISSN 0257-2478. (ARE 015)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Research highlights 1988. Patancheru, A.P. 502 324, India: ICRISAT. 52 pp. ISSN 0257-2532. (RHE 010)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Progres de la recherche 1988. Patancheru, A.P. 502 324, India: ICRISAT. 52pp. ISSN 0257-2494. (RHF 010)

Newsletters

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. At ICRISAT nos. 25, 26, 27, and 28. Patancheru, A.P. 502 324, India: ICRISAT. ISSN 0257-2486. (NAE)

Other Publications

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The citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT.

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

RESEARCH SUPPORT ACTIVITIES

Genetic Resources Unit

The ICRISAT Genetic Resources Unit has established the world's largest germplasm collections of its five mandate crops and six minor millets. In the past, much emphasis was being given to the collection, characterization, and conservation of germplasm. At present we are giving increased emphasis to systematic multilocational evaluation, screening for resistance traits, enhancement for utilization, classification, and documentation, besides continued maintenance and conservation of the assembled material. As the long-term storage facility became operational, we are now concentrating on seed increase of accessions to obtain sufficient seed stocks for long-term conservation. Multilocational evaluation of germplasm in India, Kenya, Nigeria, and Venezuela resulted in the identification of locally adapted germplasm, which is being used to broaden the genetic base.

In future, emphasis will be placed on germplasm maintenance, long-term conservation, diversification, genetic studies, germplasm enhancement through conversion and introgression, development of trait-specific germplasm pools, and limited germplasm collections of crops and their wild relatives from areas threatened by genetic erosion. Special attention will be given to identify and study the nature and the possible utilization of useful traits found in wild relatives of mandate crops. Priorities for future strategic research were identified during the Cereals and Legumes Global In-house Reviews and the joint ICAR/ICRISAT workshop.

Germplasm Collection and Assembly

This year, we added 3282 accessions of mandate crops and 308 minor millets (Table 1) to the existing 96 200 accessions, raising the total gene bank holdings *to* 99 790. In collaboration with scientists in the National Agricultural Research System (NARS), germplasm collection missions were launched to Central African Republic, India, Indonesia, Malawi, Pakistan, and Togo where we collected 2200 samples consisting of 782 sorghum, 831 pearl millet, 161 chickpea, 77 pigeonpea, 237 groundnut, and 112 minor millets (Table 2). All the 1342 germplasm samples including 309 sorghum, 759 pearl millet, 48 chickpea, 11 pigeonpea, 203 groundnut, and 12 minor millets collected from outside India were handed over to the Plant Quarantine Regional Station of the National Bureau of Plant Genetic Resources (NBPGR), Rajendranagar, for quarantine examination and subsequent sowing in the Post-Entry Quarantine Isolation Area (PEQIA) for inspection and seed increase.

Table 1. Additions to ICRISAT germplasm collections in 1989.

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
Africa						
Botswana	-	17	-	-	-	-
Burkina Faso	-	204	-	-	-	-

Continued

Table 1. *Continued*

Origin	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets
Cameroon	241					
Ethiopia	-	-	9	-	-	-
Kenya	122	-	-	16	2	-
Malawi	-	-	-	-	6	-
Mali	-	-	-	-	17	-
Morocco	19	-	-	-	-	-
Mozambique	-	-	-	-	4	-
Niger	-	5	-	-	-	-
Senegal	-	-	-	-	1	-
Somalia	26	-	-	-	.	-
Sudan	105	-	-	-	1	.
Tanzania	-	-	5	-	27	17
Zambia	-	-	-	49	•	-
Zimbabwe	-	869	-	-	46	188
Asia						
Bangladesh	-	-	3	-	-	-
China	-	-	-	-	2	-
India	274	340	m	51	116	103
Iran	-	-	3	-	-	-
Japan	-	-	-	-	1	-
Korea, Republic of	-	-	-	-	15	-
Myanmar	-	-	-	-	34	-
Pakistan	-	-	2	-	-	-
Sri Lanka	-	-	-	-	1	-
Syria	-	-	162	-	-	-
Europe						
Greece	-	-	-	-	1	-
Italy	-	-	-	11	-	-
Americas						
Brazil	-	-	-	1	-	-
Jamaica	-	-	-	1	-	-
Mexico	-	-	1	-	-	-
Saint Lucia	-	-	-	2	-	-
USA	-	-	-	-	273	-
Oceania						
Australia	-	-	-	1	-	-
Unknown	-	-	-	-	5	-
Total in 1989	787	1435	376	132	552	308
Cumulative total to date	31817	21231	15 940	11 172	12712	6918

Table 2. Germplasm collection missions launched jointly by ICRISAT, NARS, and other agencies, and number of samples collected during 1989.

Country/ State(s)	Period	Number of samples[1]						
		SG	PM	CP	PP	GN	MM	Total
Central African Republic	Jan	218	129	-	5	91	-	443
Indonesia	Nov-Dec	2	-	-	2	75	-	79
Malawi	Sep	-	-	36	-	-	-	36
Pakistan	Sep	55	150	12	-	-	12	229
Togo	Aug-Sep	34	480	-	4	37	-	555
India								
Bihar	Mar-Apr	-	-	89	45	-	-	134
Madhya Pradesh	Nov-Dec	155	-	-	-	-	-	155
Madhya Pradesh	Nov-Dec	6	1	2	3	14	2	28
Maharashtra	Sep-Oct	32	70	11	9	18	51	191
Maharashtra and Karnataka	Feb	177	1	11	3	2	-	194
Tamil Nadu	Jan	92	-	-	-	-	41	133
Tripura	Nov-Dec	11	-	-	6	-	6	23
Total		782	831	161	77	237	112	2200

1. SG = Sorghum, PM = Pear! Millet, CP = Chickpea, PP = Pigeonpea, GN = Groundnut, and MM = Minor Millets.

Germplasm Maintenance

We rejuvenated 15 466 cultivated accessions of our mandate crops, and 230 wild relatives of sorghum, besides 316 minor millets, mainly during the postrainy season. These include 7545 sorghum, 1418 pearl millet, 1212 chickpea, 1300 pigeonpea, and 3991 groundnut accessions. As the long-term storage facility became operational, we shifted our priority to systematic rejuvenation and seed multiplication. Some 337 groundnut accessions were released from quarantine, 1803 exotic introductions consisting of 1016 sorghum, 627 pearl millet, 87 pigeonpea, and 72 minor millets samples were grown in the PEQIA for inspection, seed multiplication, and maintenance

Germplasm Conservation and Seed Biology

We initiated long-term conservation of germplasm of mandate crops this year. About 125 g ol seeds, of each of the 1822 sorghum and 1220 pearl millet accessions, were dried to 5-7% moisture content at 15°C and 15% relative humidity in the drying cabinet and sealed in laminated aluminum foil packets for storage at -20°C. The initial viability of the accessions stored under long-term conditions was tested and the data together with other information relating to conservation were stored in a retrievable form in a microcomputer.

Monitoring viability of germplasm conserved under medium-term conditions was continued and germination of 1280 sorghum, 2321 chickpea, 477 pigeonpea, and 744 groundnut accessions was tested. A total of 383 accessions consisting of 37 sorghum, 237 chickpea, 34 pigeonpea, and 75 groundnut accessions, whose viability was reduced to less than 85%, was identified for immediate rejuvenation.

Germplasm Evaluation

A total of 8463 accessions consisting of 1005 sorghum, 2306 pearl millet, 544 chickpea, 617 pigeonpea, and 3991 groundnut accessions was characterized and evaluated at ICRISAT Center. At Kano, Nigeria, 2010 sorghum germplasm accessions were evaluated and 96 agronomically elite lines were selected. In Kenya, 16 elite pigeonpea germplasm lines were selected for large-scale multilocational testing and three entries from this set are being considered for release in the country. Joint evaluation of germplasm by ICRISAT and NBPGR scientists in various locations in India (Table 3) led to the identification of promising accessions: 65 sorghum accessions for grain and 147 for forage, 10 chickpea accessions, and 3 pigeonpea acces-

Table 3. Collaborators, locations, number of accessions, and type of material characterized/evaluated jointly during 1989.

Crop	Collaborator	Location	Number of accessions	Type of material
Sorghum	NBPGR, India	Issapur	1200	Selected germplasm for forage
	IGFRI, India	Jhansi	1200	
	NRCS, India	Rajendranagar	1200	
	NBPGR, India	Akola	1000	Selected germplasm for grain
	TNAU, India	Coimbatore	1000	
	NRCS, India	Rajendranagar	1000	
	UAS, India	Bijapur	1002	Selected germplasm for postrainy-season program
	MPKV, India	Mohol	1002	
	NRCS, India	Rajendranagar	1002	
	WASIP, Nigeria	Bagauda	2010	Early-maturing germplasm
Pearl millet	NBPGR, India	Jodhpur	2000	Diverse germplasm
	AICPMIP, India	Pune	2000	Diverse germplasm
	TNAU, India	Coimbatore	2000	Diverse germplasm
Chickpea	NBPGR, India	Akola	1200	Short duration
	NBPGR, India	Issapur	1200	Long duration
	ICRISAT, India	Patancheru	1200	Medium duration
Pigeonpea	NBPGR, India	Akola	1000	Medium duration
	NBPGR, India	Vadodara	1000	Medium duration
	ICRISAT, India	Patancheru	1000	Medium duration
	NBPGR, India	Kanpur	1000	Long duration
	NBPGR, India	Dholi	500	Long duration
	NDFRC, Kenya	Katumani	453	Long duration
	NDFRC, Kenya	Kampiyamave	385	Long duration
	FONAIAP, Venezuela	Quibor	500	Vegetable type
Groundnut	NBPGR, India	Akola	1000	Selected germplasm
	NRCG, India	Junagadh	1000	Selected germplasm

sions. Elite sorghum germplasm was classified as sterility maintainers or restorers. After screening 968 accessions of *Arachis hypogaea* ssp *fastigiata*< 57 accessions with fresh seed dormancy were identified. Supernumerary chromosomes were observed in *Sorghum nitidurn,* a recently collected wild species in Western Ghats, India.

Documentation

Passport and evaluation data for new accessions have been compiled to enable computerization. Passport data of sorghum subsequent to IS 25240 and up to IS 33000 have been entered into the ICRISAT Data Management and Retrieval System (IDMRS) computer program. Passport and evaluation data of pearl millet accessions from IP 12432 to IP 15617 were tabulated (or entering into the IDMRS data base. Passport data of 376 new accessions and evaluation data of 544 accessions of chickpea were computerized. The characterization data of pigeonpea at Patancheru for 1987/1988 rainy season and the passport data on new accessions were entered into the computer and the 1988/1989 characterization data are being documented. Compilation of passport, evaluation, and characterization data has been completed for 12 160 groundnut accessions which was supplied to the Computer Services for entering into the data base. A part of this data has been analyzed and inferences have been drawn on spectrum of variability for specific desirable traits. Computer printouts of our mandate crops were supplied on request to various research organizations.

Germplasm Distribution

A total of 60 843 samples of mandate crops was distributed this year. These include 11 547 samples of mandate crops to various disciplines within ICRISAT (Table 4) mainly for screening against various biotic and abiotic stress factors. In addition, we dispatched 32 075 samples to scientists in India mainly for joint ICRISAT/NBPGR germplasm evaluation program, and 17 221 samples to scientists in other countries (Table5).

Sorghum Germplasm

This year, 787 new accessions from six countries were assembled by collection and correspon-

Table 4. Seed samples supplied to ICRISAT crop programs during 1989.

	Cereals		Legumes			
Discipline	Sorghum	Pearl Millet	Chickpea	Pigeonpea	Groundnut	Total
Agronomy	1	-	-	78	-	79
Physiology	290	268	18	-	97	673
Pathology	1975	420	2 591	4	1916	6906
Entomology	372	-	-	-	68	440
Breeding	350	79	312	192	289	1222
Biochemistry	15	2	811	579	334	1741
Cell biology	-	-	4	9	75	88
Training	17	-	-	-	24	41
Nematology	1	-	96	174	25	296
Quarantine	-	10	21	-	-	31
Others	-	-	10	20	-	30
Total	3021	779	3 863	1056	2828	11547

Table 5. Germplasm samples distributed by GRU, ICRISAT, during 1989.

Crop	ICRISAT Center (1)	Within India (2)	Other countries (3)	Total samples distributed (1+2+3)	No. of countries
Sorghum	3021	11569	5236	19 826	25
Pearl millet	779	7902	4011	12692	16
Chickpea	3863	4239	4586	12688	14
Pigeonpea	1056	5041	998	7095	16
Groundnut	2828	2876	2064		12
Minor millets	-	448	326	774	5
Total in 1989	11547	32075	17221	60 843	-
Cumulative total to date	438 539	243 110	235 744	9 17 393	-

dence to our gene bank raising the total to 31 817 (Table 1). In January, we organized a collection mission in Tamil Nadu in collaboration with NBPGR Regional Station (RS), Trichur, Kerala, and Tamil Nadu Agricultural University, Coimbatore, where 92 primitive landraces, including a rare wild species of *Sorghum stapfii,* were collected. In February, we organized a collection mission to postrainy-season sorghum-growing areas of Maharashtra and Karnataka in collaboration with NBPGR-RS, Rajendranagar, Hyderabad, and Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, where we collected 177 samples which promise to be of great value in the Indian postrainy-season sorghum improvement program. In collaboration with NBPGR, New Delhi and Jawaharlal Nehru Krishi Vishwavidyalaya (JNKV), Indore, we organized a collection mission during November-December to Malwa, Hoshangabad, Khargone, and Khandwa areas of Madhya Pradesh (Fig. 1), where we collected 155 samples which included landraces like Vidisha, Chikini, Peela amla, Gehuri, Kalatosa, Dodhana, Safed, Nanibai, Ghuggar, Doodmogar, Agyapeli, Dhani, Neel, Amneri, and controljowar. Among these, Gehuri is stated to be like wheat, Nanibai is good for popping, and Agyapeli is tolerant to *Striga.* Control jowar looks like 'Hegari' (Caudatum-kafir) introduced long back from USA and is popular in Jhabua district of Madhya Pradesh, because of its short duration. Two wild forms, *Sorghum miliaceum* and *Sorghum purpureosericcum,* were also collected in this mission. Most of the landraces collected from Madhya Pradesh

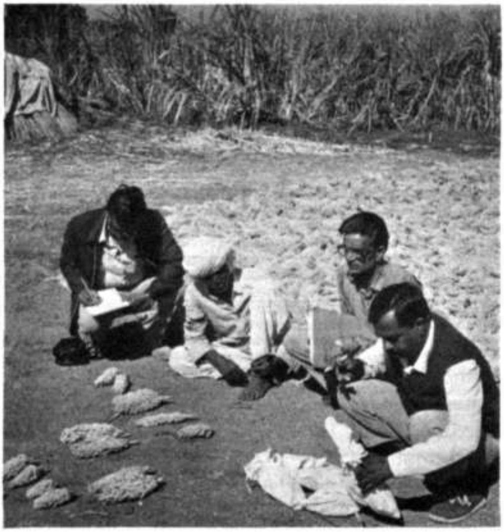

Figure 1. Collection of sorghum germplasm in the Malwa and Hoshangabad areas of Madhya Pradesh in collaboration with the National Bureau of Plant Genetic Resources (NBPGR), India.

belong to race Durra and race Guinea (subrace Roxburghii).

We grew 1016 samples from Botswana (29), Cameroon (13), Central African Republic (209), Maldives (10), the Philippines (6), Rwanda (31), Venezuela (213), and Zimbabwe (505) in the PEQIA for inspection, seed increase, and release.

In the rainy and postrainy seasons, we characterized 1005 new accessions at ICRISAT Center. With an objective to provide a wide range of diverse germplasm to produce commercial hybrids, selected agronomically elite landraces from different sorghum-growing countries in Africa and Asia were crossed with male-sterile lines ICSA 73, ICSA 81, ICSA 86, ICSA 92, 296A, and 2219A to test for fertility restoration. Out of 917 F,s sown during the rainy season, 536 flowered late, and among the early lines, 346 were identified as restorers, 17 as maintainers, and 18 as partial restorers. The same set was also sown in the postrainy season to confirm its behavior. The newly identified maintainers can be used in developing male steriles on diverse genetic backgrounds, and restorers can be used in hybrid program as direct lines or with some improvement.

We collaborated with NBPGR, National Research Centre for Sorghum (NRCS), Rajendranagar (Andhra Pradesh) and agricultural universities in India, to evaluate 1000 selected germplasm accessions for grain at Rajendranagar, Akola, and Coimbatore (Table 3). Some 65 accessions including 14 from ICRISAT conversion collection have been selected by sorghum scientists from NRCS, Rajendranagar, and sorghum breeders at Punjabrao Krishi Vidyapeeth (PKV), Akola (Maharashtra). A total of 1200 germplasm accessions for forage has been evaluated in collaboration with NBPGR, Issapur (New Delhi), Indian Grassland and Fodder Research Institute (IGFRI), Jhansi (Uttar Pradesh), and NRCS, Rajendranagar. A total of 147 accessions has been selected by forage breeders based on forage qualities. Some of them, like IS 131, IS 2034, IS 2132, IS 3191, IS 3196, IS4717, IS 4752, IS 6016, IS 6067, IS 6152, IS 6304, IS 6337, IS 18667, and IS 20557, have been identified for utilization in forage improvement.

Figure 2. Joint evaluation of sorghum germplasm by sorghum breeders and germplasm scientists at the Bagauda farm, Kano, Nigeria to select diverse source material for use in the West African Sorghum Improvement Program (WASIP).

A postrainy-season basic collection, constituted at ICRISAT Center was sent to Mohol, Parbhani (Maharashtra), Annigeri and Bijapur (Karnataka), and Tandur and Rajendranagar (Andhra Pradesh), India, for evaluation. Sorghum breeders from NRCS and agricultural universities, and a sorghum botanist and physiologist from ICRISAT visited the crop, and selected 104 accessions for further testing and utilization in the Indian postrainy-season program.

A total of 2010 early-maturing sorghum germplasm accessions from the world collection was sown at the Bagauda farm, Kano, Nigeria, during the rainy season, for a systematic joint evaluation by sorghum breeders and germplasm scientists (Fig. 2) to identify promising lines for use in the West African Sorghum Improvement Program (WASIP). Considering maturity, agronomic eliteness, and freedom from leaf diseases, 96 IS numbers were selected. The Hegari and

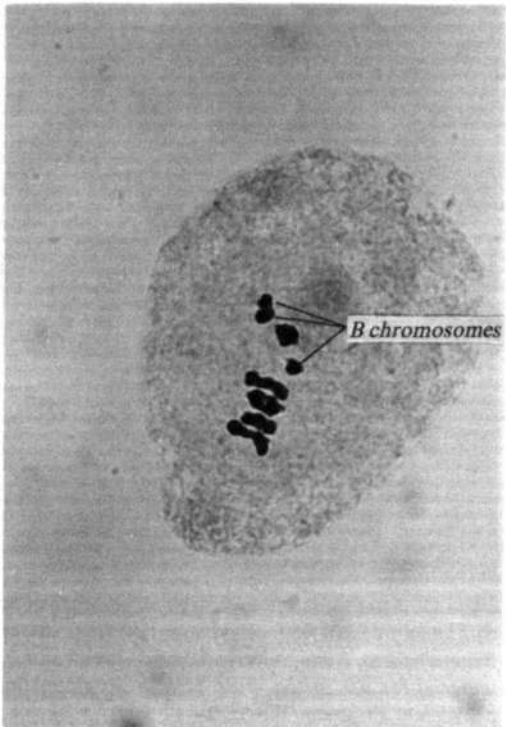

Figure 3. B chromosomes in Sorghum nitidum *showing five bivalents and IIB + IB chromosomes during diakinesis.*

Feterita forms from Sudan and Kafirs from southern Africa were found promising for various agronomic traits.

Seeds of the 69 promising accessions of germplasm selected in Somalia during 1988 were increased at ICRISAT Center during this year and supplied to Eastern Africa Regional Cereals and Legumes (EARCAL) Network for testing and utilization in East African Sorghum Improvement Program.

Cytological studies were conducted to determine the chromosome numbers of the newly acquired wild species of sorghum. *Sorghum nitidum, S. aff. stipoideum, S. stipoideum, S. matarankense, S. brevicallosum* have 10 chromosomes each (n=5); 5. *stapfii,* and *S. australiens* have 20 chromosomes (n=10); while *S. laxiflorum* has 40 chromosomes (n=20). Meiosis was regular in all species except *S. australiens,* where multivalent formation was observed. In *S. nitidum,* in addition to the 10 standard chromosomes, three supernumerary chromosomes (B chromosomes) were found in each pollen mother cell (Fig. 3).

Pearl Millet Germplasm

We added 1435 accessions from Botswana (17), Burkina Faso (204), India (340), Niger (5), and Zimbabwe (869), raising the total number of cultivated accessions in the gene bank to 21 231 (Table 1). In collaboration with the Ministry of Rural Development, Bangui, Central African Republic (Fig. 4), we collected 129 samples during January. Considerable variation in spike shape, size, and compactness, grain color, shape, and size was observed. This material appears to be a good source for white grain color. A pointed germplasm collection mission to northern Togo was launched during August-September in collaboration with ICRISAT Sahelian Center, Sadore, Niger, and Department of Agricultural Research, Lome, Togo, to collect early-maturing forms of pearl millet (Fig. 5). A total of 480 samples was collected. The millet breeder who participated in the mission visually evaluated and selected 159 samples from 50 different farmers' fields and households. Togo germplasm is a good source for large grain and early maturity. In collaboration with the Pakistan Agricultural Research Council, Islamabad, millet-growing areas along the borders of the Thar desert were explored during September and 150 samples were collected. In collaboration with NBPGR-RS, Akola, we collected 63 cultivated and 7 wild *Pennisetum* samples from Western Ghats and adjoining areas of Maharashtra, India, during September-October.

We grew 627 accessions from Algeria (11), Central African Republic (99), Chad (35), Niger (3), Nigeria (5), Sudan (10), Togo (458), and Tunisia (6) in the PEQIA. We evaluated and characterized 2306 accessions at ICRISAT Cen-

Figure4. In Central African Republic, wild relatives grow along with cultivated pearl millet, being collected by the national counterpart.

ter during the rainy season. All the new additions from northeastern Andhra Pradesh, Haryana (India), and Zimbabwe were classified into different cultivar groups based on flowering, plant height, spike, and grain characters.

The effect of grain maturity on quality, viability, and longevity of pearl millet seed was studied using a male-sterile line DSA 105A. Germination percentage, dry matter accumulation, and seedling vigor were maximum at 28 days after pollination, but seeds harvested at 35 days after pollination survived longer than others under accelerated aging conditions.

We further evaluated 2000 diverse accessions each at NBPGR- RS, Jodhpur, Rajasthan; All India Coordinated Pearl Millet Improvement Project (AICPMIP), Pune, Maharashtra; and Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, in India.

Pearl millet accessions collected from Ghana and Botswana during 1982 were space planted in quarantine isolation area and the emerging heads were bagged. At maturity, 24 plants from five accessions from Ghana and seven plants from two accessions from Botswana were selected, based on seed-set. Their anthers were shrunk without shedding pollen, and the plants produced several aerial tillers. Maintainer lines were identified and the stable male-sterile lines developed were DSA 59-1, DSA 105, DSA 118, DSA 134, and DSA 144-1 from Ghana and PMC 23 and PMC 30 from Botswana. All the new male-

Figure 5. Early-maturing pearl millet from Togo with large spikes and grains (selected by farmers for use as seed) were collected by ICRISAT and will be very useful in millet improvement.

sterile lines, except PMC 30 flowered early and produced large grain.

To determine the distribution and geographic specificity of male-sterility maintainers, 428 diverse germplasm accessions representing variation from 12 countries were crossed with a male-sterile line 5141 A. The F_1 hybrids were classified either as male fertile or male sterile, based on anther morphology and the seed-set on bagged earheads. Among these, 87 (20.3%) were classified as male fertile, 32 (7.5%) as male sterile, 282 (65.9%) as segregating for male fertility/male sterility, and 27 (6.3%) behaved as male fertile in the rainy season and as male sterile in the post-rainy season. Restorer lines were distributed in all the countries studied, except Cameroon and USSR. Maintainer lines were observed from several countries, but most were concentrated in India. They may prove to be useful sources of material for generating new male-sterile lines. The restorers can be used to produce commercial hybrids.

Several naturally occurring mutants including midribless ones were identified. Leaf anatomy of the midribless mutant showed reduction in the number of vascular bundles, absence of prominent keel, and reduction in sclerenchymatous tissue on both abaxial and adaxial sides of the large vascular bundles. These cause leaves to droop in the midribless mutants. Meiosis was studied in the genus *Pennisetum* (L.) Rich, having species with chromosome numbers that are multiples of x=5,7,8, and 9. The occurrence of higher associations in three species: *P. ramosum* (Hochst.) Schweinf., *P. schweinfurthii* Pilger, and *P. mezianum* Leeke was attributed to homology in the basic complement following duplication and differentiation during the evolution of these species. Based on the higher association observed in the diploid complement of P. *schweinfurthii,* it was assumed that the chromosome complement in *Pennisetum* has evolved from a basic chromosome number x=5. The occurrence of *P. ramosum* with chromosome number x=5 further supports this view.

One spontaneous triploid (3x=27) plant was identified among the diploid cytotypes (2n=18) of *P. hohenackeri Hochst.* ex Steud. The triploid plant resembled the diploid in most morphological characters, except for the reduced number of spikelets. Chromosome associations of 9 II+9 I were observed at diakinesis and metaphase I. The bivalents divided normally, while the univalents lagged and formed a separate nucleus, which was included in one of the daughter cells. On the basis of these studies, this plant was considered to be an allotriploid and might have originated as a spontaneous hybrid between diploid *P. hohenackeri* and an unknown tetraploid (amphidiploid) taxon with one of its genomes homologous to that of diploid *P. hohenackeri*

Minor Millets Germplasm

We assembled 308 new accessions consisting of 277 finger millet *(Eleusine coracana* [L.] Gaertn.), 11 foxtail millet *(Setaria italic a* Beauv.), and 20 barnyard millet *(Echinochloa colona* [L.] Link.) from India (103), Tanzania (17), and Zimbabwe (188), raising the total gene bank holdings to 6918 (Table 1). We received 72 accessions of finger millet and foxtail millet from Maldives, Taiwan, and Zimbabwe which were sown in the PEQIA for inspection and release. A total of 316 accessions of finger millet (281), foxtail millet (11), and barnyard millet (24) was rejuvenated during the year. We supplied 774 accessions to Djibouti, Federal Republic of Germany, India, Kenya, and Zimbabwe for utilization in their crop improvement programs.

Chickpea Germplasm

With the addition of 376 samples, the world collection has increased to 15 940 accessions (Table 1). The new accessions are from Bangladesh (3), Ethiopia (9), India (191), Iran (3), Mexico (1), Pakistan (2), Syria (162), and Tanzania (5).

In Bihar, India, we carried out a germplasm collection mission in collaboration with the NBPGR-RS, Cuttack, Orissa and the Rajendra Agricultural University, Dholi, Bihar during March-April where we collected 89 samples. Chickpeas from Bihar arc the desi type, characterized by small seed size, often with spreading growth habit, and of medium duration. The mission in Malawi was organized jointly with the Ministry of Agriculture, Malawi, during September, where we collected 36 samples. Chickpeas in Malawi are grown after the rains, on residual soil moisture, during March-April to August-September. Chickpea landraces in Malawi are characterized by purple flowers, green stems, and angular, white seeds.

At Patancheru, we sowed 796 accessions for preliminary evaluation and 1070 accessions were sown for seed increase. For rejuvenation and seed increase, we sowed 142 accessions in which seed viability declined to less than 85%. We raised a set of 1200 medium-duration accessions as part of a germplasm multilocational evaluation and identified a spontaneous dwarf mutant with a large number of branches (Fig. 6). We also tested five sets of germplasm accessions from Madhya Pradesh (India) for agronomic performance in relatively larger and replicated plots. Some very superior lines identified were ICC 14614, ICC 14627, ICC 14817, ICC 15115, and ICC 15129. A set of 1200 long-duration chickpeas was evaluated at NBPGR, Issapur (New Delhi) and five agronomically superior lines ICC 97, ICC 602, ICC 1022, ICC 1362, and ICC 10495 were identified. Another set of 1200 short-duration accessions was evaluated at Akola and 22 lines with better local adaptation were selected.

We summarized data on character correlations in chickpea on a set of 25 short- and medium-duration accessions that represent the widest possible range for the morphoagronomic traits. Interesting observations noted are that leaf area is positively associated with seed mass but had negative correlation with number of pods, seeds pod^{-1}, seed yield, and seed protein content. We observed negative correlations between seeds pod^{-1} vs seed mass and seed protein vs seed mass, while days to flowering indicated inverse relationship with the seed yield.

Pigeonpea Germplasm

We added 132 pigeonpea accessions originating from India (51), Zambia (49), Kenya (16), Italy (11), Saint Lucia (2) and one each from Australia, Brazil, and Jamaica, raising the gene bank total to 11172 from 52 countries (Table 1). A total of 87 samples originating from Venezuela (84), Central African Republic (2), and Maldives (1) was sown in the PEQIA for inspection and further release. In a joint ICR1SAT/NBPGR germplasm exploration mission to Tripura, four pigeonpea accessions and two *Atylosia* species were collected during November-December.

We sowed 617 accessions for characterization, which include 209 new collections and 408 accessions with incomplete data from earlier evaluations. The crop stand and growth were excellent for collecting data from most of these accessions,

Figure 6. Scientists examining ICC 3644, a new chickpea type having long fruiting branches, ICRISAT Center, 1989.

We grew 1300 accessions for rejuvenation and seed increase, including 34 accessions with low seed viability (<85%). We carried out studies on variability in seed protein content and cooking time in collaboration with the Biochemistry Unit. We raised 45 entries to test protein content and 40 entries to test cooking time in three replications. We screened 207 accessions for photoperiod insensitivity out of which 90 accessions were identified as less sensitive.

In collaboration with NBPGR, India, we are evaluating 1000 medium-duration accessions each at Akola and Vadodara in addition to Patancheru. We are also evaluating 1000 long-duration accessions at Kanpur and 500 at Dholi (Table 3).

In collaboration with Fondo Nacional de Investigaciones Agropecuarias (FONAIAP), we assembled a working collection of 1000 pigeonpea accessions in Venezuela and characterized 500 accessions for important morphoagronomic traits (Table 3). We jointly carried out agronomic evaluation of 56 elite mid-late duration vegetable types. Selection of entries for this trial was based on our joint evaluation of elite germplasm in Kenya, in collaboration with National Dryland Farming Research Center (NDFRC), Kenya (Fig. 7). Thirteen entries of this trial yielded over 2 t ha^{-1}, three entries (ICP 12069 and ICP 12143 from Tanzania, and ICP 7613, India) yielded over 3 t ha^{-1}, while the average yield in Venezuela including that of the released

At ICRISAT Center we grew 3991 accessions this year, in two seasons, for seed increase, evaluation, and characterization. We also evaluated many new accessions assembled recently. For collaborative multilocational evaluation of germplasm through a joint ICRISAT/NBPGR program, a set of 1000 accessions each was supplied to NBPGR-RS, Akola, and National Research Centre for Groundnut (NRCG), Junagadh.

Lack of fresh seed dormancy has been a major constraint in groundnut cultivars belonging to *A. hypogaea* ssp *fastigiata,* which dominate world cultivation. Hence, we screened genotypes for fresh seed dormancy in this subspecies. This year, we tested 968 freshly harvested accessions under optimum conditions of temperature and humidity and identified 57 accessions having fresh seed dormancy for a minimum of 30 days.

We have initiated efforts to broaden the genetic base of *A. hypogaea* through introgression of desirable traits from wild *Arachis species* into *A. hypogaea.* To start with, an accession of a compatible diploid species *A. correntina* ($2n$= 20) (section *Arachis),* with multiple resistance was successfully crossed with three cultivars belonging to three botanical varieties of *A. hypogaea,* whence F_0 seeds were obtained. Our efforts to cross another incompatible species *A. paraguariensis* (belonging to section *Erectoides)* with *A. hypogaea* have not been successful. We are attempting to understand the barriers to hybridization and to find suitable technique to hybridize this species with *A. hypogaea.* At present, attempts are being made to cross this species with a diploid species of section *Arachis,* which also contains tetraploid cultivated species *A. hypogaea.*

West Africa - ISC

The breeding subprogram of the ISC Pearl Millet Improvement Program hosts a team of two geneticists from the Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM) that investigates the origin and domestication of pearl millet. During 1989, the ORSTOM team continued to investigate the genetic diversity in cultivated pearl millet (*Pennisetum glaucum)* and its wild progenitor (P. *violaceum)* and the genetic barriers to natural crossing between these two botanical forms. For details, see Pearl Millet section of this Annual Report under 'Evolutionary Genetics of Pennisetum'.

Germplasm Characterization in SADCC

We sowed 1413 sorghum accessions from the SADCC region in three different locations at Aisleby (irrigated), Mzarabani (rainfed, low altitude), both in Zimbabwe, and Ilonga, Tanzania (long-season, rainfed) for evaluation and characterization. We recorded 14 descriptors and analyzed some of them. Seedling vigor was more than average in a number of accessions from Lesotho (98%), Angola (87%), and Botswana (86%). Three accessions, IS 23784 and IS 23790 (from Malawi), and IS 23253 (from Zambia), had brown midrib color. The dominant midrib color in the SADCC accessions was white (43%) followed by yellow (28%) and dull green (22%). Very few (3.4%) of the accessions had mostly waxy bloom, while 11.3% had medium waxiness and 30%; had no waxy bloom. Seed color in the region's germplasm ranged from white to cream (straw) (both 66% of total) to brown (30%) and red (4%). This observation is interesting in relation to the issue of bird damage and grain utilization in the region. Countrywise classification based on seed color shows that indigenous farmers' varieties are mostly white in Botswana (62%), Lesotho (77%), Malawi (73%), and Zimbabwe (68%). In Tanzania, both white (55%)- and brown (45%)-seeded varieties are grown almost equally. It is only in Swaziland that most indigenous sorghums are brown (69%) seeded. Two accessions IS 24042 and IS 24120, from Tanzania, have an average of eight synchronous tillers with very small cigar-shaped compact heads which may be useful as forage types.

Plant Quarantine

Plant quarantine is carried out by the National Bureau of Plant Genetic Resources (NBPGR), the national plant quarantine services, for all ICRISAT seed and plant material. During 1989, at the Plant Quarantine Unit we processed and certified seed material for export, and the NBPGR's Plant Quarantine Regional Station at Hyderabad cleared the new plant introductions procured by ICRISAT. We provided active assistance to NBPGR in processing seeds for export, making sure they are free from quarantine objects by using inspection methodology aimed at 'exclusion'. We fumigated seeds and tested them by blotter and agar plate as well as by washing methods. We recorded *Glomerella cingulata,* the perfect stage of *Colletotrichum gloeosporioides,* on sorghum seeds for the first time. We assisted NBPGR in the release of healthy imported germplasm that ICRISAT obtained from various collaborating agencies by carrying out cooperative field inspections in the Post-Entry Quarantine Isolation Area (PEQIA) (Fig. 1).

In view of the recent changes made in the Indian plant quarantine regulations for the purpose of import of seeds into India, we liaised with the Ministry of Agriculture, Government of India, for regulating ICRISAT seed imports on the same basis as in the other institutes under the Indian Council of Agricultural Research (ICAR). The Director, NBPGR, has since been authorized to issue import permits for germplasm imports by ICRISAT, thus enabling expeditious import of seeds and plant material.

Figure 1. New sorghum introductions for Cooperative Cereals Research Network (CCRN) being inspected jointly by NBPGR/ICRISAT staff in the PEQIA.

Plant Material Exports

During the year, we exported total quantum of 3700 kg of seed material comprising 42 401 seed samples of ICRISAT mandate crops and minor millets, 94 units of rhizobial, mycorrhizal, and fungal cultures, and 1320 samples of plant material of several crops to scientists and cooperators in 93 countries (Table 1). While 359 sets of 56 different trials and nurseries formed the major portion of the exports, the other types of material sent included germplasm accessions from the gene bank, pest- and disease-resistant genotypes, lines for screening against viruses, and samples for food quality and biochemical analyses. The wide variety of plant material dispatched consisted of green gram (*Vigna radiata),* black gram (*Vigna mungo),* and cowpea (*Vigna unguiculata)* to compare their behavior in drought situations; pearl millet stems, leaves, and sheath tissue for analyzing components for fodder quality, pigeonpea plant tissue for 15 N determination; different plant parts of castor *(Ricinus communis),* maize *(Zea mays),* neem *(Azaridicta indica),* thread-awned grass *(Aristida adscensionis),* rhodes grass *(Chloris barbata),* para grass

Table 1. Seed and plant material exports of ICRISAT mandate crops during 1989.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Africa							
Algeria			270				
Benin	192			131			
Botswana					75		
Burkina Faso	284	2				17	
Cameroon	697	11		3			1
Cape Verde				2			
Chad	7						
Cote d' Ivoire	14				10		
Djibouti	50			20		10	
Egypt	141						
Ethiopia	343		823	30			
Ghana	283			2	123	4	
Guinea				110			
Kenya	1009		275	690		32	
Libya	25						
Malawi		19	10	128	1237		
Mali	1686	13		4			
Morocco			12				
Mozambique	50						
Namibia		1					
Niger	748	1653	7	12	572		
Nigeria				15			
Rwanda	392	17			12		
Senegal			18	20			

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Somalia	242						
Sudan	75	32	206	1			
Swaziland					49		
Tanzania			161	24			
The Gambia				2			
Togo				4			
Tunisia			150				
Zaire				2			
Zambia	176	65			73	193	
Zimbabwe	1 194	124	96	145	15	80	
Asia							
Bangladesh	42		746	7	9		
Bahrain				155			
Bhutan			10	205	50		
Indonesia	375			271	2685		6
Iran	264		10901		22		
Iraq	20						
Israel	55		8				
Japan				60	29		72
Korea, Republic of		8					
Malaysia					10		
Mauritius				6			
Myanmar	144		487	47	130		
Nepal			850	603	76		
Oman	6			100			
Pakistan	682		649	378	73		
People's Republic of China	649				125	200	
Saudi Arabia	20	20	18	7	63		
Sri Lanka			81	59	31		8
Syria			4081		24		
Taiwan					62	270	
Thailand	321		365	116	116		6
The Philippines	363	22	353	65			
Vietnam	5	21		222	48		
Yemen Arab Republic	50		150				
The Americas							
Argentina	98	4	150				
Belize				50	17		
Bolivia				88			
Brazil			24	99	6		
Canada			217	2			
Chile			155				

Continued

Table 1. *Continued.*

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Cuba					7		
El Salvador	50						
Grenada	72						
Guatemala				186			
Haiti	25						
Honduras				13			
Mexico	3244	28	460			1	
Nicaragua	5						
Paraguay					4		
Peru	10		150	96	26		
Trinidad and Tobago				3			
USA	1209	18	174	301	53	1	15
Venezuela	5	5		53			
Europe							
Belgium	61				2		
Cyprus					163		
Federal Republic of Germany	2	6		1		1	21
France	157		132	2	22		
Greece			10				
German Democratic Republic					3		
Italy	10	6	22				
Poland			1				
Portugal			260				
Spain			331				
The Netherlands	3	3		10			
Turkey			85				
UK	26	9	6	5	45		1191
USSR			5	10			
Oceania							
Australia	51	30	66		28		
Fiji		19					
Total	15 632	2136	13 164	4565	6095	809	1320

(Brachiaria cruciformis), spear grass *(Heteropogon contort us),* bermuda grass (*Cynadon dactylori),* pitted blue grass *(Bothriocloa pertusa),* and marvel grass *(Dicanthium annulatum)* for assessment of the deviation of isotopic contents of (and N. Dried cysts of pigeonpea cyst nematode *(Hcterodera cajani)* for DNA analysis, and rust- *(Puccinia penniseti)* infected pearl millet leaves, and samples of rust uredospores for determination of their correct taxonomy and comparative morphology through greenhouse experiments also formed a part of the material exported.

Several pathogens of plant quarantine importance such as *Ascochyta rabiei, Claviceps fusiformis, C. sorghi, Colletotrichum cajani, Fusarium oxysporum* f. sp *ciceri, Peronosclerospora sorghi, Sclerospora graminicola, Sphacelotheca cruenta, S. reliana, S. sorghi, Tolyposporium ehrenbergii, T. penicillariae, Xanthomonas campestris,* and peanut mottle virus were intercepted during the seed pathology studies of germplasm for export, accounting for 2.2% detention of samples submitted for processing. A critical study of the records from 1982 to 1989 revealed the occurrence of 157 microflora belong-

Table 2. Seed and plant material imports of ICRISAT mandate crops made during 1989.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Others
Africa							
Cameroon	13						
Central African Republic	209	99		2	115		
Ethiopia	28		1				
Kenya	120						
Malawi			36		1		
Niger		70			80		
Nigeria	14						
Rwanda	31						
Togo	33	458					
Zimbabwe	411	1					
Asia							
Iran	6						
Nepal					14		
Pakistan	46	163	60				
Syria			43				
Taiwan						29	
Thailand	3						
The Philippines	13						
The Americas							
Mexico	47		21				
USA	45	1	3		13		10
Venezuela	213			84			
Europe							
Cyprus					2		
Italy	6		17				
Turkey			1				
UK	734						
Oceania							
Australia				105			
Total	1972	792	182	191	225	29	10

ing to 74 different genera, on the seeds of the mandate crops. There are 54 host/pathogen interactions in which the pathogen is reported to be seed borne in one or more of our crops, out of which only 14 are of quarantine importance.

Plant Material Imports

The NBPGR released 50 consignments comprising 3401 seed and plant samples of the mandate crops and minor millets from 25 countries (Table 2). It also released one consignment of soil, and another of pepper, watermelon, and tomato seeds. The sorghum and groundnut releases also included samples for biochemical and food quality analyses.

Post-entry Quarantine Isolation Area (PEQIA)

The seeds and seedlings released by NBPGR were subjected to postentry growout in the PEQIA under strict quarantine conditions for observation during one growing season to determine whether or not they were free from pests. This cannot be easily detected by inspection at the time of entry. We grew a total of 2241 samples *of* the mandate crops and *minor* millets under the supervision of the NBPGR/ICRISAT personnel, observed until freedom from pests and diseases was assured and healthy progeny released to us for utilization.

Farm Development and Operations

ICRISAT Center

Operations and Services

During 1989, we sowed 408 ha of experimental crops (Table 1). We spent 12 088 machine hours on land preparation, sowing, and cultivation. We maintained and improved roads, drains, culverts, and the fence on the farm area (1390 ha), using 18 338 machine hours. All harvesting, threshing, and seed drying requirements took 7 202 machine hours (Table 2). We weeded about 306 ha employing 15 730 temporary farm labour (TFL) averaging 51 man-days ha^{-1} (Table 3). During the year, we received and attended to 3873 work requests for various field operations (Table 4).

On the basis of insect surveillance data (Table 5), we sprayed pesticides when considered necessary by concerned scientists. We sprayed herbicides to control weeds (Fig. 1).

We applied very little irrigation during the

Table 1. Area under experimentation, excluding watersheds, during 1989.

Crops	Rainy season (ha)	Postrainy season (ha)	Total (ha)
Pearl millet	42.22	27.96	70.18
Sorghum	46.17	43.71	89.88
Chickpea	0.50	47.90	48.40
Groundnut	54.85	21.10	75.95
Pigeonpea	52.27	7.04	59.31
RMP fields	23.99	2.40	26.39
Trainees' fields	12.31	0.00	12.31
Postentry quarantine fields	0.30	4.16	4.46
Others	13.42	8.32	21.74
Total	246.03	162.59	408.62

Table 2. Use of farm machinery during 1989.

Items	Machine hours	Machine hours ha^{-1}
Tillage, sowing cultivation, and research support (408 ha)	12088	29
Farm maintenance, and improvements (1390 ha)	18 338	13
Harvesting, threshing, and drying (408 ha)	7 202	17

Table 3. Weeding by the temporary farm labor (TFL), area weeded, man-days, and man-days ha^{-1}, during 1989.

	Weeding		
Crops	Area (ha)	Man-days	Man-days ha^{-1}
Pearl millet	74.34	3421.00	46.02
Sorghum	43.40	1 906.50	43.93
Chickpea	64.39	1 575.50	24.47
Groundnut	71.45	4 982.00	69.73
Pigeonpea	32.67	2444.00	74.80
GRU fields	5.70	448.00	78.59
Postentry quarantine fields	6.70	417.00	62.23
RMP fields	4.15	328.50	79.15
Trainees' fields	3.70	208.00	56.22
Total	306.50	15 730.50	51.32

rainy season since rains were well distributed and in abundance, but in the postrainy season, we irrigated most crops throughout the season (Fig. 2). We met all the service requirements for greenhouse experiments and maintained the campus landscape.

Development Activities

A Senior Engineer from FDO carried out development work at Kano (Nigeria) for the West African Sorghum Improvement Program (WASIP). He also traveled to Vietnam for a 1-month consultancy on groundnut seed handling and storage. Our Land Development Engineer visited Kenya and developed 11 ha of land at Kiboko for the Eastern Africa Regional Cereals and Legumes (EARCAL) Program. We completed the drainage system at the Gwalior Cooperative Research Station by constructing a catchment tank and installed an underground irrigation system at the Anantapur Cooperative Research Station.

We reclaimed additional land in the Post-Entry Quarantine Isolation Area (PEQIA) for growing material for the Cooperative Cereals Research Network (CCRN), and improved drainage in the six fields at the Center. We constructed new culverts, and erected culvert indicators on main traffic roads to improve safety measures. We established tree belt in the drainage areas by sowing 5000 saplings to protect the land and improve the environment.

Table 4. Farm operations requests attended to during 1989.

	Number of requests					
Program	Farm machinery	Irriga-tion	Labor operation	Plant protection	Seed processing	Total
Cereals	766	180	217	179	208	1550
Legumes	462	312	184	353	330	1641
RMP	209	5	18	156	96	484
GRU	37	26	7	13	7	90
Training	24	2	-[1]	2	20	48
Postentry quarantine fields	20	9	6	2	11	48
Others	5	-	-	6	1	12
Total	1523	534	432	711	673	3873

1. - = No requests received.

Table 5. Insect pest incidence on mandate crops during 1989.

Crops	Pests	Monthly means											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sorghum[1]	Shoot fly	1.55	1.07	0.50	0.24	-	0.23	2.21	3.17	0.88	2.24	3.45	1.88
	Stem borer	2.77	5.01	4.50	5.13	3.64	4.73	1.92	5.56	1.66	0.46	1.48	2.79
	Mythimna sp	0.06	0.10	-	0.03	0.06	0.09	0.24	5.29	1.88	0.49	0.45	0.90
	Head bugs	1.16	1.91	5.19	10.84	5.47	5.56	0.13	0.86	20.17	25.23	1.16	0.63
Pearl millet[1]	*Helicoverpa* sp	0.06	0.01	0.24	1.34	2.58	-	0.01	5.40	7.18	0.85	0.45	0.03
	Shoot bug	2.86	3.26	3.77	4.60	3.57	2.25	2.12	7.02	2.82	7.85	7.16	6.35
	Mythimna sp	-	0.04	0.29	0.07	0.03	-	0.06	3.62	0.65	1.00		0.50
Groundnut[2]	Leaf miner	0.06	0.22	0.60	1.10	0.20	0.23	0.18	0.86	1.71	1.24	-	0.51
	Thrips (SC)	1.73	2.86	1.89	0.64	0.42	0.66	0.47	1.43	1.36	0.70	0.35	1.91
	Spodoptera sp	-	0.03	0.08	0.07	-	0.03	-	0.11	0.45	0.47	-	0.08
Pigeonpea[3]	*Helicoverpa* sp	0.68	0.27	0.42	0.33	0.11	0.01	0.02	0.01	0.52	0.46	1.11	0.91
	Leaf webber	-	-	0.01	0.02	0.01	0.09	0.31	0.71	0.61	0.59	0.28	0.06
	Exalastis sp	-	0.18	0.21	-	-	-	-	0.01	-	0.04	0.12	0.19
Chickpea[3]	*Helicoverpa* sp	1.09	1.02	-	0.30	-	-	-	0.15	0.23	0.61	1.07	1.16
	Spodoptera sp	-	-	-	-	-	-	-	-	0.30	0.29	0.30	-

1. Incidence in percentage of plants infested.
2. Incidence in insects m^{-1}.
3. Incidence in insects $plant^{-1}$.

Figure 1. Preemergence herbicide being sprayed alter sowing groundnut in a field at ICRISAT Center, 1989. Note difference in color in treated and nontreated areas.

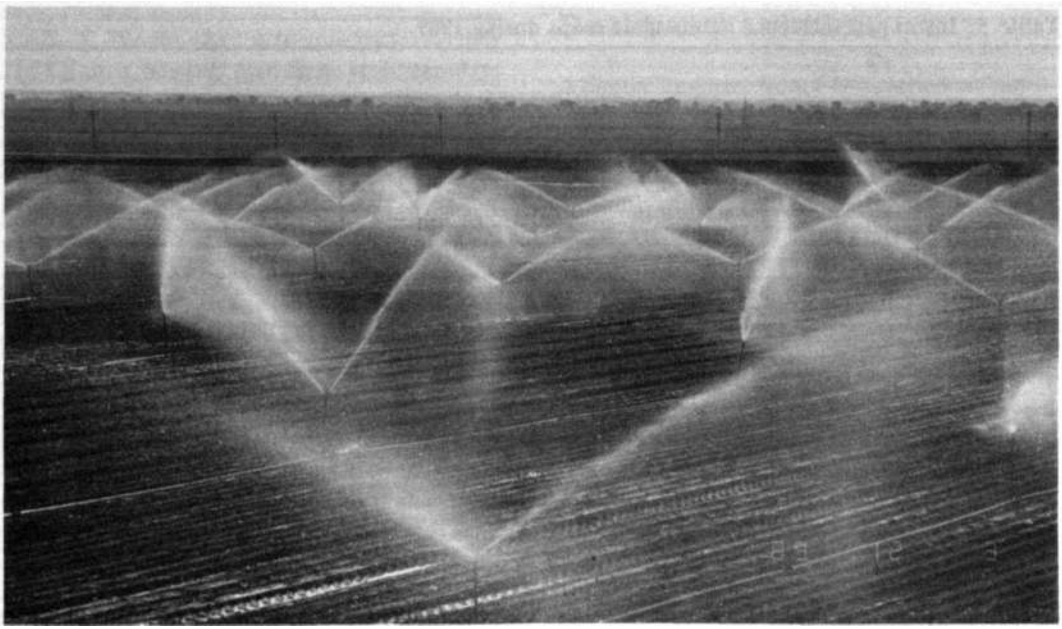

Figure 2. Sprinkler irrigation at ICRISAT Center, 1989.

Improvements

We followed suggestions made by the Consultant who visited FDO and minimized the use of crawler tractors. We used landplaning and ripping operations only in the fields that needed improvements, in order to reduce cost of land preparation. We further improved the accuracy of the chickpea planter and refined the plot-length measuring and seed-tripping devices and field tested it on a large scale (Fig. 3). We modified the tractor track and wheel spacing to cultivate crops at 60-cm row spacing, and ordered new equipment to improve cultivation.

Communication and coordination between the FDO staff and the scientists were further strengthened by nominating coordinators from each program and by constituting a Tillage Advisory Committee. We demonstrated new modifications on equipment to scientists and prepared an FDO catalog of services and procedures for the information of scientists. The information on our activities is widely circulated through quarterly reports and 'Plant Protection Reporter'. We now publicize our daily work schedules on all the VAX terminals. Our field history records, and land and services requests are also on the Institute's computer network to facilitate information flow. We have most of our management information on PCs for processing and scheduling of work.

We followed the Farm Research Committee's (FRC) recommendations and adhered to deadlines for sowing and harvesting to implement the 'close-season' for effective pest control.

Training

We contributed to training the station managers from the Southern African Development Coordination Conference (SADCC) countries at

Figure 3. Planter fitted with a plot-length measuring and seed-tripping device at ICR1SA T Center, 1989.

Bulawayo (Zimbabwe). We trained in-service trainees in field operations and plant protection. We also conducted in-house training for our operators and technicians in various field operations (Fig. 4).

SADCC/ICRISAT, Zimbabwe

Operations and Services

We sowed all the trials and nurseries and managed them well (Table 6). The coefficients of variation were below 20% for the first time. For the 1989/90 rainy season, we ripped and/or plowed, and disced most of the fields at Matopos and Lucydale, and sowed the experiments. Germination in the machine-sown experiments was excellent. We established a legume-based crop rotation to break the cereals monoculture, and at Mzarabani, a crop 'close-season' is being followed from 1 December 1989 through 15 February 1990 to control insect-pest buildup.

During 1989, bird scaring was a labor-intensive activity. We are working out alternative strategies to minimize labor costs on bird scaring. In weed control, however, labor saving has been effective with the help of mechanical cultivation, and by assigning jobs on task basis. We irrigated crops at Aisleby and Mzarabani but applied only life-saving irrigation at Matopos.

Table 6. Area under experimentation during 1988/89.

	Crops		
Location	Sorghum (ha)	Millets (ha)	Total (ha)
Matopos	15.0	8.0	23.0
Mzarabani	2.8	3.5	6.3
M/arabania (off-season)	2.66	3.52	6.18
Aisleby	4.0	3.6	7.6
Lucydale	1.7	1.2	2.9
Total	26.16	19.82	45.98

Development and Maintenance

We developed a block of 2.84 ha at Matopos for plant protection research. To augment the culvert capacity, we constructed road inverts at all the drain crossings, and maintained roads, drains, and fences. We smoothened out land to maintain field slopes.

We completed the construction of dormitory, catering, and recreational facilities, and the simplex housing for staff and visiting scientists, and commissioned these facilities. Landscaping around the hostels and duplex houses is in progress. We also constructed a field shelter and put it to use.

The food/feed laboratories and pilot processing plants, greenhouses, headhouse and houses for two senior support staff are under construction and will be commissioned in early 1990.

Figure 4. Farm machinery operators learning field adjustments on a plow at ICRISAT Center, 1989.

We got a borehole dug and connected it to the domestic water supply. A detailed underground water potential study for the station was carried out, and we identified a high-potential borehole to augment the existing critical domestic water supply.

A Mechanic/Transport Officer has been employed to be in charge of repairs and servicing of vehicles at Matopos. Two tractors and a number of cars were repaired. Six threshers and a tipper trailer for Mzarabani were procured.

At Mzarabani, we are developing 30 ha of land. We completed bush clearing, grid survey, soil mapping, and developed fields based on soil type, soil depth, and slope of the land. Field sizes vary from 0.5 to 2.5 ha with slopes ranging from 0.5 to 2.9%. We leveled two fields having deep soils and landplaned the rest to obtain uniform slopes for drainage. We constructed drains totaling 3940 m, and laid 2441 m of roads. Of the 19.24 ha developed, 11.01 ha will be under experimentation and the rest will be cropped to check uniformity. We marked the location of four boreholes for drilling. In the 'M' block, we landplaned 6.18 ha to improve drainage, and reshaped roads and drains.

Assistance to National Agricultural Research Systems (NARS)

We erected and commissioned prefabricated two-bedroom houses at Kasama (Zambia) and Kasinthula (Malawi); in addition, erected similar houses at Pandamatenga and Sebele (Botswana) and one at Golden Valley (Zambia).

We planned and partially executed land improvement in 5.25 ha at Sebele (Botswana) and 6 ha at Kasinthula (Malawi).

We cleared 10 ha of land at Kasinthula (Malawi) and fenced it for use in pearl millet research. We surveyed 44.8 ha at Golden Valley (Zambia) for land improvement, and surveyed and landplaned six fields of 0.3 ha each at Panmure (Zimbabwe) for regional and national pathology trials. We plan to develop a research station at Hombolo (Tanzania) in collaboration with the staff at Ilonga (Tanzania).

A reconditioned pick-up truck was given to Matopos Research Station and we assisted in repairing one MF 265 tractor for Henderson Research Station (Zimbabwe). We assisted the National Agricultural Research Systems (NARSs) in Zambia, Malawi, Tanzania, and Botswana by providing implements for land preparation and sowing.

Training and Consultancy

We conducted a 6-week course in Station Development and Management from 30 January to 10 March 1989. Fifteen Farm Managers from six countries in the region attended the course.

The staff visited SADCC countries and gave on-the-job training in the use of farm equipment, operations, and station development. We organized a Field Day at Matopos for the Agritex provincial officers and crop specialists, and handed over 50 kg of sorghum cultivar ICSV 112 (SV 1) breeders' seed to the Director of Agritex in consultation and agreement with the Breeder of Research and Specialist Services (Zimbabwe) to promote adoption.

We also produced 41 each of sorghum cultivar ICSV 112 and DC75, 6 t each of ICMV SD 870 14 and RMP1, and 2 t of finger millet (two varieties) to meet seed requirements for the NARS trials.

Statistical Services

In the Statistics Units at ICR1SAT Center and ICRISAT Sahelian Center (ISC), we provide consultancy services to the ICRISAT scientific community and also to scientists from collaborative projects at various stages of their research, from planning experiments to analysis of data and interpretation of results. We also deliver lectures to in-service trainees on the principles of experimentation and also on the use of MSTAT, a statistical data-processing package on the microcomputer. We review scientific papers for the Editorial Committee, and articles for newsletters and the annual report.

During the year, we assisted one PhD student and one MSc student on the statistical analysis of data and interpretation of results.

We processed a number of data sets for various programs at ICRISAT Center, Southern African Development Coordination Conference (SADCC), and ISC. We developed various computer programs in GENSTAT for use by the plant breeders and other scientists.

During the year, we provided consultancy to scientists at 1CR1SAT Center and also to collaborators. They averaged over 70 per month. The consultancies included planning of experiments, statistical analysis of data, interpretation of results, and usage of statistical packages.

We carried out simulation studies and analysis of data from field experiments, to compare the incomplete block designs with duplicated augmented designs, which resulted in a journal article submitted to the Editorial Committee for subsequent publication.

Our Statistician was on sabbatical leave until July. During his leave, he worked on different topics of interest which included biometrical genetics, robust regression, correlation, response surface methodology, and income inequality assessment.

We had a consultant statistician for 3 months. He provided consultancy on pattern analysis, multilocational data analysis, analysis of data from augmented designs, and quantitative genetics. He also provided analysis support to test some of Resource Management Program's modeling efforts.

Computer Services

ICRISAT Center

The Computer Services Division at ICRISAT Center provides time-sharing 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 systems, which are connected as a network. We develop interactive systems, provide data-entry services, install VAX software packages and microcomputer software, and give seminars, training courses, and individualized instruction on computer usage to staff members of the Institute.

As an aid to research, the PC-based FDO Planning and Recording Information System was completed and released for regular use, as also phase II of this project, comprising the VAX-based Field History System. A VAX-based land request system has been developed and all requests for experimental land allocation are now processed through this online system, with relevant data being transferred to the planning and recording system. The sales and publication system developed for Information Services was revised. The PC data entry component of a new Research Project Management System was completed and released to the research programs. On the administrative side, the PC-based RWF Employees Information System was completed and released for regular use. A PC-based Disposal Items Tracking System was completed and released. The Purchase Order Tracking System, set back again by an unexpected resignation, was completed in December and released to the Purchase Division for final testing, and a revision of the payroll system is nearing completion. An administrative support system has been developed for the Delhi Office, and is awaiting the receipt of new equipment before final testing and release.

A 72-line terminal server was installed in October permitting more flexible terminal connections to both VAX computer systems, a high-density tape drive was added to the VAX-11/780, and a heavy-duty dot matrix printer was ordered to specifically support specialized printing requirements of the administrative divisions.

A FAX machine was installed in February, and incoming FAX traffic has increased steadily since then. An interference problem in the exchange had made it virtually impossible to send outbound FAXes from ICRISAT. The problem was later rectified, and outgoing messages meeting certain conditions are accepted for transmission. The E-Mail facility that permits E-Mail messages to be sent to FAX addresses was announced, and users are taking advantage of this service. A telex interface card was installed in a microcomputer in June, and telexes have been sent and received using this computer since then. Telex preparation is much simplified, and outgoing messages can be queued for retry during the night. We contracted with Videsh Sanchar Nigam Limited (VSNL) in November to provide dial-up access to the international packet-switched gateway at Bombay via Hyderabad. This has permitted us to take complete charge of our E-Mail activities. We no longer use the relay system provided by CGNet Services between the USA and ICRISAT's VAX, a system which served us faithfully and well for nearly 5 years. In addition to improved E-Mail capabilities, this link has also simplified the Library's access to DIALOG for online information retrieval services.

The National Institute of Information Technology (NUT) was contracted to provide training in the use of PC software during May and June. Hundred and sixty-two staff members were trained in the use of PC DOS, WordStar, LOTUS 1-2-3, and dBASE III Plus. A programmer/analyst from the ICRISAT Sahelian Center (ISC) spent 2 months with Computer Services working on a microcomputer-based financial accounting system for ISC, and on improvements in the electronic mail system at ISC.

The Division Head attended the Spring DEC Users' Society meeting in Atlanta in May. One staff member attended four weeks of training at Digital Equipment Corporation in USA, and attended the Spring DECUS meeting. Four staff members attended the Computer Society of India Annual Meeting in Bangalore during September. Several staff members attended training courses in India in 1989: three attended a seminar on Expert Systems; two attended courses on OS/2, a new microcomputer operating system, and on strategies for information center management; two attended a workshop on data base management; four attended a course on hard disk management; two attended a course on the C programing language; and one attended a workshop on Novell Netware for local area networking applications.

Funding was secured for the replacement of the VAX-11/780 computer system by a MicroVAX 3900, providing four times more computing power and online storage capacity. Networking hardware is also on order and this will permit networking of microcomputers located in the laboratories with the VAX systems. The new MicroVAX will also be connected with the existing MicroVAX 3600 as a local area VAXCluster to facilitate system management, sharing of resources, and the flexible addition of new systems in the future. Wide-area networking hardware, included with the Micro VAX 3900, will set the stage for direct system access to packet-switched networks and computer systems, including other IARC systems.

ISC, Niger

A Computer Services Unit was established at the ICRISAT Sahelian Center (ISC) in 1989 to provide a center for shared facilities such as scanners, digitizers, and plotters; to develop applications for both administration and research; to evaluate new software; and to provide advice, assistance, and training to staff in the use of available software. The current staffing of the Computer Services Unit at ISC consists of a Head, a programmer/analyst, a computer operator, and a typist. This unit, and the existing and future plans described below, are based on a consultancy by CGNET Services International in 1987 which developed a comprehensive, phased plan to provide computing capabilities at ISC. This plan was subsequently revised based on experience at ISC.

Computing power at ISC is distributed to the end-users through the use of multiple microcomputers. Most scientists have access to PC AT compatible microcomputers for data analysis, with PC/XT compatible microcomputers for data entry. Microcomputer versions of Genstat, SAS, and Systat are used by the scientists for their data analysis. In the administrative area, multi-user 80386-bascd systems with the Xenix operating system are being used to develop centralized, integrated administrative applications, in addition to the use of PC AT and PC/XT compatibles for specialized applications and data entry. There are currently about 140 microcomputers in use at ISC. The maintenance of these microcomputers is primarily the responsibility of Physical Plant Services (PPS).

The long-term goal is to connect the microcomputers as a local area network (LAN) to permit sharing of expensive resources such as laser printers, digitizers, and plotters, and to facilitate data sharing and data security. Laboratory balances will be interfaced directly to microcomputers, and optical scanners will be used to assist in text data entry.

Publications

Institute Publications

Workshop and Symposia Proceeding

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Collaboration on Genetic Resources: summary proceedings of a Joint ICRISAT/NBPGR (ICAR) Workshop on Germplasm Exploration and Evaluation in India, 14-15 Nov 1988, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT. 124 pp. ISBN 92-9066-170-4. (CPE 052)

Journal Articles

Appa Rao, S., Mengesha, M.H., Harinarayana, G., and Rajagopal Reddy, C. 1987. Collection and evaluation of pearl millet germplasm from Maharashtra. Indian Journal of Genetics and Plant Breeding 47(2): 125-132. (JA 479)

Appa Rao, S., Mengesha, Melak H., and Rajagopal Reddy, C. 1989. Identification, characterization and geographic distribution of male-sterility restorer and maintainer lines from diverse pearl millet germplasm. Euphytica 40(1 and2): 155-159. (JA719)

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Mengesha, Melak H. 1988. Genetic resources activities at ICRISAT. Indian Journal of Plant Genetic Resources 1(1 and 2):49-58. (JA 788)

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Saideswara Rao, Y., Appa Rao, S., and Mengesha, Melak H. 1989. New evidence on the phylogeny of basic chromosome number in *Pennisetum.* Current Science 58(15):869-871. (JA 820)

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Singh, Murari, and Singh, Rajendra P. 1988. Approximation of first two moments and sampling distribution of Gini's coefficient. Journal of the Indian Society of Agricultural Statistics 40(2): 154-163. (JA 607)

Conference Papers

Appa Rao, S., Mengesha, Melak H., and Rajagopal Reddy, C. 1989. Development of cytoplasmic male-sterile lines of pearl millet from Ghana and Botswana germplasm. Pages 817-823 *in* Perspectives in cytology and genetics: proceedings of the Sixth All India Congress of Cytology and Genetics, 12-17 Oct 1987, Jammu, India (Manna, G.K., and Sinha, U., eds.). Kalyani, West Bengal, India: All India Congress of Cytology and Genetics. (CP 424)

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ICRISAT Center

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Y.L.Nene, Deputy Director General (from Apr)
M. Goon, Assistant Director General (Administration)
K.B.Srinivasan, Assistant Director General (Liaison) (until May)
B.C.G.Gunasekera, Advisor to Director General for Donor Relations (from Jun)
B.K.Patel, Special Assistant to Director General for Planning (from Jun)
P.Reavey, Special Assistant to Director General for Educational Affairs
V.Balasubramanian, Sr Executive Officer (Director General's Office)
J.Gay, Sr Adm Secretary to DG
P.Rama Murthy, Adm Officer, Office of Advisor to DG (DR)
P.Subrahmanyam, Sr Adm Officer, Office of the DDG (until Apr)
G.J. Michael, Adm Officer, Office of the DDG (from Apr)
Sheila Vijayakumar, Sr Research Associate, Office of the DDG (from Jun)
K.Sampath Kumar, Adm Secretary, Office of the DDG (until Apr)
S.Krishnan, Asst Manager (Admn) Admn Services (Delhi Office, from Dec)
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)
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
P.M.Menon, Personnel Manager (Acting)
K.K. Vij, Asst Manager (Admn) (from Dec)
N.S.L.Kumar, Sr Personnel Officer
P.Suryanarayana, Sr Personnel Officer
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 (on leave from Feb)
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
T.Gopalakrishnan, Purchase Officer
A.Lakshminarayana, Sr Scientific Liaison Officer (Visitors' Services)
Harish Sethi, Scientific Liaison Officer
G.Fredericks, Adm Officer (Visitors' Services)
K.K.Sood, Sr Security Officer
K.K.Vij, Asst Manager (Admn) (Delhi Office until Dec)
K.Santhanam, Manager (Internal Audit) (on contract)
V.Satish Kumar, Audit Officer
N.Surya Prakash Rao, Sr Resident Medical Officer
K.Jagannadham, Transport Officer
A.Rama Murthy, Travel Officer
V.V.Ramana Rao, Adm Officer

Research Programs

Cereals

Program Office

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V.S. Swaminathan, Sr Adm Officer (until Apr)
N.V.N. Chari, Adm Officer (from Apr)

Sorghum Group

J.W.Stenhouse, Principal Plant Breeder (from Nov)
L.K.Mughogho, Principal Plant Pathologist
J.M.Peacock, Principal Plant Physiologist
K.F.Nwanze, Principal Cereals Entomologist
C.M.Pattanayak, Principal Coordinator CCRN
G.Alagarswamy, Plant Physiologist
B.L.Agrawal, Plant Breeder (on leave from Aug)
Belum V.S.Reddy, Plant Breeder
P.K.Vaidya, Plant Breeder
N.Seetharama, Sr 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 (until Nov)
K.David Nicodemus, Sr Research Associate
P.S. Raju, Sr Research Associate (until Apr)
V.L. Chidley, Sr Research Associate
M.Peterschmitt, Postdoctoral Fellow
C.S.Busso, Postdoctoral Fellow
H.Kokubu, Postdoctoral Fellow (until Feb)

M.A.Osman, Postdoctoral Fellow
F.Pinard, Postdoctoral Fellow (from Sep)
S.D.K.Trichur, Research Scholar (until Apr)
K.G.Kausalya, Research Scholar
Mohd Hassan Aden, Research Scholar
Hassan A. Hassan, Research Scholar (until Feb)
S.S.Poranki, Research Scholar (from Jun)
A.P.P. Kumari, Research Scholar (from Aug)
G.Ravi Kumar, Research Scholar (from Oct)
Mahad Abdi Farah, Research Scholar (from Oct)
S. Sithole, Research Scholar (until Oct)

Pearl Millet Group

F.R.Bidinger, Principal Plant Physiologist
S.B.King, Principal Plant Pathologist (on study leave from Jun)
J.R.Witcombe, Principal Plant Breeder
K.N.Rai, Plant Breeder
B.S.Talukdar, Plant Breeder
S.B.Chavan, Plant Breeder (until Oct)
V.Mahalakshmi, Plant Physiologist
S.D.Singh, Sr Plant Pathologist
R.P.Thakur, Sr Plant Pathologist
K.R.Krishna, Microbiologist (until Oct)
B.P.Reddy, Sr Research Associate
E.Weltzien, Postdoctoral Fellow (until Nov)
P.J.Lynch, Research Scholar (from Jun)

Kenya

V.Y.Guiragossian, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa
S.Z.Mukuru, Principal Sorghum Breeder

Mexico

C.L.Paul, Team Leader and Principal Sorghum Agronomist (on sabbatical until Oct)
C.T.Hash, Principal Sorghum Breeder
R.Clara Valencia, Scientist, Sorghum Breeder

Legumes

Program Office

Y.L.Nene, Program Director, Legumes (until Mar)
D.McDonald, Program Director (Acting from Mar)
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C.L.L.Gowda, Sr Legumes Breeder, AGLN
D.M.Pawar, Sr Agricultural Officer (Cooperative Trials, LEGOFTEN)
Sheila Vijayakumar, Sr Research Associate (until Jun)
G.J.Michael, Adm Officer (until Apr)
K. Sampath Kumar, Adm Officer (from Apr)

Pulses Group

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Laxman Singh, Principal Plant Breeder, Pigeonpea (until Aug)
M.P.Pimbert, Principal Entomologist
J.Arihara, Associate Principal Physiologist (until Nov)
N.Ae, Associate Principal Microbiologist (until Nov)
K.Okada, Asst Principal Microbiologist
K.C. Jain, Plant Breeder, Pigeonpea
Onkar Singh, Plant Breeder, Chickpea
M.P. Srivastava, Sr Plant Breeder (on contract until Jun)
K.B.Saxena, Sr Plant Breeder, Pigeonpea
V.K. Sehgal, Sr Scientist (Entomology) (on contract until Feb)
S.S.Lateef, Entomologist
M.P.Haware, Plant Pathologist
S.C.Sethi, Plant Breeder, Chickpea
N.P.Saxena, Sr Crop Physiologist
O.P.Rupela, Crop Physiologist
K.R. Krishna, Crop Physiologist (from Oct)
J.V.D.K. Kumar Rao, Crop Physiologist, LEGOFTEN
C.S. Pawar, Entomologist, LEGOFTEN
A.M.Ghanekar, Plant Pathologist
Jagdish Kumar, Plant Breeder, Chickpea
S.C.Gupta, Plant Breeder, Pigeonpea
M.V.Reddy, Sr Plant Pathologist
Y.S.Chauhan, Crop Physiologist
S.B.Sharma, Plant Nematologist
N.V.Ratnam, Sr Research Associate (until Jun)
J.H.Miranda, Sr Research Associate, Chickpea (until Sep)
L.Krishna Murthy, Sr Research Associate
M.Chenchi Reddy, Sr Research Associate
A.Srinivasan, Postdoctoral Fellow (from Jun)
S.K.Singh, Postdoctoral Fellow (until Jan)
F.B.Lopez, Postdoctoral Fellow (until Jun)
T.Das Gupta, Postdoctoral Fellow (until Oct)
G.S.Chipyngahalo, Research Scholar (until Jun)
A.Schroth, Research Scholar (until Jan)
Uma M. Telugu, Research Scholar (from Jun)
A.Kubota, Research Scholar (from Jun)
L.M.T.Sijen, Research Scholar (until Feb)
G.V.Subba Rao, Research Scholar (until Sep)
M.van Eijk, Research Scholar (from Aug)

Groundnut Group

D.McDonald, Principal Plant Pathologist and Acting Director, Legumes Program (from Apr)

J.P.Moss, Principal Cell Biologist
D.V.R.Reddy, Principal Plant Virologist
J.H.Williams, Principal Plant Physiologist (until May)
J.A.Wightman, Principal Entomologist
S.N.Nigam, Principal Plant Breeder (on sabbatical from Jun)
N.Horn, Assistant Virologist (from Jun)
L.J.Reddy, Plant Breeder
P.Subrahmanyam, Sr Plant Pathologist
P.T.C.Nambiar, Cell Biologist
P.W.Amin, Coordinator and Sr Entomologist, LEGOFTEN
G.V.Ranga Rao, Entomologist
A.K.Singh, Cell Biologist
V.K.Mehan, Plant Pathologist (on sabbatical until Ma
D.C.Sastri, Cell Biologist
M.J.Vasudeva Rao, Plant Breeder (until Jan)
S.L.Dwivedi, Plant Breeder
R.C.Nageswara Rao, Crop Physiologist
V.M.Ramraj, Crop Physiologist
N.Sivananda Reddy, Sr Research Associate
Y.Sudhakar, Postdoctoral Fellow (until Apr)
C.S.Gold, Postdoctoral Fellow (until Sep)
W.R.Sacks, Postdoctoral Fellow (until Sep)
Shashi Gupta, Postdoctoral Fellow (until Jan)
J.Watterott, Research Scholar (until Mar)
T.Shanower, Research Scholar (until Apr)
Zhang Xinyan, Research Scholar (until Dec)
Nguyen Hai Nam, Research Scholar
P. Balan, Research Scholar (until Nov)

Kenya

Laxman Singh, Principal Pigeonpea Agronomist (from Sep)

Syria

K.B.Singh, Principal Chickpea Breeder

Pakistan

M.S.Rahman, Principal Chickpea Breeder/ Plant Pathologist (until Aug)

Resource Management

Program Office

J.L.Monteith, Program Director
R.S.Aiyer, Sr Adm Officer
S.Ramachandran, Adm Officer (until Apr)

Agronomy Group

S.M.Virmani, Principal Agroclimatologist
C.K.Ong, Principal Agronomist
D.R.Butler, Principal Microclimatologist
M.M.Anders, Principal Production Agronomist
Piara Singh, Soil Scientist (on sabbatical from Jun to Dec)
A.K.S.Huda, Agroclimatologist
A.Ramakrishna, Agronomist
N. Venkataratnam, Sr Research Associate (from Jun)
S.K. Sharma, Sr Research Associate (from Mar)
L. Mohan Reddy, Sr. Research Associate (from Mar)
A.A.H.Khan, Engineer
J.N.Daniel, Postdoctoral Fellow (until Aug)
J.C.W.Odongo, Postdoctoral Fellow
T.Bapi Reddy, Postdoctoral Fellow (from Dec)
P.P.Motavalli, Postdoctoral Fellow (from Jun)
F.M.Marshall, Research Scholar (from Apr)
S.Ravi Kumar, Research Scholar (from Oct)
R.Ranganathan, Research Scholar (from Oct)

Soil Group

J.R.Burford, Principal Soil Chemist
K.B.Laryea, Principal Soil Physicist
G.D.Smith, Principal Soil Scientist, ICRISAT/QDPI (until Feb)
D.F.Yule, Principal Soil Scientist, ICRISAT/QDPI (from Feb)
K.K.Lee, Principal Microbiologist
A.Schiitt, Asst Principal Engineer (ICRISAT/University of Hamburg)
K.L.Sahrawat, Sr Soil Chemist
T.J.Rego, Soil Scientist
D.P. Verma, Soil Scientist/ Soil Chemist, ICRISAT/IFDC (on contract)
Sardar Singh, Soil Scientist
Prabhakar Pathak, Agricultural Engineer (on sabbatical until Sep)
K.L.Srivastava, Agricultural Engineer
R.C.Sachan, Agricultural Engineer
N.K.Awadhwal, Agricultural Engineer/Soil Physicist
S.P.Wani, Microbiologist (on sabbatical from Oct)
M.Bonsu, Postdoctoral Fellow (until Aug)
S.Shailaja, Research Scholar (until Apr)
P.Vershney, Research Scholar (until Jun)
S.K.Samantra, Research Scholar (until Nov)
Bibhudutta Das, Research Scholar (from Dec)
M. Dayi S. Abdurahman, Research Scholar (from Sep)
S. Singer, Research Scholar (from May)

Economics Group

T.S.Walker, Principal Economist
R.A.E.Mailer, Principal Economist

T.G.Kelley, Asst Principal Economist (from Sep)
N.S. Jodha, Sr Economist II (until Apr)
R.P.Singh, Economist
M.Asokan, Sr Research Associate (on study leave)
K.G.Kshirsagar, Sr Research Associate (on study leave)
K.V.Subba Rao, Sr Research Associate
V.Bhaskar Rao, Sr Research Associate
P.Parthasarathy Rao, Sr Research Associate
A.G.Mengesha, Research Scholar
M.Gautam, Research Scholar (until Jul)
M.Bhende, Research Scholar (until Sep)

Support Programs

Biochemistry

R.Jambunathan, Principal Biochemist and Program Leader
Umaid Singh, Biochemist
V.Subramanian, Biochemist
S.Sivaramakrishnan, Biochemist (until Oct)
Santosh Gurtu, Sr Research Associate
M.S.Kherdekar, Sr Research Associate
S.Suryaprakash, Sr Research Associate
P. Venkateshwara Rao, Sr Research Associate
T.R.K.Satyanarayana, Adm Officer (until Jun)
Kamini Devi, Research Scholar (from Apr)

Radio Isotope Lab

S. Sivaramakrishnan, Biochemist (from Oct)

Electron Microscope Unit

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 II
V.Ramanatha Rao, Botanist II (on leave from Jul)
S.Appa Rao, Botanist II
P.Remanandan, Botanist II (on sabbatical until Jul)
A.K. Singh, Botanist II (from Aug)
Y.Saideshwara Rao, Postdoctoral Fellow (until Jan)
Surendra Mohan, Sr Adm Officer

Plant Quarantine

N.C.Joshi, Chief Plant Quarantine Officer (on contract)
Upendra Ravi, Sr Research Associate
V.S.Raju, Adm Officer (until Apr)
P. Subrahmanyam, Sr Adm Officer (from Apr)

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

J.B.Wills, Head
S.D.Hall, Research Editor
E.M.McGaw, Research Editor (from Jun)
S.M.Sinha, Asst Manager, Art and Production
D.R.Mohan Raj, Sr Editor (on leave from Jun)
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
A.N.Venkataswami, Sr Adm Officer
B.B. Sahni, Editor (on contract from Sep)
Savitri Mohapatra, Sr French Translator

Statistics

Murari Singh, Statistician (until Jun)

Computer Services

J.W.Estes, Head
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 (until Apr)
G.Subba Raju, Computer Programmer/Analyst
G.Padmaja, Computer Programmer/Analyst
A.Ram Murthy, Computer Programmer/Analyst (from Dec)

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 until May)
Daulat Jotwani, Library Officer

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 (until Apr)
V.S.Raju, Adm Officer (from Apr)

Physical Plant Services

V.P.McGough, Manager (on secondment to ISC)
D.Subramaniam, Manager (Acting)
Sudhir Rakhra, Chief Engineer (Civil)
N.S.S.Prasad, Sr Engineer (Electronics and Instrumentation)
A.R.Das Gupta, Sr Engineer (Communication) (on secondment to Niger)
D.C.Raizada, Sr Engineer (Airconditioning)
A.N.Singh, Engineer (Heavy Equipment and Tractors) (on leave until Jun)
S.W.Quader, Engineer (Office Equipment) (until Sep)
K.R.C.Bose, Engineer (Civil) (on secondment to Mali)
K.Satyanarayana Raju, Engineer (Machine shop)
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.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
A.Hamced, Adm Officer (until Apr)
S. Ramachandran, Adm Officer (from Apr)

West African Programs

ICRISAT Sahelian Center, Niger

Administration

R.W.Gibbons, Executive Director, West African Programs, and Director, ICRISAT Sahelian Center
A.Jagne, Regional Adm Officer
K.P.Nair, Regional Purchase and Supplies Manager
M.D.Diallo, Regional Fiscal Officer
J.Banji, Purchase Officer (On special assignment, until Apr)
S.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
L.Marchais, Principal Geneticist (ORSTOM)
S.Tostain, Principal Geneticist (ORSTOM)

Groundnut Improvement Program

B.J.Ndunguru, Principal Groundnut Agronomist and Team Leader
D.C.Greenberg, Principal Groundnut Breeder
F.Waliyar, 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
J.Baidu-Forson, Principal Economist
R.J.Van Den Beldt, Principal Agronomist/Agroforestry
J.H.Williams, Principal Physiologist (from Jun)
A.Bationo, Principal Soil Chemist (IFDC)
B.R.N'tare, Principal Cowpea Breeder/Agronomist (IITA)
J.C.Hopkins, Visiting Scientist (IFPRI)
J.Lambourne, Principal Animal Nutritionist, Special Consultant (ILCA)
M.Welte, Program Corodinator, University of Hohenheim
J.Toll, IBPGR Field Officer for West Africa
M.Powell, Principal Agroecologist (from Aug) (ILCA)

D.B.Roxas, Principal Animal Nutritionist (from Sep) (ILCA)
T.O.Williams, Principal Economist (from Oct) (ILCA)
P.Ouedraogo, Sr Research Asst

Support Programs

Farm Operations

P.G.Serafini, Research Farm Manager (on sabbatical until Aug)
P.Koudogbo, Chief Mechanic (until Jul)
R.van Midde, Farm Manager (until Jul)

Physical Plant Services

A.R.Das Gupta, Manager
J.Henry, Training Consultant (Mechanic)

Construction

V.P.McGough, Facilities Unit Manager

Statistics

B.Gilliver, Principal Statistician (until Aug)
G.Ouoba, Computer Programmer

Information/Documentation

C.Giroux, Regional Information Officer (on sabbatical leave)

Training

J.Q.Nguyen, Principal Training Officer (from Aug)

West African Sorghum Improvement Program (WASIP)

Mali

Administration

K.V.Ramaiah, Principal Cereal Breeder—*Striga* and Team Leader
A.Schulz., Administrator
K.R.C.Bose, Project Development Officer

Research

M.D.Thomas, Principal Sorghum Pathologist and SAFGRAD/ICRISAT Coordinator (from May)
S.N.Lohani, Principal Millet Breeder (on sabbatical until Mar)
A.Adesina, Asst Principal Economist
G.Hoffman, Principal *Striga* Agronomist (CIRAD)
P.Salez, Principal Agronomist (IRAT)
A.Ratnadas, Principal Entomologist (IRAT)
C.Luce, Principal Breeder (IRAT)

Nigeria

Administration

O.Ajayi, Principal Sorghum Entomologist and Team Leader
A.Banerji, Adm Officer

Research

D.S.Murty, Principal Sorghum Breeder
R.Tabo, Principal Sorghum Agronomist
S.N.Kapoor, Farm Manager (until Apr)
D.J.Flower, Principal Physiologist
R.Stumpo, Asst Principal Physiologist

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 Forage and Millet Breeder
W.A.J.de Milliano, Principal Cereals Pathologist
M.Osmanzai, Principal Cereals Agronomist
K.Leuschner, Principal Cereals Entomologist
D.Rohrbach, Principal Economist
H.Ssali, Soil Scientist (IFDC)
M.I.Gomez, Principal Food Technologist
C.M.Matanyaire, Principal Station Management and Development Officer
L.Tendengu, Regional Training Officer
N.Katuli, Regional Station Development and Operations Officer
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

SADCC/ICRISAT Groundnut Project (Malawi)

K.R.Bock, Principal Groundnut Pathologist and Team Leader
G.L.Hildebrand, Principal Groundnut Breeder
V.S.Swaminathan, Adm Officer (from May)

Acronyms and Abbreviations Used in this Annual Report

ACIAR	Australian Centre for International Agricultural Research
ACT-2	Arhar Coordinated Trial-2
ADB	Asian Development Bank
AGLN	Asian Grain Legumes Network (ICRISAT)
AGRHYMET	Centre regional de formation et d'application en agrometeorologie et hydrologie operationnelle (Niger)
AGR1S	International Information System for Agricultural Sciences and Technology (FAO)
AGT	Advance generation testing
AICPIP	All India Coordinated Pulses Improvement Project
AICPMIP	All India Coordinated Pearl Millet Improvement Project
AICSIP	All India Coordinated Sorghum Improvement Project
APAU	Andhra Pradesh Agricultural University (India)
ARA	Acetylene-reducing activity
ARFSN	Asian Rice Farming Systems Network (IRRI)
AT	Animal traction
AV	Audiovisual
AVRDC	Asian Vegetable Research and Development Center
AWHC	Available water-holding capacity
BARC	Bhabha Atomic Research Center (India)
BARI	Bangladesh Agricultural Research Institute
BBF	Broadbed and furrow
bmr	Brown mid-rib
BND	Bud necrosis disease
BNF	Biological nitrogen fixation
BSEC	Bold-seeded early composite
BU	Brabender units
CAAS	Chinese Academy of Agricultural Sciences
CABI	CAB International (UK)
CCRN	Cooperative Cereals Research Network (ICRISAT)
CD-ROM	Compact Disk-Read Only Memory
CEC	Cation exchange capacity
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGIAR	Consultative Group on International Agricultural Research
CGR	Crop growth rate
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency (Columbia)
CIDR	Centre d'information et de documentation pour le developpement rural
CILSS	Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (Mali)
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico)
CIP	Centro Internacional de la Papa (Peru)
CIRAD	Centre de cooperation internationale en recherche agronomique pour le developpement (France)

CLAIS	Comision Latinoamericano de Investigadores en Sorgo (Guatemala)
CM	Carbendazim and mancozeb
CRIDA	Central Research Institute for Dryland Agriculture (India)
CRIFC	Central Research Institute for Food Crops (Indonesia)
CRSP	Collaborative Research Support Program (USA)
CSCRTI	Central Soil Conservation Research and Training Institute
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CTT	Cumulative thermal time
cv	Cultivar
CV	Coefficient of variation
DAE	Days after emergence
DAF	Days after flowering
DAS	Days after sowing
DM	Downy mildew
DOA	Department of Agriculture
DP	Diastatic power
DRA	Direction recherche agronomique
DSR	Disease severity ratings
DT	Determinate
EACT	Early Arhar Coordinated Trial
EARCAL	Eastern Africa Regional Cereals and Legumes Program (ICR1SAT)
EARSAM	Eastern Africa Regional Sorghum and Millet Network
EC	Early composite
EC	Electrical conductivity
EESYT	EARSAM Elite Sorghum Yield Trial
ELISA	Enzyme-Linked Immunosorbent Assay
ELPN	Elite Products Nursery
ELS	Early leaf spot
EPR	External Program Review
ESD	Extra-short duration
ET	Evapotranspiration
EXACT	Extra-early Arhar Coordinated Trial
EXP1T	Extra-short-duration Pigeonpea International Trial
FAO	Food and Agriculture Organization of the United Nations (Italy)
FM	Fluorescence microscopy
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias
FYM	Farmyard manure
GIS	Geographic Information System
GLIP	Grain Legume Improvement Programme (Nepal)
GLM	Groundnut leaf miner
GLS	Gray leaf spot
GMS	Gridded mass selection
GRU	Genetic Resources Unit (1CRISAT)
GRV	Groundnut rosette virus

GSND	Groundnut streak necrosis disease
GTZ	Deutche Gesellschaft fur Technische Zusammenarbeit (Federal Republic of Germany)
HAU	Haryana Agricultural University (India)
HI	Harvest index
HiTIP	High-tillering population
HPLC	High pressure liquid chromatography
IAR	Institute of Agricultural Research (Nigeria)
IARC	International Agricultural Research Center
IARI	Indian Agricultural Research Institute
IBSRAM	International Board for Soil Research and Management (Thailand)
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas (Syria)
ICGVT	International Confectionery Groundnut Varietal Trial
ICHRN	International Chickpea *Helicoverpa* Resistance Nursery
IDRC	International Development Research Centre (Canada)
IDRGVT	International Drought Resistance Groundnut Varietal Trial
IEGVT	International Early-maturing Groundnut Varietal Trial
IER	Institut d'economie rurale (Mali)
IFDC	International Fertilizer Development Center (USA)
IFDRGVT	International Foliar Diseases Resistance Groundnut Varietal Trial
1GFRI	Indian Grassland and Fodder Research Institute
IIPRGVT	International Insect Pest Resistance Groundnut Varietal Trial
IITA	International Institute of Tropical Agriculture (Nigeria)
ILCA	International Livestock Centre for Africa (Ethiopia)
IMLGVT	International Medium- and Late-maturing Groundnut Varietal Trial
IMZAT	ICRISAT Pearl Millet Zone Adaptation Trial
INERA	Institut national d'etudes et de recherches agricoles (Burkina Faso)
INRAN	Institut national de recherches agronomiques du Niger
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPPRN	International Pigeonpea Pest Resistant Nurseries
IRAG	Institut de recherche agronomique de Guinee
IRRI	International Rice Research Institute (the Philippines)
ISAR	Institut des sciences agronomiques du Rwanda
ISC	ICRISAT Sahelian Center (Niger)
ISNAR	International Service for National Agricultural Research (the Netherlands)
ISTN	International Sorghum Trials and Nurseries
ISVHAT	International Sorghum Variety and Hybrid Adaptation Trial
IVC	Inter-varietal composite
IVPD	In vitro protein digestibility
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya (India)

KARI	Kenya Agricultural Research Institute
LASIP	Latin American Sorghum Improvement Program (ICRISAT)
LEGOFTEN	Legumes On-Farm Testing and Nursery Unit (ICRISAT)
LER	Land equivalent ratio
LLS	Late leaf spot
LSW	Leaf surface wetness
MAFI	Ministry of Agriculture and Food Industry (Vietnam)
MAHYCO	Maharashtra Hybrid Seeds Company
MARIF	Malang Research Institute for Food Crops (Indonesia)
MASVYT	Mesoamerican Sorghum Variety Yield Trial
MC	Medium composite
MD	Medium duration
MFR	Multifactor-resistant populations
MHYT-88	Mesoamerican Hybrid Yield Trial
MIR	Multiple insect resistance
MLO	Mycoplasma-like organism
MORIF	Moros Research Institute for Food Crops (Indonesia)
MOU	Memorandum of Understanding
MPAY	Medium-duration pigeonpea advanced trial
MPKV	Mahatma Phule Krishi Vidyapeeth (India)
MStV	Maize stripe virus
NARS	National Agricultural Research System
NBPGR	National Bureau of Plant Genetic Resources (India)
NDFRC	National Dryland Farming Research Center
NDT	Indeterminate
NELC	New elite composite
NGLIP	National Grain Legume Improvement Programme (Nepal)
Nonnods	Nonnodulating mutants
NPU	Net protein utilization
NRCG	National Research Centre for Groundnut (India)
NRCS	National Research Centre for Sorghum (India)
NRSA	National Remote Sensing Agency (India)
ODNRI	Overseas Development Natural Resources Institute (UK) (now NRI)
OPSCAR	Operational-scale Research
ORSTOM	Institut francais de recherche scientifique pour le developpement en cooperation (France)
PB	Phytophthora blight
PCARRD	Philippine Council for Agriculture and Resource Development
PCMMV	Peanut chlorotic mild mottle virus
PDRGVT	Preliminary Drought Resistance Groundnut Varietal Trial
PEGVT	Prelaminary Early Groundnut Varietal Trial
PEQ1A	Post-Entry Quarantine Isolation Area
PET	Potential evapotranspiration
PKV	Punjabrao Krishi Vidyapeeth (India)

PSI	Particle size index
PStV	Peanut stripe virus
RBD	Randomized-block design
RESCAP	Resource Capture Model
RGR	Relative growth rate
RH	Relative humidity
RMP	Resource Management Program (ICRISAT)
RNA	Ribonucleic acid
RSAVT	Regional Sorghum Advanced Variety Trials
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 (ICRISAT)
SD	Short duration
SDAHT	SADCC Advanced Hybrid Trial
SDEHT	SADCC Elite Hybrid Trial
SDI	Selective Dissemination of Information
SDPHT	SADCC Preliminary Hybrid Trial
SDT	Semi-determinate
SDU	Sorghum diastatic units
SLV	Specific loaf volume
SM	Sterility mosaic
SMIC	Sorghum and Millets Information Center (ICRISAT)
SMIP	Sorghum and Millets Improvement Program (SADCC/ICRISAT)
SSP	Single superphosphate
SStD	Sorghum stripe disease
STCE	Sorghum testcross evaluation
SWM	Semi-wet milled
TADD	Tangential abrasive dehulling device
TD	True protein digestibility
TDM	Total dry matter
TGMR	Threshed grain mold rating
TIA	Trypsin inhibitor activity
TNAU	Tamil Nadu Agricultural University (India)
TSWV	Tomato spotted wilt virus
UNDP	United Nations Development Programme (USA)
UP	Utilizable protein
USAID	United States Agency for International Development
VLS	Village-level studies
WADMON	West African Downy Mildew Observation Nursery
WADMVN	West African Downy Mildew Variability Nursery
WASAT	West African Semi-Arid Tropics

WASDRN	West African Sorghum Disease Resistance Nursery
WASHAT-88	West African Sorghum Hybrid Adaptation Trial-88
WASIP	West African Sorghum Improvement Program (ICRISAT)
WASSN	West African Sorghum *Striga* Nursery
WASVAT-88	West African Sorghum Variety Adaptation Trial-88
WCASRN	West and Central African Sorghum Research Network
WINE	Water Interacting with Nitrogen Experiment
YAI	Yield Advantage Index

Cumulative list of currently cultivated ICRISAT cultivars and parents issued before 1989 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 (1984).	84/8
		SPV 351	Released cultivar in Malawi (1989)	
SPV 386	ICSV 2	ZSV 1	Released cultivar in Zambia (1983).	84/15
SPV 475	ICSV 112	SV 1	Released cultivar in Zimbabwe (1985).	86/1
		CSV 13	Released cultivar in India (1988)	
			Recommended for release in India (1987).	
		UANL-1-187	Released cultivar in North Mexico (1987).	
PM 11344	ICSV 197	-	Highly resistant to sorghum midge *(Contarinia sorghicola)*	86/2
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
AGROCONSA I	AGRO-CONSA I	AGRO-CONSA I	Released cultivar in El Salvador (1987). Male sterile, ATx 625, from Texas A & M University.	88/7
Pearl millet cultivars/varieties				
WC-C75	ICMV 1	WC-C75	Released cultivar in India (1982).	84/1
			Released cultivar in Zambia (1987).	
IBV 8001	ICMV 2	-	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	Released cultivars in Niger (1985).	86/5
ITMV 8002	ICMV 6	ITMV 8002		86/6
ITMV 8304	ICMV 7	ITMV 8304		86/7
MP 124 (ICTP 8203)	MP 124 (ICTP 8203)	MP 124 (ICTP 8203)	Released in Maharashtra and Andhra Pradesh, India (1988)	88/3
Pearl millet male-sterile and maintainer lines				
81A	ICMA 1	-	Female parent of ICMH 451.	86/8
81B	ICMB 1	-		86/8
843A	ICMA 2	-	New male-sterile lines for the production of new hybrids	84/3
843B	ICMB 2	-		84/3
842A	ICMA 3	-		84/3
842B	ICMB 3	-		84/3
834A	ICMA 4	-	Female parent of ICMH 501.	84/3
834B	ICMB 4	-		84/3
ICMA 841	ICMA 841	ICMA 841	Female parent of hybrids Pusa 23 and ICMH 423. Highly resistant to downy mildew.	88/1
ICMB 841	ICMB 841	ICMB 841		

Continued

Cumulative list *continued.*

Original name	ICR1SAT name	Release name	Remarks	Notice
Pearl millet inbred lines				
ICMPE 13-6-27	ICML 1	-	Sources of resistance to ergot *(Claviceps fusiformis).*	84/4
ICMPE 13-6-30	ICML 2	-		
ICMPE 134-6-25	ICML 3	-		
ICMPE 134-6-34	ICML 4	-		
SSC FS 252-S-4	ICML 5	-	Sources of resistance to smut (*Tolyposporium penicilliariae).*	84/5
ICI 7517-S-1	ICML 6	-		
EBS 46-1-2-S-2	ICML 7	-		
EB 112-1-S-1-1	ICML 8	-		
NEP 588-5690 -S-8-4	ICML 9	-		
P 489-S-3	ICML 10	-		
IP 2696-1-4	ICML 11	-	Source of resistance to rust *(Puccinia penniseti)* controlled by a single dominant gene.	84/7
P7	ICML 12	-	Sources of resistance to downy mildew *(Sclerospora graminicola).*	84/13
SDN 503	ICML 13	-		
700251	ICML 14	-		
700516	ICML 15	-		
700651	ICML 16	-		
700481-21-8	ICML 17	-	Sources of resistance to rust *{Puccinia penniseti)*	84/14
IP 537 B	ICML 18	-		
IP 11776 (Souna Mali)	ICML 19	-		
IP 2084-1	ICML 20	-		
P 24	ICML 21	-		
D 212-P1	ICML 22	-		
Pearl millet populations (sibs of sister lines)				
1CMPES 1	ICMP 1	-	Sources of combined resistance to ergot *(Claviceps fusiformis),* smut (*Tolyposporium penicillariae),* and downy mildew *{Sclerospora graminicola).*	84/6
ICMPES 2	ICMP 2	-		
ICMPES 28	ICMP 3	-		
ICMPES 32	ICMP 4	-		
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
ICMH 423	ICMH 423	ICMH 423	Released hybrid in India (1987).	88/2
Chickpea cultivars/varieties				
ICCC 4	ICCV 1	ICCC 4	Released cultivar in Gujarat state,	84/9

continued

Cumulative list *continued.*

Original name	ICRISAT name	Release name	Remarks	Notice
			India (1983), and Nepal (1987).	
ICCL 82001	ICCV 2	'Swetha' in India	Released in Andhra Pradesh in 1989	84/10
ICCL 83006	ICCV 3	-		
ICCL 83004	ICCV 4	-	Combine acceptable kabuli seed-type	84/10
ICCL 83009	ICCV 5	-	with wilt resistance and short duration	
ICCC 32	ICCV 6	-	Identified for release in India.	86/11
ICCX 730008-8-1 -1P-BP-8EB	ICCV 7		Identified by AICPIP as donor parent for *Helicoverpa armigera* resistance.	86/12
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
Pigeonpea cultivars/varieties				
ICP 8863	ICPV 1	Maruti	Recommended by A1CPIP as source of resistance to wilt *(Fusarium udum)*. Released in Karnataka state, India (1985).	84/11
ICPL 87	ICPL 87	Pragati	Short-duration, high-yielding variety. Released in India (1986).	86/9
ICPL 151	ICPL 151	Jagriti	Short-duration, high-yielding variety. Prerelease in India as Jagriti.	86/10
Pigeonpea male-sterile line				
MS 4A	ICPM 1	-	Source of transluscent anther-type of genetic male sterile	84/12
Groundnut cultivars/varieties				
Robut 33-1-7-4	ICGS 1	-	A selection from ICGS 1 released as Spring Groundnut 84 in Punjab state, India (1986)	86/13
Robut 33-1 -18-8-B1	ICGS 11	ICGS 11	Released for postrainy-season cultivation in Central and peninsular India (1986).	86/14

List of elite ICRISAT plant material issued by the Plant Material Identification Committee (PMIC) in 1989.

Original name	ICRISAT name	Release name	Justification/Present status	Notice
Pearl millet inbred lines				
IP 2696-30	ICML 89030	No release name	Photoperiod insensitive pearl millet line selected from accession IP 2696, a landrace collected from Chad and maintained as genetic stock in the ICRISAT gene bank.	89/7
Pearl millet cultivars/varieties				
ICMV 84400	ICMV 84400	ICMV 155	Recommended for general cultivation in India by AICPMIP workshop, April 1989.	89/8
Chickpea cultivars/varieties				
ICCL 80074 (ICCC 37)	ICCL *80074*	Kranthi	A short-duration desi type chickpea variety resistant to fusarium wilt race 1 and moderately resistant to dry root rot, released in Andhra Pradesh as "Kranthi" in 1989.	89/9
Pigeonpea cultivars/varieties				
ICPL 332	ICPL 332	Abhaya	A high-yielding pigeonpea variety with tolerance to *Helicoverpa* pod borer, released in Andhra Pradesh as "Abhaya" in 1989.	89/10
Groundnut cultivars/varieties				
ICGS 44	ICGV 87128 (ICGS 44)	ICGV 87128 (ICGS 44)	Released by the Central Subcommittee on Crop Standards, Notification, and Release of Varieties, Govt, of India,for the postrainy season cultivation in the state of Gujarat.	89/1
ICGS 76	ICGV 87141	ICGS 76	Recommended for release by the Central Sub-committee on Crop Standards, Notification and Release of Varieties, Govt, of India, for cultivation in the rainy season, in Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, and parts of Maharashtra states in India.	89/11
Groundnut genetic stocks				
ICGL 1	ICGL 1	ICGL 1	Non-nodulating pure line with distinct morphological features: Erect growth habit, sequential flowering, orange flower color, belongs to Valencia group.	89/2
ICGL 2	ICGL 2	ICGL 2	Non-nodulating pure line with distinct morphological features: Decumbent 3 erect growth habit, sequential flowering, garnet flower color, belongs to Manyema group.	89/3

continued

Cumulative list *continued.*

Original name	ICRISAT name	Release name	Remarks	Notice
ICGL 3	ICGL 3	ICGL 3	Non-nodulating pure line with distinct morphological features: Erect growth habit, sequential flowering, garnet flower color, belongs to Manyema group.	89/4
ICGL 4	ICGL 4	ICGL 4	Non-nodulating pure line with distinct morphological features: Erect growth habit, alternate flowering, orange flower color, belongs to Valencia group.	89/5
ICGL 5	ICGL 5	ICGL 5	Non-nodulating pure line with distinct morphological features: Erect growth habit, sequential flowering, orange flower color, belongs to natal group.	89/6

RA-00155

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ISSN 0257-2478 Printed at ICRISAT Center ICR 90-0023