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ICRISAT Report 1990

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Abstract

ICRISAT Report 1990 *is the first progress report in a new format. It replaces the two previous yearly progress reports published by ICRISAT: the* ***Annual Report****, which has been published since 1973/74, and* ***Research Highlights****, published since 1979. The change was made in an effort to reach the increasingly wide range of readers of the Institute's publications. The document contains two main sections consisting of Directors' Reports and Research Highlights. The latter comprises four designated themes: Abiotic Stress; Integrated Pest Management; Assistance to National Programs, Networking, and Technology Exchange; and Sustainability. These main sections are supported by brief descriptions of ICRISAT's crops and its research environment and progress reports from Research Support units. The appendices include Financial Highlights, a list of publications, and a staff list.*

Résumé

*L'****ICRISAT Report 1990*** *constitue le premier rapport d'activité dans le nouveau format. Il remplace les deux rapports d'activité annuels publiés précédemment par l'ICRISAT : le* ***Annual Report****, qui a paru depuis 1973/74, et le* ***Research Highlights****, publié depuis 1979 (une version française de ce dernier,* ***Progrès de la recherche****, a commencé à paraître à partir de 1980). Ce changement de présentation est réalisé pour essayer de mieux communiquer avec la diversité de plus en plus croissante de l'audience de l'ICRISAT. Ce document se divise en deux parties principales, présentant les Rapports des Directeurs et les Progrès de la recherche. Cette deuxième section comprend quatre thèmes : Contraintes abiotiques; Lutte intégrée contre les ravageurs; Assistance aux programmes nationaux, Réseaux et Echange de technologie; et Productivité agricole soutenue. Ces rubriques principales sont soutenues par de brèves descriptions des cultures faisant l'objet du programme de l'ICRISAT et de l'environnement de ses travaux de recherche, ainsi que par des rapports d'activité des unités d'Appui de Recherche. Enfin, sont présentés en annexe l'Etat financier, une liste de publications, et une liste des cadres de l'Institut.*

Resumen

ICRISAT Report 1990 *es el primer informe integral en el nuevo formato. Este sustituye los dos informes anuales publicados anteriomente por ICRISAT:* ***Annual Report*** *(Informe anual), que ha sido editado anualmente desde 1973/74,* ***y Research Highlights*** *(Actividades relevantes de investigación), publicado desde 1979. Este cambio se efectuó con el propósito de poder llegar a la cada vez más creciente gama de lectores de estas publicaciones. Este documento contiene dos secciones principales, constituidas por los informes de los Directores de programa y las actividades relevantes de investigación en las diversas áreas. Esta última sección abarca cuatro temas principales: Estress abiótico; Manejo integrado de plagas; Ayuda a los programas nacionales, Red de ensayos comparativos, Intercambio tecnológico; y Sostenibilidad. Estas secciones contienen además una breve descripción de los cultivos asignados a ICRISAT y las condiciones de investigación, como así tambien, los informes de investigación de las respectivas unidades de apoyo. El apéndice incluye los aspectos financieros relevantes, la lista de publicaciones y la nómina de personal.*

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The watercolor drawing on the cover depicts ICRISAT's mandate crops.

PN-ABJ-654

ICRISAT Report 1990

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India
1991

The International Crops Research Institute for the Semi-Arid Tropics is a nonprofit, scientific, research, and training institute receiving support from donors through the Consultative Group on International Agricultural Resarch (CGIAR). Donors to ICRISAT include the following governments and agencies.

Core Funding

Australia
Belgium
Canada
China
European Economic Community
Finland
France
Germany
India
Italy
Japan
Netherlands
Norway
Sweden
Switzerland
United Kingdom
United States of America
African Development Bank
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International Fund for Agricultural Development
United Nations Development Programme
World Bank

Special Projects

Agricultural University of Wageningen
Asian Development Bank
Australian International Development Assistance Bureau
Belgium
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Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
International Development Research Centre
Institut des recherches agronomiques tropicales
International Fertilizer Development Center
International Fund for Agricultural Development
Japan
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United Nations Development Programme
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Contents

Introduction

The past year was indeed an eventful one for ICRISAT. The CGIAR's External Program and Management Reviews of the Institute commenced in March and were completed in September. Panel members inspected every ICRISAT program and nearly every ICRISAT location. They also visited partner countries in Africa and Asia. At the end they submitted a highly positive report. We shall quote two paragraphs.

"ICRISAT has a very good record of achievements and there is already clear evidence of its impact. In India alone, more than 4 million ha of pearl millet, or a third of the total area grown in the country, are planted with ICRISAT-bred cultivars or cultivars based on ICRISAT materials. Private and public seed companies play an important role in the diffusion of this technology. Groundnut production in India has increased by 35% during the last 5 years, thanks largely to ICRISAT's technology which in turn encouraged the Indian Government to implement a price policy that was more favorable to farmers....

"Impact in other areas and for the other mandate crops is not yet as visible, but there are many good reasons for optimism about the future. The donors who support ICRISAT have every reason to continue that support with confidence, but they must remember that ICRISAT's mandate region, the semi-arid tropics, is one of the most difficult in the world to work in, and that it contains some of the poorest countries in the world."

Much time during the year was devoted to drafting ICRISAT's first Strategic Plan. The Plan, entitled **Pathways to Progress in the Semi-Arid Tropics**, was formally presented to the Group's Technical Advisory Committee in Paris in March 1991 and to the CGIAR in May.

An important event in 1990 was the publication and release of a book entitled **Village and Household Economies in India's Semi-arid Tropics**. This book, written by Dr Thomas S. Walker and Dr James G. Ryan, distills the essence of 10 years of research carried out by the staff of the Economics Group of the Resource Management Program. The book records many important changes in the lives of rural people in the central zones of India.

Progress is evident with all our crops and in all our regions. In central India a variety of pearl millet ICTP 8203 has almost completely replaced WC-C75. It was reported to have been sown on approximately 1 million ha in Maharashtra during the last two rainy seasons. A majority of farmers interviewed stated that ICTP 8203 produced *chapatis* as good as those made from local varieties. After testing and selection by the SADCC/ICRISAT Sorghum and Millets Improvement Program in Zimbabwe, ICTP 8203 has also been released for use in Namibia. This may be the first CGIAR contribution to the development of that new nation.

Recent surveys have shown that the demand for forage sorghums is increasing rapidly in India. The grain : fodder price ratio has dropped from around 7 : 1 twenty years ago to about 2.5 : 1 today. The results signal a major change for the direction of sorghum improvement research in India and in the kind of research to be done by ICRISAT.

Two ICRISAT chickpea varieties, ICCC 32 and ICCL 82108, were released in

Nepal for general cultivation. The number of ICRISAT chickpea cultivars now released in Nepal is four. Two additional selections from the ICRISAT/ICARDA nurseries in Syria have been released as Jabeiha 2 and Jabeiha 3 for commercial cultivation in Jordan. Winter chickpea shows considerable promise throughout the West Asia/North Africa (WANA) region. Because the yield of winter chickpea exceeds that of spring chickpea, it can provide an alternative legume to lentil in rotation with cereals.

Trial data on short-duration pigeonpea lines were received from two countries, Peru and Vietnam, where pigeonpea is a new crop. High yields were harvested in both countries.

In Ghana, ICGS 114, a groundnut line supplied from ICRISAT Center in 1985, has been released as Sinkarzei. In a 4-year, four-location test, Sinkarzei gave 9% more yield and 2% higher shelling turnover than the local variety; it also matured 16 days earlier.

Research to develop genome maps of sorghum and pearl millet was commenced with collaborators in Italy, the UK, and the USA last year. We have now commenced similar research with groundnut. A collaborative project with the Scottish Crop Research Institute, UK, was initiated to determine linkage between genetic markers and various important agronomic traits. A genomic library of the breeding line TMV 2 is being constructed and will be exploited in future work.

Emphasis on the search for more sustainable technologies will be important in ICRISAT's future directions and is one of the major themes of this Report. We firmly believe that farming systems can be developed to increase production, use inputs efficiently, maintain genetic diversity, and protect the environment. We recognize the need to quantify sustainability and to establish long-term trials that will indicate the likely impact of improved technologies upon the environment. Medium- and short-term systems will receive major emphasis, including water conservation measures in dryland agriculture, integrated pest management, and the use of low-cost tools and machinery. Farmer participation in research design and implementation will be extended beyond our social sciences research to biological and physical studies as well.

A Geographical Information System (GIS) that can manage and display multiple levels of spatially distributed data has been installed at ICRISAT Center. Two staff members of the Resource Management Program have been trained in its use at the Asian Institute of Technology in Bangkok. ICRISAT will now be able to build an integrated, readily available base of pertinent data to delineate agroclimatic zones, assess their suitability for specific cultivars or cropping systems, and to examine links between the outbreak of diseases and pests due to weather or soil conditions.

Resource management and operational scale research at ICRISAT Sahelian Center (ISC) have together developed what appears to be a modest but technologically and economically feasible improvement in cropping systems for the Sahel. The results of a 4-year study suggest that the application of phosphorus to a manually cultivated rotation of millet with cowpea or an annual millet/cowpea intercrop can be recommended to farmers as a viable and profitable technology. The recommendations are particularly relevant to the poorest farmers who have no access to animal traction, who cultivate only small areas of land, and who cannot afford large cash outlays or lack access to institutional credit. The results are sufficiently positive to encourage us to participate with national scientists and farmers in on-farm trials, and to encourage national extension programs and development agencies to commence cautious pilot schemes at the village level.

During 1990, the Training Program at ICRISAT Center was renamed the Human Resource Development Program in line with recommendations in **Pathways to Progress**. Eighty-one rainy-season participants from 33 countries completed the 6-month program.

An in-country legumes production training course was held at Peradeniya in collaboration with the Sri Lankan Department of Agriculture in July. The purpose was to update staff on the latest technology to enhance legumes production in the country. There were 24 participants with a training staff of 16, six of whom were ICRISAT employees.

A group of directors of six national agricultural research systems in Asia (China, Indonesia, Myanmar, Nepal, Philippines, and Sri Lanka) toured various universities, institutes, and seed companies in India in mid-October. While visiting ICRISAT Center, they expressed their wish that ICRISAT maintain its research excellence and increase the momentum of technological development of its mandate crops and associated technologies in Asia.

An International Workshop on Biotechnology and Crop Improvement in Asia, held at ICRISAT Center in December, was jointly sponsored by the Asian Development Bank and ICRISAT. The workshop recommended that an Asian network for plant biotechnology research be established and coordinated by ICRISAT.

In November, ICRISAT hosted an international workshop on Consequences of Intellectual Property Rights in cooperation with the CGIAR Secretariat. Representatives of seven international centers attended the meeting.

Good facilities for research have now been created at most ICRISAT locations. In 1990 we dealt with needed facilities in Kenya and Mali. The facilities of the Eastern Africa Regional Cereals and Legumes Program (EARCAL) at the Kiboko Research Station of the Kenya Agricultural Research Institute were inaugurated on 25 June by the Kenyan Deputy Minister of Agriculture. A new research station at Samanko in Mali was completed in November and will be inaugurated early in 1991.

ICRISAT continued to be financially sound and healthy in 1990, but some problems were encountered with cash flow in the middle of the year. Property, plant, and equipment were maintained in good repair.

Like its sister centers of the CGIAR system, ICRISAT's ability to carry out its research and technology transfer activities depends on donor funding. The Institute receives funding from donors in more than 20 countries. Unrestricted contributions make up 51% of the total, restricted contibutions 49%.

ICRISAT's funds are allocated to six major units, which assign them to various activities. More than two-thirds of the total is spent on research. The rest is divided between human resource development, information, administration, and operations.

ICRISAT's complete financial statements have been prepared as a separate document and are available upon request.

A Memorandum of Understanding was signed in April between the USSR and ICRISAT at ICRISAT Center. The document was signed on behalf of the USSR by Academician N.Z. Milashenko of the V.I. Lenin All-Union Academy of Agricultural Sciences. Following the agreement, an ICRISAT delegation traveled to the USSR in November to draw up a work plan. We will collaborate with the Academy in the improvement of four mandate crops—sorghum, groundnut, chickpea, and pigeonpea.

The Governing Board of the Institute has been busy during the year with the search for a new Director General following the announcement by the incumbent of his resignation. A Search Committee headed by the Board Chairman considered a large number of candidates which was reduced step by step to a short list of three from which the new Director General, Dr James G. Ryan, was chosen in early 1991. We are both confident that Dr Ryan, who is expected to take up his duties in mid-August, will prove to be a worthy Director General and carry ICRISAT to new heights.

We acknowledge with gratitude the support and contributions of ICRISAT donors, and the many institutions that work with us at the various ICRISAT locations. We are thankful to ICRISAT's host governments, and particularly the Government of India, the host of our headquarters and largest center, for their support, contributions of many kinds, and commitment to the furtherance of ICRISAT's objectives.

A.B. Chitnis

William T. Mashler
Chairman, Governing Board

Leslie D. Swindale
Director General

Important Visitors

ICRISAT Center, India

18 Jan	**Mr Timothy Lancester**, Permanent Secretary, British Overseas Development Administration
5 Feb	**Mr Peter Goldmark** (President) and **Dr Robert W. Herdt** (Director of Agricultural Sciences), The Rockefeller Foundation
9 Mar	**H.E. Mr S.S. Naraine**, High Commissioner for the Cooperative Republic of Guyana, and **H.E. Mr A.P. Neewor**, High Commissioner for Mauritius
23 Mar	**H.E. Sir David Goodall**, British High Commissioner in India, and **Mr A.B.N. Morey**, British Deputy High Commissioner (Madras)
2 Apr	**H.E. Dr Rodolfo Molina Duarte**, Ambassador of Venezuela in India
24 Apr	**Academician Dr N.Z. Milaschenko**, First Deputy President of the V.I. Lenin All-Union Academy of Agricultural Sciences, USSR
1 Aug	**Mr Chhea Song**, Honorable Vice Minister of Agriculture, Cambodia
18 Aug	**Mr Surajuddeen B. Yabuku**, Honorable Minister for Agriculture and Natural Resources, Kaduna State, Nigeria
7 Sep	**H.E. Dr Frank Bracho**, Ambassador of Venezuela in India
16 Nov	**H.E. Mr Bhanu Pratap Singh**, Governor of Karnataka

ICRISAT Sahelian Center, Niger

31 Jan	**Professor Hamidou Sekou**, Minister of Higher Education and Technology, Niger
22 Feb	**M Michel Levallois**, Chairman of the Governing Board of the Institut français de recherche scientifique pour le développement en coopération (ORSTOM), and **M Gerard Winter**, Director General of ORSTOM
23 Feb	**Mr Shiro Yoshida**, Japanese International Cooperation Agency
16 Jun	**S.E. M Michel Lunven**, Ambassador of France in Niger
21 Aug	**Mr Adamou Souna**, Honorable Minister of Agriculture, Niger

SADCC/ICRISAT, Zimbabwe

12 Jun	**H.E. Mr Steven Rhodes**, U.S. Ambassador to Zimbabwe

Awards and Distinctions

Dr William Mashler, Chairman of ICRISAT's Governing Board, was awarded the President's Medal by the City University of New York in recognition of his dedicated service to the Ralph Bunche Institute.

Dr Claude Charreau, Member of the Governing Board, was made "Chevalier de l'Ordre de la Légion d'Honneur" by the Government of France.

Dr Lukas Brader, after appointment as Director General of the International Institute for Tropical Agriculture, left ICRISAT's Governing Board.

In August, **Dr Y.L. Nene**, our Deputy Director General, was elected to the fellowship of the American Phytopathological Society. He is only the second Indian to receive this recognition.

Dr L.R. House, Executive Director of ICRISAT's Southern African Programs, received the International Agronomy Award for 1990.

Dr P.V. Shenoi, Assistant Director General (Liaison), was awarded the 1990 Borlaug Award for outstanding service to Indian agriculture.

Dr S.B. Sharma, ICRISAT Center Nematologist, was honored with the Pran Vohra Award for his work by the Indian Science Congress Association.

Dr Nand K. Awadhwal, Agricultural Engineer/Soil Physicist, was awarded the Distinguished Services Certificate by the Indian Society of Agricultural Engineers.

ICRISAT's Mandate

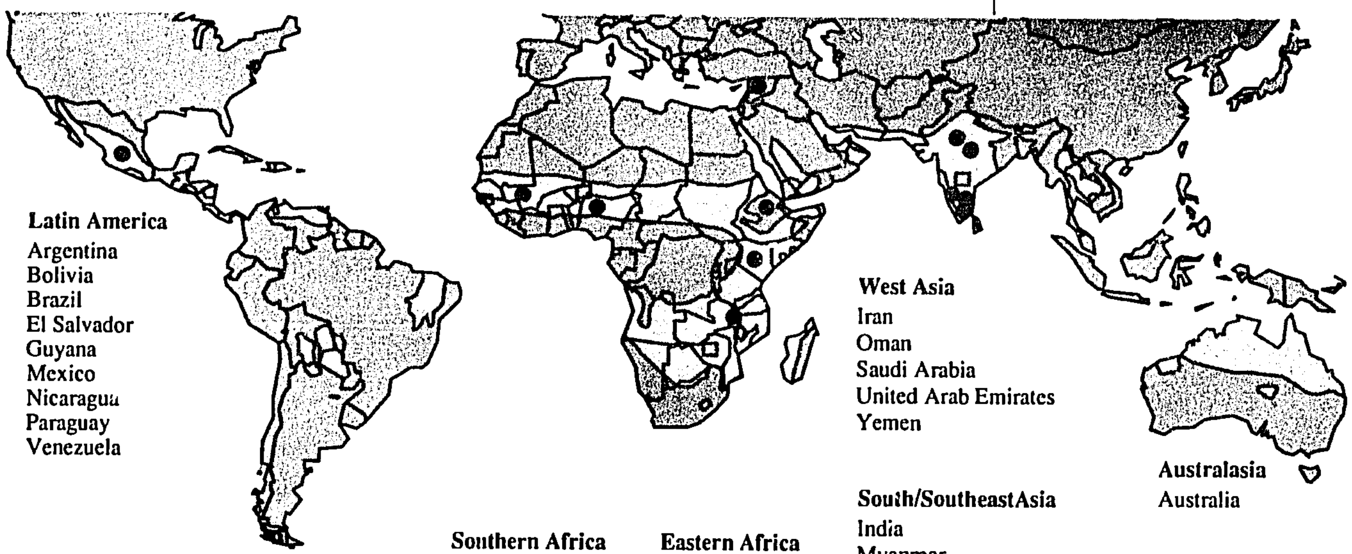
1. *Serve as a world center for the improvement of grain yield and quality of sorghum, millets, chickpea, pigeonpea, and groundnut and act as a world repository for the genetic resources of these crops.*

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.*

4. *Assist in the development and transfer of technology to the farmer through cooperation with national and regional research programs, and by sponsoring workshops and conferences, operating training programs, and assisting extension activities.*

ICRISAT's Partners in the Semi-Arid Tropics



Latin America
Argentina
Bolivia
Brazil
El Salvador
Guyana
Mexico
Nicaragua
Paraguay
Venezuela

Western Africa
Benin
Burkina Faso
Cameroon
Central African Republic
Chad
Gambia
Ghana
Guinea
Guinea Bissau
Mali
Mauritania
Niger
Nigeria
Senegal
Togo

Southern Africa
Angola
Botswana
Madagascar
Malawi
Mozambique
Namibia
Zaire
Zambia
Zimbabwe

Eastern Africa
Ethiopia
Kenya
Somalia
Sudan
Tanzania

West Asia
Iran
Oman
Saudi Arabia
United Arab Emirates
Yemen

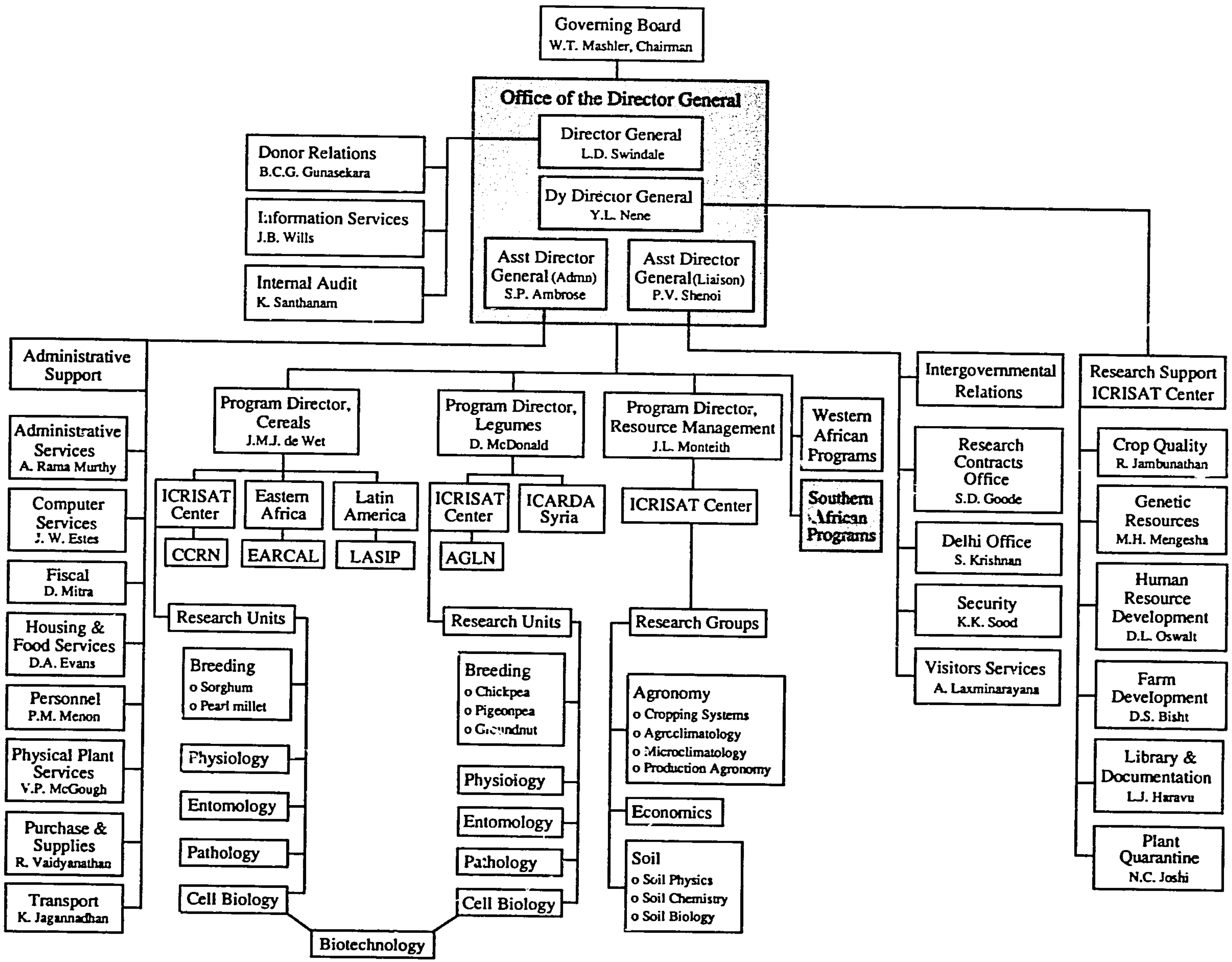
South/Southeast Asia
India
Myanmar
Pakistan
Sri Lanka
Thailand

Australasia
Australia

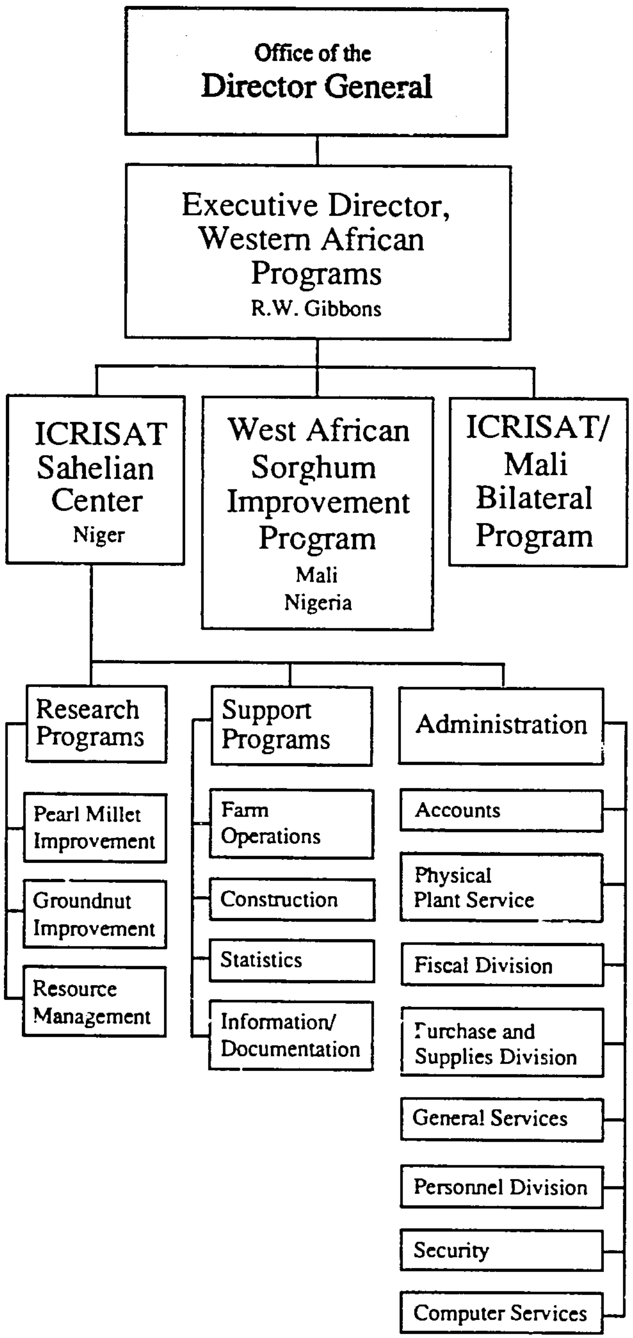
The semi-arid tropics
Principal ICRISAT locations
Other staff locations and collaborative research stations

Organization Charts

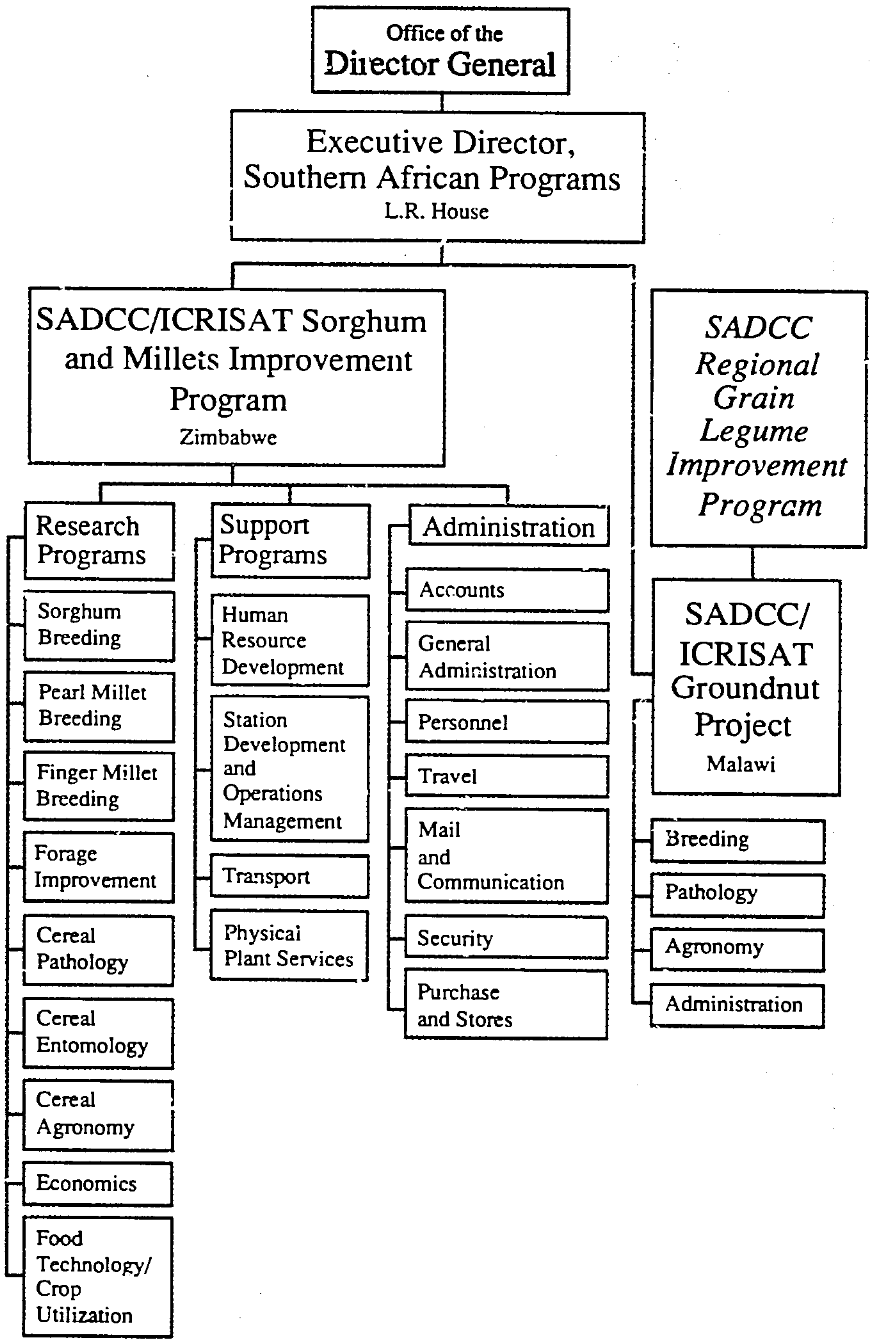
ICRISAT Center



Western African Programs



Southern African Programs



The Mandate Crops

Sorghum

Sorghum bicolor (L.) Moench

French	sorgho
Portuguese	sorgo
Spanish	sorgo
Hindi	jowar, jaur

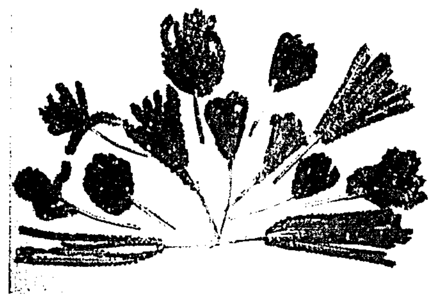
Sorghum is the fifth most important cereal in the world and a major staple in the diets of the people of the semi-arid tropics. It is the second most important cereal in Africa and is next in importance to rice and wheat in India. Sorghum is grown on over 40 million hectares in both temperate and tropical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

Pearl Millet

Pennisetum glaucum (L.) R.Br.

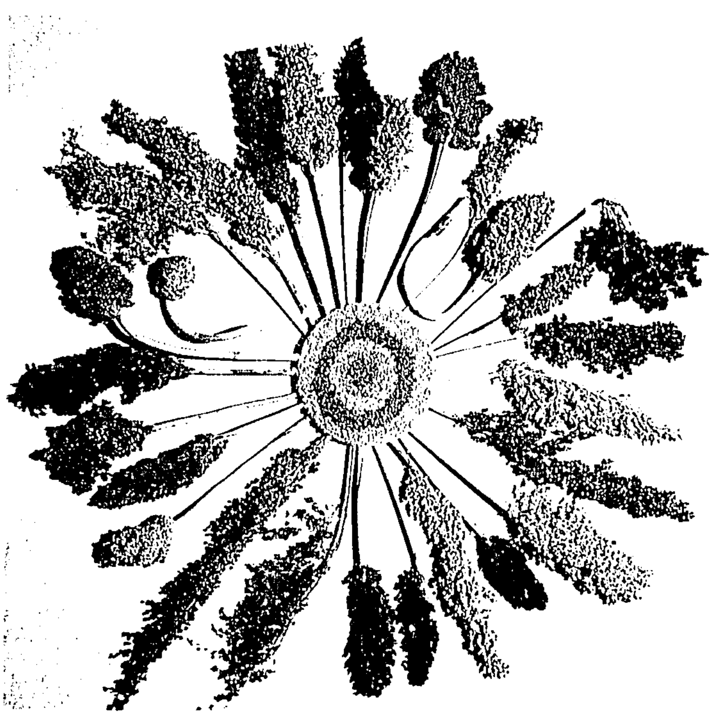
French	mil
Portuguese	painco, perola
Spanish	mijo perla
Hindi	bajra

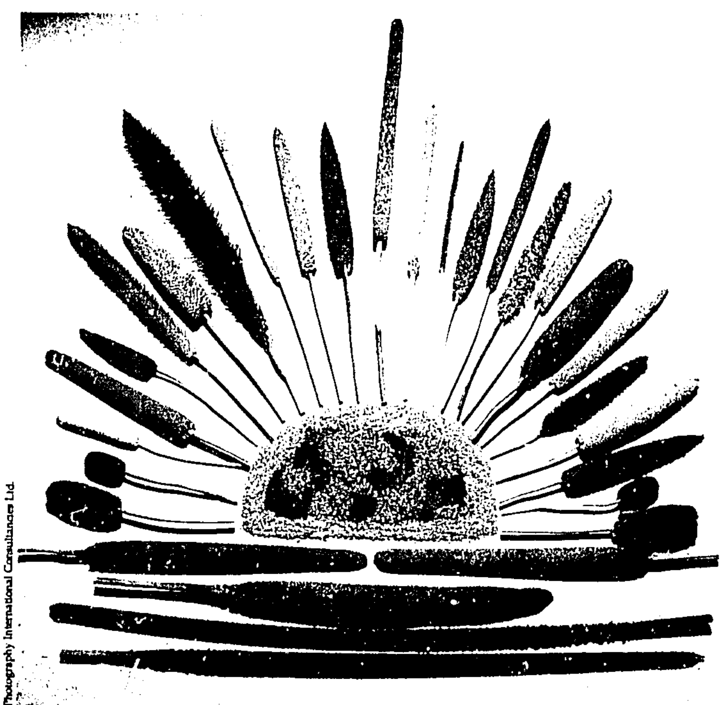
Pearl millet is the sixth most important cereal in the world. The most widely cultivated millet in the semi-arid tropics, it is grown on an estimated 25 million hectares. Pearl millet is a hardy cereal suited to dry regions with sandy infertile soils where rainfall is low and erratic. It can be successfully cultivated in areas too dry for sorghum. The grain is used to make unleavened bread (*chapatis*) in South Asia and prepared as gruel, dumplings, *couscous*, and beer in Africa. It is also used as animal feed and forage.



A.B. Chitnis

*Finger Millet (*Eleusine coracana *[L.] Gaertn.), an important cereal in Africa and India in areas with 900-1200 mm of rainfall per annum, was designated as an additional millet for special study in the highlands of eastern and southern Africa, where it is particularly important as a food crop.*





Photography International Consultancies Ltd.

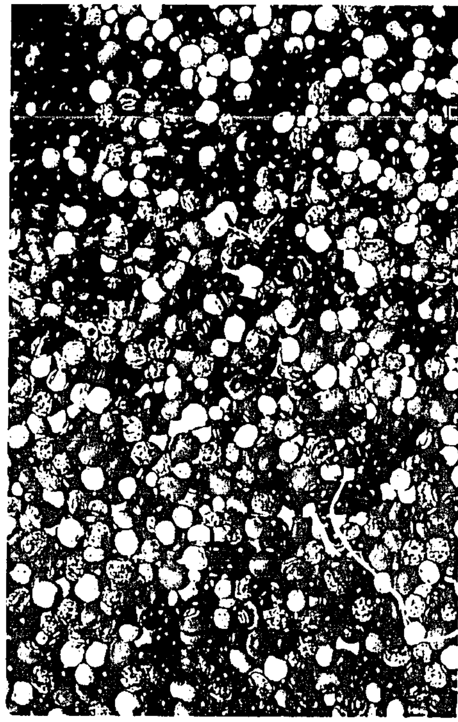
Variability in sorghum **(left)** ***and pearl millet*** **(right).**

Chickpea

Cicer arietinum L.

French	pois chiche
Portuguese	grao-de-bico
Spanish	garbanzo
Hindi	chana

Chickpea is the most important pulse crop in South Asia where the small-seeded desi type predominates. In West Asia/North Africa, the larger-seeded kabuli types are more important. Chickpea cultivation is increasing in Australia, Mexico, the southern USA, and eastern Africa. Chickpea is an important source of dietary protein and is of particular significance in the largely vegetarian diets of South Asia. The grain and haulms are also used as animal feed.



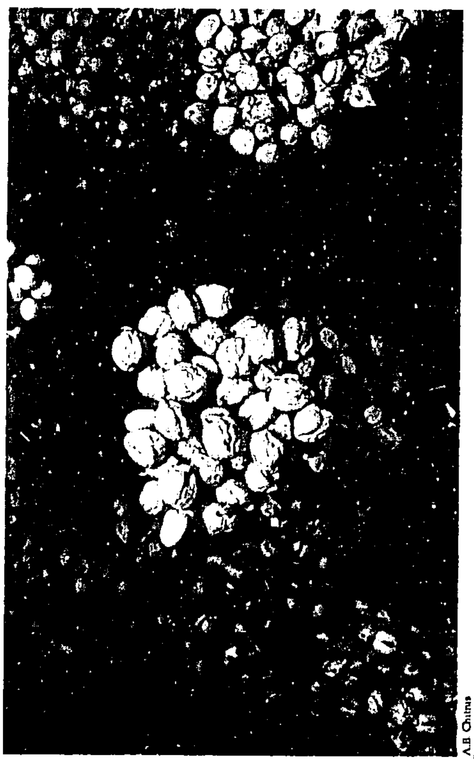
A.B. Chitrus

Groundnut

Arachis hypogaea L.

French	arachide
Portuguese	amendoim
Spanish	maní, cacahuate
Hindi	mungphali

Groundnut is widely grown between latitudes 40°N and 40°S and is the most important oilseed of the semi-arid tropics. It provides a high-quality cooking oil and is an important source of protein for both humans and animals. The haulms are important as livestock feed, especially in the drier parts of the semi-arid tropics. Groundnut is a cash crop for many resource-poor farmers; it also provides much needed foreign exchange to semi-arid tropical countries when sold in the international market.



A.B. Chitrus

Pigeonpea

Cajanus cajan (L.) Millsp.

French	pois d'Angole
Portuguese	guando
Spanish	guandul
Hindi	arhar, tur

Pigeonpea, like chickpea, is predominantly a crop of South Asia. However, its importance as a pulse crop in the Caribbean region and in eastern Africa is increasing. The true extent of this crop is difficult to estimate as pigeonpeas are often grown as intercrops or as hedges and windbreaks. It is also important as forage, green manure, and fuelwood. Prepared and consumed in a wide variety of forms, pigeonpea is important to many people in the semi-arid tropics.

A.B. Chitrus

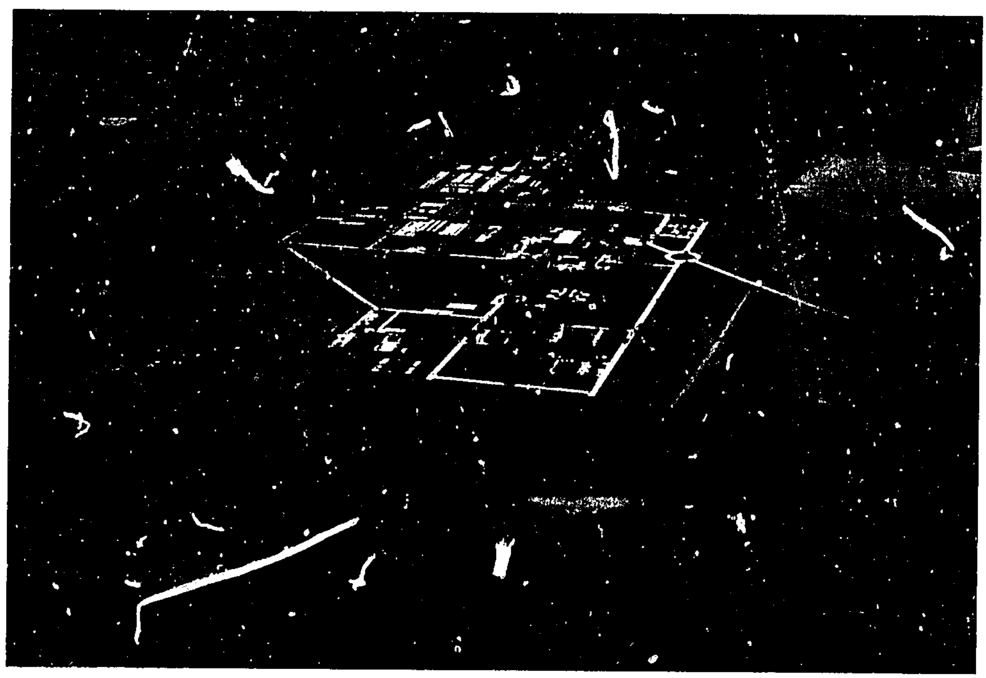
Where We Work

ICRISAT Center

ICRISAT Center, the Institute's main research facility, is located at Patancheru, in Andhra Pradesh State, in south-central India. ICRISAT Sahelian Center (ISC), at Sadoré, near Niamey, Niger, is the Institute's largest facility outside India. ICRISAT scientists are also posted in six other African countries (Ethiopia, Kenya, Malawi, Mali, Nigeria, and Zimbabwe), in Mexico and Syria, and at cooperative research stations in India.

ICRISAT Center lies 26 km northwest of Hyderabad. The farm consists of 1400 hectares and includes two major soil types found in the semi-arid tropics: Alfisols (red soils) and Vertisols (black soils). Alfisols are light and prone to drought. Vertisols retain two to three times as much water as Alfisols in the root zone of crops. Access to both soil types enables ICRISAT scientists to conduct experiments under conditions representative of many semi-arid tropical areas.

ICRISAT scientists undertake crops research from two distinct perspectives. The first is to use the highest technology available to provide an optimal growing environment. The second is to replicate the resource-poor farmer's conditions with modest technological inputs. Beteween these two levels of input, we seek compromises that are both productive and sustainable for the farmers of the semi-arid tropics.



H.S. Duggal

ICRISAT Center.

Seasons. Three distinct seasons characterize the Indian semi-arid tropics. In the Hyderabad area, the rainy season, also known as the monsoon or *kharif*, usually begins in June and extends into early October. Because more than 80% of the annual rainfall (usually about 780 mm) occurs during this period, rainfed crops are constrained by a limited growing season. The postrainy season (mid-October through January), also known as *rabi*, is dry and cool. During this period, crops can be grown on Vertisols using stored soil moisture and on Alfisols with irrigation. The hot, dry season, which begins in February, lasts until rains begin again in June. Any crop grown during this season requires irrigation.

Crops. ICRISAT's mandate crops have different environmental requirements that determine when and where they are grown. Pearl millet and groundnut are usually sown on Alfisols during June and July at the beginning of the rainy season. Pigeonpea is generally sown at the beginning of the rainy season and continues to grow through the postrainy season. An irrigated crop of short-duration pigeonpea is also sown in December to provide genetic material for the breeding program. Two sorghum crops are grown at the Center each year, one on both Alfisols and Vertisols during the rainy season and the other only on Vertisols in the postrainy season. Chickpea, a single-season crop, is grown on Vertisols during the postrainy season on residual soil moisture.

Weather. In 1990, annual rainfall at Patancheru was 831 mm, 6% above average. Rainfall was about average, but because October was exceptionally wet, prospects for postrainy-season crops were good. Daily maximum air temperatures were 3-5°C lower than average during the rainy season and cloud cover was greater than usual.

Unseasonal rainfall in May and the early onset of the rainy season created problems for land preparation and sowing. Sorghum crops were good but the pearl millet crop was poor because of excessive rain. Pigeonpea and groundnut stands were normal. Due to continuous rains, mechanical weeding was difficult on Vertisols.

Other Research Locations in India

ICRISAT has established collaborative research stations at four agricultural universities in India to conduct cooperative research under various agroclimatic conditions.

Anantapur

This is a drought-prone area in southwestern Andhra Pradesh. Although September was very dry, rainfall in October and November was above average. Because the soils in Anantapur are very shallow, there was much runoff and soil erosion during these late rains. No rainfall was recorded in either December or January. Although early sown crops yielded well, crops grown with residual moisture on Vertisols were affected by drought and iron chlorosis.

Bhavanisagar

Located in western Tamil Nadu, Bhavanisagar is bioclimatically similar to the Southern Sahelian Zone of Africa. Here screening for diseases and pests is conducted on sorghum and pearl millet on Alfisols. Rainfall during 1990 was 13% less than the average of 570 mm.

Gwalior

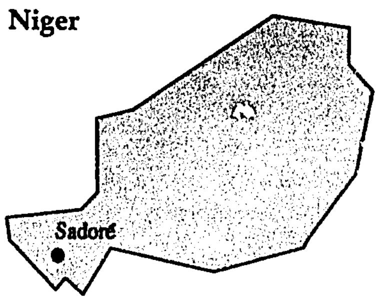
Gwalior, in northern India, lies in Madhya Pradesh State near the borders of Uttar Pradesh and Rajasthan. Most of India's long-duration pigeonpea is grown here. Total rainfall during 1990 was 7% above average. Waterlogging occurred during September, when a total of 500 mm rainfall was recorded. Total rain during the rainy season was 888 mm, 11% above average.

Hisar

This collaborative research station is situated west of Delhi in Haryana State. Here chickpea can be tested under the cool climatic conditions prevailing in many regions where this crop is grown. Annual rainfall in 1990 was 510 mm, 14% above average. Yields were better than average for rainy-season crops, but crops grown on conserved moisture during the postrainy season were adversely affected by persistent drought.

ICRISAT Sahelian Center, Niger

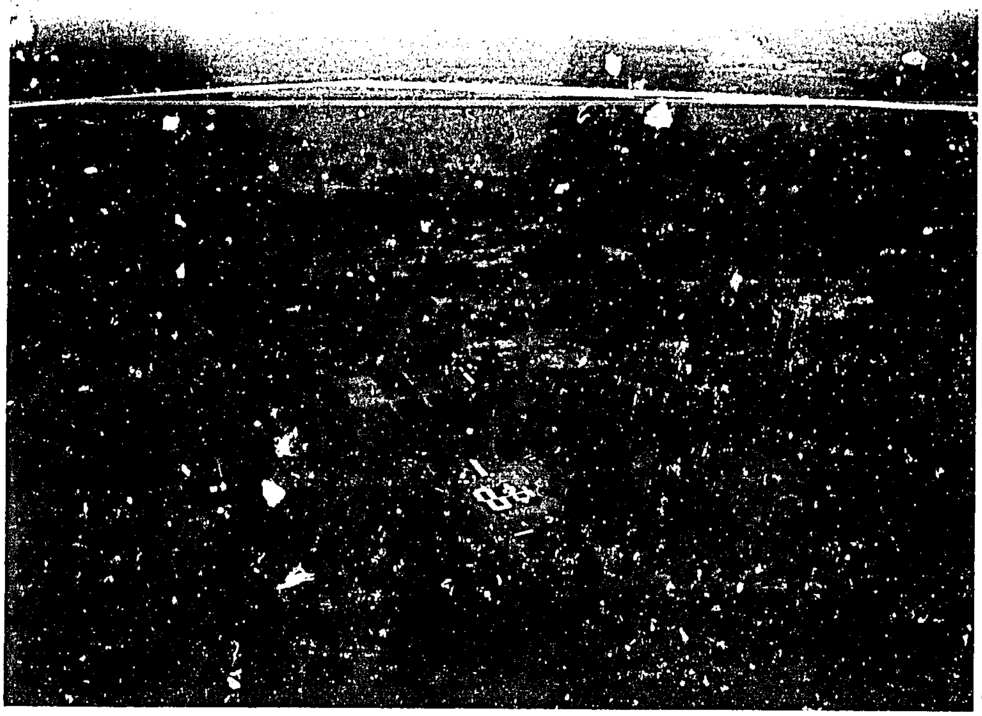
Niger



ISC is ICRISAT's principal research base in the Sahelian region of western Africa. The Center has three programs: the Pearl Millet and Groundnut Improvement Programs and a Resource Management Program which investigates the farming systems associated with these crops. The Center is located at Sadoré, near the village of Say, 45 km south of the capital city of Niamey. The experimental farm extends over 500 hectares of crumbly, reddish, sandy soils with low native fertility and low organic matter content.

Seasons. The climate in Sadoré is characterized by a short rainy season (about 90 days) from June to September. The average annual rainfall is 570 mm. It is irregular and normally comes in the form of electrical storms. During the dry season dust storms from the north and east occur frequently. Temperatures are warm all the year round and average 29°C.

Crops. The main crop in the Niamey region is short-duration pearl millet. It is sown with the first rains. An irrigated nursery is cultivated from January to April to advance generations and help in seed multiplication. Intercropping pearl millet with cowpea, the region's major legume, is common. Cowpea is



ICRISAT Sahelian Center, Sadoré, Niger.

normally sown between pearl millet rows 2-3 weeks after the millet emerges, by which time rains are more frequent.

Weather. Rainfall at ISC during 1990 was 400 mm, 30% below average. Early rains were normal but August was particularly dry and September was drier than usual. Crop yields were low because of stress during grain filling. It was a difficult year for Sahelian farmers.

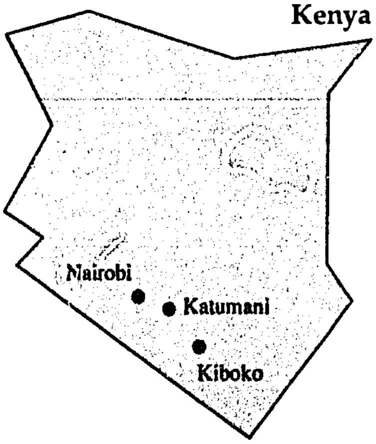
Ethiopia

In September, an ICRISAT engineer was posted at the International Livestock Centre for Africa (ILCA) to work in collaboration with Ethiopia's Institute for Agricultural Research and Alemaya Agricultural University. The objective of this collaborative work is to develop Vertisol watersheds at sites near Addis Ababa.

Kenya

ICRISAT's Eastern Africa Regional Cereals and Legumes Program (EARCAL) is based in Nairobi. EARCAL has six member countries: Burundi, Ethiopia, Kenya, Rwanda, Somalia, and Uganda. Its work is to evaluate sorghum and pearl millet cultivars in four major agroecological zones: highlands, intermediate elevations, low elevations, and very dry lowlands. Researchers screen sorghum, pearl millet, and pigeonpea for dry short-season adaptation in the long rains and intermediate adaptation in the short rains. The Kenya Agriculture Research Institute (KARI) has provided land to ICRISAT at its Katumani and Kiboko stations as well as research facilities at stations in other agroecological zones.

Kenya



Katumani

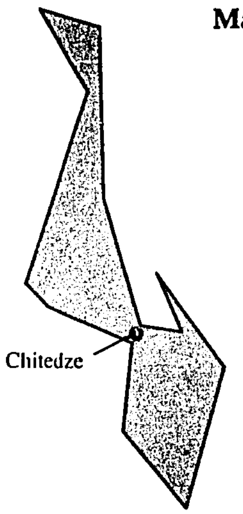
This site is located 1° south of the equator 10 km from the town of Machakos. The altitude is 1575 m and the rainfall, which averages 718 mm, is bimodal. The first rainfall period peaks in April and the second in November. The soils at Katumani are a loamy reddish brown. They are deep and well drained. In 1990, the total rainfall received was 975 mm, 36% above normal. Rainfall in March and April was much higher than usual, causing short-term waterlogging and nutrient losses.

Kiboko

Kiboko is located 170 km southeast of Nairobi on an erosional plain at an altitude of 1300 m. The soil is a clayey, friable loam. The color is reddish-brown or dark red. During 1990, a total of 735 mm of rainfall was received, 18% above normal. From January to March it was particularly heavy.

Malawi

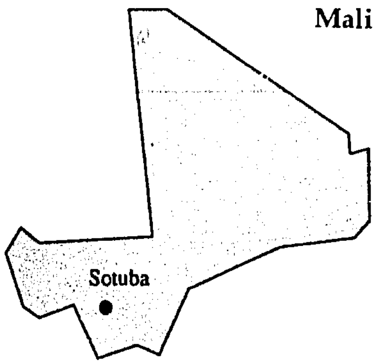
Malawi



Chitedze Agricultural Research Station of Malawi's Ministry of Agriculture is located on the Lilongwe Plain east of the capital. It provides a base for the SADCC/ICRISAT Groundnut Project. The area has a tropical continental climate with one rainy season from October/November to March/April, typical of groundnut-growing areas of southern Africa. Rainfall during the growing season was 934 mm (5% above normal). A late-season drought occurred in mid-March and crops on some fields were severely wilted. Because copious rains in late March and April helped recovery, yields were not markedly affected. In fact, yields of spanish types were double those recorded in 1988/89. Virginia trial yields were similar to those of the previous growing season, but due to late rains some seed discoloration occurred.

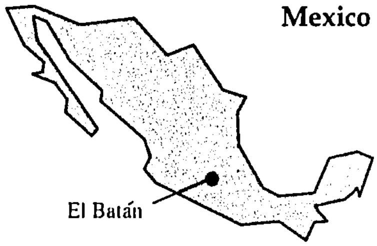
Mali

Located near Bamako, the capital of Mali, Sotuba Research Station typifies the Sudanian Zone of sub-Saharan Africa. Here an interdisciplinary team of scientists evaluates sustainable land-use systems for farming areas constrained by a 150-day growing season. The soil consists mainly of loam and clay. Sorghum, pearl millet, groundnut, and maize are the major crops. Total rainfall in 1990 was 828 mm, 23% below average. Early rains were timely and adequate, and crop establishment was good. However, a severe mid-season drought in late July and early August adversely affected growth of all crops. Later, in August and September, the weather was unusually wet. Maize yields were thus below normal, but both sorghum and pearl millet showed remarkable recovery, producing normal yields.



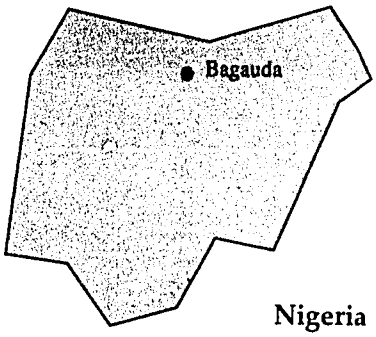
Mexico

ICRISAT's team in Mexico is based at the Centro Internacional del Mejoramientio de Maíz y Trigo (CIMMYT) at El Batán, north of Mexico City. Here research is carried out on high-altitude, cold-tolerant sorghum adapted for low and intermediate elevations in Latin America and the Caribbean. The rainfall in El Batán totalled 726 mm in 1990, 120% above average. The rains started in April, a month ahead of normal, and lasted until October. Rainfall throughout the rainy months was far above normal, resulting in prolonged cloud cover and low temperatures during the growing season. Fortunately, the late season frosts, which delayed sorghum maturation at the soft dough stage in 1989, did not occur. All sorghum genotypes performed well.



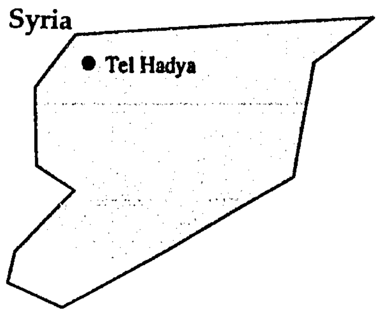
Nigeria

Bagauda Research Station, near Kano in northern Nigeria, is the regional base for ICRISAT's West African Sorghum Improvement Program (WASIP). The main thrust at Bagauda is to screen high-yielding sorghum cultivars of good quality and to determine the agronomic requirements for sustainable production in the Sahel. Total rainfall for 1990 was 556 mm, 37% below the long-term average for Kano. Early rains in May and June were sparse. Farmers who risked early sowing suffered crop establishment problems. The first sowing rains did not fall until early July, and a mid-season drought was experienced during late August and early September. While good yields were recorded from short-duration cultivars, severe lodging was observed in other lines.



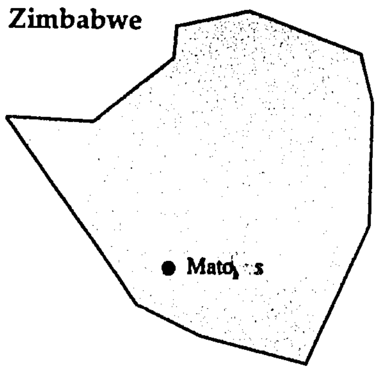
Syria

In Syria, ICRISAT cooperates with the International Center for Agricultural Research in the Dry Areas (ICARDA) near Aleppo, in the northwestern part of the country. The two centers share the world mandate for chickpea, although ICARDA's focus is on the kabuli types which are sown in spring or winter in the WANA region and in certain areas of Latin America. ICRISAT's work on kabuli

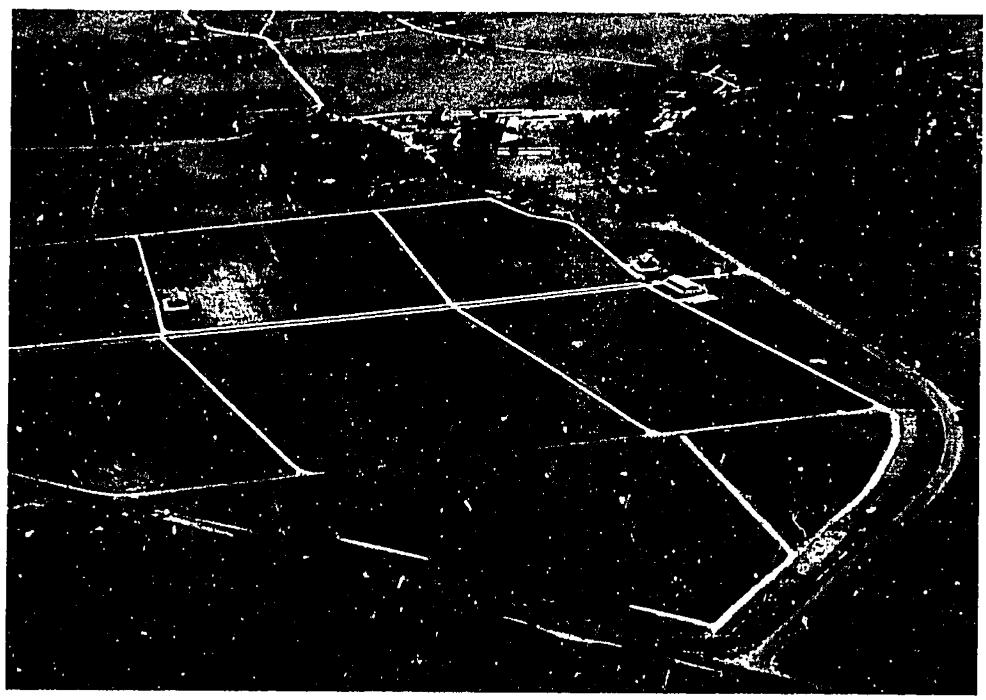


cultivars is therefore conducted primarily at ICARDA. The growing season in Aleppo lasts from November to June. The 1989/90 season, during which temperatures dropped to freezing on 56 days, was the driest and coldest in 14 years. A record low temperature of –8.9°C was recorded on 17 March during the preflowering stage. The crop was devastated. Many winter-sown chickpea entries were killed and others were damaged. The spring-sown crop, however, was unaffected. The total rainfall during the season was 233 mm against the average of 330 mm. This was the second consecutive drought year. The twin stresses of cold and drought affected chickpea productivity throughout the WANA region.

Zimbabwe



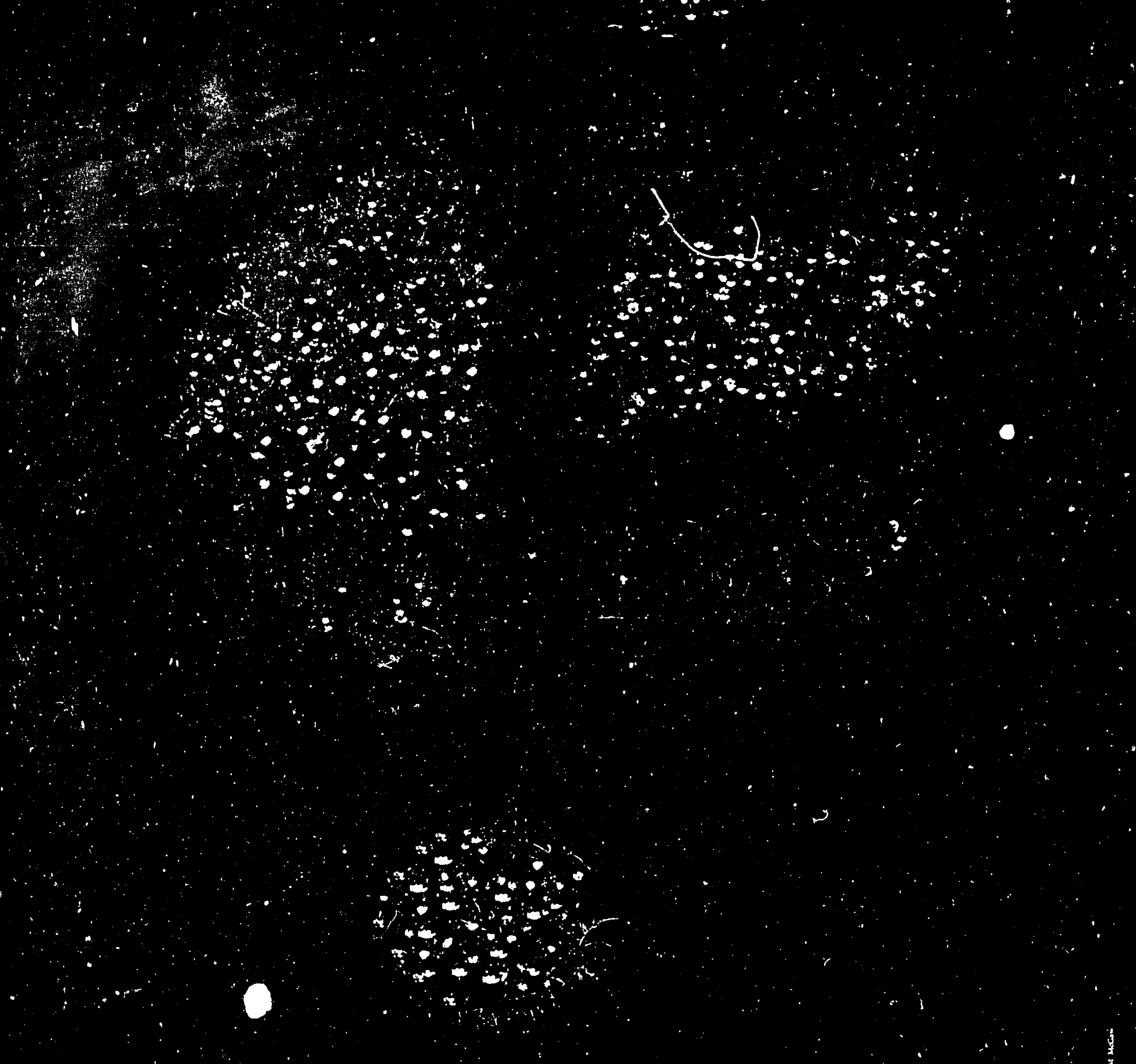
The SADCC/ICRISAT Sorghum and Millets Improvement Program (SMIP) for the 10 countries of the SADCC region is based at Matopos, near Bulawayo, in southwestern Zimbabwe. The SADCC countries are Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe. The growing season lasts from October/November to March/April. Soils range from sandy to clayey. Rainfall between September 1989 and August 1990 was 512 mm, only 12% less than average, but the rainfall recorded during the cropping period was 25% less than average. Crops suffered a dry spell at the end of December, but due to efficient soil and water management, yields were normal. Lesotho and Swaziland had particularly good seasons, while crops in Tanzania were damaged by waterlogging.



Photography International Consultancies Ltd.

SADCC/ICRISAT facilities at Matopos, Zimbabwe.

Directors' Reports



This flower garden representing the ICRISAT logo was designed by FDO's Landscaping Unit at ICRISAT Center.

Cereals

Johannes M.J. de Wet, Program Director

Pearl millet cultivation in southern Africa.

Cereals research at ICRISAT concentrates on the genetic improvement of sorghum, pearl millet, and finger millet; the collection, characterization, documentation, and conservation of these cereals and the minor millets of the semi-arid tropics; and the identification of new cultivars of these cereals for improved or established agro-ecosystems in the semi-arid tropics.

Program research responsibilities are divided regionally at ICRISAT Center in India for Asia, the Pearl Millet Improvement Program at ISC and the West African Sorghum Improvement Program (WASIP) teams in Mali and Nigeria for western Africa, the SADCC/ICRISAT Sorghum and Millets Improvement Program (SMIP) in Zimbabwe for southern Africa, the Eastern Africa Regional Cereals and Legumes Program (EARCAL) in Kenya for eastern Africa, and the Latin American Sorghum Improvement Program (LASIP) in Mexico for Latin America and the Caribbean. EARCAL and LASIP report administratively to the Cereals Program Director at ICRISAT Center.

The cereals improvement programs in eastern and western Africa have regional network coordinators to facilitate research cooperation among national agricultural research systems, and between the national systems and ICRISAT. Regional networks are assisted by steering committees consisting of national scientists and administrators. Committees meet annually to plan network activities and advise ICRISAT on regional research needs. The program at ICRISAT Center has a Cooperative Cereals Research Network (CCRN) responsible for international sorghum trials and nurseries and for coordinating research between ICRISAT and national programs in Asia.

Research Goals and Organization

The Cereals Program has four research goals.

1. *To improve our crops by identifying:*
   - *sources of resistance to temperature extremes and drought;*
   - *resistance to diseases, insect pests, and parasitic weeds;*
   - *sources of high quality food, feed, and fodder; and*
   - *grain yield potential and stability.*
2. *To develop new industrial, feed, and food uses for these cereals.*
3. *To assemble a well-documented world collection of sorghum, pearl millet, finger millet, and minor millets.*
4. *To breed improved cultivars that will allow for increased cereal production in the semi-arid tropics of Asia, Africa, and Latin America.*

Research on Production Constraints

Sorghum

The Cereals Program is enlarging the genetic base of sorghum breeding populations. A range of durra and durra-caudatum germplasm, and germplasm resistant to downy mildew, anthracnose, rust, midge, shoot fly, and stem borers is being introduced into advanced breeding populations. We expect that seed parents derived from these populations will overcome the yield plateau that breeders have been battling with in India for several years.

Resistance to grain molds in sorghums bred to escape terminal heat and drought stress by maturing before the end of the rains remains a major constraint to sorghum production across the semi-arid tropics. ICRISAT Center and WASIP breeders are making progress in selecting for resistance to grain molds in white-grain populations (hard grains). A project to breed red-grain hybrids resistant to grain molds was initiated at ICRISAT Center.

Sorghum entomologists and physiologists, in cooperation with microclimatologists of the Resource Management Program, demonstrated that the degree of surface wetness in the whorl of the youngest seedling leaf influences resistance to shoot fly. By manipulating the degree of leaf surface wetness through reduced soil moisture content, shoot fly damage was reduced by 30% and grain yield was increased by 22%.

Pest surveys showed that sorghum midge and head bug incidence were high in 12 districts in Tamil Nadu (India), and that stem borer infestation was high in Somalia and Tanzania and was the major pest in most farmers' fields.

Midge-resistant lines ICSV 743 and ICSV 745 were tested by almost 300 farmers in Tamil Nadu. These lines yielded 3-5 times more than the commercial hybrids under midge infestation.

In collaboration with the Institute of Agricultural Research (IAR), Samaru, Nigeria, our pathologists at WASIP-Nigeria conducted a survey of sorghum diseases in Nigeria to ascertain their prevalence in different agroecological zones. Maize mosaic virus, maize stripe virus, and a potyvirus were found in the Sudanian, Northern Guinean, and Southern Guinean Zones. Maize mosaic virus was the predominant virus in these regions. Viral diseases were not detected in the Sahel. Anthracnose (*Colletotrichum graminicola*) was the most common and widely distributed disease. Long smut (*Tolyposporium ehrenbergii*) was severe in the Sahel, while head, covered, and loose smuts were moderate to severe in the other three ecological zones.

Ergot (*Claviceps sorghi*) is a serious disease of sorghum in several countries of Asia and Africa. During the past 3 years, ICRISAT pathologists, in collaboration with the Ethiopian and Rwandan national programs, identified ergot-resistant local landraces. Sorghum is susceptible to ergot when grown in areas with low night temperatures (9-11°C), a condition suspected to reduce self-pollination efficiency and thus enhance ergot susceptibility. In controlled environment experiments at ICRISAT Center, several lines with good self-pollination efficiency and ergot resistance at low night temperatures were identified. Breeders are using these lines to develop ergot-resistant hybrids. In Rwanda, the weeds *Cenchrus ciliaris* and *Panicum maximum* were found to be primary sources of the ergot inoculum that infect sorghum in the field. Similar investigations at ICRISAT Center showed that ergot inocula from the common grass weed *Urochloa panicoides* and from soilborne honeydew initiated ergot infection. Inoculum in the form of macroconidia in the honeydew was spread by wind-driven water splash but not by insects, and secondary conidia were spread by wind.

Pearl millet

Multilocational comparisons of open-pollinated varieties and topcross hybrids of pearl millet, using these varieties as pollinators on two early seed parents, have shown that topcrossing can be an effective procedure to utilize adapted, but low-yielding, open-pollinated varieties. Hybrids were more responsive to

An ICRISAT breeder and a millet farmer discussing his crop in Rajasthan.

improved environmental conditions than their parent varieties, with no evidence of either inferior grain yield in low-yielding, dry environments, or any lower yield stability across environments, than their variety parents.

We have successfully used restriction fragment length polymorphism (RFLP) mapping of mitochondrial DNA to characterize 12 male-sterile lines according to their hybridization patterns using a set of cloned DNA fragments. This characterization allowed for classification of the 12 lines into four groups that largely coincided with a grouping derived from fertility restoration patterns of hybrids made on these lines. The availability of this RFLP technology for characterizing new sources of male-sterile cytoplasm will be important in the diversification of sterile cytoplasms in pearl millet.

Two years of experiments indicated that high soil-surface temperatures resulting from the failure of postsowing rains in western Rajasthan (India) are a probable cause of seedling death. Anatomical and radioactive carbon studies confirmed that mortality in seedlings exposed to high soil-surface temperatures is due to restriction of carbohydrate flow in plant tissue. A heat-girdling technique has been devised to screen for genetic variation in tolerance for high soil-surface temperatures. This technique together with field experiments indicates that good sources of tolerance are available in Rajasthani landraces. Selected lines are being studied to determine the molecular or physiological basis of tolerance.

Simulated selection studies using data from evaluation experiments done on a set of landraces from the arid areas of northwestern India indicated that selection for adaptation to such areas is much more efficient when carried out in these areas than at ICRISAT Center. The results obtained may explain why improved varieties selected under nonstressed, high-productivity environments have had low adoption rates in arid areas. Varieties intended for these areas are therefore being selected under representative stress conditions.

Studies with three-way hybrids indicated that first-generation hybrid male steriles yielded significantly more seed than their parent lines with the same pollinator, and that their downy mildew resistance and earliness is comparable to the better of the two parental lines. Further, the yield of the three-way hybrids was shown to be equal to the average of the yield of the single-cross hybrids made with parental lines. Other studies indicated that variation of the three-way hybrids is somewhat greater than that of the single-cross hybrids, but is much less than the variation of commercial open-pollinated varieties. Three-way hybrids thus appear to offer distinct advantages to the hybrid seed industry without any apparent disadvantages.

Variability in *Sclerospora graminicola*, the cause of pearl millet downy mildew, is a major problem in hybrid breeding in India. Greenhouse studies initiated to learn more about the nature and control of this disease indicate that *S. graminicola* can undergo host-directed shifts in virulence, and that virulence is likely governed by one or a few genes.

Cereals scientists have demonstrated, for the first time, that there are clear differences in virulence in the pearl millet rust pathogen among isolates from India, southern and western Africa, South Asia, and North America. Data from a limited number of isolates did not suggest virulence differences within India.

Cell biologists standardized a technique to regenerate functional plants from cells of a range of pearl millet genotypes. This breakthrough will contribute substantially to the eventual successful transformation of pearl millet.

Minor millets

The Cereals Program has considered the need to increase research on three other millet species. These are finger millet (an important cereal in India and Africa in areas with 900-1200 mm of annual rainfall), foxtail millet, and proso or common millet. Foxtail and proso millet are important cereals in India, semi-arid South Asia, and temperate Eurasia.

The Indian national system has excellent research projects on these millets, and needs no assistance from the Cereals Program. Little research, however, is being done to improve the yield potential of finger millet in Africa. This millet is particularly important as a food crop in the highlands of eastern and southern Africa.

Projects have been initiated by EARCAL and SMIP to cooperate with national programs in identifying and improving finger millet genotypes with high yield potential. Priority research will be to breed cultivars resistant to blast disease caused by the fungus *Pyricularia*.

Cultivar Releases

Cereals researchers have also been successful in applied research. Material bred by ICRISAT scientists is widely used in sorghum and pearl millet improvement projects by national programs and by private and public seed producers in Africa, Asia, and Central America.

A survey during 1989 in India indicated that ICRISAT-bred pearl millet variety ICTP 8203 was grown on over 1 million ha in Maharashtra during the rainy season. Farmers harvested up to 3 t/ha of grain from ICTP 8203 where this cereal followed cotton or sugarcane. Variety ICTP 8203 was also grown in northern Namibia during 1990.

The national program in Zambia reported that a selection from the ICRISAT-bred pearl millet late composite population was released as Lubasi, and ICMV 82132 was released as Haufala for cultivation this year. These releases show that ICRISAT pearl millet cultivars do well in southern Africa. Lubasi, for example, yielded 4-5 t/ha in Zambian pearl millet trials. The top eight entries from variety trials at ICRISAT Center will be included in future Zambian trials.

Pearl millet variety WC-C75 remains popular in Tamil Nadu and Karnataka states in India. However, ICMV 84400, which has consistently yielded 12% more grain and 9% more fodder than WC-C75, and which has shown excellent resistance to downy mildew and ergot, is now ready for release. It has been accepted for seed multiplication by several seed producers and it is expected that this variety will eventually replace WC-C75.

The Program is encouraged with results from the pearl millet topcross hybrid project. One such hybrid, ICMH 88088, is in the advanced All India Coordinated

Pearl Millet Improvement Project (AICPMIP) trials. Data indicate that topcross hybrids are equal in yield stability to two-way crosses, and that they are in no way inferior to standard hybrids or local varieties in their tolerance for temperature or drought stresses.

The Program is making progress in producing an acceptable pearl millet topcross hybrid that will mature within 65 days. Of the several topcross hybrids currently under test, ICMH 89951 shows particular promise.

Variety ICSV 112 remains the most popular sorghum cultivar bred by ICRISAT. It is grown in India as CSV 13, in Zimbabwe as SV 1, in northern Mexico as UANL-1-87, in southern Mexico as Pacífico, and in Nicaragua as Pinolero. In Central America ICSV 112 yields over 5 t/ha in farmers' fields.

In the Indian state of Karnataka, the University of Agricultural Sciences, Bangalore, proposes the release of sorghum variety ICSV 745 for cultivation in midge-infested areas at both state and national levels. It has a yield potential exceeding 3 t/ha under severe midge infestation. It is also being tested in farmers' fields in Andhra Pradesh, Maharashtra, Gujarat, and Tamil Nadu.

Sorghum hybrid SPH 296 was the highest yielder for the third consecutive season in the All India Coordinated Sorghum Improvement Project (AICSIP) trials, and is being multiplied and sold by several private sector seed companies.

ICRISAT sorghum cultivars are also doing well in western Africa. In trials throughout the region, ICSH 507 and ICSH 780 were consistently ranked first or second in grain yield. Yields of over 5 t/ha were obtained at Bagauda (Nigeria) under rainfed conditions.

Collaborative Research with Mentor Institutes

The Program is making progress in constructing molecular genetic maps of sorghum and pearl millet in collaboration with the University of Milan in Italy on sorghum, and with the Institute for Plant Science Research, UK, on pearl millet. These RFLP markers will be used to detect chromosome segments carrying quantitative and recessive traits in genetically segregating populations. Projects were also initiated to construct genetic maps of these cereals.

A study of heat shock proteins being conducted in cooperation with the University of Milan was completed. A procedure was developed by which inflorescences were subjected to a temperature of 50°C for up to 2 hours at the time of pollen shed. Progenies from these treatments were insufficient to judge the effectiveness of this selection procedure for improving heat tolerance in breeding lines. The technique requires further exploration using a range of treatments (temperature, duration, number of heat shocks).

In cooperation with the Welsh Plant Breeding Station at Aberystwyth, UK, the Program is making progress in understanding the molecular biology of adaptation for seedling survival under high temperatures. In sorghum and pearl millet seedlings, normal protein synthesis is suppressed at temperatures above 45°C, but a novel set of heat shock proteins are produced. Although the function of these proteins is not yet known, available evidence suggests that they are associated with a physiological change that raises the threshold temperature at which damage to tissue occurs. This heat shock system provides potential for developing an effective method to screen for sensitivity to high temperatures among genotypes.

Research cooperation with the University of Chicago, USA, has identified three compounds that determine resistance of sorghum to the parasitical weed *Striga*. In susceptible genotypes, a hydroquinone is released by the sorghum root that stimulates germination of *Striga* seed already in the soil. A second compound produced by the sorghum root orients the growth of the parasite's root towards the host root. A third compound allows for the formation of the haustorium that integrates the host and parasite root systems. Germination is the most critical of these three recognition events. The transition from dormancy to germination is irreversible, and the parasite cannot survive without a host for more than 4 days. Since we now understand how these low molecular weight compounds control both the spatial and temporal requirements for efficient parasitism, we are in a position to develop stable analogs of these compounds to control this parasitic weed. The interdependence of genes that control the production of the three recognition compounds are being studied as a first step in their identification and cloning.

Eastern Africa Regional Cereals and Legumes Program (EARCAL)

EARCAL does adaptive and applied research on sorghum, pearl millet, finger millet, and pigeonpea. Although pigeonpea research at EARCAL is administered by the Cereals Program Director, the involvement of Legumes Program scientists is a key factor in EARCAL's work. (See also the Legumes Program Director's Report.) Scientists from ICRISAT Center assist program scientists in strategic research. Program scientists conduct research as cooperative projects with national program scientists in the region. Cooperating countries are Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, and Uganda.

EARCAL provides research support for the Eastern Africa Regional Sorghum and Millets (EARSAM) Network, which serves all EARCAL countries plus Tanzania.

The Program has cooperative research projects on screening sorghum breeding lines for resistance to long smut and covered smut (Kenya), ergot (Ethiopia and Rwanda), anthracnose (Ethiopia), and *Striga* (Ethiopia). The national program in Somalia is cooperating with EARCAL on breeding sorghum resistant to stem borers. A survey indicated that the stem borer *Chilo partellus* is a serious pest on sorghum in Somalia. The Program at ICRISAT Center assisted scientists at Bonka Research Station, Somalia, to establish a facility for rearing this insect. All breeding material now passes through a screen for tolerance before it is used in breeding projects.

The Program at ICRISAT Center assisted scientists at the University of Nairobi in Kenya and the Food Research Centre in Sudan to improve facilities for studies on food quality of sorghum and pearl millet. Research at these institutions demonstrated that sorghum variety SPV 475, bred at ICRISAT Center, compares favorably with traditional cultivars in food quality.

In Kenya the Program cooperates with scientists of the Kenya Agricultural Research Institute (KARI). This institute provides facilities for EARCAL at Katumani, Kiboko, and other research stations. The Program has developed 20 ha of research fields at Kiboko, of which 6 hectares can be irrigated. It has constructed a building for seed threshing and storage, and a guest house. The guest house is operated and maintained by KARI.

Research on pigeonpea started in 1990. Pigeonpea is traditionally grown as an intercrop with sorghum or maize. Adaptation trials identified medium- to long-duration cultivars bred at ICRISAT Center that are superior in yield and disease resistance to traditional cultivars in this cropping system. Experimental trials demonstrated that short-duration pigeonpea can successfully be grown in rotation with wheat.

Latin American Sorghum Improvement Program (LASIP)

The Program cooperates with national programs of Mexico and countries in Central America and the Caribbean in cooperative on-farm testing of cultivars and cropping systems involving sorghum. It was demonstrated that short-duration sorghums can compete with maize in marginal areas of the Mexican highlands under rainfed conditions.

LASIP has concentrated its efforts in Central America on breeding for cold tolerance and on fitting new cultivars into the cropping systems of resource-poor farmers at medium to high elevations. This cropping system, however, represents less than 5% of all sorghum grown in a region where commercial hybrids grown in lowland areas are widely used to supplement wheat flour in food products. Demand for sorghum as animal feed far exceeds production in South America. Sorghum is particularly well adapted to the acid soils of the *llanos* that are now being brought into cultivation.

The Cereals Program has therefore decided to reduce its activities in Central America. It plans to assist the region primarily through the regional network Comisión Latinoamericano de Investigadores en Sorgo (CLAIS), transferring ICRISAT-bred material to national programs in the region. The Cereals Program does not believe that LASIP should expand its direct involvement in sorghum improvement in Central America. Instead, the Program will investigate the possibility of cooperation with a national program or an international research institution in South America to develop a regional sorghum improvement program. The Cereals Program at ICRISAT Center will continue to assist national programs in Latin America by providing facilities to train national scientists.

Sorghum in El Salvador.

Legumes

Duncan McDonald, Program Director

During 1990, the Legumes Program engaged in research and technology exchange activities aimed at the improvement of chickpea, pigeonpea, and groundnut in Asia, eastern Africa, and the West Asia North Africa (WANA) region. Basic research was carried out at ICRISAT Center and in cooperation with various mentor institutions. Strategic and applied research was conducted mainly at ICRISAT Center and at the cooperative research stations in India, at ICARDA in Syria (on kabuli chickpeas), and in Kenya by EARCAL (on pigeonpea). Applied and adaptive research activities in South, Southeast, and East Asia have been facilitated by the Asian Grain Legumes Network (AGLN) which is coordinated from ICRISAT Center. The ICRISAT Center Legumes Program worked in close cooperation with the Groundnut Improvement Program at ISC and with the SADCC/ICRISAT Groundnut Project in Malawi.

Problems

For all three legumes the average yield is around 0.8 t/ha in the semi-arid tropics, much below the potential yields of more than 7 t/ha for groundnut and more than 4 t/ha for the two pulse crops. In addition, legume yields are unstable because of unreliable rainfall and attacks by diseases and pests. Most of the varieties traditionally cultivated by farmers in the semi-arid tropics are landraces adapted more for survival than for high production. They are often highly susceptible to biotic stresses.

Research

The Legumes Program's research has been directed at alleviating production constraints of chickpea, pigeonpea, and groundnut with particular emphasis on rainfed conditions and low-input farming systems.

Crop duration and adaptation

Because chickpea is generally grown as a postrainy-season crop on residual soil moisture, drought and heat stress at flowering and fruiting are common. Crop duration is therefore a key factor in the productivity of chickpea. We deal with short-duration (75-110 days), medium-duration (120-140 days), and long-duration (more than 150 days) types, suited to growing seasons in different latitudes. Where drought, diseases, and pests are not constraints, productivity is

A Nepali technician examining ICPL 85063. This medium-duration pigeonpea line was sown in the postrainy season.

usually linked to crop duration as longer-duration crops generally give the highest yields. But in recent years, extra-short-duration materials have escaped drought and given good yields in some environments, e.g., ICCV 2 in Myanmar and India. The short-duration variety ICCV 10 (ICCL 83228) has given high yields (2-3 t/ha) in central and peninsular India and in Bangladesh. The medium-duration varieties ICCV 89230, ICCV 88110, ICCV 89344, and ICCV 89244 and the long-duration varieties ICCV 88106 and ICCV 89701 have done well in national evaluation trials in India.

Crop duration in pigeonpea is determined by interactions between photoperiod, temperature, and genotype. The main duration groups are: extra-short-duration (less than 110 days), short-duration (110-130 days), medium-duration (130-160 days), and long-duration (more than 180 days).

Recently bred extra-short-duration genotypes have retained a high yield potential. They increase options for escaping drought and can fit into gaps in the cropping cycle previously inaccessible to pigeonpea.

The short-duration hybrid ICPH 8 has outyielded open-pollinated varieties by 40-50%.

It has proved difficult to combine resistance to fusarium wilt and tolerance for pod borer (*Helicoverpa armigera*), but these traits have now been brought together in medium-duration pigeonpea lines.

A survey in Kenya showed that long-duration pigeonpeas were predominant, generally intercropped with cereals or with legumes such as cowpea and mung bean. There is excellent potential for expanding pigeonpea production in eastern Africa both for local use and for export.

We recognize three crop-duration groundnut types—short-duration (less than 100 days), medium-duration (100-120 days), and long-duration (more than 120 days). Short-duration varieties are required for areas with unreliable rainfall, for residual moisture situations such as a post-rice crop, and for multiple cropping systems. Medium- and long-duration varieties are preferred for areas with longer rainy seasons; they can recover and perform well in regions characterized by midseason drought stress. We have identified 15 short-duration varieties which yielded better than the popular Indian cultivar JL 24 when harvested 75 days after sowing, and 10 that did better than JL 24 when harvested 90 days after sowing.

Drought

Having identified considerable genotypic variability in drought tolerance in the three legumes, we are now investigating its physiological basis. Chickpea lines selected for vigorous rooting are being evaluated for drought response, and some appear promising compared with established drought-tolerant controls. Screening for early growth vigor is continuing, as this character is important to allow chickpea to attain maximum biomass and grain yield in environments with short periods of available soil moisture.

Characters considered useful for drought tolerance in short-duration pigeonpea include leaf retention during stress periods, ability to regrow after stress alleviation, non-synchronous flowering (as in indeterminate types), small pod size with few seeds per pod, and large seed mass.

In a cooperative study with Australian researchers, isotopic carbon discrimination techniques are being evaluated to estimate differences in water-use efficiency among groundnut genotypes.

Temperature

In subtropical South Asia, night temperatures near freezing prevent pod-set in standard chickpea cultivars and thus extend reproductive growth into periods of increasingly unfavorable high temperature, moisture deficit conditions, and increased risk of pod borer attack. Genotypes able to set pods under cold conditions have been identified, and the physiological mechanisms involved are being studied. High day temperatures were found to alleviate low night temperature effects.

In the WANA region, temperatures below freezing limit vegetative growth and grain yield of winter-sown chickpea. An extremely cold 1989/90 winter at ICARDA, with 55 days at below freezing, facilitated selection for cold tolerance in breeding lines.

Photoperiod

The successful ICRISAT groundnut varieties ICGS 11, ICGV 87128 (ICGS 44), ICGS 76, and ICGS 37 are all photoperiod insensitive. Pod yields are lower under long-day conditions in most of the photoperiod-sensitive groundnut genotypes tested. Advanced lines from resistance breeding programs were screened for sensitivity to photoperiod. Several disease-resistant lines were insensitive, or only mildly sensitive to photoperiod, and were high yielding.

Nutrition

An international workshop on "Phosphorus Nutrition of Grain Legumes in the Semi-Arid Tropics" was held at ICRISAT Center in January. The report of root exudates of pigeonpea and chickpea enhancing phosphorus availability in soils was highlighted.

Root distribution of pigeonpea in both sole crops and intercrops is being quantified in relation to fertilizer application and waterlogging, and the data are being used to model the growth of pigeonpea root systems and effects of environmental factors on root growth.

Development of non-nodulating and partially nodulating lines of chickpea is continuing for the purposes of quantifying nitrogen fixation in this crop and for basic studies on its nitrogen nutrition.

Positive residual effects of both short- and medium-duration pigeonpea on a subsequent sorghum crop were again obtained from trials on a Vertisol. These effects were largely attributable to nitrogen inputs by the legume. Urea and phosphorus application alleviated iron deficiency symptoms in groundnut, but excess application of iron chelate induced manganese deficiency.

Pests and diseases

Fungal diseases. Research continued on fusarium wilt. Chickpea lines ICC 9032 and ICC 11223 were resistant to wilt at 10 locations in India. Twenty-one new sources of resistance to wilt were discovered. *Cicer cuneatum* was resistant to both wilt and root rot. A third gene, dominant for late wilting, was identified in the long-duration cultivar H 208.

We induced pycnidial formation by the root rot pathogen *Rhizoctonia bataticola* on chickpea root pieces indicating potential for pycnidia to form on chickpea stubble.

Botrytis gray mold disease was successfully managed by growing tall, erect, compact chickpea genotypes, at wide inter-row spacing in a field test at Pantnagar, India. This disease is important in India, Bangladesh, and Nepal. An international working group has been proposed to integrate research on this disease.

High yield has been combined with multiple resistance to and tolerance for important diseases (wilt, root rot, stunt, ascochyta blight, and botrytis gray mold) in one desi (ICCV 89443) and one kabuli (ICCV 90301) chickpea variety.

Pigeonpeas at several locations in India were severely damaged by phytophthora blight. Three short-duration breeding lines, ICPX 820006, ICPX 830033, and KPBR 80-1, showed resistance to the disease which is particularly important in wet years.

In tests at several locations in India we confirmed that the risk of preharvest aflatoxin contamination was much lower in groundnuts grown on Vertisols than in groundnuts grown in light sandy and red sandy loam soils.

Thirty-three additional rust-resistant groundnut lines were identified, bringing the total of resistant germplasm accessions to 157. The variety ICG (FDRS) 10 (ICCV 87160) was released in India in 1990, the first genotype resistant to both rust and late leaf spot to be released.

Nematode diseases. The pigeonpea cyst nematode *Heterodera cajani* and the reniform nematode *Rotylenchus reniformis* were found to be widely distributed in major pigeonpea production districts of Karnataka, India. A greenhouse resistance screening method for evaluation of pigeonpea genotypes was therefore developed. Incidence of root-knot nematodes (*Meloidogyne* spp) on groundnut and pigeonpea was low.

Resistance to *M. javanica* was discovered in one groundnut genotype (ICG 6689) and in three chickpea genotypes (ICCC 42, N 31, and CPS 1).

Insect pests. A Consultative Group meeting at ICRISAT Center in March reviewed the behavior of the key pest *Helicoverpa armigera* in the context of the chemical substances and physical attributes of the plant that influence the feeding behavior of the larvae and egg laying by the adult.

Four resistant pigeonpea varieties were evaluated by a group of women farmers in Andhra Pradesh, India. Preference was not given automatically to the highest-yielding varieties. This has provided a model for product testing by farmer participation and a video has been made of the procedure to demonstrate this approach (see box on p.000).

Through cage experiments with chickpea (Annigeri) and pigeonpea—ICPL 87 (Pragati)—we determined the relationships between population density of *H. armigera* larvae and crop yield.

High jassid numbers in groundnut crops allowed us to demonstrate a relationship between jassid density and yield loss.

In cooperation with scientists of the Natural Resources Institute of the Overseas Development Administration, UK, we identified the chemicals involved in resistance to *Spodoptera litura* in wild *Arachis* species. It was found that aphid resistance in the groundnut cultivar EC 36892 is due to the presence of an antibiotic tannin and the low concentration of a feeding stimulant.

Viral diseases. Research on viral diseases covered a wide spectrum of activities involving links with mentor institutions and national systems.

We improved purification methods for tomato spotted wilt virus (TSWV), the cause of bud necrosis disease in groundnut. Using the high-quality polyclonal antiserum produced by these methods, we showed that the virus isolate from India does not react with antisera for TSWV isolates from the USA, the Netherlands, Japan, or Australia. The Indian isolate was shown to be transmitted by *Thrips palmi*.

We screened groundnut germplasm and breeding lines for tolerance for peanut mottle virus and for nonseed transmission. Four germplasm accessions showed only slight losses in yield, and four advanced lines (ICGS 1, ICGS 5, ICGS 65, and ICGS 76) did not show any seed transmission.

A collaborative project was initiated with the Scottish Crop Research Institute to produce complementary DNA probes capable of detecting many peanut clump virus isolates, and to produce transgenic groundnut plants expressing the virus coat protein gene.

Research on pigeonpea sterility mosaic disease, the etiology of which is not known, was restricted to screening of advanced breeding lines and assessment of variability in the pathogen and/or mite vector utilizing a set of differential hosts. High incidence of this disease is causing concern among producers of medium- and long-duration pigeonpea in South Asia.

We have shown that in addition to the usual form of chickpea stunt disease caused by a luteovirus, a similar disease is caused by a previously unreported geminivirus. Purification procedures were developed for this new virus and a polyclonal antiserum has been prepared. Emphasis is now on vector studies and development of virus detection methods.

Cell biology

In the rainy season we examined a range of interspecific groundnut hybrid derivatives and confirmed that 35 were resistant to rust and 56 were resistant to late leaf spot. Twenty-five genotypes combined resistance to late leaf spot with good agronomic traits.

We are trying to access genes from species not easily crossable with cultivated groundnut. We used a technique developed for this purpose to make a hybrid between *A. hypogaea* and the wild *Arachis* species 276233, a tetraploid member of section Rhizomatosae. This produced pods with immature ovules. We then rescued the embryos and cultured them in vitro to obtain seedlings.

We initiated collaborative projects with the Scottish Crop Research Institute on transformation and gene mapping in groundnut.

We cultured hybrid embryos from crosses between *Atylosia platycarpa* and the cultivated pigeonpea *Cajanus cajan* and obtained callus and shoot buds.

Exogenous application of hormones facilitated pod growth and seed maturity in interspecific crosses of three *Cicer arietinum* genotypes with *Cicer echinospermum*. Using a previously established in vitro technique, we micropropagated the first generation plants, which were morphologically distinct from their female parents.

Quality

Data obtained on 68 pigeonpea germplasm accessions showed that cooking time of whole seed was correlated with grain hardness. The protein quality of pigeonpea *tempeh* (fermented and fried) was lower than that of boiled *dhal* samples.

We studied the oil absorption of deep-fried products made from five desi and five kabuli chickpea cultivars. The mean oil absorption of the extruded product of the desi cultivars was higher than that of the kabuli cultivars.

Headspace chromatograms of the flavor compounds of raw samples of several high-yielding groundnut genotypes showed that their flavor quality needs to be improved before they can be used in confections. A method to evaluate the cooking quality of boiled-in-shell groundnut was standardized.

We identified 14 valencia groundnut lines with 3- or 4-seeded pods, tan/rose or tan seeds, high protein content, low oil content, and sweet taste as suitable for confectionery use in Southeast Asia.

The oil quality and shelf life of groundnuts and groundnut products are largely determined by the ratio of oleic acid to linoleic acid; the higher the ratio the longer the shelf life. We identified 38 advanced confectionery groundnut varieties with ratios between 1.6 and 2.7, and several of them outyielded the control varieties Chandra and Chalimbana while showing stable 100-seed mass (at least 70 g) and desirable pod/seed characteristics.

Technology Exchange

The AGLN organized review and planning meetings to facilitate ICRISAT collaboration with the national systems of Bangladesh, China, Indonesia, Nepal, Philippines, Sri Lanka, and Thailand. New contacts were established with Bhutan, Iran, Malaysia, and USSR.

We supplied germplasm evaluation trials, nurseries, and segregating populations of chickpea, pigeonpea, and groundnut to cooperating scientists. Chickpea varieties were released by Jordan, Nepal, and Turkey, the hybrid pigeonpea ICPH 8 was identified for release in India, and groundnut varieties were released in Ethiopia and India.

Program scientists visited various Asian national agricultural research systems to carry out cooperative research and to advise on various problems. National program scientists also visited ICRISAT Center and ICRISAT projects in eastern Africa (EARCAL) and Syria (ICARDA).

A meeting in Malaysia was jointly organized by ICRISAT and the Australian Centre for International Agricultural Research (ACIAR) to plan cooperative research on bacterial wilt disease of groundnut. Australian scientists are developing cooperative research with China, Indonesia, and ICRISAT, and are linking their efforts with those of mentor institutions to address the difficult problem of managing this disease.

A meeting was held in Montpellier, France, to consider advances made by the working group on groundnut rosette viruses and to plan for an expanded effort to address all virus disease problems of groundnut in Africa.

An adaptive on-farm research activity funded by the United Nations Development Programme (UNDP) was initiated in four countries—Indonesia, Nepal, Sri Lanka, and Vietnam. Rapid rural assessments and planning meetings were arranged to develop the projects that address problems of groundnut production at the farmers' level.

Training activities included a course in China on identification of legume viral diseases involving Chinese, ICRISAT, and Peanut-CRSP scientists as faculty, and

Technology exchange in Bhutan. Local scientists examining chickpea in a trial supplied by ICRISAT.

a course in Sri Lanka on legumes production, using Sri Lankan, Asian Vegetable Research and Development Center (AVRDC), and ICRISAT scientists as faculty.

Our staff participated in meetings organized by ACIAR, the International Rice Research Institute (IRRI), FAO, and the ICRISAT regional programs in western and southern Africa. A study tour of India was organized for Asian Agricultural Research Directors in October, and an AGLN Coordinators' Meeting was held in December at ICRISAT Center to discuss progress and formulate plans for the future.

Resource Management

John L. Monteith, Program Director

Goals and Directions

The primary function of the Resource Management Program (RMP) is to find ways in which farmers of the semi-arid tropics can use the scarce resources of the region more efficiently and without making them even scarcer by damaging the environment. In this context, the terms "resource" and "environment" refer to soil and climate, to seed, and to economic and social circumstances that are often the ultimate constraints on production for very poor farmers.

A broad spectrum of disciplines is needed to meet this challenge and ICRISAT's global resource management thrust includes soil scientists, agroclimatologists, agronomists, and economists. Currently, the Resource Management group at ICRISAT Center works mainly on black and red soils and on systems of cropping, including agroforestry, in which the Institute's mandate crops are grown with compatible species such as castor, cotton, safflower, soybean, sunflower, and upland rice. Increasingly, research projects within ICRISAT Center encompass two or more disciplines so that we are better placed to tackle problems involving interactions between different types of constraints when faced by problems of production in the real world.

Since the Program was constituted in 1985, it has developed a series of related themes to provide a structure for its work. The first is the quantification of physical, chemical, biological, and economic resources in the semi-arid tropics. This provides a base for examining constraints in the form of resources that limit production or that prevent potential resources from being used efficiently. Understanding how constraints operate enables better systems of management to be developed in collaboration with national services which then have the primary responsibility of adapting them to suit the needs of farmers in specific locations. Finally, the Program has a mandate to assess the success of ICRISAT-related technologies as judged by their performance in long-term, on-station trials and ultimately by their adoption by farmers.

These steps in the design, development, and implementation of technology provide the framework for the review of the Program's work that follows.

Defining the Environment

Village studies. The need for benchmark studies of farm households in the semi-arid tropics was recognized by ICRISAT economists soon after the Institute began to operate in 1972. Staff were posted to six villages where comprehensive household record-taking started in 1975 and continued for 10 years. These data have been analyzed since 1977 and a synthesis of findings was published in 1990 by The Johns Hop! ins University Press under the title **Village and Household Economies in India's Semi-Arid Tropics.**

Key facts emerge from this study that are at variance with conventional wisdom. Examples include the competitiveness of village labor markets, the absence of distress sales of land, the beneficial role of moneylenders in financing productive investment, the lack of seasonality and income constraints to nutrient intake, and, more recently, the greater relative gains in income by poorer households. Other findings such as the inefficiency of production by sharecropping confirm established perceptions.

Monitoring and analyzing weather. When ICRISAT Center was developed for experimental work in 1972, a conventional weather station was installed near the highest point and manual readings were taken at standard times prescribed by the Indian Meteorological Department. To provide a continuous record of weather, often needed for the analysis of biological measurements, we have now installed an automatic weather station that measures all the major elements of weather once every 15 minutes. The station is linked to a computer in the Agroclimatology Unit that can be interrogated at any time. The input is processed to obtain hourly, daily, and monthly mean values. This database is now available to scientists concerned with the response of organisms to short-term changes of weather.

During the year we helped to analyze records from other parts of the semi-arid tropics brought to us by visitors from national services.

Evaluating sources of phosphorus. In a 2-year trial on a shallow Alfisol at ICRISAT Center, we tested the effectiveness of Mussoorie rock phosphate that had been partially acidulated with sulfuric acid to assess its effectiveness as a fertilizer for the Indian semi-arid tropics. All previous testing of this product had been on very sandy soils at ICRISAT Sahelian Center in collaboration with the International Fertilizer Development Center. At ICRISAT Center, the product gave responses comparable with single superphosphate but was substantially cheaper. Sorghum (CSH 6) responded to this source of phosphorus provided nitrogen was supplied at not less than 60 kg/ha, and for every tonne of grain harvested about 2 kg of phosphorus was released either from acidulated rock phosphate or single superphosphate.

Estimating loss of organic matter. Many tropical soils are deficient in organic matter even when substantial quantities in the form of crop residues are added to the soil every season. Rates of decomposition of organic matter are well known from field measurements in temperate climates, but tropical measurements are very rare. As part of a collaborative project with the University of Hamburg funded by GTZ, the rate at which carbon is lost from labeled straw has now been determined on our black and red soils.

When straw was incorporated near the surface of an Alfisol at the beginning of the 1989 growing season, about 44% of the carbon it contained was lost by


C.K. Ong

Field worker measures soil moisture using a neutron probe in sorghum grown in the postrainy season.

decomposition in 1 week and 76% was lost in 30 weeks. Corresponding figures for a Vertisol site were 27% and 62%. In 1990, the initial loss was slower but the eventual rates of loss were comparable with rates in 1989. After 18 months, the losses were 82% for the Alfisol and 70% for the Vertisol. Repeated natural cycles of wetting and drying appeared to accelerate the rate of loss from the Alfisol. Rates of decomposition measured under controlled conditions in the laboratory demonstrated that rates of decomposition are significant even from air-dry soil, but it is clear that losses of carbon in the field occur mainly during the rainy season.

Geographic Information System. The work reported above represents an extremely small fraction of the information that the Institute gathers each year on the resources of the semi-arid tropics and their relation to crop production. Because much of this information is site-specific, we have taken the first steps to install a Geographic Information System known as ARC/INFO which has the capacity to store, manipulate, display, and correlate information on our mandate crops and on the environments in which they are grown. Databases containing information on our mandate crops as well as on soil and the environment have been prepared for several countries in South and Southeast Asia. Several sets of climatic and soil records for other Asian and African countries were generously provided by the United Nations Environment Programme offices in Bangkok and Nairobi, and two RMP staff were trained to operate the system at the Asian Institute of Technology in Bangkok.

Identifying Constraints

Root behavior. Although the ability of root systems to take up water and nutrients is one of the main constraints to crop growth in the semi-arid tropics, very few systematic measurements have been made because accurate sampling is difficult. We have tried to exploit an indirect way of specifying the growth of a root system by determining the maximum depth to which water is extracted at a given time. This depth appears to increase at an almost constant rate defining an "extraction front velocity". For postrainy-season sorghum, we found that velocity increases with nitrogen application to a maximum of 3 cm/day but decreases when water limits growth. Similar information is needed for the other mandate crops in order to model growth as a function of the soil environment.

Rhizosphere conditions in rice-based systems. Intercropping upland rice with legumes can substantially increase annual production because the crops are complementary. Rice is shallow-rooted while pigeonpea extracts water from as deep as 2 m. Unlike rice, however, pigeonpea is sensitive to waterlogging. A trial was designed to measure the sensitivity of rice to drought and to shading by pigeonpea as well as the tolerance of pigeonpea cultivars for excess water. Oxygen concentration near the surface was measured every 5 days. Pigeonpea cultivars differed in their tolerance for low oxygen concentration. The concentration was higher in the intercrop than in sole pigeonpea but the difference was not enough to reduce pigeonpea mortality. However, the combination may still be appropriate for upland rice areas where soils have a lighter texture and drainage is better than on Vertisols.

Erosion and crop production. Erosion reduces crop production in several ways. It can selectively remove finer particles or increase the risk of crusting or compaction. In 1988, we established plots on an Alfisol with different levels of erosion simulated either by protection with nets to reduce natural rates of

Photography International Consultancies Ltd.

Erosion in a groundnut field in Zimbabwe's sand veldt.

erosion or by scraping to increase them. In 1990, these plots were split and sorghum was grown to examine responses to fertilizer. We found that natural erosion reduced growth more than scraping, possibly because of the loss of fine particles with a relatively large cation exchange capacity.

Diseases and pests. At three contrasting sites in India (ICRISAT Center and Anantapur in Andhra Pradesh, and Anand in Gujarat), groundnut cultivar TMV 2, which is susceptible to leaf spot, was grown with and without fungicide. Growth, disease, and weather were recorded to provide information for testing models of disease in relation to weather. At ICRISAT Center, weather was not conducive to the rapid spread of infection until 29 days after emergence (DAE) (10 July), but the first lesions appeared at 20 DAE and both early and late leaf spot as well as rust developed subsequently. Infection does not occur until leaves remain persistently wet for a minimum period (**ICRISAT Annual Report 1989**, p.214). Initially, rust was dominant, but late leaf spot was responsible for near-complete defoliation at 90 DAE. At final harvest, pod yield was only 0.2 t/ha compared with 1.5 t/ha in plots treated with fungicide.

Iron chlorosis in groundnut. Although many soils are rich in iron, plants show chlorotic symptoms (a yellowing of the normally green parts) when it is not present in an available form. Considerable variation exists between species and even between cultivars in their sensitivity to this form of chlorosis. Three of our mandate crops are sensitive: groundnut, chickpea, and sorghum.

Widespread occurrence of chlorosis in groundnut has been consistently reported from postrainy sowing on alkaline soils with high calcium content in several Indian states. In response to these reports, we conducted rapid rural appraisal surveys in Andhra Pradesh and Maharashtra in collaboration with Technology Transfer Project staff of the Indian Council of Agricultural Research (ICAR). The survey confirmed that chlorosis was usually associated with irrigation on alkaline soils and revealed that the symptoms were often mistaken for nitrogen deficiency and treated accordingly. Yield losses were estimated to be 25% on average.

A study using pots in a greenhouse identified waterlogging as a major factor in the development of chlorosis that increased with the application of nitrogen. Based on these conclusions, on-farm diagnostic trials will be conducted at seven sites in Andhra Pradesh and Maharashtra where treatments will include cultivation of the crop on broadbeds to improve drainage and foliar application of iron.

Developing Better Systems of Management

Production technologies for Vertisols. In 1976, ICRISAT's Farming Systems Program established production-size plots at two sites within a Vertisol watershed at ICRISAT Center. These sites were used to demonstrate differences between traditional management by farmers and ICRISAT's Vertisol package. Traditional plots were flat-sown, fallowed during the rainy season, and received no fertilizer or only small amounts of farmyard manure. The improved system of management introduced sequential and intercropping systems and plots received fertilizer, pesticide sprays, and other additives.

When records from this extended trial were analyzed in 1989, it was found that grain and fodder production using improved management had always exceeded production from traditional management. However, changes in treatments and in management between years prevented the assessment of trends in single components.

In 1990, a new program of technology evaluation was established with four major objectives:

- to maximize biological and economic efficiency using both traditional and improved management;
- to assess long-term effects of both types of management on plant production and soil properties;

- to measure losses due to pests and diseases; and
- to collect comprehensive sets of measurements (biomass, value, environment) for subsequent analysis of efficiency and sustainability.

Agroforestry systems. We have continued to explore the potential of agroforestry systems in which perennial pigeonpea is used as a tree substitute. Following exceptional rainfall of 140 mm in May 1990, the biomass production of pigeonpea in the dry season was a record for our trials — between 5 and 7 t/ha on different sites. Before the rain arrived, we lost through drought and disease about 40% of plants in sole pigeonpea stands grown at 8 plants/m^2, but only 5-10% in stands designed for intercropping with 0.5 plants/m^2.

In a new trial, we examined the effect of root residues from perennial pigeonpea on soil fertility. In the absence of nitrogen fertilizer, residues increased biomass production of maize from 2.5 to 3.5 t/ha and, when residues were supplemented with 80 kg/ha nitrogen, corresponding figures were 3.4 and 4.8 t/ha. However, this beneficial effect of residues disappeared after the first season. Leaf litter from pigeonpea applied at 2.5–10.0 t/ha appeared to have no effect on cereal yields, presumably because of rapid decomposition.

In a study of pigeonpea phenology to determine appropriate ecological niches, we established that both medium-duration and perennial genotypes were strongly sensitive to photoperiod. When sown on 15 June, the medium-duration genotypes flowered after 118 days and the perennial genotypes after 145 days; compared with 66 days (medium-duration genotypes) and 96 days (perennial genotypes) when sown on 15 November so that they were exposed to shorter days. The lower limit for these responses was about 11 hours. Flowering was delayed when maximum air temperature exceeded 35°C.

Rice-based cropping systems. Trials in 1988 and 1989 demonstrated that intercropping upland rice with grain legumes could increase grain production by 60–80% compared with sole rice (**ICRISAT Annual Report 1989**, p.229). Pigeonpea was one of the best companion crops in terms of biomass and crop value. Rice yielded more when grown with short-duration genotypes of pigeonpea because competition was minimized. In 1990, we further explored the importance of pigeonpea duration using extra-short-, short-, and medium-duration genotypes in a trial on a low-lying Vertisol site. In contrast to previous experience, the extra-short-duration genotypes were found to be very sensitive to waterlogging and to phytophthora blight. On the other hand, the medium-duration genotypes grew so well that rice was unduly shaded.

Rotations. A long-term rotation experiment initiated in 1983 was designed to compare the productivity and nitrogen economy of several systems which incorporate crops commonly used by farmers in the Indian semi-arid tropics. Both single- and double-cropping systems were included. Consistent residual effects of nitrogen fixed by legumes became apparent after the 1st year and are now well documented.

Nonfertilized sorghum grown in the postrainy season yielded 1.4 to 2 t/ha. Lowest yields came from traditional systems where the land is left fallow during the rainy season and sorghum is sown every year in the postrainy season.

Highest yields came from a 2-year rotation of fallow followed by chickpea in year 1 and fallow followed by nonfertilized sorghum in year 2. A rotation in which mung bean was followed by sorghum every year gave intermediate yields around 1.7 t/ha.

Crop residues and conservation. Staff from the Land Management Research Branch of the Queensland Department of Primary Industry, Australia, seconded to ICRISAT, are responsible for the management of a long-term trial to establish the extent to which management practices on an Alfisol can improve soil structure and reduce runoff and erosion. There are 15 treatments involving crop residue, farmyard manure, tillage depth, and perennial crops, replicated three times on 28 x 5-m plots.

In 1989, runoff from plants receiving straw at 5 t/ha was 123 mm compared with 255 mm for untreated bare soil and 210 mm for plots receiving 15 t/ha of farmyard manure. Deep tillage initially reduced runoff to a lesser extent than straw; but later in the season runoff was higher on tilled than on untilled plots, indicating the temporary nature of the initial improvement in structure by tillage. Straw mulch increased annual infiltration by 127 mm on average (a substantial fraction of the water used by an annual crop) and tillage by only 26 mm. Plots that were not tilled but treated with straw received 100 mm more water by infiltration than those tilled to 20 cm to simulate conventional farming practices on the Deccan Plateau in India. Straw also reduced the loss of soil from 1.9 t/ha (bare plots) to 0.75 t/ha. For plots growing perennial crops such as pigeonpea and pasture species, the mean soil loss was only 0.28 t/ha.

Adoption of ICRISAT products: a Gujarati farmer with a seed bag of ICCC 4 (ICCV 1), ICRISAT's first chickpea variety released in that state.

Assessing Actual and Potential Adoption

Pigeonpea: progress and problems. Our economists assisted pigeonpea scientists to evaluate the production and economic potential of short-duration pigeonpea (SDP) at three benchmark sites in peninsular India. On-farm trials from 1987 to 1989 indicated that SDP, grown as a rainfed crop, faces such major constraints as intermittent drought in shallow soils, waterlogging in poorly drained soils, and persistent attack by insect pests. There appeared to be good potential for expanding SDP into irrigated areas as an alternative to rice with its higher input costs. More recent surveys suggest that adoption of SDP has been slow for several agronomic and economic reasons. The main constraint appears to be difficulty in controlling *Helicoverpa*, which was responsible for severe losses in 1990.

Cereals: demand and supply. Recent evidence on the demand and supply of sorghum in India was reviewed by our economists for scientists at the 20th Annual Sorghum Workshop of the All-India Coordinated Sorghum Improvement Project. The consumption of sorghum per head declined sharply during the 1980s and is projected to fall at about 0.5% per year in the next decade. Total food demand for sorghum is still increasing, but at a declining rate.

Nationally, projected changes in grain production should enable a small increase in demand to be met, but the demand for fodder is increasing much more rapidly. In Rajasthan, our surveys reveal a strong demand for fodder attributable to rising demand for milk and to larger numbers of ruminants which increased at 3.4% annually between 1956 and 1983. During severe drought in 1986 and 1987, fodder prices rose much more sharply than grain prices because of weaknesses inherent in the fodder market, e.g., transport costs. The trend of increasing fodder prices is expected to continue with implications for the criteria we adopt when evaluating new varieties or hybrids of pearl millet. In collaboration with the Central Arid Zone Research Institute, Jodhpur, we are conducting a survey of fodder management to discover how farmers rate the advantages and disadvantages of modern pearl millet cultivars. Preliminary responses indicate that most farmers perceived that modern cultivars yielded less fodder than traditional types, particularly in dry years. The farmers also report that they consider the quality of modern cultivars to be inferior to that of traditional types.

Sharing Knowledge and Technology

Indian institutions

Central Research Institute for Dryland Agriculture (CRIDA). For several years we have shared trials based on CRIDA's two experimental farms near Hyderabad. At Hayatnagar, we introduced equipment to measure the flow of water in the trunks of trees to establish how much water different species use in agroforestry systems. At Gunegal, we tested the performance of perennial pigeonpea grown as a sole crop or as an intercrop with cereals and legumes. Production was at the same level as from the same trial at ICRISAT Center. We also tested the performance of different land configurations and found pitting very effective in reducing runoff and soil loss.

Andhra Pradesh Agricultural University (APAU). Along with ICRISAT Breeders, Agronomists, and Economists, we collaborated on 14 APAU substations to examine the feasibility of extra-short-duration pigeonpea as a replacement for groundnut and cotton in rainfed agriculture. On sandy loams in northern and coastal regions of Andhra Pradesh, growth was exceptionally good and flowering occurred early enough to avoid severe losses from *Helicoverpa* damage, provided crops were sprayed three or four times. Legume scientists confirmed that although there was little damage to pods by *Helicoverpa*, yield in many districts was restricted to 1.0–1.2 t/ha by blister beetles and by *Maruca*.

All India Coordinated Research Project on Dryland Agriculture (AICRPDA). Work in cooperation with AICRPDA is progressing well. New data for the 1988-90 seasons were received and entered in a database management system. Thirty sets of crop, soil, and weather records for groundnut are now available and are being used by the University of Florida, ICAR, and ICRISAT to improve the groundnut model 'PNUTGRO'.

State agricultural universities. In 1989, Winrock International contracted a Natural Resource Economist to ICRISAT to strengthen the capacity for research and graduate education in this field within India. Since his arrival in India in January 1990, he has been active in the applied economics departments of the state agricultural universities in Karnataka, Tamil Nadu, and Himachal Pradesh. Short courses given at these universities have introduced basic concepts and helped staff and students to design research projects.

Ethiopian institutions

Since 1985, several Ethiopian institutions together with ICRISAT, ILCA, and the International Board for Soil Research and Management (IBSRAM) agreed to combine their resources to improve the management of Vertisols that are widespread in the wet Ethiopian Highlands. Following short exchange visits between staff of ICRISAT, the Institute of Agricultural Research, and the Alemaya University of Agriculture, an RMP engineer was posted to Addis Ababa in September 1990. His first reports drew attention to the fact that although Ethiopian farmers had been using hand-made broadbeds and furrows for centuries to improve drainage, increased runoff from one field often caused problems on lower fields. There was clearly a need to design systems of broadbeds on the scale of watersheds so that all farmers would benefit from land shaping. Moreover, runoff from a watershed can be stored in ponds to supplement scarce supplies in rural areas.

Western African Programs

Ronald W. Gibbons, Executive Director

ICRISAT Sahelian Center

ICRISAT's western African programs are largely coordinated from ICRISAT Sahelian Center (ISC) at Sadoré, Niger. The Center's three programs are Pearl Millet Improvement, Groundnut Improvement, and Resource Management. ICRISAT also assigns research teams to Mali and Nigeria to investigate the cultivation of sorghum in the region. The West African Sorghum Improvement Program in Mali (WASIP-Mali) is located near Bamako, and WASIP-Nigeria is located near Kano. Both teams are administered by the Executive Director, Western African Programs. The Executive Director's administrative duties also include the ICRISAT/Mali Bilateral Program. Finally, ICRISAT supports two cereals networks, the West and Central African Sorghum Research Network (WCASRN) and the West and Central African Millet Research Network (WCAMRN). WCASRN is coordinated from WASIP-Mali and WCAMRN from ISC.

The 1990 season was characterized by below-average rainfall in most parts of western Africa. Sowing was delayed in Nigeria until July. The onset of rainfall in northern Mali was normal, but this was followed by dry spells, early insect attacks, and sandstorms. Nevertheless, research results were encouraging.

Resource Management Program

Since 1981, a total of 16 ha have been fenced on the ISC site at Sadoré, Niger. The vegetation, originally a herbaceous fallow, was surveyed in 1984, 1985, and 1989. The comparison of the surveys shows that the herbaceous cover has decreased from 89% in 1985 to 74% in 1989 and shrubs and trees have become more important. Among the woody plants, *Combretum glutinosum* is the most important. We will attempt to manage parts of the protected area, emphasizing either wood production or forage production, depending on our objectives.

We have analyzed the variability of the onset of rains in the Sahel using long-term daily rainfall data for Niamey from 1905 to 1989. The results of the study indicated differences in the proportion of rainy days in the early part of the growing season (May to July) for the three onsets (early, medium, and late) of rain groups. There was, however, no evidence of differences in the subsequent rainfall pattern in August and September. This supports the view that the pattern of rainfall at the end of the season is independent of the date of onset of rains, and growing season lengths can therefore be computed quite simply from the actual onset of rains in a given year.

Because soil is the most important natural resource for farmers, its characterization is important in helping them to use it properly. Surface soil samples were taken at 31 locations in the major millet-producing regions of the western African semi-arid tropics. The total sand content ranged from 71% to 99% (mean 87%). Generally speaking, soils have an inherent low fertility over the locations. Total nitrogen content ranged from 31 to 1800 ppm (mean 266 ppm). Cation exchange capacity is generally low and is associated with the organic matter content (mean 0.75%), low clay content (3.6%), and the kaolinitic mineralogy of the soil system. The total phosphorus content ranges from 25 to 349 ppm (mean 110 ppm).

On-farm surveys based on interviews and informal observations were conducted in different parts of Niger to obtain information on animal management practices and utilization of crop and animal by-products. In general, two systems of animal production—extensive and semi-intensive—were identified. In some villages farmers utilize a combination of on-farm and communal grazing. Farmers obtain manure by paddocking animals in fields. Cattle and donkeys are used for transportation but not for tillage. In other villages farmers practice a semi-intensive system of animal production. Grazing period per day is short and farmers tend to rely more on their own and purchased crop residues than in other areas. Hand-spreading of manure collected from the village compound and taken to the fields by animal-drawn carts is common. In all locations, most of the animals reside in and around the villages for most of the year.

In the Sudanian and Sahelian Zones of western Africa, wind has significant effect on productivity. In the past two decades, the use of marginal lands, overgrazing, and removal of trees and shrubs have aggravated wind erosion. The rainy season is generally preceded by dust storms with wind speeds that can exceed 100 km/hour. This contributes to erosion and can damage young crop seedlings by abrasion or by burning.

As a part of the wind erosion research thrust, we started a collaborative project in 1990 to study the influence of wind erosion and wind barriers on millet growth, development, soil water content, and yield. We monitored the sand trapped at eight heights above the soil surface (up to 275 cm) using sand traps. Wind speed was measured at 30 cm above the soil surface. The coverage of millet pockets was quantified after each erosion event. Millet plants from the uncovered and partially covered pockets were monitored for differences in growth and phenology until final harvest. The results of the study showed that even limited protection measures against wind erosion should have high potential in the Sahelian region.

At the end of an experiment conducted since 1983 involving treatments with or without mineral fertilizers (180 kg/ha nitrogen in 6 years) and with or without crop residues, we calculated the nitrogen balance. Pearl millet was grown across the treatments and nitrogen removal was calculated from the yields. We found a negative value for nitrogen in the treatment without crop residues and fertilizers. The other treatments led to positive nitrogen balance with a gain between 34 and 79 kg/ha nitrogen in 6 years or 6 and 13 kg/ha of nitrogen per year. Crop residue application increased the annual nitrogen net gain from 7 to 13 kg/ha per year.

A study of the rhizosphere indicated that nitrogen-fixing bacteria are mainly responsible for the nitrogen input and the number of bacteria is therefore positively correlated with crop residue application.

From 1986 to 1989, different cropping systems combining pearl millet, grain, and forage legumes were studied. Cowpea was the grain legume; *Sesbania pachycarpa* and *Stylosanthes hamata* the forage legumes.

The cereal/legume association, particularly when a perennial legume such as *Stylosanthes* is used, allows a better use of resources, mainly water and nutrients. However, in dry years (such as 1987) competition between cereals and legumes can depress or even inhibit cereal yields. Cereal yields in normal years are acceptable with intercropping, and total biomass production (straw plus forage) can exceed 7 t/ha in the millet/*Stylosanthes* association. Water-use efficiency is dramatically increased and the *Stylosanthes* still uses water from the soil profile after pearl millet and annual legumes have been harvested. This system seems promising for the Sudanian and Sahelian Zones and proper management practices must be examined in order to minimize competition.

In 1990 we compared the results of soil chemical analyses of land under fallow since 1981 with those of soils cultivated since 1982. It was clear that cultivation with or without mineral fertilization had a negative effect on soil characteristics. After 8 years, the pH decreased from 5.5 to 4.7, the exchangeable base from 0.813 to 0.315 cmol/kg, and the aluminum saturation increased from 12% to 46%. The total organic matter content of the soil under cultivation decreased from 0.4% to 0.2%.

When comparing various treatments, we developed models to assess the relationships between soil chemical properties and yield potential of pearl millet. Organic matter, total nitrogen, and available phosphorus are the most important factors for millet production.

Collaborative Feed Studies with ILCA

Experiments were conducted at ISC by the ILCA team to determine the intake and nutritive value of indigenous feeds that can be used to supplement pearl millet stover and low-quality pastures, especially during the dry season.

In one experiment, leaves from four indigenous browse species were collected and dried. Measurements showed that intake of leaves from two species were high, one was unpalatable, and the other was intermediate.

A 4-month ILCA/ICRISAT collaborative trial was conducted (November 1989 to March 1990) to investigate the diet selection of six sheep and goats grazing a 1.2-ha area of millet stover with strips of six browse species planted as windbreaks.

The results showed that goats predominantly browsed, whereas sheep almost exclusively grazed millet stover and weeds. *Acacia lannea* was the least selected browse by goats, followed by *Azadirachta indica* and *Bauhina rufescens*. Weeds were heavily grazed by both sheep and goats during the first 3 weeks of the study, and continued to be selected by sheep until they were completely consumed by the 9th week of the study. Millet leaves were important components of both sheep and goat diets during the later weeks of the trial.

Pearl Millet Improvement Program

We studied the growth of roots in five pearl millet varieties to examine the extent of genetic variability in root growth, and to explore the possible relationship of root length density with drought response during the 1988, 1989, and 1990 summer seasons. Grain yields were not correlated to root length density in the medium- and high-fertility treatments, but were negatively correlated in the low-fertility treatment.

During 1990, we studied the movement of the millet head caterpillar (*Heliocheilus albipunctella*) prior to its pupation at Sadoré in a plot sown with pearl millet variety 3/4 HK on 31 May. Fertilization and weeding were done as normal. When the pearl millet was at the milk dough stage, heads were examined and traps (supported by T-shaped metal standards) were installed on infested heads. The bottoms of the traps were then covered with a nondrying insect glue so that larvae migrating from the pearl millet head would be trapped as soon as they contacted the surface. Hourly observations of the trapped larvae and of the distances from the stem to where the larvae were trapped were recorded. Hourly temperature and humidity recordings were obtained from the Agroclimatology Unit.

The data show that larval migration is most important between midnight and 0600 with peak activity around 0400-0500, coinciding with the period of lowest temperature and high humidity. Further testing is needed to determine the role of temperature, humidity, and light on larval activity.

Over the past 5 years we have run a trial examining the long-term effects of removal of *Striga* from fields at four locations in Niger (Bengou, Sadoré, Chikal, and Samari). There was substantial variation in the data but combined analyses over years at Samari showed that the continued removal of *Striga* increased yield by 50%.

Breeding materials were screened for a number of factors including downy mildew, smut, ergot, and *Striga* at Sadoré and Bengou. The material included wild millet and germplasm lines collected by ORSTOM scientists working with ICRISAT. These materials were grown in pots at Sadoré and screened for resistance. Of the 45 collections one had less than 1% smut incidence and one had less than 5% ergot. Thirty percent of the collections had less than 20 emerged *Striga* plants per plot. Numerous lines were tested for downy mildew (400 at Bengou and 571 at Sadoré). Results showed that 25% of the lines screened at Bengou and 15% of those at Sadoré had less than 5% infection.

The 1990 West African Regional Millet Yield Trial was conducted at 13 locations. From the data available, ICMV IS 88305, SOSAT-C 88, ICMV IS 88224, and ICMV IS 88212 were among the top entries.

The ICRISAT/IAR (Institute of Agricultural Research, Nigeria) joint trial tested 29 entries from which 10 were chosen for further testing. Data on the trial

Pearl millet is the only staple cereal that can be grown in many parts of the Sahel.

were obtained from most of the locations to which seed was sent. Although six entries had promising yields, no entries ranked among the top 10 at all three locations.

The 1990 Pearl Millet Advanced Varieties Trial was conducted with 11 test entries at Cinzana in Mali, Samaru in Nigeria, and Sadoré and Tara in Niger. The most promising entries were ICMH IS 88301, ICMV IS 89305, and ICMV IS 88271.

Groundnut Improvement

The effects of foliar diseases were assessed at nine locations in western Africa—three in Niger, two in Benin, and one each in Burkina Faso, Cameroon, Gambia, and Guinea. Disease pressure was quite variable, probably because of rainfall variability. Diseases were not serious at Sadoré or Maradi in Niger. Early leaf spot developed rapidly at Bengou but slowed down from mid-August when drought occurred. The highest-yielding susceptible entry, ICGS 11, showed a 33% yield advantage from spraying but yield losses were significantly less on resistant lines. Late leaf spot was important at the Ina station in Benin and rust also appeared late in the season.

In Burkina Faso all three foliar diseases were present but early leaf spot did little damage. Although rust caused about 25% yield loss, rust-resistant lines were little affected. Varietal differences in early leaf spot susceptibility were confirmed at Bengou and several entries reported as resistant in 1989 also performed well in 1990. From these various trials several entries appear to have multiple resistance to foliar diseases. Seed dressing trials at Bengou showed the benefit of treating seed with fungicide.

Confirmation of dry seed resistance to *Aspergillus flavus* contamination was again confirmed at Sadoré. Seed of ICRISAT cultivars had between 3% and 17% seed infection compared with 66% for the most susceptible line. Two other lines, ICGV 87094 and ICGV 87095, had only 4% infected seed. On average, seed was little affected at either Maradi or Bengou.

In collaboration with ICRISAT Center, ISC scientists studied the host range of various parasitic nematodes in the root and rhizosphere of 13 crop species. Most nematodes were found on pearl millet, and in descending order on groundnut, sorghum, cowpea, sunflower, and bambara groundnut. Other crops were little affected. *Scutellonema clathricaudatum* was the only endoparasite found in the roots of all the crops.

In collaborative studies with ORSTOM, the Institut de recherche pour les huiles et oléagineaux (IRHO), and ICRISAT Center, we continued to study the host range of peanut clump virus (PCV) using the same crop plants as for the nematode study. The highest levels of the antigen were found in groundnut, pigeonpea, millet, bambara groundnut, and maize. Sunflower was the only crop that did not contain the PCV antigen.

A series of cultivar trials was conducted at various locations during the season. Medium- and long-duration lines were obtained from ICRISAT Center and SADCC and tested at five locations. ICGV 86529 ranked highest at all three sites in Niger with a mean yield of almost 3 t/ha compared with the best local control which yielded 2.2 t/ha.

A short-duration trial was also conducted at the same sites with material from India and Malawi. ICGV 86015 was ranked first at all sites in Niger with a mean yield of 3.1 t/ha compared with the mean yield of 2.6 t/ha from the widely grown Senegalese cultivar 55-437.

Agronomy and drought screening trials continued at Sadoré. Through the use of irrigation we compared 36 genotypes in stressed and nonstressed situations at the end of the season. In nonstressed conditions genotypes ICGM 614 and ICGV 87185 were among the top yielders, and had significantly higher crop growth rates. However, they also had low partitioning rates. In the stressed treatment yields were low but three categories of genotypes emerged: those combining reasonable pod and haulm yields, those producing reasonable pod or haulm yields but not both, and those giving both poor pod and haulm yields. Only two genotypes, ICGV 85043 and ICGV 86024, were included in the first category.

In collaboration with the University of Hohenheim, Germany, we examined the effects of crop residues, chelates, and application of phosphorus and molybdenum on groundnut yields. The application of 4 t/ha of crop residues was as effective as the application of phosphorus and molybdenum.

Using intercropping data from 1988 and 1989 we computed trade ratios for grain and fodder to assess the tolerance of groundnut cultivars for intercrop competition at Bengou, Sadoré, and Tara. Generally, the introduction of groundnut into pearl millet at any spacing substantially reduced the yield of millet straw and grain and did not vary with groundnut genotype. Except at Bengou, where groundnuts defoliate because of leaf spot infection, the decrease in millet/straw yield was well compensated by the production of groundnut haulms that are more palatable and nutritious. In all cases the most profitable intercrop arrangement was where low populations of millet were used.

We also continued studies aimed at optimizing the productive potential of a pearl millet/groundnut intercrop by manipulating the dates of sowing of the component species. Sowing-date intervals were approximately 2 weeks, but the actual dates depended on moisture availability. Sowing delays resulted in significant yield decreases for both millet and groundnut at Tara. At Sadoré, responses were more erratic due to poor rainfall.

Rhodes grass (*Chloris gayana*) has been used as a rotation crop in Africa to reduce nematode levels in tobacco production. We used Katombora Rhodes grass in long-term trials with groundnuts at Tara and Sadoré. Although results were somewhat inconsistent, the nematode population at Sadoré was drastically reduced in the plots that had carried Rhodes grass during the previous year.

West African Sorghum Improvement Program - Nigeria (WASIP-Nigeria)

The International Shoot Fly and Stem Borer Nurseries were repeated at Bagauda in 1990. Infestation levels of both pests were low as in 1989, despite late sowing to induce attack. A survey of stem borer incidence in farmers' fields was conducted in Kano and Katsina States (Sudanian Zone) and in Kaduna and Sokoto States (Northern Guinean Zone). There was a progressive increase in stem borer incidence as the survey went south. Most of the collected larvae were identified, after rearing, as *Busseola fusca*.

Six trials were conducted on head bugs at Bagauda. Head bug populations per 5 panicles at the dough stage varied from 3 on IS 17645 to 30 on IS 13560 in the Head Bug Resistant Varieties Trial. Nagawhite, a high-yielding cultivar in the Semi-Arid Food Grain Research and Development (SAFGRAD) regional trials, had the lowest number of head bugs per panicle when 32 cultivars were artificially inoculated.

There was an unprecedented outbreak of spittle bugs on sorghum in Nigeria during 1990. Two spittle bug species were identified. *Prophilus maculatus*, which is gray, was dominant. *Locris rubra*, a red species, was less abundant. Infestation in farmers' fields ranged from 22% to 100%. Infestation was invariably accompanied by yellowish blotches on the leaves which later dried up. These symptoms resemble those described earlier in Nigeria as being caused by a

Pseudomonas bacterial species. This suggests that the bacterial infection may be secondary. When the number of spittle bug nymphs reached 100/plant, young sorghum plants died, and the leaves of the older plants dried up, resulting in poor panicle exsertion. There were no signs of varietal resistance to this pest.

A large number (233) of short-duration preliminary hybrids produced from seven female parents were tested in eight replicated yield trials, and 40 were selected for further testing. Severe terminal drought allowed for selection pressure on stalk lodging resistance. Promising hybrids yielded more than 5 t/ha with good grain quality and disease resistance. Five new male-sterile lines were identified from 23 preliminary selections, and these will be tested for combining ability in 1991.

In the varietal improvement program, 17 short-duration cultivars were tested in replicated trials. ICSV 400, which yielded 5.1 t/ha, had short duration, medium height, resistance to stem lodging, and good grain quality. It has been tested by a local brewery as it possesses superior malting and brewing qualities. ICSV 111, which yielded 4.8 t/ha, is already being multiplied and distributed by the Crops Research Institute, Nyankpala, in northern Ghana.

A regional hybrid trial, the West African Sorghum Hybrid Adaptation Trial, was organized under the auspices of WCASRN and seeds were sent to 12 western African locations. Seeds of short-duration varieties and hybrids were contributed to the state trials conducted by IAR in northern Nigeria. Seeds were also supplied to private large-scale farmers and to national programs in Burkina Faso, Côte d'Ivoire, Mali, and Niger. Cooperative studies on the malting quality of sorghum commenced with the Food Technology Department of the University of Ibadan. The team is also cooperating with the Scottish Crop Research Institute to develop efficient sorghum malting quality evaluation techniques. A short training course on hybrid sorghum seed production was held in Kano during early September for Nigerians in both the public and private sectors.

Continuing studies on determining the optimal plant density for newly developed sorghums for the Sudanian Zone showed that in 1990, a poor rainfall year, optimal yields were obtained from 5.3 plants/m^2 compared with 10.6 plants/m^2 in 1987. All cultivars responded significantly to increased nitrogen levels in 1990.

In further research on sorghum-based cropping systems, sorghum/soybean and sorghum/pigeonpea intercrops were tested. In collaboration with the International Intstitute of Tropical Agriculture (IITA), we used three sorghum cultivars in sorghum/soybean tests, one short-duration soybean cultivar, and three row arrangements. Soybean intercropped with Samsorg 14 gave a yield advantage of 26% but only a 10% advantage was obtained with ICSH 247 and ICSH 507. The best row arrangement was one row of sorghum and two rows of soybean. Lack of water caused yield reductions. With similar trials with three cultivars of sorghum and three cultivars of pigeonpea, two of the sorghums did not produce any grain yield due to drought. There were no yield advantages with this system in 1990 due to drought and insect damage.

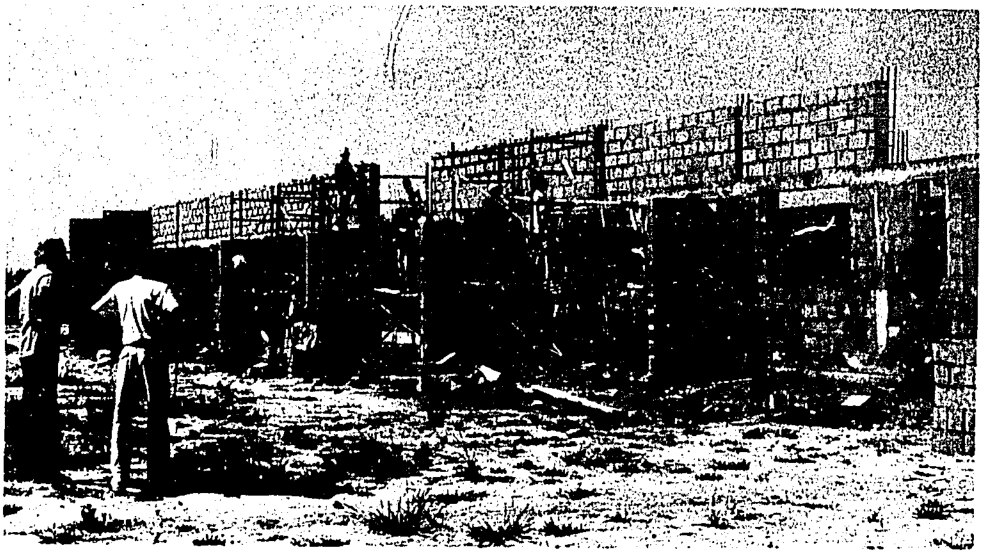
West African Sorghum Improvement Program - Mali (WASIP-Mali)

During 1990, the construction of a new research center at Samanko was completed. The new facilities will enhance the Program's capacity to undertake research in this important area of the Sahel.

Trials on spraying a moderately resistant and a susceptible sorghum cultivar with systemic and contact fungicides to control leaf anthracnose (*Colletotrichum graminicola*) showed that three sprays were ineffective, even on the moderately resistant line. Six sprays were effective but are inappropriate for small-scale farmers and indicate the need to seek more effective genetic and integrated methods of control.

Control methods for *Striga* were continued. Three sorghum cultivars, resistant and susceptible, and three agronomic control methods (hand-pulling, herbicide, and straw mulch) were used. *Striga* was more abundant in 1989 than in 1990. All control methods were effective, giving an average of 60% yield advantage. The mulch treatment reduced vegetative development of *Striga*. More trials are needed to evaluate the effects of crop rotation on *Striga* incidence.

In the West and Central African Sorghum Research Network (WCASRN) organized by SAFGRAD and coordinated by ICRISAT, both short- and medium-duration cultivars were tested regionally in replicated yield trials. Each trial consisted of 20 entries contributed by WASIP-Mali and by the national programs of Benin, Burkina Faso, Cameroon, Ghana, Mauritania, Niger, and Senegal. In the short-duration trial, yields ranged from 1.3 to 2.9t/ha. No cultivar outyielded the control Nagawhite on an overall site mean, although ICVS 1079 was the second highest yielder. Different cultivars performed well at individual sites. ICSV 1177 BF, for example, bred by the ICRISAT program in Burkina Faso,



K.V. Ramaiah

The WASIP-Mali facility at Samanko under construction.

yielded 3.5 t/ha at Saria and ranked first at this site. It also yielded well in Mali (at Farako-Bâ) and in Ghana (Nyankpala). In the medium-duration trial, ICSV 1171 BF was the overall highest yielder at nine locations (2.4 t/ha). It ranked between first and fourth at seven of the nine locations. In the hybrid yield trial, with many entries from WASIP-Nigeria, ICSH 507 gave a mean yield of 3.7 t/ha at eight locations, followed by ICSH 780 (3.6 t/ha). The entry from Niger also yielded 3.6 t/ha.

Agronomic trials compared sorghum, cotton, and legumes as sole or associated crops with cowpea, groundnut, and soybean. At Samanko, groundnut was the best preceding crop for sorghum, with or without fertilization. Sorghum following groundnut gave a yield advantage. At Longorola (1000 mm average annual rainfall), sorghum benefitted most, around 50%, from a preceding cowpea crop.

ICRISAT/Mali Bilateral Program

The ICRISAT/Mali Bilateral Program was established in 1976 to assist Mali's national program to develop a strong sorghum and pearl millet research infrastructure, and to conduct long-term research on these two crops and their cropping systems. During 1990, the Program continued to demonstrate the value of close collaboration between a national and an international research organization.

Southern African Programs

Leland R. House, Executive Director

The Southern African Development Coordination Conference (SADCC) countries are Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Tanzania, Swaziland, Zambia, and Zimbabwe. The SADCC/ICRISAT Sorghum and Millets Improvement Program (SMIP) is based in Matopos, near Bulawayo, Zimbabwe. The primary objective of the Program is to strengthen national research capability for the improvement of these cereal crops. This objective is approached in three ways: research, human resource development, and improvement in research facilities. The Executive Director is also responsible for the administration of the SADCC/ICRISAT Groundnut Project in Malawi.

SADCC/ICRISAT Sorghum and Millets Improvement Program, Zimbabwe

Research

Progress has been made in the development of new sorghum hybrids and varieties. One hundred and eighty-five new sorghum lines tested at two locations in Zimbabwe had a range in yield of 4.6 to 6.5 t/ha. These yields compared favorably with local controls. Twenty-nine new hybrids ranged in yield from 3.5 to 6.8 t/ha compared with the commercial hybrid control DC 75 (4 t/ha).

The best seed parents have been identified as ICSA 19, ICSA 20, D2A, and ATx623.

Attention is being given to crop residue. Six hybrids have very high green stover mass (16.5–25.4 t/ha) compared with DC 75 (14.9 t/ha).

Pearl millets grown in southern Africa are variable in type. In Malawi and Zambia tall long-duration types are morphologically very similar. In Botswana, Zimbabwe, and Namibia, short- to medium-duration types are preferred, whereas in Tanzania photosensitive types are grown. We have developed composite populations based on maturity groups to satisfy the needs of these variable agroecologies. In addition, four populations have been developed with specific traits (Bold Grain, White Grain, Dwarf, and Bristled) and a population specifically targeted for Namibia. In an attempt to identify which composite population was best adapted to which SADCC country, we evaluated all our composite populations at seven locations throughout the region. We observed that the White Grain Composite was best overall, and well adapted to Namibia.

For Zimbabwe, the Early and Medium Composites performed the best, while in Botswana the Bristled and Dwarf Composite were most suitable. This trial will be repeated one more time.

During the off-season of 1989, we derived 1216 progenies from Early, Bold, Medium, Late, and White Grain Composites. From these populations, 30 new varieties have been selected and are currently undergoing preliminary testing.

Collections of finger millet have been evaluated at relevant locations in the region. As crossing in millet is very difficult, a dominant genetic marker is used in the pollinator parent so that hybrids (successful crosses) can be identified in the seedling stage. Several hundred crosses were successfully made during the year. A joint research project for finger millet improvement was signed between Malawi and SMIP.

The brown midrib gene is being backcrossed into high-yielding forage sorghum and pearl millet lines, as well as into high-yielding dual-purpose types where there is interest in feeding stover. These brown midrib genes are known to reduce lignin content, thereby increasing feed efficiency.

National program researchers are making increasingly important contributions. Many cultivars were contributed by national scientists to regional trials at the Seventh Regional Workshop held in September (Table 1).

Table 1. Entries contributed by national program researchers to regional trials at the Seventh Regional Workshop (17-21 Sep 1990).

Country	No. of entries contributed				
	Sorghum	Pearl millet	Finger millet	Forage	
Botswana	9	1			
Malawi	11		8		
Swaziland	2				
Tanzania			3		
Zambia	47	6	4	2	
Zimbabwe	33	7	7		
SMIP	62	22			
Total	**164**	**36**	**22**	**2**	**= 224**

Varieties and hybrids for release and for advanced testing of sorghum, pearl millets, and finger millets are being identified by breeders in several national programs in collaboration with SMIP. All releases are made by the national programs. The situation in the SADCC region is shown in Figure 1.

Availability of seed is of increasing concern. While the quantity of variety and hybrid seed developed from material originating from ICRISAT Center for the 1990/91 season is not large, the participation of the national programs in the development of improved seed constitutes a step forward in addressing seed requirements in southern Africa. The regional program continues to contribute to seed technology with concern for production and processsing, human

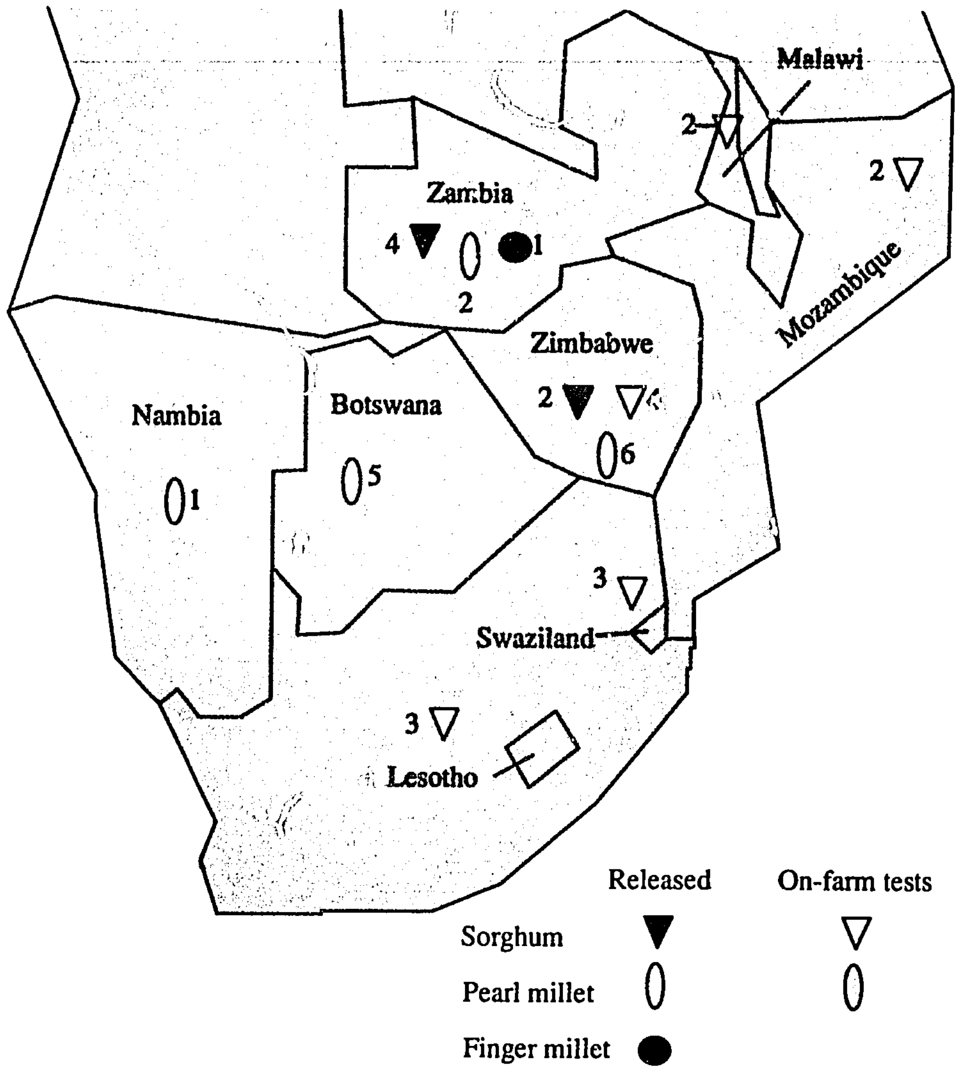


Figure 1. Released and advanced varieties and hybrids in the SADCC region.

resource development, and information. A significant contribution was the collaboration with SMIP and Zamseed in Zambia in the organization and execution of a successful seed production and crop utilization meeting in Zambia in October.

Progress has also been made in the area of forage. Promising forage types have been identified in several SADCC countries for demonstrations and on-farm testing. Some 60 farmers in Zimbabwe are now using interspecific hybrids between pearl millet and napier grass developed by SMIP, and interest in these hybrids is rapidly increasing. A continuing effort is being made to identify additional high-yielding material and a laboratory has been established to evaluate its quality.

Agronomic testing of high-yielding sorghum varieties and hybrids indicates advantage of hybrids over varieties—three comparisons indicated percentage advantages of 36, 23, and 16 for the hybrids. Under low-moisture conditions at Matopos (450 mm rainfall) a sorghum hybrid outyielded maize by 54% (4.2 vs 2.7 t/ha). Such comparisons of hybrid sorghum and hybrid maize yields are encouraging as previous yield comparisons of hybrid maize with landraces, even in relatively low-rainfall conditions, generally favored hybrid maize.

Effective screening for resistance to important diseases and pests in the region is continuing. We have been particularly concerned about ergot in hybrid sorghum seed production fields where parent yields can be severely reduced by the disease. Good progress was made by learning more about timely availability of abundant pollen and the effect of location on ergot expression. A uniform set of regional trials contributed to this information. The biology and taxonomy of this fungus was studied in cooperation with the University of London.

Photography International Consultancies Ltd.

SADCC/ICRISAT staff inspecting bird damage to sorghum at Matopos.

Progress was made with insect pests using a poisoned bait to control attack by the wingless armoured cricket. Of the various control methods tried, the bait appeared most promising, although further testing is needed. The cricket initially feeds on grass seeds, but when these are consumed it migrates to cultivated plants where it devours the seeds.

In light sandy soils, nematodes can seriously affect sorghum stand establishment and uniform crop growth. Control using carbofuran is effective, and the chemical has been found to be very cost-effective if used as a seed treatment.

In order to ensure that new varieties and hybrids are not more susceptible to pests than the currently used cultivars, breeding stock is routinely screened.

Crop utilization has become increasingly important. SMIP's Food Technologist has collaborated closely with Botswana's Ministry of Health to undertake a project in close collaboration with a milling company, Foods Botswana, to create a weaning food from a mixture of sorghum and soybean flours.

A micromalting technique has been standardized and used to evaluate the malting quality of sorghum and finger millet. The application of this technique to micromalting sorghum was used in support of a PhD thesis.

ICRISAT scientists, interacting with the food industry in Zimbabwe, have evaluated the pearling and milling characteristics of several sorghum cultivars. Exploratory work has been carried out blending wheat and sorghum flours to make bread, biscuits, cookies, and pasta products.

The evaluation of sweet-stemmed sorghum for alcohol production is proving of interest to the private sector in Zimbabwe. Alcohol is traditionally produced from cane sugar for blending into petrol, but due to years of drought the water supply for irrigation has become more and more restricted. Preliminary research is encouraging and further investigation is warranted.

The lack of availability of good quality grains from the marketing boards of Botswana, Zambia, and Zimbabwe led to a meeting to discuss grading standards and their implementation. One important consideration at this meeting was the issue of market liberalization permitting contract growing to help ensure the availability of quality grain.

Economic investigations examine the competitive position of sorghum and millets on national markets, the evolving struicture of national grain demand, and technical research priorities. Particular attention has been directed toward the assessment of how national price and market policies affect decisions to use sorghum and millets as industrial inputs, the analysis of the potential impact of grain market liberalization on the development of rural grain markets, and the evaluation of national strategies for promoting crop production in semi-arid regions.

Investigations in Zimbabwe and Zambia reveal how market controls and princing policies favoring maize have reduced industrial incentives to use sorghum and millets. Market liberalization could encourage greater industrial utilization of these crops. But the greatest potential for expanding utilization of theses cereals exists in rural areas which face consistent food deficits. Over time, many of these areas have come to rely on subsidized maize meal. As national budget constraints lead to the reduction or elimination of these subsidies, sorghum and millets should become increasingly important.

Research throughout the SADCC region indicates the need to match the deregulation of national grain markets with policy and investment strategies designed to encourage the development of competitive trading institutions. The construction of efficient private grain markets will be most difficult in outlying regions where sorghum and millets are produced. The combined development of improved production technologies and more efficient rural markets will contribute significantly to national and household food security.

A policy analysis training program involving economists from Botswana, Ethiopia, Kenya, Malawi, Swaziland, Tanzania, Zambia, and Zimbabwe was launched in collaboration with CIMMYT. A combination of collaborative research support and methodological training workshops supports the improvement of skills in research design, economic analysis, and the reporting of results. We encourage research leading to policy recommendations concerning the input and product development markets and the evaluation of sectoral priorities.

Human Resource Development

Initially, advanced degree training in the SADCC region was subcontracted to the USAID Title XII International Sorghum/Millet Collaborative Research Support Program (INTSORMIL). Anglophone participants in the program were enrolled at various agricultural universities in the USA, and Portuguese-speaking participants were enrolled at Viçosa, Brazil. Advanced-degree candidates can now be enrolled at SADCC universities as well. It is estimated that by 1994, about 120 degrees will have been conferred on regional scientists, and over 400 technicians and farm managers will have received in-service training.

Sixteen individuals participated in the annual 6-month in-service training program at ICRISAT Center, of which 12 were supported by the Regional Program.

SADCC/ICRISAT Training Courses

- *Station development and management*
- *Crossing block management and crossing techniques*
- *Pest identification and scoring*
- *Food technology (two students from Bulawayo Polytechnical Institute undertook in-service training with the Food Technology Unit, one for 3 months, the other for 9 months)*
- *Thesis research (6 SADCC scientists)*
- *In-service training (10 University of Zimbabwe students spent their 3-month summer vacation working with SMIP scientists)*
- *Surveying and land smoothing (this training course, conducted at the Sebele Station near Gaborone in Botswana, was the first in a national program)*

Improvement in Research Facilities

Improvement in research facilities is given high priority by national programs in the SADCC Region. This activity is important because it assists scientists to conduct good quality research. During 1990, improvement of research fields was provided to the Golden Valley Station in Zambia, the Kasinthula Station in

Malawi, the Pandamatenga and Sebele Stations in Botswana, and the Henderson and Panmure Stations in Zimbabwe.

ICRISAT has also contributed toward the supply and repair of farm equipment and vehicles and laboratory equipment.

A meeting of Directors of several SADCC countries with ICRISAT Station Managers and an agricultural engineer from the University of Arkansas was held in February to explore possibilities of strengthening this activity to be more responsive to SADCC needs.

Conclusion

Interaction between national and regional scientists for crop improvement and utilization has been strengthened. An increasing focus has been placed on the availability of seeds. Collaboration with the milling, brewing, and fuel alcohol industries has expanded, as have interactions with several regional universities. We feel that SMIP remains relevant to SADCC concerns.

SADCC/ICRISAT Groundnut Project, Malawi

The SADCC/ICRISAT Groundnut Project is located at the Chitedze Research Station near Lilongwe, the capital of Malawi. Its purpose is to encourage and promote research on groundnut production in the SADCC region.

During 1990, the Project carried out a large new hybridization program for both the Project and for national programs. The Project also identified lines from earlier hybridizations for further selection and yield testing. Numerous selections introduced from ICRISAT Center were evaluated in preliminary and international variety trials.

The most promising selections identified in advanced yield trials during the 1988/89 growing season were included in 1989/90 regional yield trials in five SADCC countries. Test entries regularly outperformed local control cultivars. Locally bred virus-resistant selections performed well in these trials, although seed size was disappointingly small.

ICGV-SM 83708 (ICGMS 42) has now been approved for release in both Malawi and Zambia following its performance in the trials. Zimbabwe's national program is also showing an interest in growing this genotype commercially.

Several entries exhibited moderate levels of resistance to early leaf spot in the disease screening nursery. These will be evaluated further and the best will be included in the hybridization program.

Studies in 1989/90 of the effect of fungicides on groundnut indicated a lack of response to single applications, probably due to the reduced rates of development of early leaf spot during the severe dry spell experienced in the latter part of the 1989/90 growing season.

We noted unexpectedly high susceptibility during field screening of groundnut varieties resistant to rosette virus. This caused concern as it questions the effectiveness of our previously very successful field screening technique.

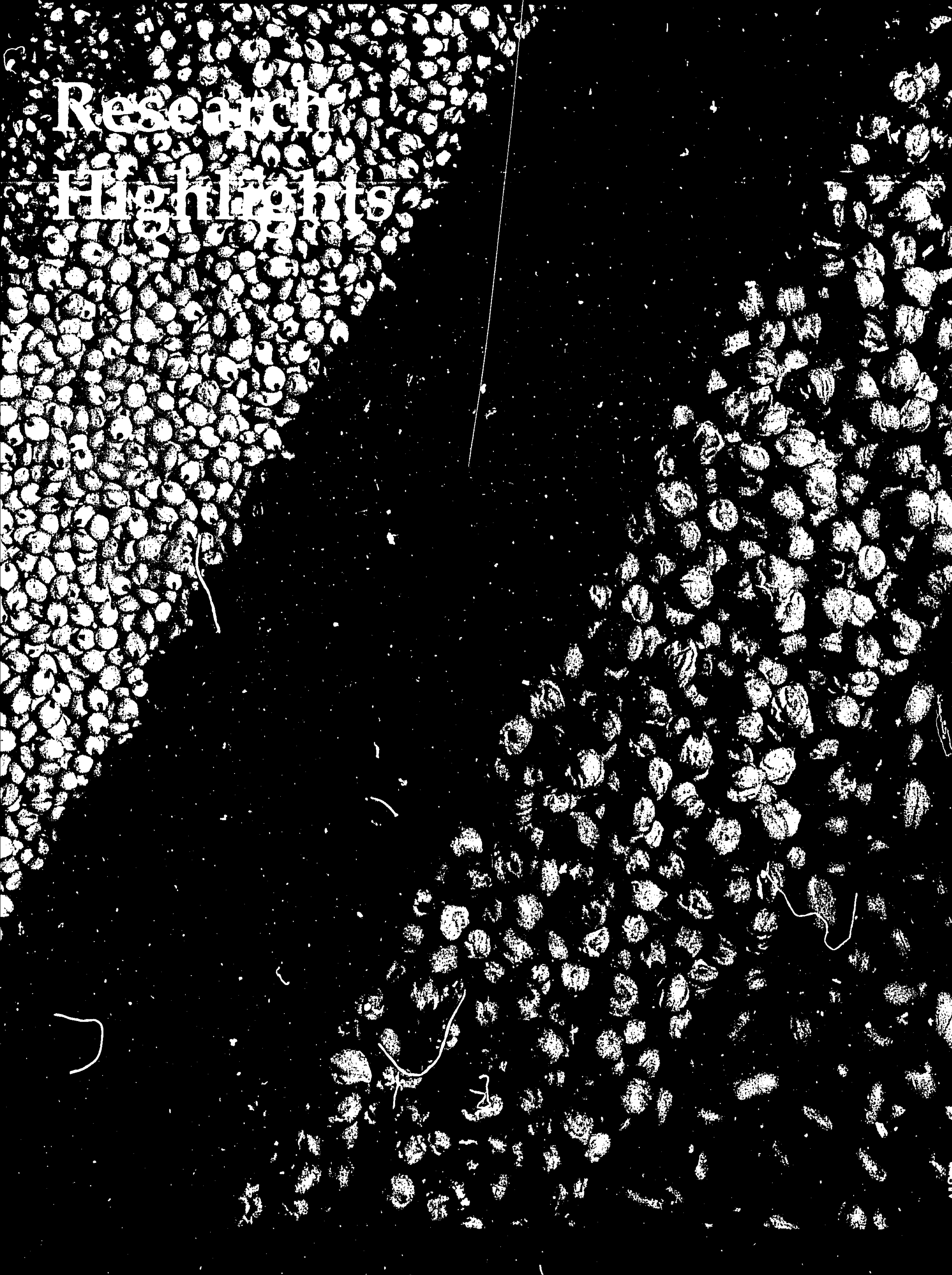
Photography International Consultancies Ltd.

Greenhouses at Chitedze Agricultural Research Station, Malawi.

Investigation of possible change in the transmission efficiency of our aphid culture, which we have maintained for 5 years, may prove necessary.

Groundnut streak necrosis disease again occurred in our fields at Chitedze during 1989/90. Although the disease has fortunately remained at low levels, we are preparing to screen our germplasm resources for genetic resistance under greenhouse conditions.

Four groundnut varieties selected for intercropping with maize did not cause any appreciable reduction in maize yield below the sole crop level. However, groundnut yields were strongly depressed by intercropping with maize. An interaction between cropping system and groundnut variety indicated a differential tolerance for the adverse effects of maize competition. In general, however, maize/groundnut intercropping does not provide a significant advantage over sole cultivation of the two crops.


Research
Highlights

Abiotic Stress

We must not wait for favours from Nature; our task is to wrest them from her.

Ivan Vladimirovich Michurin, 1856–1935

All crops are prone to abiotic stresses that can severely reduce yields. To increase food supplies and to make them more stable, the impact of stress can be moderated in several ways: by breeding cultivars less susceptible to a particular stress or set of associated stresses such as heat and drought; by designing systems of cropping that buffer responses to stress; or by improving the environment in which a crop is grown. This section is concerned mainly with attempts to select cultivars of ICRISAT's mandate crops tolerant of heat and drought on the one hand, and cold and wet conditions on the other. The systematic matching of cultivars to specific agroecological zones is also considered. Other long-term aspects of stress management through the choice of cropping systems or environmental improvement are dealt with in the section on Sustainability.

ICRISAT Sahelian Center

Heat and drought stress combine to make the Sahel a particularly difficult environment.

Drought

Selection of Pearl Millet under Natural Conditions

The arid areas of the summer rainfall regions of the globe pose a special challenge to plant breeders. High temperatures and long drought spells reduce the efficiency of selection. This is why plant breeders frequently prefer to work under nonstress, high-yield conditions. If, however, the correlation between performance from nonstress and stress conditions is low, selection under stress conditions may lead to higher gains when measured in the stress environment.

Since pearl millet in northwestern India grows mostly in extreme stress environments, two ICRISAT Center breeders decided to investigate the conditions for varietal testing and to compare gains from selection under stress conditions with gains from selection under nonstress conditions.

A set of landrace populations originating from different pearl millet-growing areas of northwestern India were used. The breeders grew 104 populations in two locations for 2 years (1988 and 1989) in Rajasthan. All trials experienced drought in at least one stage of growth. The trial mean grain yields across four environments ranged between 0.07 and 1.84 t/ha. The trials were also conducted at ICRISAT Center during the same years under nonstressed conditions with mean grain yields of 1.35–1.74 t/ha. With the exception of the 1989 Jodhpur trial, when plant stands were severely reduced due to drought stress at germination, satisfactory heritabilities and large genetic variation were observed at these locations.

The response to selection under drought conditions was tested by using two of the four environments in northwestern India as selection environments and the corresponding pair as testing environments. In this way six different pairwise tests could be performed. In all cases, the top 15 entries were selected. The mean grain yields at ICRISAT Center over 2 years were used to test the effectiveness of selection under nonstress conditions.

The average selection response over two generations for grain yield in Rajasthan was 10%, with little variation between environments. The low variation of the selection response indicates that, despite the big differences in mean grain yield in the four trials, the tested varieties reacted similarly to these environments. In other words, genotype-environment interactions for this material did not override the genetic differences. In comparison, the selection response for grain yield at ICRISAT Center was only 4%, which is insignificant, indicating strong genotype-environment interactions between northwestern and central Indian conditions for this set of landrace populations.

A focus of this ICRISAT physiologist's research is on developing millet varieties with heat and drought tolerance.

Sorghum in Nigeria

Local sorghum landraces are a valuable genetic resource in Nigeria. This material is a source of resistance to many abiotic stress factors. A major abiotic stress in northern Nigeria is terminal drought. Because flowering is timed to coincide with the end of the rains, landraces are often able to fill grain under conditions of terminal drought stress. ISC's Sorghum Physiology Unit has therefore initiated a series of studies to determine the extent of terminal drought resistance present in western African landraces.

Thirty-six local sorghum lines were obtained from the Kano State Agricultural Development Project. The lines included white-seeded (Farafara), yellow-seeded (Kaura), and red-seeded types, many with bold grain. Plant height was linearly related to time to flowering and ranged from 2 to 4 m. Flowering occurred from 55 to more than 120 days depending on the origin and photoperiod sensitivity of the material. The maximum leaf area index of the crops increased from 0.9 to 3.1 as time to flowering increased from 55 to 80 days. In later-flowering lines, leaf area index fell as a result of the prevailing drought conditions. All cultivars converted radiation into biomass with an efficiency of about 1.7 g/MJ from 39 to 71 days after sowing.

The harvest index (proportion of grain to the total dry mass) was high (0.45) in short-duration lines but fell to 0.32 when flowering was delayed to 80 days. Crops which flowered later than 80 days suffered terminal drought stress and the harvest index fell drastically (0.32 to 0). Grain yields of short-duration landraces were low (1.5 t/ha) despite their high harvest indices due to poor interception of radiation. Grain yields reached a maximum of 3.5 t/ha in crops which flowered at 80 days. The drastic decline in harvest index in long-duration lines was the direct result of poor grain filling due to terminal drought.

Promising ICRISAT sorghum hybrids such as ICSH 507 escape the effects of terminal drought because of their short duration. In order to study the effects of terminal drought stress on this material and to compare it with the long-duration local landraces, an experiment was conducted using a range of sowing dates. The first rains fell on 6 June and crops were sown 6, 13, 20, 25, and 32 days later at a density of 10.7 plants/m^2. All crops flowered within 66 days after sowing with little difference in plant height, indicating that the stress occurred predominantly during the grain-filling period.

The high harvest index of the hybrid (0.45) was substantially higher than that of landraces of a similar maturity. When sowing was delayed, both hybrids and landraces that flowered later than 80 days after the first sowing rains suffered a drastic reduction in harvest index. Crops that flowered later than 100 days gave negligible yield. Yield decreased from 5.1 to less than 1 t/ha when sowing was delayed from 6 to 32 days. This decrease in yield resulting from terminal drought stress was similar in both ICSH 507 and local landraces. Measurements of soil water balance will provide useful data in comparing the performance of contrasting material in the Kano environment.

Groundnut

Drought is the principal constraint inhibiting groundnut production in the semi-arid tropics since it deters efforts to combat the nutrient, disease, and pest stresses through managerial practices, besides its direct effect in reducing groundnut yields.

From the drought resistance trials conducted at ICRISAT Center during the 1989/90 postrainy season, ICRISAT groundnut breeders selected three varieties (ICGV 87354, ICGV 86014, and ICGV 86124) with 36–54% pod yield superiority over the drought-tolerant control, ICG(FDRS) 55.

ICGV 86976 was the best drought-tolerant variety during the 1989 and 1990 rainy-season trials with 80% higher pod yield than ICG(FDRS) 55.

Pigeonpea

A 3-year evaluation at ICRISAT Center of extra-short-duration (ESD) genotypes for their adaptation to terminal drought environments and soil types with different available water-holding capacities (AWHCs) suggested that ESD material yields best on medium-deep red soils with an AWHC of about 100 mm. When sown at the beginning of the rainy season, ESD genotypes yielded 2.9 t/ha in 110 days under rainfed conditions, greater than that of short- or medium-duration genotypes. The superior yield was due mainly to a better matching of growth and maturity with the period of soil moisture availability. In addition, ESD responded positively to increase in plant population up to 66 plants/m^2, higher than that required for short-duration pigeonpea. When protected from insect pests, their yield level compared favorably with that of short-season legumes such as cowpea and black gram. Experiments suggested the need to identify lines tolerant of or resistant to waterlogging and to intermittent stress to strengthen their adaptability to black soils (AWHC = 200 mm) and shallow red soils (AWHC = 50 mm).

Chickpea

Drought is perhaps the most important abiotic stress affecting chickpea. The Legumes Program has made steady progress in selecting for drought tolerance by segregating progenies of drought-tolerant parents. Thirteen selections, along with drought-tolerant and susceptible controls, formed part of replicated drought screening trials at ICRISAT Center in the 1989/90 postrainy season with and without irrigation. The deep and vigorous rooting characteristics of ICC 4958 were especially important in selection trials.

Most of the selections performed satisfactorily under stress, correlating well with the drought tolerance indices. A total of 136 plants and 33 progenies with increased root length and volume will be tested for agronomic traits during 1991.

Social Consequences in an Indian Village

Farmers in peninsular India suffered one of the driest years of this century in 1987. That year also marked the end of a 3-year drought. In a collaborative research project, scientists from ICRISAT and the Institute for Rural Health Studies, Hyderabad, analyzed the economic, health, and nutritional consequences of drought in Dokur, a sample village in Andhra Pradesh which relies on tank and well irrigation.

A decline in cropped area severely affected household income and employment. Median per caput household income fell 25% below 1985 levels in 1986, and 50% below 1985 levels by 1987. In the second drought year more than one quarter of the households recorded negative income. Unemployment in the village agricultural labor market rose sharply during the drought from 12% to 37%.

Although the mid-1980s drought was the harshest in living memory, food grain price stability and the widespread availability of consumption credit permitted villagers to maintain their consumption pattern of normal years. Indeed, the consequences of drought were rather mild given the shortfalls in income suffered by many households during the second drought year.

Still, the Dokur experience should not be considered completely successful. Much of the unemployment endured by laborers, particularly women workers, could have been averted by a timely and locally available public works program. The lack of water, potable or otherwise, was probably the greatest constraint to the well-being of all villagers. When compounded with the severe shortage of electricity to pump existing supplies, the scarcity of readily available clean water led to a sizable increase in water-related illnesses in the second drought year: diarrhea, eye infections, and scabies (Fig.2).

The Dokur findings are in conflict with conventional wisdom on consequences of drought. The most immediate source of disagreement concerns the absence of widespread and adverse consequences on nutritional status. Although physical health did not deteriorate greatly, the improvements in dietary intake noted from two earlier studies of Dokur were halted. Undernutrition is still the norm among rural inhabitants and the very young child is most frequently the victim.

In Dokur, the burden of drought was broadly shared by most of the village population. Foodgrain price stability meant that farmers, who planted less rice and groundnut because of water shortages, could not compensate for lost revenues through rising output prices. By the same token, laborers could not make up for lost employment because relief in the form of public works programs was not forthcoming. Women's labor income was further reduced by the sharp fall in the nominal wage rate.

The results suggest certain policy interventions to minimize the effects of drought. Some of these are:

- adequate provision of clean water and a more assured supply of electricity during times of drought;
- availability of local public works programs during drought; and
- continuation of policies to maintain food price stability.

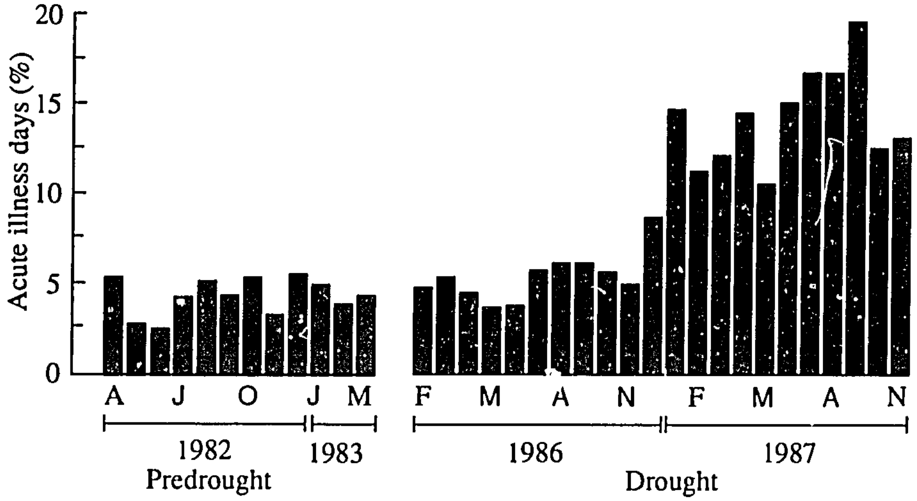


Figure 2. The incidence of acute illness during predrought and drought years by month.

Heat

Pearl Millet

The success of pearl millet in the harsh environments of the arid and semi-arid tropics relates largely to its ability to thrive under high temperatures when water is available, and to tolerate them when it is not.

The breeding program carried out by ICRISAT's Cereals Program in collaboration with Rajasthan Agricultural University in Fatehpur and the Central Arid Zone Research Institute in Jodhpur was established to produce breeding materials for the arid zone of central and northwestern India. Work began in 1988, and the program was formalized during 1990. The objective of the program is to combine the adaptative traits of

Heat trials at ISC using millet-stalk walls to vary soil temperature.

traditional landraces with the yield potential of improved varieties.

Any breeding program for this area must emphasize heat and drought tolerance. Earlier work showed that pearl millet seedlings in farmers' fields died after emergence when soil surface temperatures were high (greater than 50°C), despite adequate soil moisture in the root zone. A series of field experiments conducted in Rajasthan (a) confirmed that seedling death in the field was due to contact with high soil-surface temperatures and (b) demonstrated that there is genetic variation for heat tolerance. Effective methods to screen seedlings for tolerance for high temperature stress are therefore a critical part of this breeding project. Laboratory studies demonstrated that sorghum seedlings died as a result of blockage of carbohydrate flow to the roots. This heat girdling method has since been adapted to screen pearl millet lines for heat tolerance in the laboratory.

Four field experiments were conducted at Fatehpur Research Station during the summers of 1989 and 1990. Seventy-five pearl millet genotypes were screened in 1989 and 25 lines selected for further screening in 1990.

In early April and mid-May of 1989, seeds were sown by hand in a randomized block design. Fifty seeds were sown in each row at a depth of 5 cm. Before sowing, 15 mm of water were applied by sprinkler irrigation to all plots. The same area and procedure was used in 1990 except that a small hand planter was used for sowing. This ensured better placement of seed and greatly reduced the sowing time. No further irrigation was applied. In all experiments, air and soil temperature and moisture were measured every hour.

Measurements of seedling emergence commenced when seedlings were first seen in any plot and continued until there was no further emergence. After the appearance of the first dead seedling, the number of dead or dying seedlings was recorded. This continued until approximately 20 days after sowing when the plots were irrigated to field capacity to obtain a final value of seedling survival.

From these data on seedling emergence and death, a survival index was calculated as the fraction of seedlings surviving 9 days after the first death. The index was used to compare the behavior of various genotypes under heat stress. Since there was adequate moisture in the soil, seedling death could be attributed only to high soil temperature.

The percentage of seedling emergence and the survival index for the common 25 genotypes, with few exceptions, varied little between 1989 and 1990. Two genotypes (BSEC C4 and ICMV 84400) had consistently poor survival, whereas several lines including the hybrid HHB 67 and landrace material IP 3201 survived well. Across the four experiments, the heritability (h) of the survival index was shown to be high ($h^2 = 0.82$).

In an attempt to better understand the reasons for these marked differences in thermotolerance, another series of field experiments was begun in Fatehpur in May 1990. Detailed measurements of leaf expansion rates, root length, and leaf and root mass were measured on six genotypes. Initial results suggest that survival may be associated with a high root : shoot mass ratio in the early-seedling stage.

At the ICRISAT Sahelian Center, the impact of soil surface temperature on pearl millet emergence and subsequent growth was explored. Walls made from woven millet stalks 1 m high were erected running north to south. Millet was then sown in rows running east to west. The amount of shade increased with proximity to the wall. Two genotypes of millet were sown in mid-May (when the first planting rains occur) with a single irrigation and left to germinate, emerge, and grow. Plants shaded for less than 30 minutes a day did not survive beyond 10 days. As the amount of shade increased to 5½ hours, millet growth increased.

The soil surface temperatures corresponded closely to those observed under *Faidherbia albida* trees. Temperature manipulation is one of the contributions to higher yields made by this tree species.

The experiment showed that pearl millet, despite its superior high temperature tolerance relative to other crops, is limited by the early season temperature prevailing in the Sahel. Clearly, research to develop methods of soil temperature manipulation could pay handsome dividends in millet improvement programs.

Chickpea

Although chickpea is considered a cool-season, subtropical legume, much of its production falls outside the subtropics, where for part of the growing season the weather is far from cool. High temperatures can adversely affect yield. Screening potential chickpea lines for heat tolerance was initiated in 1988/89 by late sowing (January) at ICRISAT Center to expose the plants to high temperatures (greater than 30°C) at the flowering and pod-filling stages. Genotypes giving higher seed yield than the control cultivars were selected and evaluated in replicated yield tests in 1989/90 under late sowing. There were significant differences among the genotypes for seed yield and several lines produced higher seed than the control, confirming their tolerance for heat. This work is ongoing.

Cold

Sorghum in Mexico

During the late 1950s, the Rockefeller Foundation undertook a collaborative project with Mexico's national agricultural research system to identify sorghum cultivars that could substitute for maize in the dry highlands where maize was not well adapted. Although the several thousand sorghums introduced exhibited normal vegetative development and excellent biomass, they failed to produce grain. Eventually, the critical environmental factor limiting grain formation was found to be low night temperature around flowering. In 1960 several brown-grained high-tannin, sorghum landraces introduced from the eastern African highlands, succeeded in producing grain in this cool environment. However, these cold-tolerant sorghums were too late in flowering to be directly useful.

A small breeding program was therefore initiated to recombine short duration, cold tolerance, and desirable grain quality characteristics so that sorghum could be substituted for maize in marginal areas of the highlands of Mexico. Shorter duration and cold tolerance were soon recombined, but birds eliminated the low-tannin genotypes from the breeding populations. In 1977, responsibility for this cold-tolerant sorghum breeding project, inherited from the Rockefeller Foundation, was transferred by CIMMYT to ICRISAT. In 1978, the Mexican national program released three cold-tolerant sorghum cultivars, Valles Altos 110, Valles Altos 120, and Valles Altos 130. These varieties were cold tolerant, but were not agronomically elite, and had brown grains unsuitable for livestock feed or human food. Only Valles Altos 110 is still cultivated, and this on a limited scale.

In 1990, ICRISAT's Latin American Sorghum Improvement Program (LASIP) evaluated recent elite products of its cold-tolerant sorghum breeding project in a trial at El Batán, Mexico (2240 m). Conditions in 1990 were unusually favorable for maize at this location, with above-average rainfall and below-average temperatures. The maize control in this trial yielded more than 9 t/ha compared with 6.5 t/ha for the highest-yielding sorghum entry. Sorghum entries in this trial averaged 5.5 t/ha. When sorghums of this maturity range are grown under irrigation or under high rainfall conditions, they cannot compete with maize. Only shorter-duration sorghum sown under rainfed conditions in marginal areas will be capable of producing the grain yield advantage necessary for sorghum to complement maize in the highlands.

In 1991 the national program in Mexico will take up on-farm evaluation of the early-flowering, tan-plant, white-grained variety BTP 28 (C). This variety, which combines cold tolerance, short duration, and improved grain quality with the resistance to foliar disease necessary for gaining farmer acceptance is the first to reach an advanced level of testing in this traditional sorghum environment.

Chickpea in India

Chickpea sometimes follows rainy-season crops in rotations in the northern latitudes of the Indian subcontinent. Delayed harvest of these crops often results in the late sowing (in December) of chickpea beyond its optimal sowing time. Traditional cultivars are poorly adapted to delayed sowing. Several hundred germplasm lines have been screened for adaptation to late sowing at ICRISAT Center. These have been used in ICRISAT's breeding program as a base for incorporation of desired resistances to both biotic and abiotic stresses. Several improved lines have been developed and contributed to the national programs of Bangladesh, India, Myanmar, Nepal, and Pakistan.

Normally chickpea does not produce pods in freezing temperatures and the crop loses time and possibly yield. Legumes scientists have therefore selected lines that pod during the coldest months. Preliminary yield evaluations indicate that some of these lines not only outyield the controls but mature earlier. One of these lines yielded 22% higher than the control at Hisar and another 17% higher than the Gwalior control. One cold-tolerant entry was contributed to All India Coordinated Pulses Improvement Project (AICPIP) trials in India.

Chickpea in Syria

Research conducted at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria, under the ICRISAT/ICARDA Kabuli Chickpea Project has shown that chickpea in the Mediterranean region, when sown during early winter, gives substantially more yield than the traditional spring-sown crop. But winter sowing is successful only with cold-tolerant and ascochyta blight-resistant cultivars. Observations made in winter-sown chickpea indicated that during cold winters the yield loss is total in cold-susceptible lines.

During the 1989/90 season cold-susceptible lines sown during winter were destroyed. The correlation coefficients between cold tolerance and seed yield for 288 entries indicated that the higher the cold tolerance the higher the yield.

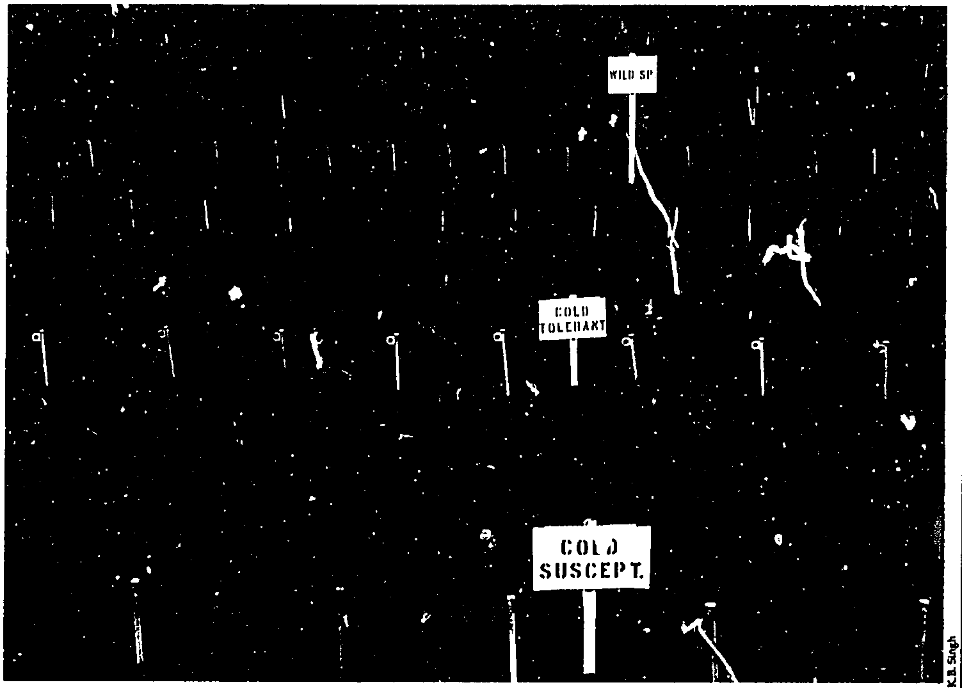
A large-scale, reliable, and convenient screening technique for evaluation of germplasm lines to cold tolerance has been developed at ICARDA. This technique involves:

- sowing in autumn (early October);
- raising the material to late vegetative stage before the onset of severe winter;
- sowing of susceptible rows and evaluating germplasm lines when indicator rows are killed; and
- confirming cold tolerance for one more season to eliminate escapes.

Furthermore, a 1–9 scale (where 1 = damage free and 9 = killed from cold damage) was developed. Using the screening technique and rating scale described above, 5978 germplasm accessions were evaluated and 16 lines found resistant with a rating of 3 or less. When 184 lines of eight wild chickpeas were evaluated for cold tolerance, 66 lines were found to be cold tolerant with a rating of 2, and another 17 lines with a rating of 3, indicating that wild species have higher levels of cold tolerance than cultivated species. Many of these wild species can be crossed with cultivated species.

A bulk pedigree breeding method has been developed to breed cold-tolerant and ascochyta blight-resistant chickpeas. The segregating generations are sown in early November, 1 month before the normal winter sowing, and usually harvested at the end of June. The material is evaluated for cold tolerance from November to February and for ascochyta blight from March to June during the same season. More than 1000 breeding lines have been developed using this technique. These lines have been supplied to many national agricultural research systems who have made good use of them in their breeding programs. A few lines have been released for winter sowing.

Efforts are under way to incorporate genes for cold tolerance from wild chickpea species to cultivated species. The mutation technique was used to create higher levels of tolerance for cold. One mutant, ILC 482-COLTOL, was identified from this study as having one of the best sources of tolerance. Genetic studies indicated that cold tolerance was dominant over susceptibility and was controlled by at least five sets of genes. Crosses made between cultivated species and cold-tolerant lines for the transfer of cold tolerance are in the second generation. The entire effort is directed towards development of chickpea cultivars capable of tolerating freezing temperatures and that can be sown during winter in the Mediterranean basin.



K.B. Singh

Cold tolerance chickpea trials in Syria.

Excessive Soil Moisture

A large portion of the area where chickpeas are grown falls between 22° and 32°N. This region is typified by long cool winters, good rainfall, and low evapotranspiration. As a result, the crop experiences excessive vegetative growth and lodges, causing severe yield losses. Dense plant canopies prevent sunlight penetration, causing etiolation and maintaining a high level of humidity that encourages foliar diseases. Since 1985/86, Legumes Program scientists have been screening potential chickpea germplasm at Hisar and Gwalior. They have been particularly interested in tall and erect breeding lines that can resist lodging and adapt to high soil fertility and moisture. Several promising lines have been identified, and a breeding program has been initiated by crossing these lines with sources of disease and pest resistance.

Agroclimatic Analysis of Network Sites

An important step in the process of identifying elite lines is to investigate the various soils and climates where the crops under study are grown. The Eastern Africa Regional Sorghum and Millet (EARSAM) Network's analysis of its diverse research sites has made excellent progress in identifying which sorghum and pearl millet lines are most


J.V.D.K. Kumar Rao

Waterlogging can be a serious problem in the semi-arid tropics, as in this plot of short-duration pigeonpea.

suitable for cultivation in various agroclimates. Agroclimatic analysis gives breeders a valuable tool in selecting the optimal environment for their work.

Soils in the region vary from very shallow and sandy (Alfisols or Oxisols) to deep clays (Vertisols). Extremes of thermal regimes are represented by network sites located at sea level and as high as 2000 m. Annual rainfall varies from 400 mm to 1500 mm. The network is therefore well positioned to undertake studies of several abiotic stresses simultaneously.

A water balance for 23 EARSAM Network sites based on monthly average rainfall and potential evaporation and soil water-holding capacity showed that the average length of the growing season ranged from less than 60 days to physiological maturity to 150 days or more (Fig.3).

The extreme diversity of the length of the growing season challenges plant breeders and agronomists to develop technologies that increase and stabilize sorghum and pearl millet production in the region. After collecting information on various agroclimatic aspects of the EARSAM network sites, several conclusions were made.

- Agronomic and crop improvement research must be integrated so that interdisciplinary teams of researchers can address production problems. Close working relationships with appropriate national system partners are necessary.

- Further progress can be made by identifying and establishing network sites for detailed physiological, climatological, and soil water balance studies.

- To expedite cultivar testing, each country should be characterized for its special growing-season requirements.

- Selected network sites should be equipped with automatic weather stations and soil moisture measuring equipment.

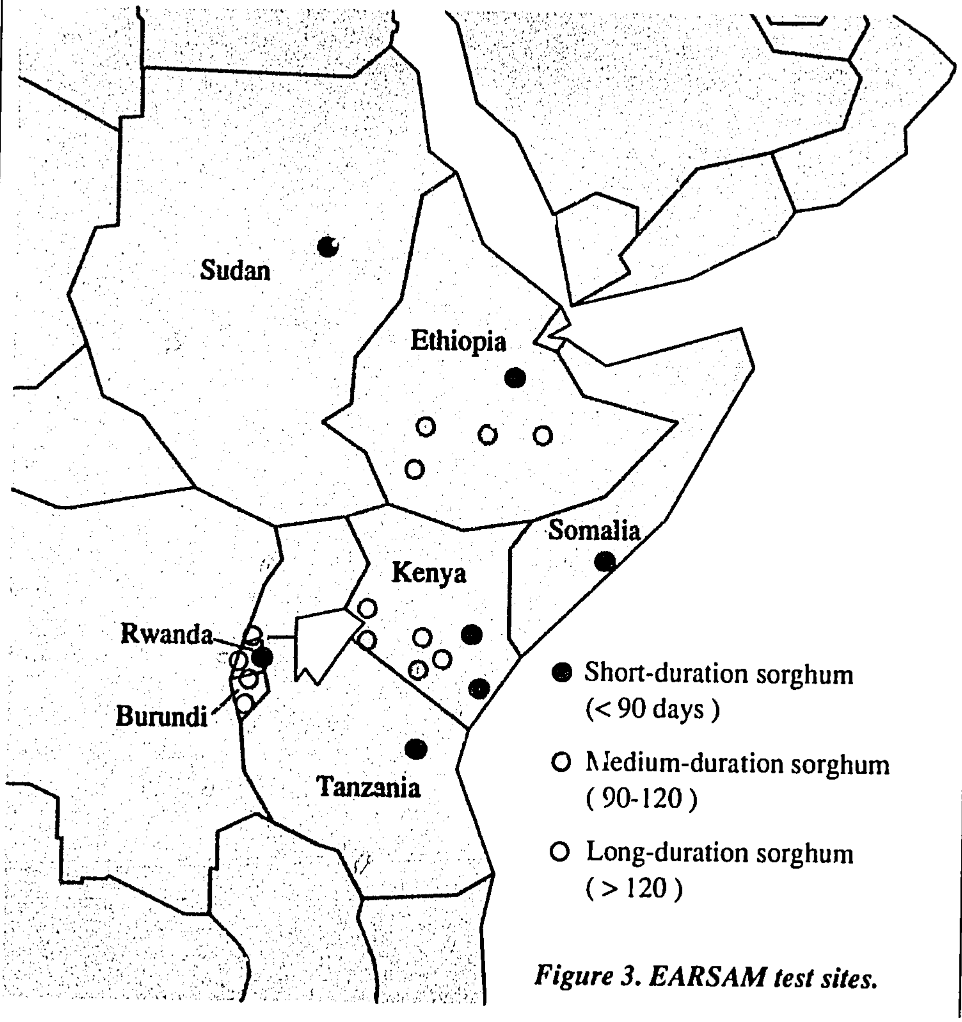


Figure 3. EARSAM test sites.

Integrated Pest Management

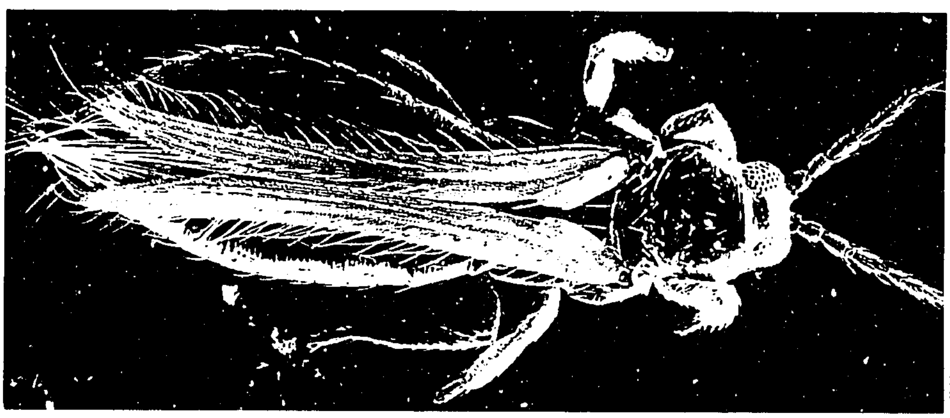
The term "integrated pest management" (IPM) refers to various techniques employed by farmers and agricultural scientists to combat devastation of crops by a range of pests (such as insects, birds, weeds, diseases, and nematodes). This report specifically focuses on the management of insect pests. IPM techniques include application of both biological and chemical means to combat infestation, as well as the use of pest-resistant varieties and the practice of cultural controls such as intercropping or varying the time of sowing and harvesting.

All ICRISAT's crops can be devastated by insect pests. In the developing world, farmers frequently react to pest infestation by doing nothing because they cannot afford pesticides. Sometimes, however, they apply them and create even worse pest problems because they have been ill advised on the use of these high-technology inputs.

Naturam expellas furca, tamen usque recurret.

Though you drive away Nature with a pitchfork she always returns.

Horace, 65-8 BC



A.K. Murthi

Thrips: an important vector of groundnut viruses (magnified 75 times).

A.K. Murthi

Birth of a pest:* Helicoverpa armigera *hatching (magnified 96 times).

IPM Thrust in Crops Research

ICRISAT regards the optimization of pest management procedures as one of the key factors in promoting sustainable agricultural systems specially tailored to the needs of the resource-poor farmers of the semi-arid tropics. The Institute's Entomologists concentrate on the pest-resisting properties inherent in the crop host. This approach focuses on ways to maintain or increase the ability of the biological systems of the farm environment to maintain pests at population densities that do not cause significant crop losses.

ICRISAT Entomologists are therefore expanding the database available to scientists in the national programs to help farmers understand the consequences of various on-farm management activities. The scope of their work extends from collaborative basic research with mentor institutions on the chemical basis of host-plant resistance to the on-farm evaluation and demonstration of the technologies developed within the relevant interdisciplinary groups responsible for pest management.

On-farm activity is carried out to obtain feedback on the value of the completed work to help re-evaluate and redefine priorities. An extension component is also necessary because farmers' perceptions of the technological advances must be periodically surveyed if these advances are to be applied.

Host-Plant Resistance

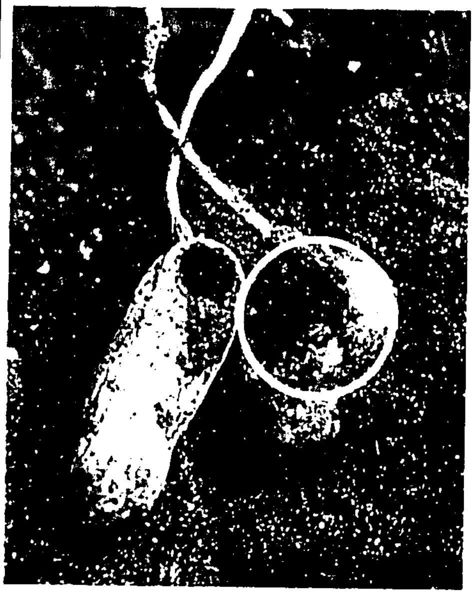
Because one of ICRISAT's primary IPM thrusts centers on host-plant resistance, joint activities are carried out with plant breeders. A breeder crosses the resistant genotypes identified by entomologists. The entomologists then collaborate to assay the progeny for insect resistance.

Collaboration with mentor institutions, such as the Natural Resources Institute of the Overseas Development Administration and the Department of Plant Science of the University of Reading, both in the UK, has facilitated the study of the genetics of aphid resistance. As a result of these collaborative studies carried out in 1990, aphid resistance can now be assayed in two ways: assessment of the rate of aphid reproduction on a given groundnut plant (the traditional, but time-consuming method), or measurement of the concentration of the phenolic chemicals in the leaflets that actually inhibit the reproductive rate of the aphids.

Pathologists and virologists are also involved in IPM because of the need to seek and breed varieties or populations with multiple resistance to insects, diseases, and virus vectors. This joint research has led to the development of advanced breeding lines of medium-duration pigeonpea with resistance to both pod borer (*Helicoverpa armigera*) and wilt disease. Simultaneously, high-yielding groundnut varieties with resistance to jassids, defoliating insects, and the thrips vectors of tomato spotted wilt virus have been identified.

Plants resist pests in many ways. Pigeonpea, for example, rapidly and repeatedly replaces flowers following pest attack. Other plants discourage pests with surface structures such as the long leaf hairs of some groundnut varieties that entangle small insects like jassids. Still others produce "anti-insect" chemicals either on the plant's surface (as does chickpea) or within the plant's tissues (as does groundnut).

Host-plant resistance is a complex subject involving a wide variety of specialists—insect sensory physiologists, electrophysiologists, plant biochemists, insect behaviorists, and others. Few research organizations have sufficient expertise to successfully combat such formidable adversaries as *H. armigera*, which regularly wreaks crippling damage on pigeonpea crops throughout the semi-arid tropics. With these considerations in mind, ICRISAT's Legumes Entomologists hosted a Consultative Group Meeting in March. Experts on all aspects of insect host-selection behavior were invited. Together, they formulated a set of



J.A. Wightman

White grub is a major underground pest of groundnut. A grub's head is indicated in the circle in the left photograph. To the right is a photograph of the whole insect.

K C Jain

Helicoverpa armigera ***is a voracious feeder. It particularly favors the nitrogen-rich flowers, buds, pods, and seeds of pigeonpea.***

recommendations for a multi-organizational approach to share knowledge of the host-selection behavior of *H. armigera* on pigeonpea.

Potent sources of resistance to two key pests of groundnut, the tobacco armyworm (*Spodoptera litura*) and the groundnut leaf miner (*Aproaerema modicella*), have not yet been found in the germplasm of the cultivated groundnut. However, there is considerable evidence that resistance to these species exists in many of the wild *Arachis* species. Research carried out by Natural Resources Institute scientists at ICRISAT Center during 1990 centered on two wild species—*A. paraguarensis* and *A. chacoense*. Quercitin-3-diglycoside, an insect development inhibitor similar to rutin, was found in both species. A caffeic acid ester similar to another insect development inhibitor, chlorogenic acid, was also found in the latter species.

Breeding Chickpea for Pod Borer Resistance

Pod borer is the major insect pest of chickpea in Asia and eastern Africa. Germplasm identified as resistant (less than 10% borer damage) to *Helicoverpa* by ICRISAT's Legumes Entomologists was extensively utilized in the resistance breeding program during the 1980s. However, the newly developed resistant lines have shown little superiority to germplasm lines in terms of borer resistance. A germplasm enhancement program was therefore initiated to improve the present levels of resistance, and seven crosses were made using a selected set of the eight most promising donor parents. A recurrent selection program is envisaged to concentrate the resistance genes in one genome.

Breeding Groundnut for Insect Pest Resistance

ICRISAT Legumes Entomologists and Breeders have identified 10 elite varieties with stable resistance to jassids across seasons. Of these, ICGV 86522 has been identified as the best adapted variety to both rainy and postrainy seasons. In addition to its resistance to insect pests, it resists bud necrosis disease and showed tolerance for end-of-season drought. Because it has performed exceedingly well in nontraditional groundnut areas, it was promoted to the advanced stage of testing by the All India Coordinated Research Project on Oilseeds (AICORPO) during summer trials. Another variety, ICGV 86400, is in the final stage of AICORPO rainy-season testing.

The value of four new resistant groundnut varieties that significantly outyielded controls at ICRISAT Center was confirmed during the rainy season.

Pest Density and Crop Loss

Attempts to manage insect pests often emphasize an understanding of the relationships between insect density and crop yield loss. This topic is directly related to the optimization of insecticide usage. It is not a simple operation, however, because many variables are involved. For instance, the stage of the crop, the weather pattern, and the season are all important. Groundnut seedlings are susceptible to relatively low population densities of defoliators, whereas established plants can withstand a considerable degree of leaf loss, more in the rainy season than in the postrainy season. Chickpea and pigeonpea are less sensitive to pod borer attack in the flowering stage than during pod formation. This is because many flowers drop off the plant without being pollinated irrespective of insect activity. Clear relationships between the density of *H. armigera* larvae and the pod yield of chickpea and short-duration pigeonpea have been demonstrated.

Enhancing Natural Control

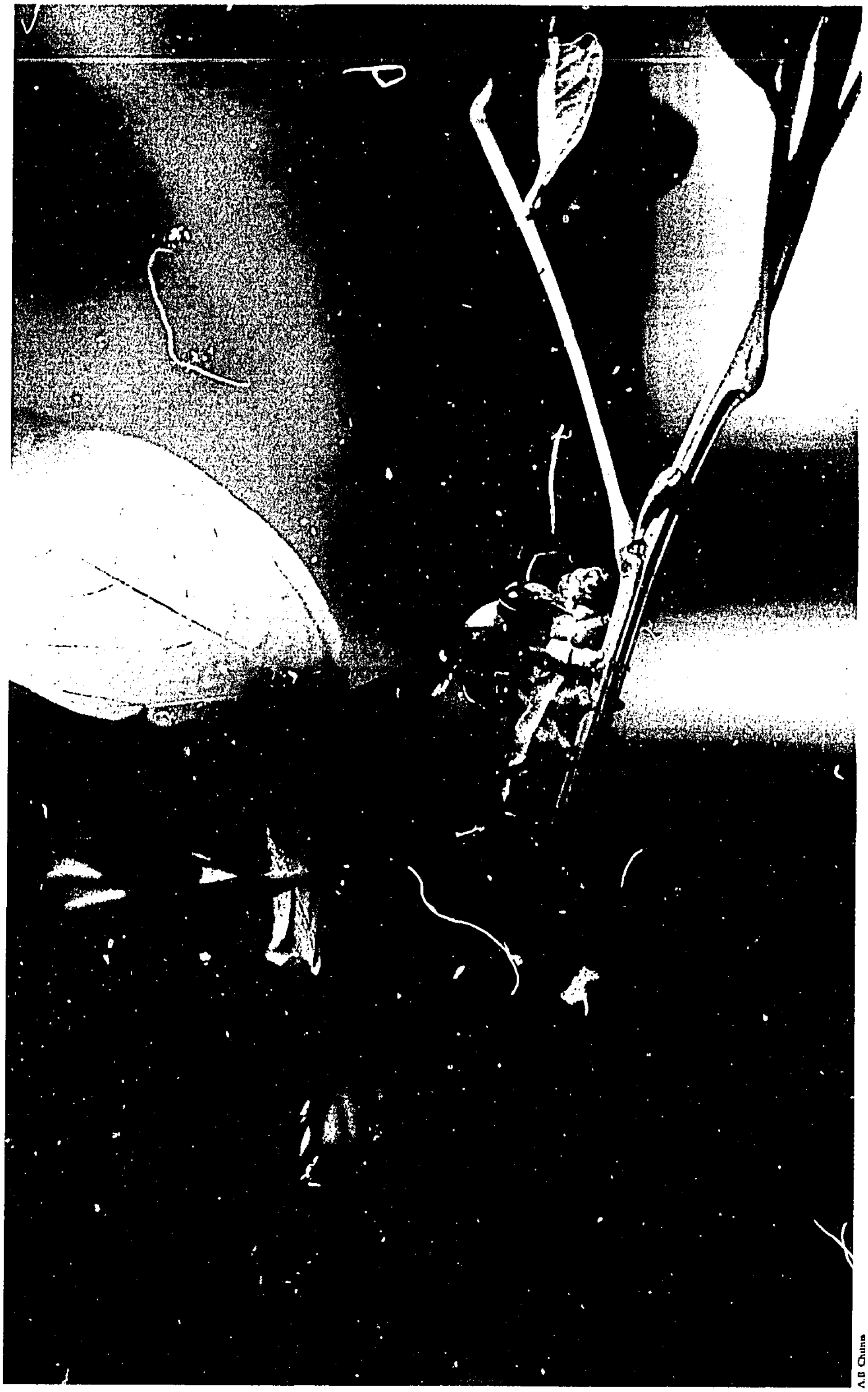
ICRISAT actively searches for ways to enrich the farm environment to make it more attractive to the predators and parasites of key pests. For example, parasites of the pod borer need nectar. Therefore, entomologists are intercropping chickpea with coriander, a high-value, nectar-bearing crop. Pod borers taken from the chickpea/coriander intercrop had 5% parasitism, compared with 0% parasitism in the chickpea sole crop.

These results are more encouraging than may be initially apparent because they were collected from farms in an area of Andhra Pradesh where insecticides are heavily applied. The need for long-term implementation and continual evaluation of chickpea/coriander intercropping is indicated. Also recommended are the introduction of resistant varieties and the reduction of insecticide application within the farming community as a whole. Making chickpea fields more attractive to important parasites is only part of a complex of interactive factors.

In this particular intercropping system, the added income from the coriander and the decreased cost of pesticides are significant factors. But not all of the farming systems assessed by ICRISAT scientists are supported by appreciable levels of cash flow. For example, few groundnut farmers in Africa can afford to apply insecticides to their crops. Perhaps this is why there are few foliage pests of groundnut in Africa.

The Judicious Use of Insecticides

Analysis of research results, in addition to comparative information concerning other pests, has enabled ICRISAT



A.B Chitna

A mud wasp attacking a **Helicoverpa armigera** *larva on pigeonpea.*

Entomologists to establish guidelines for the application of insecticides. It is clear that pesticides should be used sparingly for two reasons. Firstly, as demonstrated in trials carried out at ICRISAT Center as well as in farmers' fields, insecticides kill the natural enemies of pests, thus permitting pest outbreaks and resurgencies. Secondly, excessive use of pesticides can induce strains of pests resistant to the toxins. A cooperative project with the Natural Resources Institute was initiated in 1990 to monitor resistance to insecticides in pod borers and the tobacco armyworm.

Farmer Participation

Through their on-farm trials in Shiiapur, Karnataka, ICRISAT Legumes Entomologists have established the value of some borer-resistant pigeonpea varieties in insecticide-free conditions. For example, ICPL 84060 yielded 0.94 t/ha, which is significantly more than the 0.66 t/ha harvested from the local landrace. The pod borer caused only 5% pod damage to ICPL 84060 compared with 59% in the local variety.

Taking this process further, the Entomologists worked with a group of women farmers living in a harsh area of Andhra Pradesh to evaluate a number of pigeonpea lines. They assessed the agronomic characteristics and qualities of these lines. ICPL 84060 again scored best overall. What is interesting is that ICPL 332, which is acceptable elsewhere in Andhra Pradesh, was rejected because of its bitter taste. The farmers grew the varieties in their own fields and then rated them according to 11 agronomic criteria, including pest resistance, taste, wood production and quality, market price, and the retention of quality during storage. Most farmers rated ICPL 84060,

Farmers Know Best

Participatory rural appraisal methods allowed farmers to compare improved pest-resistant pigeonpea (ICRISAT material) with their local varieties using their own evaluation criteria. High-quality information was generated during group interviews in which Indian farmers ranked various pigeonpea varieties using tamarind seeds (1 seed = very good, 2 = good, 3 = less good). A matrix indicating their preferences is shown below.

Farmers' pigeonpea preferences, Medak District, Andhra Pradesh, India.

	Local	Improved ICPL 84060	Improved ICPL 332
Leaf production	ooo	o	oo
Flower production	ooo	o	oo
Pod production	ooo	oo	o
Pod filling	ooo	o	oo
Pest resistance	ooo	oo	o
Seed yield	ooo	oo	o
Taste	oo	o	ooo
Wood production and quality	ooo	o	oo
Market price	o	oo	ooo
Storability	o	o	o
If only one variety available:	o	o	ooo[1]

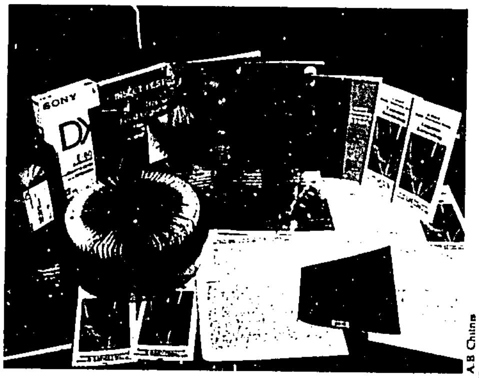
1. Rejected because of poor taste.

ICPL 87088, and ICPL 87089 superior to their landraces.

Despite the advantages of ICPL 84060, the farmers said that they still wanted to retain their landraces and other improved varieties they had tested. They believed that pest attack was lower when they grew a mosaic of varieties than when they grew a single variety. Furthermore, they wanted to take advantage of the higher yields by selling seed of the landrace on the local market so that they could keep the better-tasting ICRISAT variety for themselves.

This work was unique in several ways. It involved only women farmers in a male-dominated society. Also, the parameters considered went well beyond conventional yield and pest resistance measurement. The farmers made helpful suggestions concerning new lines of research to follow and hypotheses to evaluate. Even more important, the whole procedure was recorded on video over a 1-year period. The video, entitled "Participatory Research with Women Farmers", offers national program scientists fresh ideas about transferring the technology they are developing to their farmer partners.

ICRISAT scientists take the information and technology exchange process seriously. They have utilized video, tape-slide packages, in-country workshops, the print media, and newsletters to convey information about IPM to national scientists and farmers.



Legumes Entomology's communications thrust.

Regional Activities

Management of the Sorghum Shoot Fly in South Asia

Shoot fly bioecology and physiology. Cereals Entomologists have shown that the degree of wetness of the central whorl leaf is a major determinant of resistance to shoot fly (*Atherigona soccata*) larvae.

In collaboration with Sorghum Physiologists and the Microclimatology Unit of the Resource Management Program, Cereals Entomologists conducted studies on the diurnal fluctuation of leaf surface wetness (LSW) and found that LSW was lowest at sunset, rose through the night, was highest between 0200 and 0400, and dropped before sunset. This corresponded very closely with the hatching of shoot fly eggs. This synchronization between the insect's biology and the physiology of its host indicates a highly evolved and closely integrated insect-host relationship, an evolutionary process that guarantees the survival of the pest species.

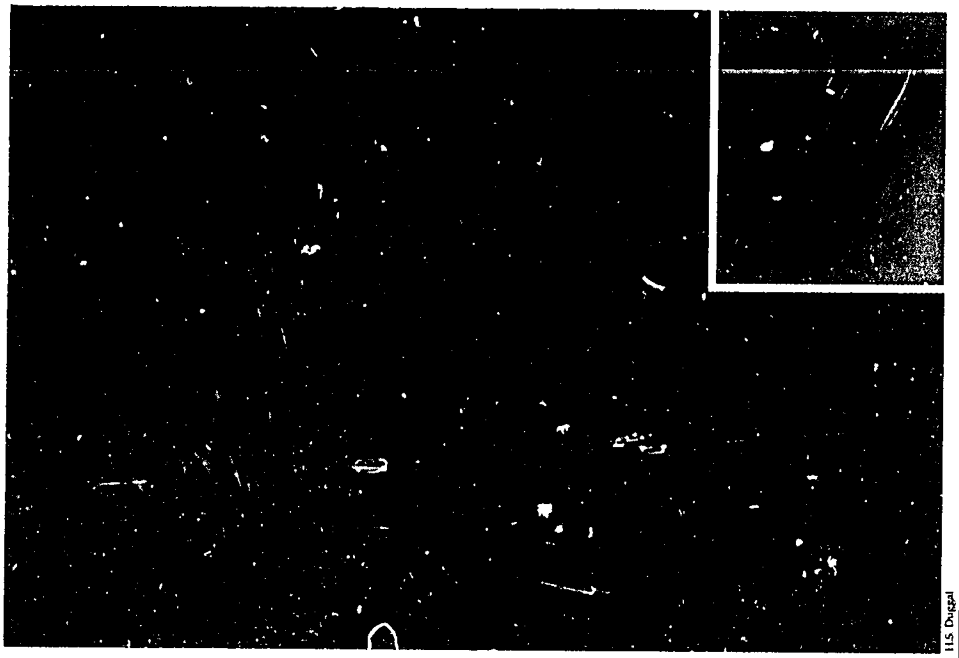
The scientists also observed that more LSW accumulation occurred during the main cropping season (June to October) than in the postrainy season (November to April). Annual fluctuation of LSW was similar to the population dynamics of shoot fly and crop infestation and was closely related to rainfall, temperature, and relative humidity.

Some questions remain unanswered. What plant morphological factors and physiological processes are involved in the production and retention of LSW? How are these processes affected by changes in the immediate edaphic and atmospheric crop microenvironment? These questions are currently under investigation in collaboration with the Electron Microscope Unit at ICRISAT Center and Long Ashton Research Station, UK.

Manipulation of LSW for shoot fly control. During the main crop season, shoot fly infestation is negligible if sowing is carried out with the first rains. However, it is a major production constraint in sorghum grown during the postrainy season. Earlier studies indicated that LSW was probably caused by moisture exudation from the plant, and not by the condensation of atmospheric moisture on the leaf surface. Based on these results and earlier studies on the bioecology and physiology of shoot fly, a set of potted seedlings was subjected to moderate drought stress and compared with normally irrigated seedlings for LSW, shoot fly oviposition, larval movement, and deadheart incidence. All were drastically reduced in the drought-stressed plants.

An interdisciplinary team of entomologists, physiologists and microclimatologists then hypothesized that if soil moisture in irrigated sorghum fields were reduced during the first 4 weeks after sowing, shoot fly damage could be considerably reduced. Using high-yielding but susceptible CSH 5, an irrigation schedule was developed in collaboration with the Sorghum Physiology Unit.

The study was conducted in the rainout shelter. Three irrigation regimes were used: the first at sowing, the second at sowing and at 5 days after seedling emergence, and the third at sowing and at 5-day intervals thereafter. All treatments reverted to a normal schedule 21 days after emergence. Reduced irrigation resulted in a decrease in LSW, but the overwhelming advantage was in the second regime. Oviposition was reduced by 50% and deadhearts by 30%. Plant biomass was increased by 20% and plant height by 39%. Flowering was delayed by 2 weeks in the control



Shoot fly trials with sorghum at ICRISAT Center. Resistant variety on left, susceptible on the right. The inset shows an adult fly magnified 10 times.

I.S. Duggal

treatment and yield data showed a 22% advantage in the second regime. An attempt will be made to duplicate these results in the field. The immediate implication of these results will affect the 1 million ha of irrigated postrainy-season sorghum in India.

Stalk Borer: IPM Research in Eastern Africa

In a collaborative research project between the Somalia National Sorghum Program and ICRISAT, a number of research activities were undertaken during the 1989 *deyr* (short rainy season) at the Bonka Dryland Agricultural Research Station.

In an insect pest survey in Somalia's Bay Region, *Chilo partellus* was the only pest recorded in all four districts. Its infestation ranged from 6% to 60%.

Facilities for rearing sorghum stalk borers (*C. partellus*) on an artificial diet were established. The insects' growth, development, and reproduction on an artificial diet were similar on sorghum, the pest's natural host.

Chemical protection against stalk borer during the early growth stage (15 days after crop emergence) resulted in significantly low leaf feeding and deadheart formation.

Identification and Field Testing of the Millet Stem Borer in Western Africa

During 1990, collaborative research between ICRISAT and the Natural Resources Institute, UK, on the millet stem borer (*Coniesta [=Acigona] ignefusalis*) pheromone (a chemical emitted by female moths to attract males) was continued at ISC. Through an improved rearing technique, a large number of adults in excellent condition were produced, resulting in high yields of pheromone. Five components of the pheromone were identified and tested in different combinations and mixture ratios for their ability to attract males. The experiment was carried out from late August to late October.

For all experiments, sticky traps were set up in different field plots at the Sadoré station to compare pheromone components with virgin females. During the first of these tests, male moths were caught either by a 5% or 10% pheromone combination or by virgin female-baited traps. Unbaited traps caught no moths.

The next step in this series of experiments was to evaluate the effect of additions of minor components to the original mixture. In the end, the removal of certain components from the mixture was found to increase the attractiveness. Polyethylene vials impregnated with the final blend of pheromone components were as attractive to male moths as virgin female moths.

Managing the Armoured Cricket in Southern Africa

The armoured cricket (*Acanthoplus speiseri*) is a serious pest in the lowlands of Botswana, Namibia, Zambia, and Zimbabwe on sorghum, millets, maize, soybean, cowpea, sunflower, and wild grasses. The problem has worsened due to a series of drought years. The SADCC/ICRISAT Sorghum and Millets Improvement Program became involved with this pest when Zambian Government representatives at Mt Makulu Research Station requested assistance in studying the biology, migration, and control of this insect. Since virtually no information was available when the project started in 1987, studies of the cricket's basic biology and migration were carried out between 1987 and 1990. Based on the results of these studies, simple pest management recommendations were developed.

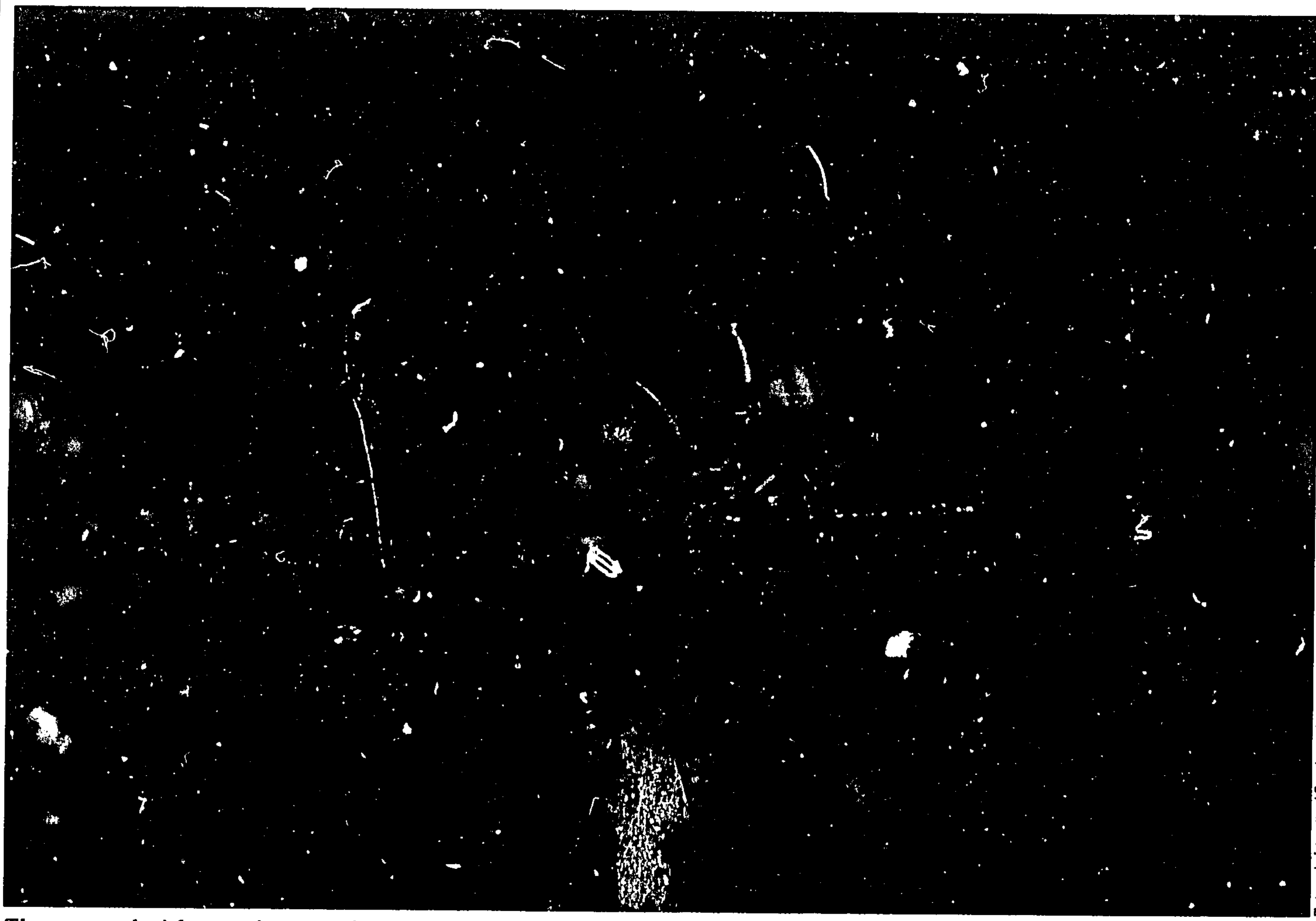
Several behavior patterns in the life

cycle of the insect that could be exploited for its control were identified.

- The insect can only develop on the maturing grain of cereal or legume plants and not on their vegetative parts.
- The insect hatches in January and develops on wild grasses over six development stages (five nymphal and one adult).
- Adults migrate in March from the wild grasses, which are by then mature, to the developing grain of farmers' crops.
- Females lay egg pods in March/April in the soil, usually along field borders under trees and shrubs.
- Adults have no wings and migrate by walking.

The following recommendations are based on the above observations.

- Spray hatching areas along field borders with carbaryl or Karate® (lambda cyhalothrin) after the first instars have hatched.
- Keep fields weed-free. Since cricket nymphs feed only to a very small extent on leaves there will be no food in the field until heading (cereals) or pod setting (legumes).
- At the onset of cricket migration (beginning of March), prepare a bait made from maize meal and carbaryl or Karate®. Place the bait along field borders and repeat the procedure after 1 week. Bait is highly attractive to migrating (invading) crickets.
- If crickets have already invaded farmers' fields, carbaryl or Karate® should be sprayed. The spray should be directed at the seed heads and [illegible]ls to have maximum effect.
- Although egg laying takes place in March/April, a certain number of egg pods are also laid in the field within crop rows. Early plowing before or immediately after the rainy season reduces survival of these egg pods by exposing them to heat and predators.



Photography International Consultancies Ltd.

The armoured cricket—an important insect pest of sorghum in southern Africa.

Assistance to National Programs, Networking, and Technology Exchange

ICRISAT realizes its primary function is to share the results of its research with its partners, the national agricultural research systems within the Institute's mandated agroecological region, the semi-arid tropics, and also in those countries outside this region wherever our mandate crops are grown.

Friends share all things.

Pythagoras, 582-497? BC

D.G. Faris

Bangladeshi and ICRISAT scientists collaborating on chickpea trials.

D.S. Murty

Regional sorghum scientists discuss sorghum trials with an ICRISAT breeder in Nigeria.

S.N. Nigam

Participants at a review and planning meeting in Hanoi—collaboration between AGLN and the Vietnamese national program.

Assistance to National Programs

Cereals Entomology

A Cereals Entomologist based at ICRISAT Center spent the 1989/90 cropping season at the Agricultural Research and Training Institute in Ilonga, Tanzania. His main objectives were to formulate and implement an entomological research program for the National Sorghum and Millet Improvement Programme and to train national entomologists in research procedures. These objectives were achieved through four activities.

- **Rearing of spotted stem borer in the laboratory.** An insect-rearing laboratory was established at Ilonga to study the spotted stem borer (*Chilo partellus*). Three generations of the insect pest were successfully reared on an artificial diet which simulated that of its natural host. Techniques were modified to suit local conditions.

- **Observation of the seasonal activity of major insect pests.** Insect pest populations and damage were monitored on sorghum. The major pest problems were found to be shoot fly, spotted stem borer, and midge.

- **Screening for host-plant resistance.** To create uniform and reasonably high shoot fly infestations, three techniques (delayed sowing, use of infester rows, and application of fishmeal) were used. These techniques increased the shoot fly population and exposed the test material to sufficiently high infestation for effective screening. Several sorghum genotypes in both shoot fly and stem borer nurseries showed good levels of resistance.

- **On-the-job training.** The entire research staff at Ilonga were trained in aspects of entomological research. Seminars and field visits organized to cover various research activities were well attended.

A Principal Cereals Entomologist, also based at ICRISAT Center, spent 2 weeks at Cameroon's National Cereals Research and Extension Program of the Institut de recherche agronomique in Maroua assessing the importance of insect pests on sorghum and millets. After conducting training in entomological research techniques and field evaluation procedures for field technicians, he visited Somalia to support ICRISAT's stem borer research and to interact with the International Centre of Insect Physiology and Ecology (ICIPE) and EARCAL staff in Ethiopia.

A third entomologist visited Ethiopia to introduce midge-resistance screening techniques for sorghum into national research programs. While helping Ethiopian scientists and technicians to adapt screening techniques used to determine insect resistance, he gained an understanding of regional pest problems and helped strengthen collaborative research in sorghum entomology.

Cooperation with National Sorghum Programs in Western Africa

Crop improvement

A cooperative project on screening for malting quality in sorghum was initiated between ICRISAT and the Department of Food Technology, University of Ibadan, Nigeria. Cooperation with several breweries in Nigeria continued. ICRISAT also cooperated with the Scottish Crop Research Institute, UK, to develop technologies for evaluating the malting quality of sorghum.

Seeds of elite hybrids and varieties were supplied in bulk quantities to the National Seed Service of Nigeria and to other interested national programs in the region including those of Mali, Burkina Faso, Côte d'Ivoire, and Niger.

H.C. Sharma

A sorghum scientist examining midge damage to sorghum in Ethiopia. Midge is one of the most important insect pests of sorghum in the semi-arid tropics.

A regional hybrid trial, the West African Sorghum Hybrid Adaptation Trial, was organized under the auspices of the West and Central African Sorghum Research Network (WCASRN) and the seeds were dispatched to 12 locations in the region.

Seeds of four short-duration varieties and four hybrids were contributed to the state trials conducted by the Institute of Agricultural Research (IAR) in northern Nigeria. ICRISAT assisted IAR in conducting these trials. Seeds of improved varieties were also supplied to two private large-scale farmers in Nigeria.

Agronomic and entomological trials were conducted jointly with IAR in Samaru, while physiological and agronomic studies were jointly executed on dry-season sorghum grown on Vertisols. Collaborative agronomic trials on multiple cropping systems were also run jointly with the International Institute of Tropical Agriculture (IITA).

Cooperative sorghum nurseries were evaluated at the Tarna Station in Maradi in collaboration with scientists from the Institut national de recherches agronomiques du Niger (INRAN).

Seeds of three short-duration and four medium-duration varieties and a hybrid were contributed to the multilocational trials conducted by IAR in Maroua, Cameroon.

Agricultural Seeds Limited, a seed company in Zaria, Nigeria, was assisted in experimenting with sorghum hybrid seed production. Seeds of four elite hybrids and their parents were also supplied.

Testing for insect-pest resistance

Reacting to the major insect pest problems in western Africa, and in anticipation of potential problems, WASIP-Nigeria and WASIP-Mali have collaborated with the national programs in the region. International nurseries for selecting sorghum germplasm resistant to four insect pests—shoot fly, stem borer, sorghum midge, and head bug—were established. This collaboration is particularly important in view of the increasing damage to farmers' fields caused by these pests.

Assistance to Southern African National Programs

Groundnut

The principal objective of the SADCC/ICRISAT Groundnut Project in Malawi is to provide national groundnut research teams with high-quality germplasm for their groundnut improvement programs or for direct commercial use.

The Project's germplasm collection of outstanding virginia, spanish, or valencia type groundnut lines of various origins are tested by the national programs to determine their adaptability to various conditions. National programs benefit by choosing optimal groundnut varieties for use in their particular countries and conditions.

Crossings conducted at the Chitedze Agricultural Research Station for both the Project and the SADCC national programs are followed by single plant selections during the early segregating generations and by bulk selections in advanced generations. Finally, the materials originating from crosses and imported lines are tested for productivity, quality, disease resistance, and other desirable traits (such as short duration and seed dormancy).

Promising lines from advanced experiments are sent to the national programs of SADCC countries as regional trials in order to determine their performance under various agroecological conditions.

In the 1989/90 season, 26 crosses were made for Malawi, 8 for Mozambique, 6 for ISC, and 106 for the Project. In 1990/1991, crosses were also made for Zambia for the first time.

National programs of Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe were again supplied with advanced virginia, spanish, and valencia breeding lines for evaluation in the 1990/91 regional trials. Germplasm was also made available to nongovernmental organizations. At Chitedze, 13 preliminary, advanced, and regional trials are scheduled during 1991. This includes four ICRISAT Center international cooperative trials.

Project scientists work with national program scientists to determine the various environmental conditions that can be exploited to select for certain qualities of particular importance to some countries or agroclimates. Botswana, for example, is favorable for screening drought resistance. Zambia has an advantage in testing for "pops" tolerance, and Swaziland for late leaf spot and rust. Delegation of regional responsibilities to those countries best suited to conducting the various types of research has proved to be one of ICRISAT's most successful strategies in assisting the national programs of southern Africa.

The breeding and plant pathology programs conducted by the Project are thus important to many southern African national programs, since the work is often beyond the means of a single national program.

Collaboration and networking is strengthened by regional activities such as groundnut workshops, specialists' group tours, individual visits, and steering committee meetings. The Fourth Regional Groundnut Workshop in March at Arusha, Tanzania, was very successful. Twenty-three national program scientists from the SADCC Region and representatives from Kenya, Mauritius, Uganda, ICRISAT Center, and ISC participated. Valuable papers were presented and subsequently prepared for publication. The workshop was followed by a Steering Committee Meeting.

Every other year, in alternation with the workshops, a specialists' group tour for either plant breeders and agronomists or plant protection specialists is organized for several SADCC countries by the Project.

Pearl millet

In southern Africa, ICRISAT provides assistance to national programs largely through collaborative regional trials. These trials are finalized at annual workshops. Increasingly, national scientists are contributing material to these trials.

Six short-duration pearl millet varieties were selected from regional trials grown the previous season. Average yields from four trials in the 1989/90 season were almost 3 t/ha. These yields compare favorably with 2.7 t/ha for the improved control and 2.5 t/ha for the local control.

Most long-duration entries are from western Africa. These varieties are best adapted in Zambia where IBMV 8502 had a yield of 3.7 t/ha, a 31% increase over the improved Zambian control and a 37% increase over the local controls.

Of pearl millet hybrids tested in Malawi, Tanzania, and Zimbabwe, SDMH 89016 was the best performer with an average yield of 2.9 t/ha, 38% better than the improved controls.

Finger millet

Four collaborative finger millet trials were conducted at a total of 32 locations in four countries. The results clearly indicated that varieties of different maturity types are required for different regions; short-duration for Zimbabwe, medium- and long-duration for Zambia and Malawi, and all types for different parts of Tanzania.

A joint project was initiated between Malawi's national program and SMIP to study breeding medium- to long-duration, high-yielding, and disease-resistant varieties of finger millet for food and malt. The breeding products derived from this project will be used in the breeding/testing programs of Malawi, Tanzania, and Zambia.

Forage

A collaborative cereal forage trial consisting of 12 entries was sown at 10 locations in six countries. Based on results from eight locations and a total of two cuttings, a sorghum variety, SDFS 103, produced the highest dry matter yield (7.9 t/ha), 7% more than Kawkandy, a released variety.

The highest-yielding pearl millet variety was SDMV 89101, which produced about 7.0 t/ha dry matter, 12% more dry fodder yield than Babala, the pearl millet control. SDMV 89101 is a selection from a wild pearl millet. Both varieties performed very well during the 1988/89 rainy season and were therefore recommended for wider testing in national trials.

Improving Short-Duration Pigeonpea for South Asian National Programs

Traditionally, farmers in South Asia sow medium- or long-duration pigeonpea as an intercrop, usually with cereals or cotton. Because progress in crop improvement has been slow, ICRISAT has shifted its attention to short-duration pigeonpea. Since 1984, when the first improved short-duration pigeonpea cultivar was released by the Indian national program, several others have been released.

On-farm performance potential and farmer acceptance studies are investigated with three objectives in mind.

- Identify specific cropping system niches where short-duration pigeonpea has either superior economic performance potential or is an attractive, alternative, low-cost crop technology.
- Evaluate farmer acceptance of improved cultivars in potential adoption zones.

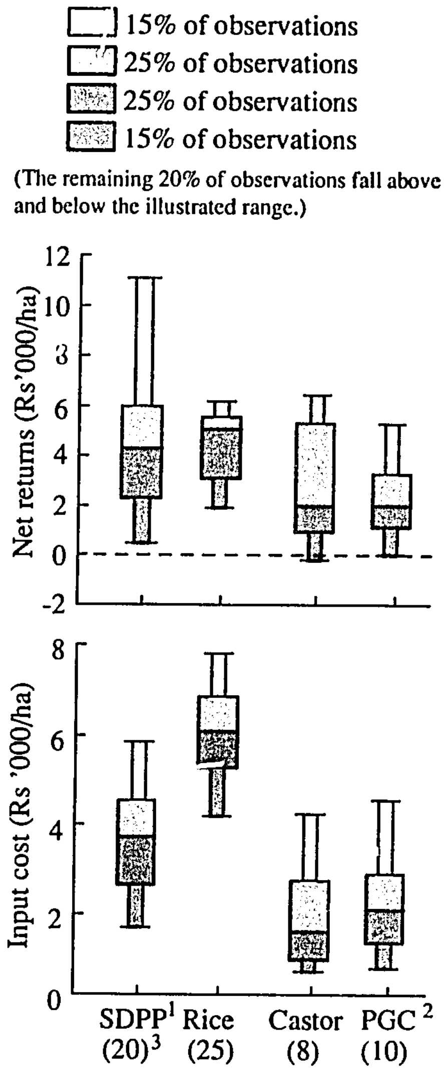


Figure 4. Distribution of cost and returns for irrigated crops at Aurepalle, 1987/88-1989/90.

1. Short-duration pigeonpea
2. Pearl millet, groundnut, and cotton.
3. Fields sampled.

- Assess the likely impact of short-duration pigeonpea cultivars on the agricultural sector and on different groups in society.

Results from on-farm adaptation trials in three ICRISAT village sites indicated that short-duration pigeonpea under rainfed conditions has only limited potential. The Aurepalle trials were typical (Fig.4). Major constraints were intermittent water deficits in shallow soils, waterlogging in deeper soils, and persistent insect pests. However, the potential for expansion into areas with uncertain supplies of irrigation water is good. Because of its significantly lower input costs, short-duration pigeonpea is an attractive alternative to high-input, high-return rice cultivation.

Based on reports from the Indian national program, rural reconnaissance surveys, and seed sales and distribution data, adoption of short-duration pigeonpea cultivars has yet to "take off". Nevertheless, the potential for expansion in many areas is good provided an effective means of controlling insects--primarily *Helicoverpa*—is found. Both agricultural officers and farmers consider this the single most important production problem in the cultivation of short-duration pigeonpea. Renewed efforts to incorporate greater tolerance for *Helicoverpa* should be given top priority. Ultimately, more attention should be given to screening genotypes for drought tolerance. The development of a drought-tolerant cultivar with moderate yield potential could have a tremendous impact that would specifically benefit resource-poor farmers throughout the semi-arid tropics.

Networking

ICRISAT's networks are mechanisms for exchanging technologies and information with national programs in specific regions. By the end of 1990, ICRISAT was an active participant in six networks—three in Africa (EARSAM, WCAMRN, and WCASRN), two in Asia (AGLN and CCRN), and one in Latin America (CLAIS). These six networks are briefly described below.

Asian Grain Legumes Network (AGLN)

Established: 1986

Coordination from: ICRISAT Center, India

Aim: To facilitate the interchange of material, information, and technology between scientists in Asian countries and at ICRISAT Center.

Membership: 800 members in 11 countries

Bangladesh	Myanmar	Sri Lanka
China	Nepal	Thailand
India	Pakistan	Vietnam
Indonesia	Philippines	

Major Activities

- Bilateral planning for collaborative research
- Coordination of germplasm supply, breeding materials, and trials
- Exchange of visiting scientists
- Organization of workshops, meetings, monitoring tours, surveys, and training courses
- Technical and financial support for regional research programs

1990 Highlights

- Bilateral meetings in Bangladesh, Indonesia, Nepal, Philippines, and Sri Lanka
- Working Group Meeting on "Host-selection behavior of *Helicoverpa armigera*" in March at ICRISAT Center
- Working Group Meeting on "Bacterial wilt of groundnut" in April at Genting Highlands, Malaysia
- Coordinators' Meeting in December at ICRISAT Center

Cooperative Cereals Research Network (CCRN)

Established: 1988

Coordination from: ICRISAT Center, India

Aim: To ensure that improved sorghum breeding lines and hybrids developed anywhere are available to national programs in the semi-arid tropics.

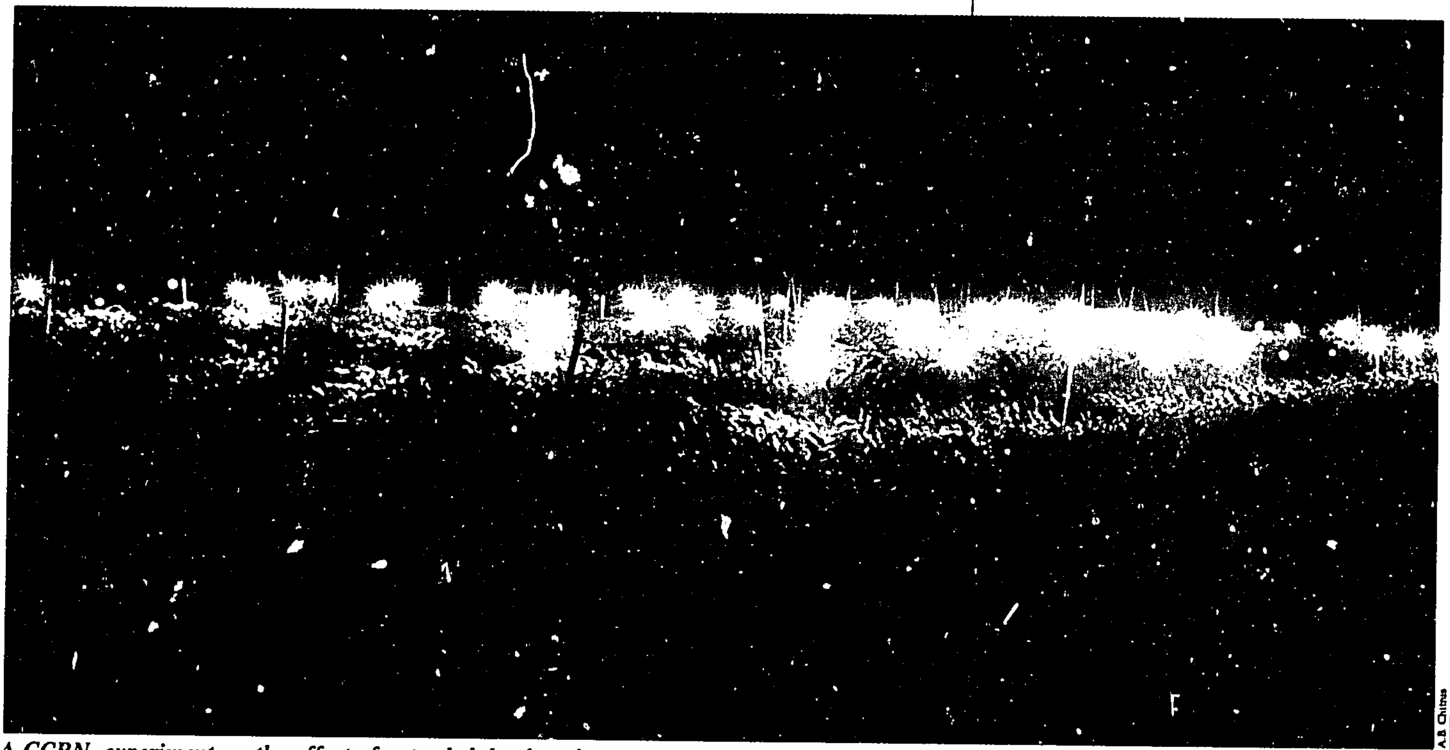
Membership: Global

Major Activities

- Organization of international trials and nurseries
- Coordination of ICRISAT's regional sorghum research network in Asia
- Characterization of the environments of sorghum test locations to improve efficiency of international testing

1990 Highlights

- Sorghum trials in Asia, Africa, and Latin America
- Nurseries dispatched to Indonesia, Philippines, Thailand, and regional programs in Africa and Latin America



A CCRN experiment on the effect of extended day length on sorghum development at ICRISAT Center.

Comisión Latinoamericano de Investigadores en Sorgo (CLAIS)

Established: 1982

Coordination from: LASIP, El Batán, Mexico

Aim: To improve sorghum cultivars to meet the needs of large- and small-scale sorghum producers in Latin America.

Membership: 10 Latin American countries

Costa Rica	Honduras	Haiti
Dominican Republic	Mexico	Puerto Rico
El Salvador	Nicaragua	
Guatemala	Panama	

Major Activities

- Coordination of regional trials and nurseries
- Organization of field days for farmers and regional scientists

1990 Highlights

- Annual Workshop in April at El Batán (combined with LASIP's first field day for public and private sectors)
- One variety trial, one hybrid trial, one variety observation nursery, one hybrid observation nursery, and one hybrid parental lines trial
- Release in Nicaragua of Pinolero I, sorghum variety reselected from SPV 475

Eastern Africa Regional Sorghum and Millets Network (EARSAM)

Established: 1986

Coordination from: EARCAL, Nairobi, Kenya

Aim: To strengthen ties between the national agricultural research systems of eastern Africa through the exchange of scientific results, experiences, and germplasm, and to share responsibilities for common problems.

Membership: 8 countries

Burundi	Rwanda	Tanzania
Ethiopia	Somalia	Uganda
Kenya	Sudan	

Major Activities

- Development of improved varieties and hybrids of sorghum and millets that will result in high and stable yields
- Development of agronomic and conservation practices that enhance crop production
- Adaptation or development of screening techniques
- Organization of cooperative testing of elite cultivars
- Development of collaborative research projects with strong national programs
- Assistance to national programs in human resource development
- Organization of regional workshops, monitoring tours, and field days

1990 Highlights

- Regional advanced elite yield trials
- Organization of regional preliminary observation nurseries
- Seed distribution to national programs
- International nurseries from both ICRISAT Center and USA provided to regional partners
- Seventh EARSAM Regional Workshop at Nairobi in June

S. Appa Rao

A Ugandan farmer selecting material for next year's crop.

West and Central African Millet Research Network (WCAMRN)

Réseau ouest et centre africain de recherche sur le mil (ROCAFREMI)

Established: 1990

Coordination from: ICRISAT Sahelian Center, Sadoré, Niger

Aim: To strengthen pearl millet research at national agricultural research institutes in the region.

Membership: The Insitut du Sahel (INSAH) of the Comité permanent inter-Etats de lutte contre la sécheresse dans le Sahel (CILSS), Semi-Arid Food Grain Research and Development (SAFGRAD), and 13 countries

Benin	Gambia	Niger
Burkina Faso	Ghana	Nigeria
Cameroon	Guinea Bissau	Senegal
Chad	Mauritania	Togo
Côte d'Ivoire		

Major Activities

- Technical and financial support for the regional program on pearl millet
- Planning and coordination of the regional research program on pearl millet
- Organization of workshops, meetings, monitoring tours, surveys, and training courses
- Exchange of visiting scientists

1989/90 Highlights

- First meeting of the Steering Committee held at ICRISAT Sahelian Center (Dec 1989)
- Regional workshop in September 1990 of all member countries, INSAH/CILSS, SAFGRAD, ICRISAT, and donors to prepare a document on the constraints to production and staff and facilities available for research on pearl millet improvement

West and Central African Sorghum Research Network (WCASRN)

Réseau ouest et centre africain de recherche sur le sorgho (ROCARS)

Established: 1986

Coordination from: WASIP-Mali, Bamako, Mali

Aim: To address the sorghum improvement problems of western Africa, concentrating on human resource development and strengthening the region's national agricultural research systems.

Membership: 17 countries

Benin	Côte d'Ivoire	Mauritania
Burkina Faso	Gambia	Niger
Cameroon	Ghana	Nigeria
Central African Republic	Guinea	Senegal
Chad	Guinea Bissau	Sierra Leone
	Mali	Togo

Major Activities

- Development of improved sorghum varieties and hybrids
- Development of agronomic/management practices that give higher and more stable yields
- Development of human resources among western African nationals at all levels
- Organization of regional workshops and field inspections

1990 Highlights

- Variety and hybrid adaptation trials
- *Striga* trials
- Leaf disease nursery trials
- Steering Committee Meetings in May (in Niamey, Niger) and December (in Bamako, Mali)

Technology Exchange

Western Africa

Prototype of a donkey-drawn hoe

Labor bottlenecks occur during weeding in nonmechanized agriculture. The mechanization of this operation by animal-drawn implements reduces weeding time and increases crop yield.

In collaboration with the University of Hohenheim, Germany, ISC staff designed an inexpensive labor-saving weeding device for resource-poor farmers.

A prototype of a donkey-drawn hoe called the 'HATA' (*houe à traction asine*) was developed and tested at ISC (Fig.5). It consists of a triangle fixed with three Iler blades (traditional hand tools for weeding) and a handle to guide the implement. The concept was based on the premise that the implement could be manufactured locally.

In experiments at ISC, traditional hand hoe weeding was compared with weeding with various animal-drawn implements. Results showed significant reductions in labor time. The HATA design was subsequently improved for better depth control by attaching a front skid to turn aside crop residue and other debris on the field, thus facilitating the unhampered performance of the cutting blades. Manufacturing costs are marginal since the skid can be fabricated from scrap material.

After 11 prototypes were distributed in villages in the arrondissements of Say, Tera, Tillabery, Ouallam, and Filingué, 66 models were manufactured by local blacksmiths. The ability of village blacksmiths to manufacture the implement was promising. Although not all of them were able to do the work satisfactorily, capable craftsmen could always be found in neighboring villages. All workshops were equipped with simple tools and none had welding equipment.

Figure 5. The 'HATA'–technology exchange in the Sahel.

Weeding time of both manual and mechanized plots was measured in farmers' fields. Both techniques required the labor of one adult, often accompanied by a child. Mechanized weeding averaged 52% reduction less labor time.

Participating farmers were questioned about implement design and animal harnessing. General response was positive. The farmers were pleased with the reduced labor time. Indeed, the second passage usually required with the manual system during thinning operations was rendered unnecessary by the HATA.

Further on-farm evaluation of the HATA will emphasize design improvements as well as managerial and economic aspects.

Technology transfer

A short training course in sorghum hybrid seed production techniques was conducted during early September 1990 (for the second successive year) for 12 Nigerians drawn from national research institutes, private and public sector undertakings, and the National Seed Service.

The second in a series of meetings between WASIP-Nigeria and sorghum scientists in eight western African countries was held in Kano, Nigeria, in September.

Summary proceedings of an IAR/ ICRISAT symposium on the "Industrial Utilization of Sorghum", which was held in Nigeria in December 1989 was published in English and French.

Southern Africa

Seed multiplication and exchange

For the 1990/91 Regional Collaborative Trials, national program scientists from

Zambia produced 45 kg hybrid and 20 kg variety seeds and Zimbabwean scientists contributed 36 kg seeds for both varieties and hybrids. Twelve kilograms of variety seeds were contributed by the national program of Botswana, 14 kg by Malawi, and 2 kg by Swaziland. SMIP scientists produced 52 kg of hybrid sorghum and 38 kg of sorghum variety seeds.

Another batch of 3 tonnes of breeder's seed required for purposes ranging from screening for disease to industrial quality testing were produced at Matopos. These seeds were sent regionally to Botswana, Lesotho, and Malawi; and internationally to Sudan, Jamaica, and the USA. Some were also made available to other departments within the regional program at Matopos.

During 1990, SMIP processed 54 individual seed requests to 12 countries in three continents. The requests ranged from 0.21 kg to 10.6 t. The total number of seed samples distributed was 2122. Some 60 farmers in Zimbabwe received cuttings of an interspecific hybrid of pearl millet and napier grass from the regional program for use on their farms.

Striga

Striga is a severe problem in Tanzania. Two years of testing at Ukiriguru indicate that the sorghum variety SAR 29 and the hybrid SPL 38A × SAR 29 support a significantly lower level of *Striga* compared with the trial mean and the susceptible control. SAR 19 has also shown promising resistance to *Striga* but these results require confirmation.

Food technology

From March to September, two interns from the Biotechnology Program of the University of Zimbabwe served 8-month internships with the Food Technology Unit. The internship program is now established as a continuing activity of the Unit. In addition, one student from the University of Zimbabwe completed a 3-month vacation assignment with the Unit.

Botswana's Food Technology Research and Technology Services requested funding assistance for training a laboratory technician at Bulawayo Polytechnic, to be followed by a 6-month practical training course within the SADCC/ICRISAT Food Technology Unit.

Technical and laboratory backup and components of training in sensory evaluation and consumer testing were provided to the Botswana Weaning Food Project.

Hands-on training in laboratory procedures and research guidance and funding was provided to a University of Zimbabwe MSc student on a collaborative project on sorghum substitution in poultry feeds.

Pigeonpea Technology Exchange

The demand for extra-short-duration and short-duration pigeonpea lines continued in 1990 as over 40 countries requested a total of 1382 lines. ICRISAT also provided 341 medium- and 175 long-duration lines. Yield data of 42 international replicated trials were received from 21 countries. The yields exceeded 2 t/ha in 12 of those trials, and over 1 t/ha in 17 of them. The highest yields were recorded in Peru, Venezuela, and Vietnam.

Hybrid pigeonpea

A new milestone for pigeonpea breeding and production was achieved in 1990 with the identification of ICPH 8, the first pigeonpea hybrid accepted by the ICAR for future release in India. Because pigeonpea is predominantly a self-pollinated legume crop, farmers grow either pure line varieties or landraces. The pure lines, particularly those of short duration, although more productive than the landraces, are noted for poor yield stability.

Pioneering research by ICRISAT scientists led to the development of several high-yielding hybrids, among which ICPH 8 is particularly important. The hybrids demonstrated both high yield potential and remarkable yield stability. However, the cause and nature of the stability mechanisms of ICPH 8 have not yet been identified. Its excessive vegetative vigor and susceptibility to wilt disease are its weak points.

Seed production

Hybrid seed production was taken up by six Indian private-sector seed companies in 1990 and several more have requested seed of the male-sterile and fertile parents. The area under seed production among the six companies is about 275 ha in Gujarat, Maharashtra, and Tamil Nadu.

Transfer of hybrid pigeonpea breeding technology

A hybrid pigeonpea network comprising 11 national system collaborators and a seed company has achieved substantial capability for hybrid pigeonpea research. Independent research programs based on ICRISAT materials and technology have been developed by Gujarat Agricultural University, Punjabrao Krishi Vidyapeeth in Akola, the Directorate of Pulses Research in Kanpur, the Indian Agricultural Research Institute in Delhi, and Tamil Nadu Agricultural University in Coimbatore. These institutions have developed their own hybrids and are also transferring male sterility to locally adapted cultivars. They have also motivated seed companies to commercialize the production and distribution of hybrid seed.

Farmers threshing bumper harvest of perennial pigeonpea in Maharashtra.

Nepal

Sterility mosaic disease is a serious constraint to pigeonpea production in Nepal. The country's best-adapted cultivar, Nepalganj Local, is a good yielder but is highly susceptible to the disease. To incorporate resistance into this variety, a backcross program was initiated at the ICRISAT Cooperative Research Station at Gwalior during the 1989/90 rainy season. The second backcrossing was continued in 1990.

ICRISAT pigeonpea scientists have developed and made available seven trials for the 1990/91 season, in addition to 70 advanced lines for testing. ICRISAT has also supplied 100 kg seed of ICPL 366 for on-farm testing at different locations in Nepal.

Five international yield trials were also evaluated under the ICRISAT/Nepal Grain Legume Improvement Program. Heavy rains in western Nepal from mid-December 1989 to early January 1990 affected the yield of medium- and long-duration pigeonpea. In the short-duration trial, however, ICPL 5027 produced over 1 tonne of dry grain, significantly more than all other cultivars except the Rampur Local.

Extra-short-duration pigeonpea was introduced to Nepal to overcome the problems resulting from cold weather after November. Since sowing was delayed, harvesting extended into the cold period. Nonetheless, ICPL 87105, ICPL 86005, and ICPL 87101 yielded 0.7 to 0.9 t/ha.

Local pigeonpea grown on the edge of a ricefield in Sarlahi District, Nepal.

Sri Lanka

The evaluation of ICRISAT's finished pigeonpea lines was continued during the 1989/90 rainy season in Sri Lanka at several dry zone locations and the mid country. An ICRISAT scientist was posted to Sri Lanka for 6 months in 1990 to assist in the evaluations, to cooperate with Sri Lankan scientists, and to participate in on-farm testing of selected cultivars.

Promising lines were tested in farmers' fields under a scheme called the People's Participation Programme. The farmers were given decision-making and management responsibilities under the guidance of extension workers. Because farmers in the target area were very impressed with the crop, the testing will be extended to other areas.

The processing of pigeonpea into *dhal* is new to Sri Lanka. Exploratory processing studies were conducted by national engineers. They have also embarked on a program to develop processing facilities that will include modifying the existing rice mills and developing dehulling machines similar to those supplied by ICRISAT for use at the village level.

Chickpea Improvement in South Asia

ICRISAT's contacts with the national agricultural research systems in South Asian countries have been strengthened through chickpea improvement work. Cooperation with Bangladesh, Myanmar, and Nepal has increased through regular exchange of ideas, visits, and materials.

Farmers and national scientists discussing pigeonpea with ICRISAT networkers during on-farm demonstrations in Sri Lanka.

ICCV 2 in Myanmar.

Bangladesh

The Pulses Program of the Bangladesh Agricultural Research Institute cooperates closely with ICRISAT to improve both chickpea and pigeonpea. Bangladesh (which does not grow kabuli chickpeas at present) may soon be able to cultivate kabuli lines ICCL 83007 and ICCL 83008. These are presently being tested in farmers' fields.

A Bangladeshi national scientist in a field sown with elite chickpea breeding lines supplied by ICRISAT.

Myanmar

Close cooperation between the Myanmar Agricultural Research Service and ICRISAT resulted in the release of two chickpea cultivars in that country. ICCV 2 (Swetha), a short-duration kabuli cultivar, was identified for farmers' field tests in the delta region. Several breeding lines are presently in advanced yield trials.

Nepal

Cooperation between Nepal's National Grain Legume Research Program and ICRISAT was strengthened with the inception of AGLN in 1986. Since then, there has been a regular exchange of breeding materials and information. Two cultivars—ICCC 6 (ICCC 32), a wilt-resistant kabuli, and ICCL 82108, a wilt-resistant double-podded type—gave excellent performance in farmers' field trials in 1989/90. They were released to farmers by the Variety Release Committee of Nepal: ICCV 6 as Koseli, ICCL 82108 as Kalika.

Publications and exchange of visits

The proceedings of an international workshop on "Chickpea in the nineties", which was held in December 1989, were published and distributed to chickpea workers, policy planners, and libraries throughout the world. The publication contains the latest information on chickpea research and development work. A booklet entitled **How to Grow Chickpea in Eastern Africa** has been published in English, Arabic, and Swahili to help research and development of the crop in that region. Plant Material Descriptions on five releases (ICCV 2, ICCV 5, ICCV 6, ICCV 7, and ICCC 37) were also published during 1990.

Cooperation with AICORPO and other Programs in India

Currently 16 ICRISAT groundnut varieties are included in the rainy-season All India Coordinated Research Project on Oilseeds (AICORPO) trials and three in the postrainy-season trials. During 1990, the Central Subcommittee on Release of Varieties of the Government of India formally notified the release of three ICRISAT groundnut varieties: ICGV 87119 for the northern zone, ICGV 87160 for cultivation in peninsular India during the rainy season, and ICGV 87187 for postrainy-season cultivation in Gujarat, Madhya Pradesh, and northern Maharashtra. The Uttar Pradesh State Varietal Release Committee released three groundnut varieties, ICGV 87119, ICGV 87121, and ICGV 87123, for rainy-season cultivation.

A total of 260 samples of released varieties and advanced breeding lines were supplied to 43 national scientists and 22 private seed companies in India during 1990. These include large quantities of breeders' seed of released ICRISAT varieties to various agencies. In addition, small seed samples of released varieties were directly supplied to 269 farmers.


L. Vidyasagar

Checking a groundnut germplasm accession for healthy and uniform plants.


C.L.L. Gowda

Farmers in Long An Province, Vietnam, with their groundnut harvest. Yield increases brought about through collaborative on-farm trials keep these farmers smiling.

Sustainability

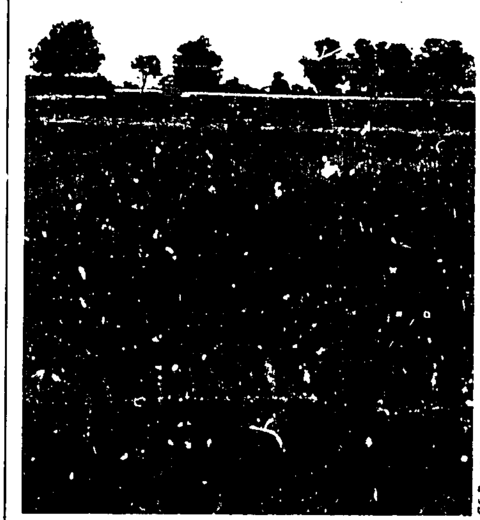
Although the achievement of 'sustainability' has become one of the major objectives of agricultural research worldwide, a definition is needed to introduce this section because the term has been interpreted in many different ways.

A sustainable system of agriculture is one in which the long-term trend in output is (a) positive and (b) achieved without damaging the environment in a way that threatens the viability of the system.

Much of ICRISAT's work is directed to the central problem of maintaining or increasing yield by using renewable resources such as rainfall more efficiently without degrading nonrenewable resources such as soil.
This section of the report deals in diverse ways both with biological productivity and with environmental protection. It covers the development of high-yielding varieties resistant to the biotic and abiotic stresses that prevail where ICRISAT scientists work, the identification and testing of cropping systems that maximize outputs when inputs are constrained, the management of soils to conserve rainfall where it falls, and the manipulation of microorganisms and of organic matter for the long-term improvement of soil fertility.

Let us give Nature a chance; she knows her business better than we do.

Michel Eyquem de Montaigne, 1533-92



A groundnut crop sown in the broadbed-and-furrow system in Andhra Pradesh.

Sustainable systems for the farmer: top—pearl millet heads on a drying platform in an Indian village; bottom—pigeonpea fodder for cattle.

Crops in Sustainable Systems

Groundnut Production

Southern Africa

The importance of legumes in general and groundnut in particular for sustainability in small-scale agriculture in southern Africa was confirmed at the Fourth Regional Groundnut Workshop for Southern Africa, which was held in March at Arusha, Tanzania.

Creating high-yielding and disease-tolerant varieties such as ICGMS 42 is crucial to sustainability in agriculture. The willingness of farmers to produce groundnut depends largely on the economics of the crop's production. A highly productive variety that fetches a high price for its quality will encourage farmers to produce more groundnut. The low prices for mediocre harvests over the last few years have resulted in a decline in groundnut production in SADCC countries. The Government of Malawi, reacting to changing market trends in overseas confectionery requirements, approved the release of ICGMS 42.

Experiments are being carried out in Malawi to assess the value of groundnut as a rotation partner with cereals. In Zimbabwe, commercial farmers have expressed interest in growing ICGMS 42 commercially, and a limited quantity of seed was multiplied in the 1990/91 cropping season. Increased groundnut production will contribute to a sustainable cropping system.

In the 1989/90 season, a combined intercropping and crop rotation experiment was initiated at Chitedze Agricultural Research Station in Malawi. It included one maize variety and four groundnut varieties sown as sole crops and in maize/groundnut intercropping combinations. The residual effects of these first-season treatments will be tested in 1991. Important differences between groundnut varieties, especially with regard to their suitability for intercropping. were identified.

Another 1990/91 development in agronomy was initiated by the national programs. Intercropping and crop rotation experiments were combined with maize/groundnut (Zambia), or with maize/groundnut/pigeonpea (Chitedze, Makoka, and Karonga in Malawi).

Sustaining Groundnut Production

Groundnut is the most widely cultivated of ICRISAT's mandate crops. Top, an HRDP 6-month participant from Vietnam harvesting at ICRISAT Center. Bottom, a farmer with ICGS 76 grown on the narrow-bed system in Maharashtra.

ICRISAT Center

Short-duration varieties. Development of short-duration groundnut varieties is an important consideration for not only rainfed areas with short rainy seasons, but for multiple-cropping systems and residual moisture situations.

The results of the 1989/90 postrainy-season trials have helped to identify four early varieties that significantly outyielded the popular Indian variety J 11 both at ICRISAT Center and in farmers' fields. The best variety, ICGV 87876, gave a pod yield of 2.3 t/ha in 115 days while J 11 yielded only 1.9 t/ha.

A total of 15 varieties harvested 75 days after sowing and 10 varieties harvested 90 days after sowing proved superior to the local control. Two widely adapted varieties with higher mean yields across six locations, ICGV 87885 and ICGV 87883, were identified.

Medium- and long-duration varieties. These varieties, which occupy a major portion of groundnut area in the semi-arid tropics, are characterized by diverse agroecological conditions. To generate populations suitable for such varied conditions, 39 adapted varieties from India, Indonesia, Malaysia, Nepal, Philippines, Sri Lanka, Sudan, and Vietnam were crossed with varieties resistant to or tolerant of pests, diseases, and drought.

Three sequentially branching varieties, ICGV 87152, ICGV 86928, and ICGV 86953, showed consistently superior performance over recently released groundnut variety ICGV 87123 for 2 years in the 1988/89 and 1989/90 postrainy-season trials. ICGV 86928 also yielded well in the rainy-season multilocational trials, indicating its suitability for both rainy- and postrainy-season cultivation.

Legumes Program Breeders identified two sequentially branching varieties, ICGV 88312 and ICGV 88329, which were consistently better than the local control JL 24 for 2 years in multilocational rainy-season trials.

An alternately branching variety, ICGV 88308, gave the highest mean yield in the multilocational rainy-season trials and performed equally well in both red and black soils at ICRISAT Center.

Chickpea Production

Chickpea is the world's third most important pulse crop and a major source of protein in many developing countries. It is grown annually on about 10 million ha. The crop is cultivated mainly under rainfed conditions with receding soil moisture and therefore has low productivity. Many biotic and abiotic stresses affect its yield and adaptation.

Extending chickpea adaptation to early sowing

On the Indian subcontinent and in eastern Africa some areas remain fallow during the rainy season because the land cannot be cultivated. Under these situations relatively early sowing of chickpea is possible, thus providing better soil moisture for growth. Advancing the sowing date by 1 month can give yield increases of about 25%. Experiments at ICRISAT Center have established that yield levels of over 2 t/ha may be achieved by sowing in early August. However, a disease called colletotrichum blight can cause heavy damage because of the high humidity and temperature prevailing during those months. Legumes Program scientists have been able to select lines that can tolerate this disease. Their yield potential is being assessed.

Extra-short-duration varieties as catch crops

Chickpea is normally grown as a postrainy-season crop. ICRISAT has developed extra-short-duration varieties that mature in 70–80 days in residual soil moisture in lower latitudes. These varieties can be grown as catch crops between two main season crops. ICCV 2, ICCV 88201 and ICCV 88202 have shown considerable flexibility in sowing time, yielding up to 1 t/ha in less than 3 months, after which another crop can be sown. If irrigation is available, a second chickpea crop can be grown. Flexibility of sowing times of these lines may allow their cultivation in other rotations as well.

Phosphorus

Role of pigeonpea in improving phosphorus uptake

Japanese scientists assigned by their Government to work on phosphorus uptake at ICRISAT Center have identified the presence of piscidic acid in the root exudate of pigeonpea. This acid was found to dissolve iron-bound phosphate in an Alfisol. Piscidic acid has been known to be present in hypnotic and narcotic drugs extracted from the Jamaica dogwood tree (*Piscidia erythrina*). However, these substances have not been studied in relation to the phosphorus-absorption ability of roots. Piscidic acid and its derivatives were not present in the root extracts of sorghum and soybean.

On Alfisols, pigeonpea grows better than sorghum without phosphorus fertilizer and does not respond so much as sorghum to phosphorus fertilizer addition. This indicates the advantage of pigeonpea in low-phosphorus soils.

Residual effects of fertilizer phosphorus

Studies on the residual effects of phosphate applications are carried out by the Resource Management Program at ICRISAT Center to improve the understanding of the behavior of phosphorus in Vertisols (black soils). This research was initiated after the discovery that the critical limit for the standard predictive soil test was much lower for Vertisols than for other soils in India.

In carrying out this research, plant responses to current applications of phosphorus and to the residual effects from previous seasons are compared. This approach leads to a more complete understanding of the effectiveness of previous phosphate application than does the measurement of residual effects alone.

The response to fertilizer phosphorus on Vertisols was markedly greater than the response with higher rates (40 kg/ha phosphorus) of application in previous years. Yield without added phosphorus treatment increased from 0.2 t/ha where no phosphorus had been added previously, to 2.3 t/ha where 40 kg/ha phosphorus had been added in previous years. The yield with 40 kg/ha phosphorus applied in the current year was 3.3 t/ha.

Crop phenology was markedly affected by phosphorus nutrition. The attainment of physiological maturity was delayed by as much as 33 days under the most extreme phosphorus deficiency.

Studies are continuing to quantitatively assess the residual effects of phosphorus on predictive soil tests and on diagnostic tissue tests.

Yield Declines in Rotations

A long-term rotation experiment on a Vertisol at ICRISAT Center, initiated in 1983, compares favorably the productivity and nitrogen economy of several cropping systems (Fig.6). These systems include both "traditional" treatments (in which the land remains fallow during the rainy season) and "improved" treatments (in which the land is cropped in both rainy and postrainy seasons). The rotations consist of various combinations of cropping systems lasting up to 2 years.

After a few years, it became apparent that the residual effects of legumes on subsequent crops of rainy-season sorghum were consistent between years. Responses were more variable in the

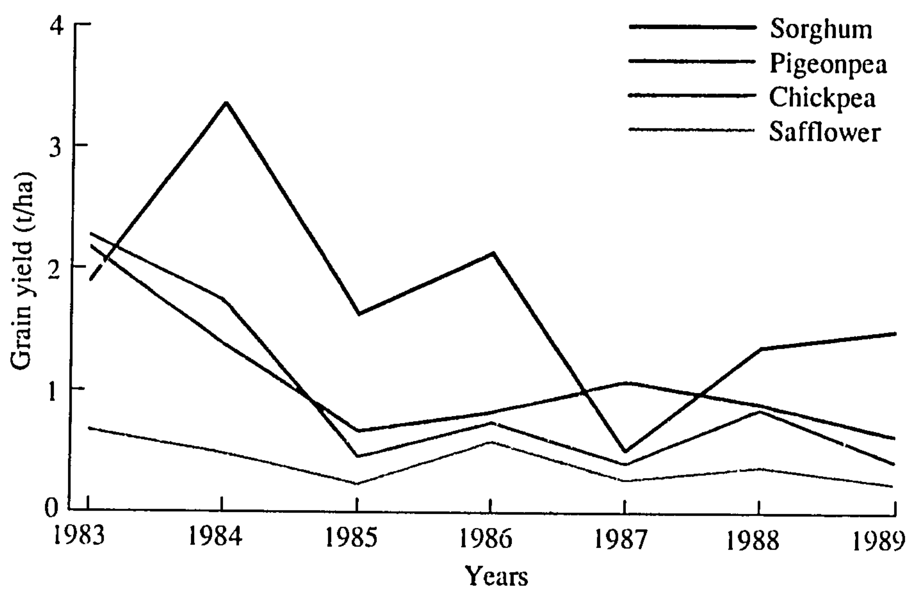


Figure 6. Yield declines in rotations.

postrainy season due to high rainfall variability and the effects of pests on crop yields. However, the 7-year cropping history provided a sufficient range of seasons and crop yields to allow an initial appraisal on the control subtreatment where no nitrogenous fertilizer was added.

Yields of all the postrainy-season crops declined with time. The decline was least for sorghum and greatest for chickpea and pigeonpea, whose grain yields decreased from over 2.1 t/ha in 1983 to less than 0.9 t/ha in 1988 and 1989. The causes of the declines are not yet fully resolved, but pests and diseases appear to be the main factors.

Chickpea yields were affected by fusarium wilt, pigeonpea yields by phytophthora blight, and safflower yields by soilborne fungi. The severity of pest attacks and yield reductions in pigeonpea and safflower were increased by a greater frequency of these crops in rotations.

These rotation experiments were initiated mainly to quantify the residual effects of nitrogen from legumes. This work is proceeding, but clearly the need exists to expand research on the biological components in rotations.

Intercropping Systems

Sorghum/soybean

In the intermediate rainfall zones (500-900 mm per year) of western Africa, the sorghum/soybean intercropping system has potential with short-duration varieties.

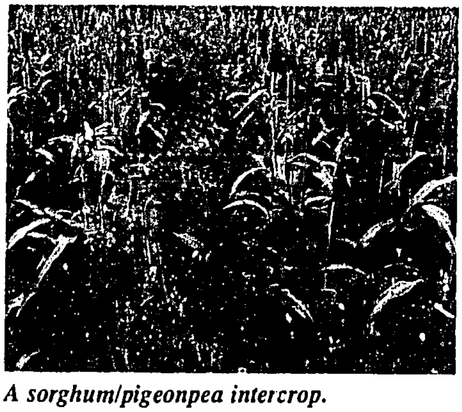
Continuing their collaborative work with the International Institute of Tropical Agriculture (IITA) on sorghum/soybean intercropping, ISC agronomists evaluated the system using three sorghum varieties, (two ICRISAT varieties and a local landrace), one short-duration soybean variety, and three row arrangements. The trial was sown on 8 July.

While soybean intercropped with the local landrace gave a yield advantage of 26%, the two ICRISAT varieties gave only a 1% yield advantage. Drought caused reduced grain yields in all varieties.

Sorghum/pigeonpea

Pigeonpea is a multipurpose crop that can provide food, fuelwood, and fodder in subsistence agriculture. It also enhances soil fertility and its deep rooting pattern enables it to exploit available moisture at greater soil depth. Its multipurpose end use makes it attractive and economical to the resource-poor farmer.

A system was evaluated at ICRISAT Center using three sorghum cultivars and three pigeonpea cultivars in an alternating row arrangement. Two of the sorghum cultivars did not produce any grain due to drought. The individual land equivalent ratios of sorghum cultivars were larger than the expected value of 0.5, whereas pigeonpea ratios were less than 0.5, implying that yield was depressed, probably because of drought and insect damage. The system as a whole did not give a yield advantage.



A sorghum/pigeonpea intercrop.

Water Use of Agroforestry Systems

Previous ICRISAT studies have concentrated on the water use of various tree species that compete strongly with crops for water. Current attention has turned to examining the water use of perennial pigeonpea, which has been explored for agroforestry uses.

Transpiration is measured in trees using the heat pulse system.

It is widely assumed that agroforestry systems increase productivity because they utilize more water than annual cropping systems. The first mechanism that enhances water use by trees is the utilization of off-season rain when there is no scope for cropping. Another mechanism is to increase the proportion of rainfall during the rainy season used for transpiration, since losses by direct evaporation, runoff, or deep percolation are large. For example, on the red soils of the Deccan Plateau of India, a traditional intercrop of sorghum/pigeonpea utilizes only 41% of the annual rainfall. The rest is lost as runoff (26%) or deep percolation (33%).

To investigate this hypothesis, the transpiration of perennial pigeonpea cultivar ICP 8094 was measured in an agroforestry system consisting of one row of pigeonpea to four rows of groundnut. The measurements were taken using a new nondestructive heat balance technique in collaboration with Washington State University, USA. Measurements were taken from December 1988 to November 1989 on 1-year-old perennial pigeonpea on a shallow Alfisol at ICRISAT Center.

Total annual transpiration amounted to 887 mm, 84% of the annual rainfall, twice the value reported for the most productive intercropping system. A large proportion of the total transpiration (416 mm or 47%) occurred from January to June when only 211 mm of rain were received, indicating that 205 mm were extracted from soil reserves. In the wet season, an excess of 420 mm was lost as runoff and percolation from July to November, a proportion similar to that lost using the sorghum/pigeonpea intercropping system. But the amount attributed to deep percolation (33%) cannot be considered lost since a substantial quantity (205 mm) was extracted by perennial pigeonpea from soil reserves during the dry season. Water use efficiency, calculated as the ratio of above-ground biomass to water transpired, was only 4.5 kg/ha per mm in the dry season (February to June), but increased nearly five-fold to 26.2 kg/ha per mm during the rainy season.

Because of the narrow (1.2 m) pigeonpea alleys in this agroforestry system, the groundnut yield was reduced to 65% of sole groundnut, implying that a lower population of pigeonpea would be more appropriate. Such a system is more typical of the traditional intercropping and agroforestry systems in the semi-arid tropics. For example, in the Anantapur district of Andhra Pradesh (annual rainfall 560 mm), a 4-6 m annual pigeonpea alley system is commonly intercropped with groundnut.

In collaboration with the University of Nottingham, UK, the water use and productivity of two spatial arrangements of perennial pigeonpea/groundnut intercrops were measured using line sowing (5.6 m pigeonpea alleys) and dispersed spacing (1.8 × 1.2 m). Transpiration measurements with the heat balance technique were taken between November 1989 and December 1990. During the dry season, there was no obvious difference in transpiration between the two intercrop arrangements. This was also apparent in biomass production. Treatment differences became obvious at the end of the dry season when dispersed sowing produced almost double the fodder yield of the alley crop. During the 1990 rainy season this treatment effect became progressively larger and almost five-fold differences in maximum transpiration rate were observed.

As control of runoff and erosion is of considerable concern, runoff plots with automatic tipping buckets were installed. During intense rainstorms, up to 30% of rainfall was lost as runoff from the sole pigeonpea plots. This loss would be expected to reduce dry-season fodder production. A maximum runoff of 5% was recorded in the other plots, with no significant response to treatment.

There was no significant reduction in the intercrop groundnut yield in 1989 compared with the sole crop. In 1990, however, when pigeonpea plants were larger, there was a 20% reduction in groundnut pod mass both in the line-sown crop and in the dispersed arrangement.

To examine the mechanisms responsible for the remarkable water use and productivity of the dispersed sowing treatment, the root system was excavated in December 1990. The root distribution of the dispersed treatment covered virtually the whole 2 × 2 m soil profile, whereas the root distribution in the line sowing covered only about 30% of the same soil profile. The results also support the observation that reduction of groundnut yield was significantly higher in the dispersed treatment.

Measurements of these systems will form the basis for the assessment of the sustainability of agroforestry systems in the semi-arid tropics. Future studies will examine the long-term consequences on soil properties and how these are related to water use and crop productivity.

Management of Soil and Water

Management of a Shallow Alfisol

Infiltration

The productivity of large areas of Alfisols is limited by soil erosion and runoff. Other constraints to productivity include poor crop establishment due to the crusting of the thin surface layers of soil and the reduced movement of rain into the root zone caused by restrictions to water flow (e.g., sealing of the surface soil during rainfall or subsoil layers that slow or prevent percolation of water). The effects of tillage (0 and 20 cm deep), mulch (farmyard manure mixed with rice straw), and perennial legume and grass species on runoff and infiltration are being studied at ICRISAT Center in 28 × 5 m plots with three replications on a field slope of 2%. Runoff is recorded each minute using tipping buckets. The trial began in 1988 (**ICRISAT Annual Report 1989**).

Throughout 1989, application of a straw mulch consistently reduced runoff, but tillage produced variable responses. Runoff was reduced for about 20 days following tillage, but during the cropping season tilled plots had more runoff than zero-tilled plots. This result suggests that tillage was followed by deterioration of soil structure. On average, straw mulch increased annual infiltration by 127 mm compared with 26 mm for tillage. These effects were not cumulative. Zero-tillage plots had 101 mm more annual infiltration than the 20 cm tillage bare plots, and most closely resembled farmers' conditions. There is also some evidence that the benefits of straw mulch are cumulative. Annual infiltration in *Stylosanthes* plots was only 13 mm more than plots without tillage but with straw mulch.

These observations underscore the potential importance of mulches in sustainable, productive dryland cropping systems for the semi-arid tropics.

Earthworms

Experiments at ICRISAT Center showed that conservation tillage systems in temperate agriculture alter both soil physico-chemical properties and soil faunal activity. These systems improve soil quality and reduce runoff and soil erosion. Few reports exist of the effects of soil management on earthworms on Alfisols in the semi-arid tropics.

As part of a major experiment to study the effects of various management practices on an Alfisol, the population, abundance, and biomass of earthworms were quantified. A wide range of treatments, including varying tillage depths, amendment levels, and plant species were imposed.

The predominant species of earthworm found in plots of the core experiment were *Ochochaetona phillotti* (67%), *Lampito mauritti* (31%), and occasionally *Drawida* sp (2%). In an adjacent long-term pasture area the dominant species was *Barogaster* sp, a relatively large and deeper-burrowing species that deposits large castings on the soil surface. *O. phillotti* and *Drawida* sp were also recorded in small numbers.

Few significant responses to the individual treatments were measured in earthworm population or biomass. In June, however, perennial species responded to tillage in all respects except numbers of adult earthworms. It was concluded that the response of earthworms to treatments within either annual cropping or perennial cropping is small and inconsistent.

Adjusted treatment means were then combined for annual and perennial crops and the mean values were compared with the data from the long-term pasture plots. Very large differences were apparent between the treatment groups in both values and trends during the season. Although the annual group and the perennial group had similar values at the initial sampling in July 1989, the changes during the season were markedly different. The plots with perennial species either maintained or increased population and biomass, but in the plots with sorghum the earthworm population rapidly declined to virtually zero.

In June, similar small numbers of juveniles were present in both annual and perennial plots of the core experiment, but again numbers in the sorghum plots declined to near zero for the remainder of the season. Meanwhile, numbers of both juveniles and adults in the perennial plots were steadily increased. In the long-term pasture plots, earthworm numbers increased through the season also, but the total numbers present were much larger and a relatively large number of adults was already present at the initial

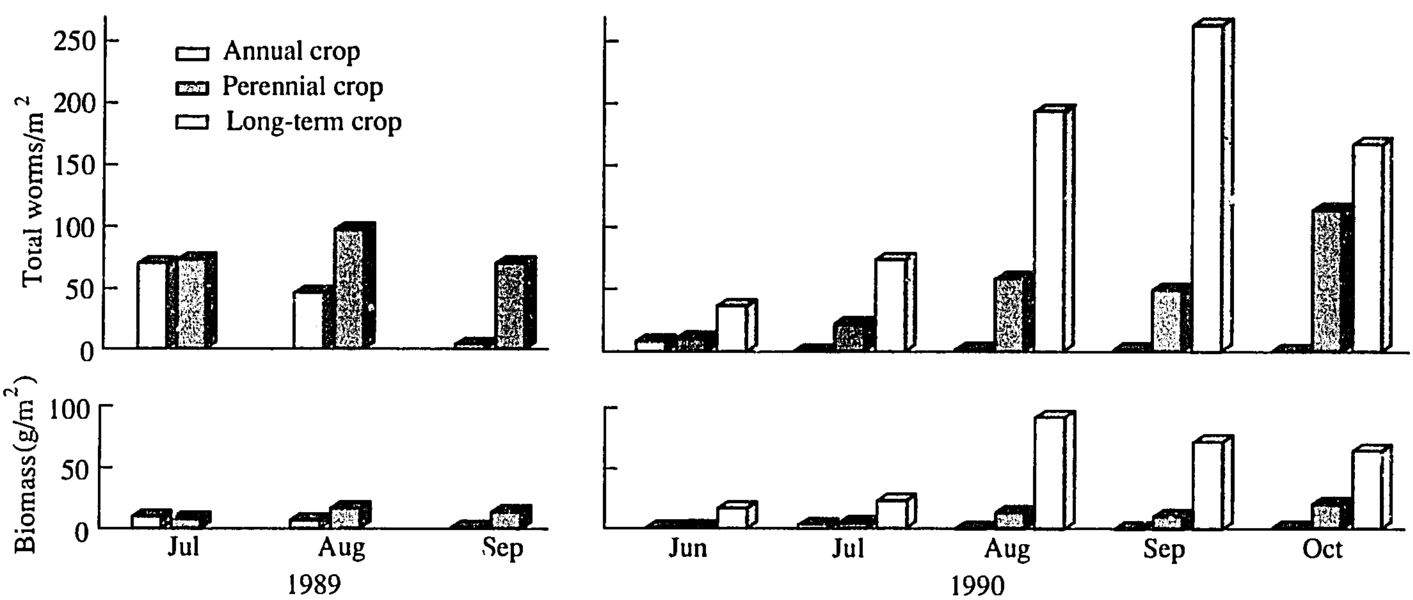


Figure 7. Temporal changes in earthworm population and biomass for three crop management systems on an Alfisol at ICRISAT Center during 1989 and 1990.

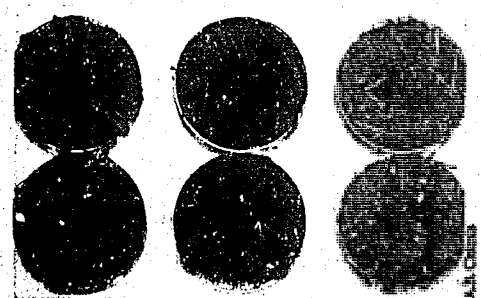
sampling of this site in June. While the pasture plots showed the expected trends of higher populations with longer time under pasture and increasing populations during the wet season, the plots cropped to sorghum consistently showed unexpected seasonal trends (decrease of earthworms to near zero) and little or no response to the applied treatments.

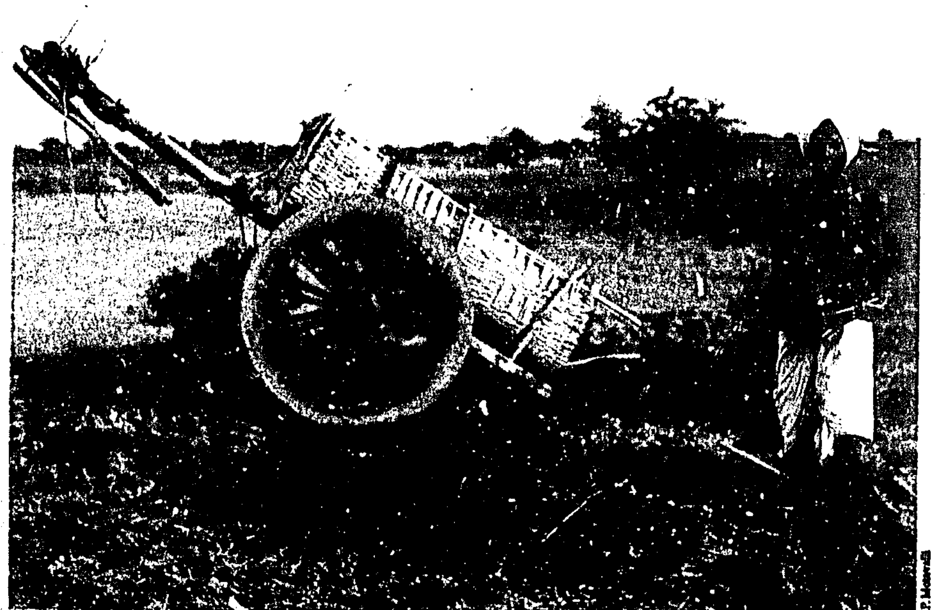
The most likely explanation for these responses is that the application of carbofuran for insect pest control also killed the earthworms. Figure 7 shows a population decline over 2 months to September 1989. The reappearance of juvenile earthworms in these plots in June 1990 was probably due to emergence from cocoons or migration from border areas. Negligible numbers of juveniles and adults were subsequently found, indicating further toxic effects due to either residual carbofuran from 1989 or the small additional application of carbofuran in 1990. This decline in the population completely masked the possible effects of tillage or amendment treatment although the few differences found did favor reduced tillage as expected.

This experiment will be replicated without applying soil insecticides to the annual crop in order to measure longer-term effects on population and biomass.

Searching for the Right Mix

A South Indian farmer spreads farmyard manure on his field (below). He depends on farmyard manure, as do millions of farmers like him throughout the semi-arid tropics, for the nitrogen his crops require. ICRISAT resource management scientists conduct experiments to identify optimal nitrogen-releasing mixtures of dung with sorghum and rice straw (right).





Crop Response to Farmyard Manure

An initial survey of farmers in 11 villages in Andhra Pradesh indicated that straw constitutes approximately 8% to 31% (by mass) of all inputs in dung pits used for the storage and composting of farmyard manure. The type of straw added, the period for which the organic material is left in the pit, and moisture levels all influence the amount of decomposition and nutrient quality of the manure when it is applied to agricultural land.

The ratio of the carbon and nitrogen contents of an organic material (the C : N ratio) is often used as an indicator of quality since nitrogen immobilization may occur when organic materials with a high C : N ratio (greater than 20) are applied to the soil. Samples of farmyard manure from 15 dung pits in a village in southern Andhra Pradesh had C : N ratios ranging from 2 at a depth of 100 cm to 36 at a depth of 20 cm. Based on the results of the survey, studies were initiated at ICRISAT Center to determine the effects of manure applications of varying straw content on both initial and residual crop N response and to examine nutrient management strategies to improve crop nutrient efficiency.

Results from greenhouse and field experiments showed that N deficiency can occur after farmyard manure containing a high proportion of straw is applied to soil. As the proportion of straw increased in the manure, crop N uptake decreased. Composting with either rice or sorghum straw, a common practice in surveyed villages, also affected manure quality since sorghum straw decomposes more slowly than rice straw. Application of farmyard manure with a high proportion of rice straw increased crop yields while the manure with a high proportion of sorghum straw did not.

The residual nutrient effects of farmyard manure applications with varying straw content can bring about higher yields in a second crop as N is released in the soil over time. Adding small amounts of N fertilizer to the second crop is a possible management strategy that showed some promise in raising yield levels while taking advantage of residual nutrient effects of the manure applications.

Combining manure applications with varying straw contents and N fertilizer for the first crop season is another possible management strategy to avoid potential N immobilization. Survey results indicate that approximately 20% of cultivated dryland already receives combined manure and fertilizer applications. An analysis of field data suggests that the combined N-fertilizer dose may need to be adjusted to match the proportion of straw in the applied manure.

Vesicular-Arbuscular Mycorrhizae (VAM)

About 95% of the world's plants have fungi (*myco*) on or in their roots (*rhiza*). Vesicles are storage pouches in plant tissue and arbuscles are branching structures. VAM form symbiotic associations with plants. The hyphae of the fungi spread into the soil and act as root extensions, thus facilitating nutrient uptake. It is generally accepted that VAM can markedly improve plant growth in soils where nutrient concentrations are low. Improved plant growth by VAM infection is most often correlated with phosphorus (P) uptake.

Resource Management Program scientists at ICRISAT Center are studying plant VAM symbiosis under different soil environments with the ultimate goal of increasing crop production through the manipulation of VAM. All ICRISAT mandate crops can be mycorrhizal. The VAM status varies with soil fertility. In soil with less P content, VAM growth is greater than with much P content. In soil poor in available P, therefore, mycorrhizal plants depend more on VAM for P uptake.

The hypothesis is that increased VAM infection, either indigenous or applied, should enhance plant growth by increasing P uptake. Previous work has indicated that application of a combination of urea, organic matter such as crop residue, and rock phosphate can stimulate VAM infection. Two experiments were conducted, one on a Vertisol with pearl millet and one on an Alfisol with sorghum, to study the effects of indigenous (noninoculated) or applied (inoculated) VAM on grain yield. On the Alfisol there was little difference between noninoculation and inoculation. However, application of VAM significantly increased grain yield on the Vertisol.

At present, the cause of this difference in inoculation response between Alfisol and Vertisol is unknown. A preliminary survey showed that Alfisols contain two to four times less indigenous VAM spores than Vertisols. This difference may have caused the difference in inoculation response.

K.K. Lee

Root segments of sorghum grown without phosphorus (left) and with 40 kg phosphorus/ha (right). The root grown without phosphorus shows mycorrhizae.

Porous Barriers

Porous barriers have a potential soil and water conservation role. One grass species, *Vetiveria zizanoides* (Vetiver grass), has been promoted widely by the World Bank. An experiment which studied the establishment and maintenance of vetiver grass in hedges was reported in **ICRISAT Annual Report 1988**. Further studies to quantify the role of porous barriers in soil and water conservation were commenced at ICRISAT Center in 1989.

Four treatments (Vetiver hedges, lemon grass hedges, stone bunds, control) on two slopes (2.8%, 0.6%) in plots 22 m long × 3 m wide were installed. The plots were kept bare. Two barriers per plot, each 10 m apart, were installed. Total runoft and soil loss were measured from natural rain and runoff rates and sedigraphs were measured during simulated rain. There were three replications. In 1990 runoff was measured from 23 storms. Two patterns of response were observed.

1. No significant effect of slope or treatment was observed on runoff from 13 storms between 8 May and 16 August. Rainfall in these storms was 398 mm. However, significantly less soil loss was observed from the gentler slope due to a smaller sediment concentration. All barriers reduced soil loss in a steeper slope.
2. The second period between 6 September and 15 October consisted of nine storms. Rainfall in these storms was 224 mm. During this period there was an abrupt change in response, consistent for each storm. Much less runoff was measured from the gentler slope and plots with vegetative barriers produced consistently less runoff. On plots with stone bunds, response was variable. There were no responses in sediment concentration to either slope or treatment and therefore the soil loss followed the same trends as the runoff.

The abrupt change in slope and treatment response followed cultivation of the plots with a rotary tiller. No conclusive explanation for this effect of cultivation has yet emerged. It is clear, however, that the porous barriers are reducing soil loss. This was due to reduced sediment concentration during the first period and reduced runoff later. Further research will investigate the mechanisms that control these processes.

Sustainability in the Sahel

In the Sahelian region of western Africa, several problems afflict agriculture. These include extreme variation of rainfall in space and time, lack of efficient management techniques to maximize water resources, loss of soil productivity from exhaustion of nutrients, and excessive wind erosion. A major objective of the research on sustainable agriculture in western Africa is to develop farming systems that maintain or improve the natural resource base and that increase productivity.

One of the main research issues concerning sustainability is the maintenance of long-term yield stability and soil productivity on farmers' fields. At ICRISAT Sahelian Center, recent research has shown good promise in three areas with perspective on sustainability.

Coping with Uncertainty of Rainfall

Increased frequency of below-average rainfall in western Africa during the past two decades has contributed to yield instability (Fig.8). Under these conditions, ensuring some degree of yield stability to the farmer is a priority for national governments and research institutions.

The lack of suitable methods for medium- and long-term forecasting of rainfall in western Africa makes it difficult to provide weather advice to farmers for adoption of appropriate cropping strategies. Analyses from over 300 locations in western Africa showed that the length of the growing season is largely determined by the date of onset of rains.

Field trials conducted by ISC scientists during 1986 and 1987 showed that in years with early onset of rains, the long growing season can be exploited by sowing a relay crop of cowpea after the

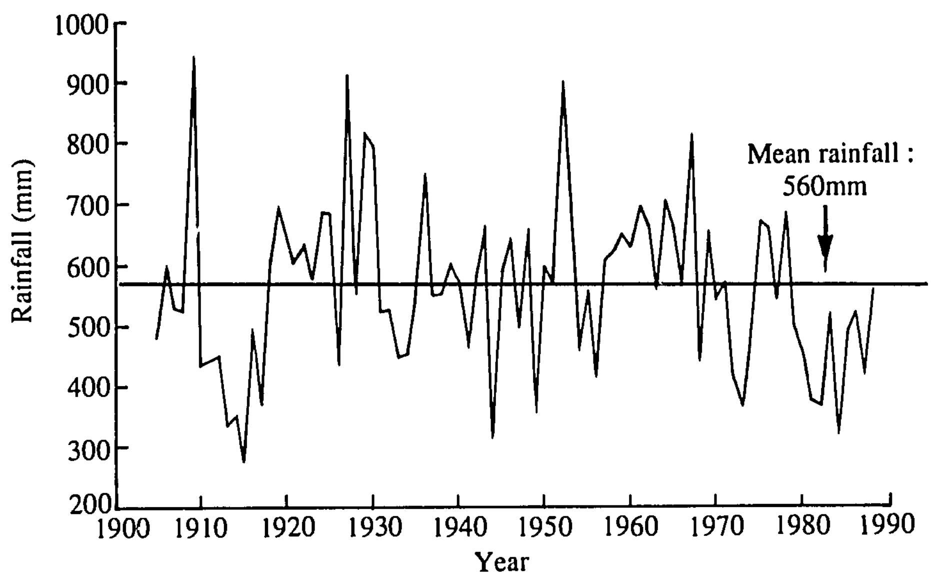


Figure 8. Annual rainfall variability at Niamey, 1905-89.

first crop of pearl millet. Cowpea is sown between the millet rows 15–20 days before the millet harvest. This relay crop is possible when the farmers adopt improved short-duration millet varieties that mature in 90 days, as opposed to the traditional varieties that take 110-120 days to mature.

Because good rainfall is unpredictable in the Sahel, a new concept called "conditional cropping systems" has been developed where the choice of a cropping system is conditioned by the actual onset of rains in a given year. Early onset, for example, indicates a millet-cowpea relay. Normal onset indicates a sole millet crop, and a late onset, sole cowpea. The system thus maximizes production in good rainfall years and copes in poor rainfall years.

In field trials that started in 1988, various conditional cropping systems were evaluated. The millet-cowpea relay crop incorporated use of improved varieties of millet and cowpea at high densities, limited use of fertilizer, and ridging. In the traditional control, which is also a millet/cowpea intercrop, traditional varieties were sown on flat soil and no (or very little) fertilizer was used.

In 1989 the first rains came on 20 May (23 days before the average date of onset on 12 June). The conditional cropping system selected was thus the millet-cowpea relay crop. Millet was sown on 20 May and cowpea on 20 August. In 1990, the first rains came on 23 May (20 days before the average date) and the conditional cropping system (the millet-cowpea relay crop) used in 1989 was repeated. Millet was sown on 23 May and relay cowpea on 19 August. In both 1989 and 1990 sowing of cowpea was delayed until late June, resulting in suppression of cowpea growth by millet.

An advantage of the relay crop is that it makes a more efficient use of the rainfall because both the millet and the relay cowpea crop are sown at high densities and therefore extract more water from the soil profile. In the intercrop system, cowpea is usually sown at a low density and the intercrop system extracts less water from the soil profile than the relay crop system.

As an indication that yield maximization can be achieved through this strategy, the relay crop gave higher yields than the intercrop in both 1989 and 1990 (with the exception of millet straw yield in 1989). Relay cropping was generally superior because the competitive effects inherent in the intercropping systems (such as sowing density, plant population, sowing dates, and spatial arrangement of component crops) were avoided. Yields of conditional cropping systems achieved in 1989 and 1990 were similar in spite of a big difference in total rainfall (653 mm in 1989 and 400 mm in 1990).

Conditional cropping systems research addresses sustainability since it aims at efficient use of the natural resource base while increasing productivity.

Coping with Soil Nutrient Deficiencies

Sandy soils in the Sahel are characterized by low organic matter content, low water-holding capacity, and poor nitrogen and phosphorus status. These characteristics, combined with generally poor socioeconomic conditions at the farm level, result in low agricultural productivity which is aggravated in dry years.

In a long-term experiment initiated in 1986, combinations of various techniques have been tested to alleviate soil-related constraints. These include modest phosphorus inputs, improved millet and cowpea varieties, use of animal traction for ridging and weeding, and legume-cereal rotation. Results have been consistently positive.

A comparative economic analysis of data from 13 treatments showed that manual cultivation of a pearl millet-cowpea rotation, plus application of phosphorus fertilizers, may be suitable packages to recommend to Sahelian farmers. These packages consistently gave higher yields than the traditional system.

Results over the 5 years of the experiment showed that the productivity of the traditional system decreased with time while the improved system showed stable productivity. On average, the traditional system yielded only 188 kg/ha per year of grain while the improved system yielded 498 kg/ha per year.

The benefits of crop rotations to productivity have long been established. In developed countries, however, the traditional practice of rotation has declined with the introduction of fertilizers and chemicals to control pests and diseases. Quite recently there has been a renewed interest in rotations.

The adoption of these low-input systems which give sustainable production is clearly justified in the Sahel where farmers can rarely afford fertilizers and chemicals.

Efforts to encourage farmers to use rotation systems are undertaken through on-farm trials carried out in Niger in collaboration with the national program.

Coping with Microsite Variation on Sandy Sahelian Soils

Faidherbia albida is well known to anyone familiar with Sahelian agriculture. Numerous authors have noted that crops grow better under its canopy than away from the tree. This "*albida* effect" has been attributed to many factors, but the traditional explanation is that the tree improves soil fertility through litter fall over an extended period of time. However, recent investigations at ISC suggest that this improved soil fertility may precede the tree. Trees in a field trial planted in 1987 have shown great variability in growth. After 3.5 years, one finds clusters of trees with exceptional height interspersed with other tree clusters that have hardly grown at all.

Seed of *F. albida* germinating on superior sites in natural regeneration situations grows faster and is likely to survive to maturity. The elevated soil fertility status carries over and is actually enhanced through phosphorus and additions of organic matter such as animal manure, tree litter, and crop residues. One way to sustain crop yields from these fertile "microsites" is to identify them in a cropped field and plant agroforestry species such as *F. albida* around them the following year.

Lime, Carbofuran, and Crop Growth Variability

Nematodes, peanut clump virus, and nutrient imbalance were found to play a very important role in crop growth variability at ISC.

In early 1989, a long-term trial on the effect of lime and carbofuran on soil pH, aluminum toxicity, nematode population, and groundnut yield was started. The field was sown with groundnut during the 1989 rainy season, followed by pearl millet in the 1989/90 dry season, and groundnut again in the 1990 rainy season. In 1989 the carbofuran treatment increased crop yield. Lime application did not affect the pH or aluminum content in the soil and did not increase groundnut yield. In the 1990 rainy season, however, the application of 10 t/ha of lime increased pH, decreased aluminum, improved crop growth, and increased the yield to the same level achieved with the carbofuran treatment. There was no effect on the nematode population, which was reduced by the carbofuran. This finding indicates the important role of aluminum toxicity and will be used to develop a practical management system for the control of crop growth variability.


M.M. Andres

Sustainability in practice in Niger. A pearl millet intercrop in a farmer's field. The millet has just been harvested.

Research Support

Farm workers weeding chickpea with hand hoes at ICRISAT Center.

A.B. Chitnis

Computer Services

The Computer Services Division provides time-sharing to ICRISAT research personnel on a MicroVAX 3900 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. The Division develops interactive systems, provides data-entry services, and installs software packages and microcomputer software. It also conducts seminars, training courses, and individualized instruction on computer usage for staff members of the Institute. Services to researchers include:

- development of the VAX-based component of the Research Project Management Information System and improvement of the PC-based component;

Responding to a request for software development.

- design and development of a PC-based genebank information system;
- design and development of a common seed dispatch record-keeping system; and
- enhancement of the Information Services sales and publications system and the AGLN record-keeping system.

Software development and maintenance

Services to the Institute's administration include:

- revision and testing of the salary processing system;
- completion and testing of the Purchase Order Tracking System;
- enhancement of the transport and income tax information systems; and
- completion and release of a record-keeping system for the Warehouse.

Hardware changes

A heavy-duty dot-matrix printer with graphics capabilities was purchased to support the printing of standard administrative reports such as payroll and leave records. An 80386/SX-based microcomputer was added to the network with other microcomputers and will eventually serve as a public resource for graphics software packages. A MicroVAX 3900 computer system was installed as a replacement for the VAX-11/780 and was made available for general use in November. A wide-area networking capability was established in October with the commissioning of a dedicated X.25 data communications circuit between ICRISAT's MicroVAX 3900 and the GPSS PAD in Hyderabad. This link permits rapid and cost-effective access to the CGNET electronic mail network based in the USA. It also provides a basis for direct intercenter networking of computer systems.

User services

Twelve redesignated Junior Office Assistants were trained in the fundamentals of microcomputers. Two staff members were specially trained in the use of WordPerfect to assist the External Review Panels and several additional staff were given specialized training in various computer techniques. The user services area was completely redesigned to better serve the user community. A public terminal and three public personal computers are available for short jobs and access to laser printers. Computer Services organized the microcomputer requirements for the External Review Panels, including consulting on usage problems where required.

Crop Quality Unit

In October the Biochemistry Unit changed its name to the Crop Quality Unit to reflect more closely ICRISAT's future priorities, which now include fodder and feed. The Unit's main activity is to analyze the advanced and prerelease cultivars developed by the research programs for nutrition and food quality. This includes determining chemical and amino acid composition, existence of minerals and trace elements, the protein and dehulling qualities of cereals and grain legumes, and food quality.

These analyses are carried out to ensure that ICRISAT cultivars are not less nutritious than other released cultivars. Recent germplasm accessions are also analyzed for specific quality parameters. For the past few years the Unit has investigated various utilization aspects of our crops, including many novel and alternative uses. The aim is to identify potential areas for new or improved utilization of ICRISAT crops, including industrial applications. Results of investigations carried out during 1990 are briefly reported here.

Sorghum

The quality of sorghum malt, which is used for making beer in Nigeria, influences the quality of the beer made from it. The concentration of sorghum diastatic activity is an important criterion in determining the malting quality of sorghum. The Crop Quality Unit examined 28 improved breeding lines and germplasm accessions, concentrating on the relationship between sorghum diastatic units and traits such as water-soluble protein content in malted grain samples. These measurements may prove to be good indicators of malting quality.

Sorghum is used for the manufacture of starch in India, Mexico, Sudan, and other countries. Starch recovery from grains is economically important in the manufacture of starch.

Grain mold incidence is currently rated visually. Determination of ergosterol concentration in 13 mold-susceptible and mold-resistant germplasm accessions and breeding lines showed that ergosterol concentration is a direct measure of fungal biomass. It could be therefore used to evaluate grain mold resistance or susceptibility of sorghum cultivars.

Pigeonpea

Evaluating pigeonpea's grain quality traits is inextricably associated with cooking time. Data obtained on 68 germplasm accessions showed that cooking time of whole seeds was positively and significantly correlated with grain hardness. Protein quality of fermented and fried pigeonpea (*tempeh*) was evaluated using rat bioassay. Net protein utilization of *tempeh* was significantly lower than that of boiled *dhal* samples used as control.

Chickpea

The Crop Quality Unit's major thrust in its work with chickpea is to determine the differences in the crop's oil absorption characteristics. Deep-fried products are made from the flour of decorticated whole seed of desi chickpeas. They are very popular as snack items on the Indian subcontinent. The Unit analyzed the oil absorption of products made from five desi and five kabuli chickpea cultivars. The mean oil absorption of the product extruded from desis was significantly higher than that of kabulis. Significant differences in oil absorption characteristics were observed among the 10 cultivars. Sensory evaluation of the products indicated no noticeable differences.

Groundnut

Because flavor plays an important role in the acceptability of such groundnut products as peanut butter, the Unit standardized a method for determinating flavor compounds in groundnut. Samples of several high-yielding genotypes showed that their flavor quality needs improvement if they are to be used as confectionery nuts. A method of evaluating the cooking quality of groundnuts by boiling them in the shell was also standardized.

A selection of groundnut products assembled by the Crop Quality Unit.

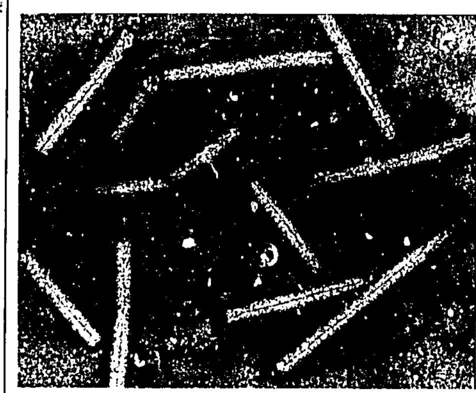
Electron Microscope Unit

The Electron Microscope Unit is a centralized service facility for processing and examining samples under electron microscopes.

A technician at work with the scanning electron microscope.

Sample processing techniques include chemical fixation, resin embedding, ultrathin sectioning, and negative staining. Immunosorbance electronmicroscopy techniques are also routinely used to detect and characterize viruses.

The scanning electron microscope is used for surface ultrastructural studies of samples prepared by critical point drying. The Unit also assists scientists by taking high quality photomicrographs. During 1990 scientists working on 11 projects in Cereals, 14 in Legumes, and one each in Resource Management and Crop Quality used the Unit's facilities.



Peanut clump virus magnified 75 000 times.

A fully developed colony of powdery mildew fungus magnified 300 times.

A video microscope system was developed to record the images of highly motile organisms. By freezing the image, fungal zoospores that are difficult to photograph can be conveniently studied. This system was made fully compatible with the imaging system of the scanning electron microscope to facilitate the recording of unstable samples under an electron beam. It is especially useful in dealing with fungal spores deposited on soil, and other spores that cannot be dehydrated for viewing under the electron microscope.

In 1990 the two microscopes registered 515 high-tension hours. The ultracentrifuges registered 2 billion revolutions.

and cultivation, plant protection, harvesting, processing, and greenhouse

Farm Development and Operations

Farm Development and Operations (FDO) at ICRISAT Center is responsible for providing services and facilities for tillage, irrigation, sowing

operations. It also develops and maintains farm land, campus grounds, and water resources. It formulates guidelines for sustainable production through cultural, crop, and land management practices and trains staff to optimize efficiency.

In addition, FDO assists in the establishment and development of ICRISAT's regional research centers in Africa and its cooperative research stations in India. It provides training in research station development and management to assist the national agricultural research systems.

Operations and services

During 1990, FDO sowed 420 ha of experimental crops in addition to about 50 ha in the watersheds. The total hectarage under cultivation during 1990, and the apportionment used by various programs and projects, is shown in Figure 9. A map of the extent to which the ICRISAT Center farm was used for experimentation is shown as Figure 10. To support these experiments, 31 machine hours per ha were spent on tillage and 17 machine hours per ha were spent on harvesting and postharvest operations. Maintenance of the farm area and grounds (1390 ha) consumed 24 machine hours per ha.

Integrated weed control methods

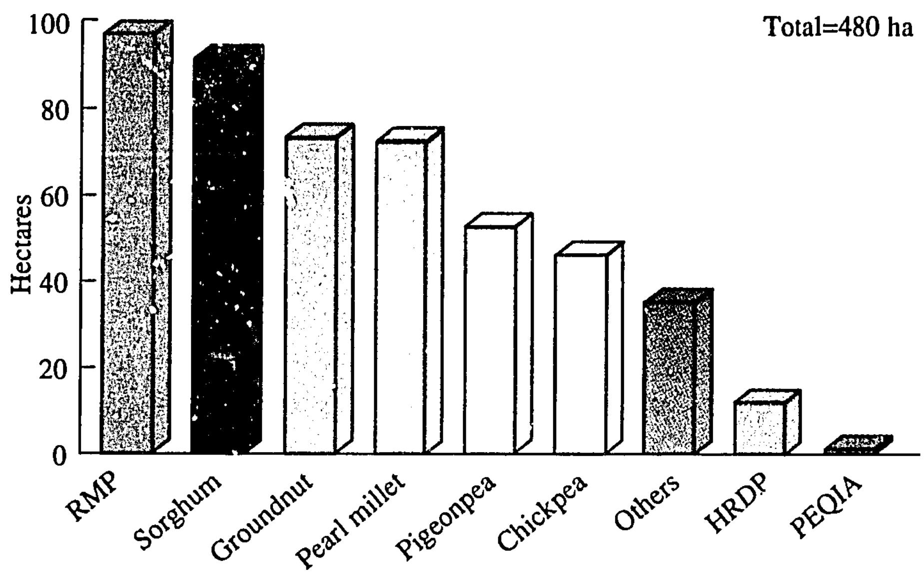


Figure 9. Area under experimentation during 1990, ICRISAT Center.

utilizing cultural, chemical, and mechanical practices proved cost-effective and temporary farm labor costs were reduced. In 1990 FDO took 45 man-days per ha to weed 288 ha of experimental crops compared with 51 man-days per ha in 1989. A total of 4287 work requests for various field operations and services were effected during the year.

Pesticides to control weeds and insects were applied according to periodic surveillance. During 1990 heavy shoot fly incidence and early stem borer infestation was experienced on sorghum, while white grub was the major insect pest in pearl millet. N tgrass was noticed even on solarized plots due to early rainfall and low temperatures in May. Rainfall in May also reduced the effectiveness of ICRISAT Center's 'close season' between 15 April and 15 May when no cropping is undertaken. This exacerbated pest buildup. Heavy *Helicoverpa* infestation occurred on medium-duration pigeonpea in September and on long-duration pigeonpea and chickpea in November. While insecticide prevented damage to chickpea, pigeonpea suffered significant damage. Groundnut was not affected by any major pests.

Little irrigation was required for rainy-season crops after mid-July due to good rainfall distribution later in the season. The largest hectarage was under irrigation for early sowing and disease development during the January-March period (32%) followed by July-September (29.4%).

FDO provided services and facilities required for greenhouse and controlled environment experiments, and used 12 437 machine hours to support them. In addition, the ICRISAT Center landscape was maintained and work requests for landscaping new areas were executed.

Development and improvements

A 4000-m^3 reservoir was constructed to collect rainwater for the Resource

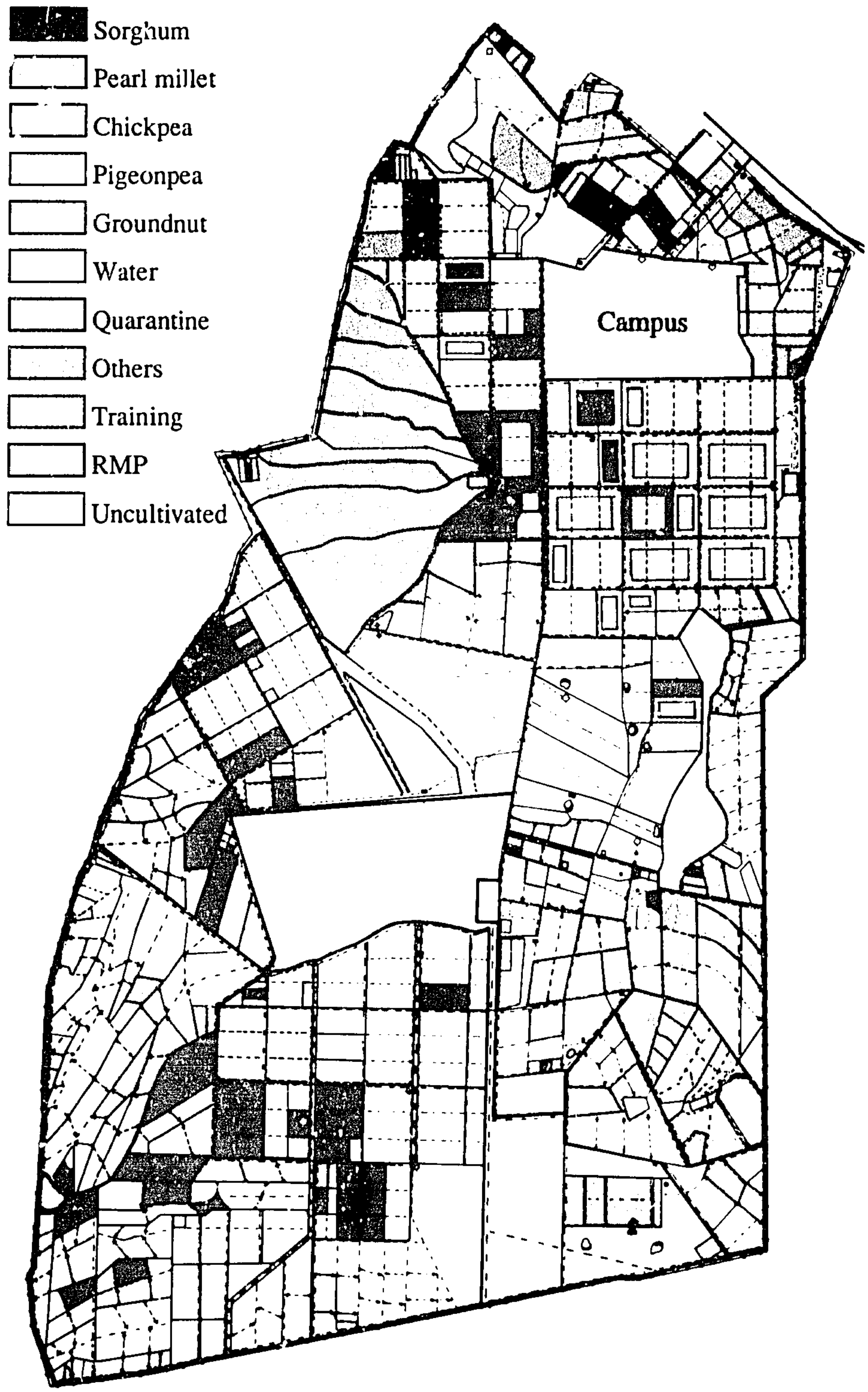


Figure 10. Crop map of ICRISAT Center, 1990.

Management Program. A 380-m chain link fence was erected for the disposal yard, and the underground irrigation system was extended to three Vertisol watersheds. FDO also developed a 2-ha Vertisol field, levelled the area under the rainout shelter, and constructed three culverts to modify the drainage. More than 5000 trees were planted along the main drain. Construction of a pesticide store and sprayer wash area was completed.

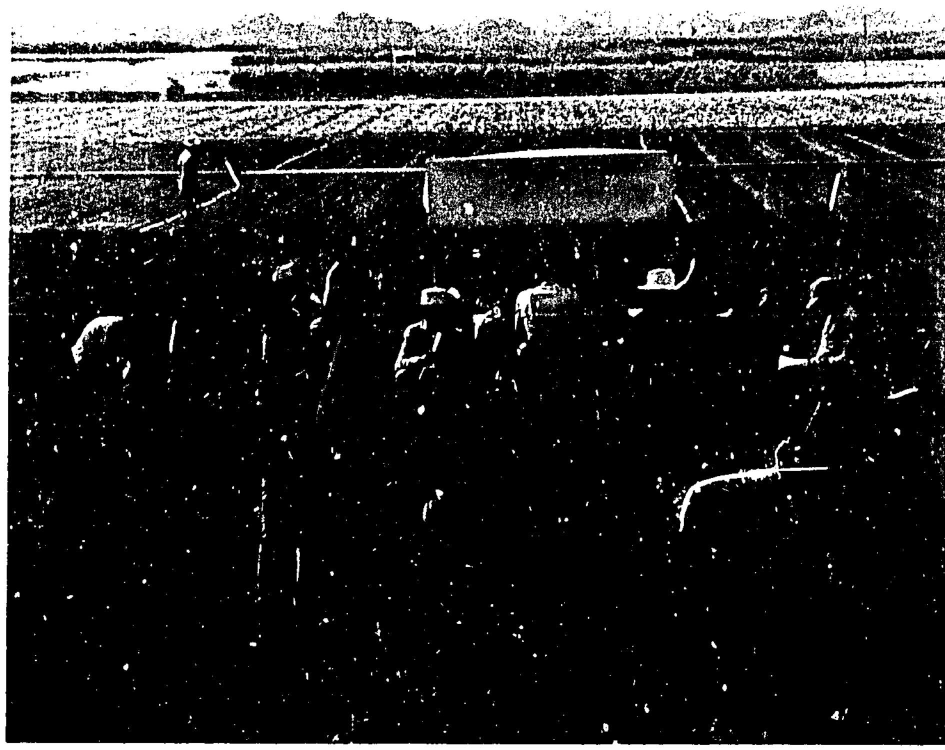
An experiment was conducted in collaboration with the Resource Management Program to evolve a strategy to control nutgrass. The aim of the experiment was to study the effect of tillage, cover crop, and herbicide (glyphosate) on nutgrass. Discing in combination with 1% glyphosate and ammonium sulphate mixture proved effective in reducing nutgrass population. The results were significant and a 98% reduction in nutgrass population was observed at the end of the second cycle.

The introduction of hand hoes for manual weeding reduced weeding cost by 14-21% (see photograph on p. 000). On the recommendation of the Farm Research Committee, FDO took total responsibility for weed control on 6 hectares of groundnut and pearl millet during the rainy season on a trial basis to evaluate the cost effectiveness of timely weed control measures. This procedure saved 50% of the weeding costs of groundnut and 33% those of pearl millet.

On the recommendations of an FDO consultant, a Service Guide was prepared to assist scientists. Vacuum planters were used extensively for groundnut sowing, and progress was made in modifying the planter with a shoe-type opener for seed placement. FDO technicians developed a cultivator for weed control on narrow-spaced groundnuts and chickpeas on broadbeds. They also developed and installed an audiovisual alarm system to safeguard against high temperatures in seed dryers. A plant protection consultant's recommendation for a sequential pest surveillance procedure was adopted, and as a result FDO's efficiency for timely pest detection has increased. After investigating hard pan formation on selected Alfisols, 0.5 ha was subsoiled, 62.2 ha were landplaned on a selective basis, and plots were combined extensively to minimize harvesting cost while hastening tillage operations to make the close season more effective.

Training

In-service training in farm operations, pest surveillance, and plant protection was conducted, as was in-house training on tillage for farm machinery operators. A 3-day training program on operation and maintenance of threshers for staff at ICRISAT's cooperative research station in Gwalior was also conducted.



FDO personnel sowing groundnut on broadbeds with a vacuum planter.

Genetic Resources Unit

During 1990, germplasm collection missions were carried out by the Genetic Resources Unit (GRU) in collaboration with national agricultural research systems in India, Indonesia, and Myanmar. With the addition of 2419 samples, 464 of which were acquired by actual collection missions, the gene bank now holds 102 209 accessions. Figure 11 shows the geographic distribution of these additions.

Multilocational evaluations were successfully conducted at several locations in collaboration with various national programs, and several promising lines were identified. Useful traits included shoot fly resistance in sorghum, early flowering and male sterility in pearl millet, and fusarium wilt resistance combined with double pods in chickpea.

ICRISAT's long-term cold storage facility is performing satisfactorily. Over 3700 seed samples were processed and packed in aluminum foil packets for long-term conservation. The Unit distributed 41 339 germplasm samples of mandate crops for use in crop improvement programs throughout the world. With these additions, the cumulative total to date is nearly 1 million (Table 2).

To strengthen the GRU, a substantial Asian Development Bank grant was made to facilitate the collection,

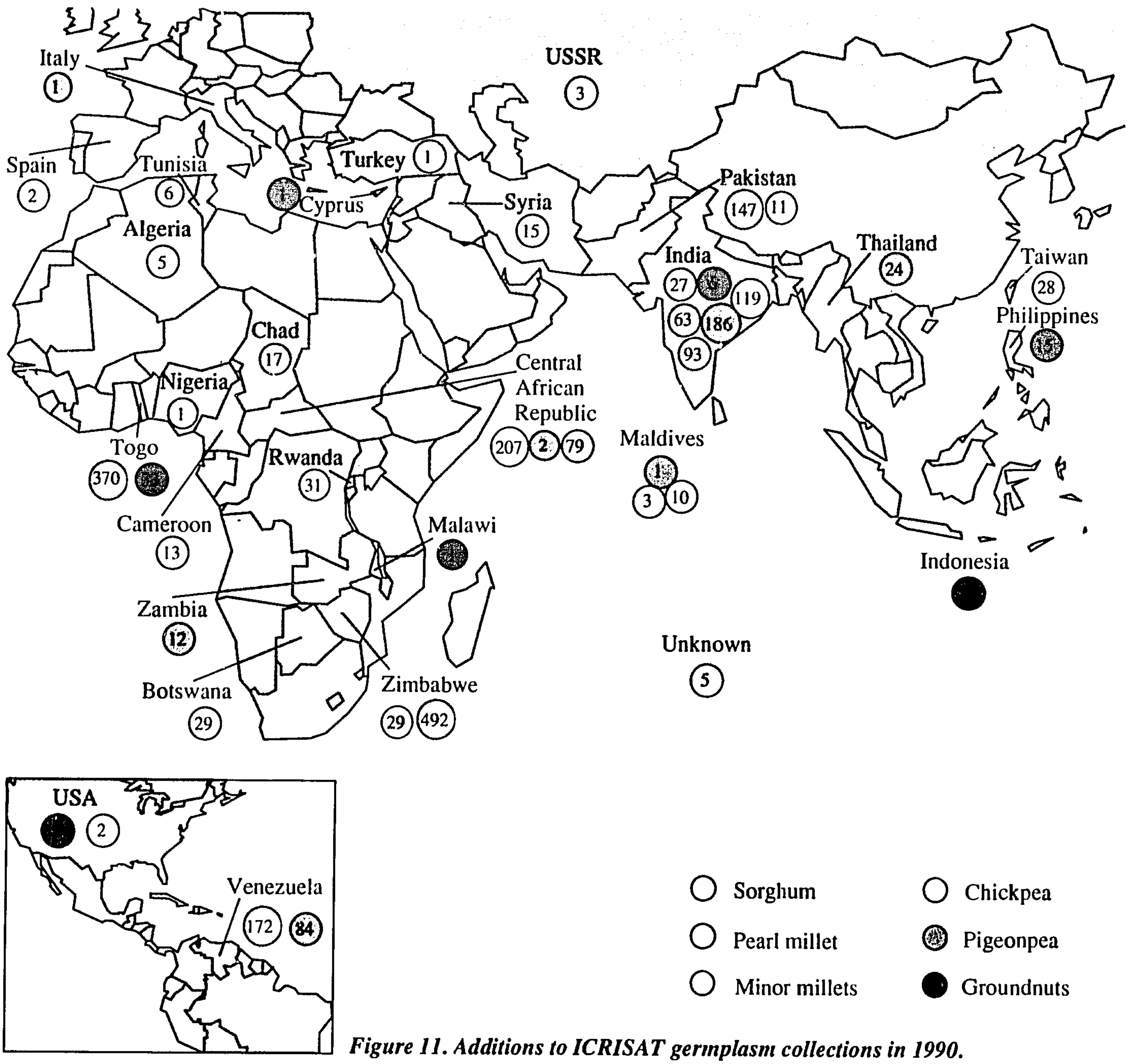


Figure 11. Additions to ICRISAT germplasm collections in 1990.

ICRISAT's long-term cold storage facility.

evaluation, conservation, and utilization of germplasm in Asia. The grant will also be used to strengthen the gene bank facility at ICRISAT Center and to support ICRISAT's collaborative efforts with national programs on uses of genetic resources.

Sorghum

Over 1000 new accessions from eight countries were added, raising the total to 32 890 accessions. One collection mission to Orissa in India succeeded in obtaining 73 accessions of primitive sorghums with vitreous grains, pearly to chalky white in color. In spite of high continuous rainfall (more than 2000 mm) to November, the grain remained free from mold.

The GRU grew 143 sorghum samples from Indonesia (2), Pakistan (46), Togo (33), and USA (62) for inspection, seed increase, and release. Over 1000 new germplasm accessions were characterized at ICRISAT Center. Promising lines from several sets of germplasm from various locations in India were selected for use in breeding programs for grain, forage, and postrainy-season sorghum improvement. A pure-line selection from IS 30468 (E 1966), a sorghum landrace from Ethiopia, was named NTJ 2 and released for postrainy-season cultivation in India.

Through regional evaluation of short-duration sorghum germplasm in western and eastern Africa, 80 lines have been selected for breeding trials. The Unit rejuvenated 5230 accessions and supplied 17 635 samples to national programs in 27 countries for testing and utilization in their sorghum improvement programs.

Pearl millet

GRU added 688 accessions from Algeria, Central African Republic, Chad, India, Nigeria, Pakistan, Togo, and Tunisia, raising the total number of germplasm accessions in the gene bank to 21 919 from 44 countries. In addition, the Unit maintains 483 accessions of 19 wild species of *Pennisetum*. In collaboration with India's National Bureau of Plant Genetic Resources (NBPGR), 93 samples were collected from Andhra Pradesh alone. Landraces exhibited diversity in plant height, spike, and grain characteristics.

A total of 3256 accessions were evaluated and characterized at ICRISAT Center during 1990. All the new additions from the Central African Republic and Togo were classified into different cultivar groups based on time to flowering, plant height, spike, and grain characteristics. Seven accessions from Togo flowered in less than 40 days. A sterility maintainer characteristic was identified for a male-sterile line from Togo. When 946 accessions of photoperiod-sensitive lines from Cameroon, India, Nigeria, and Tanzania were sown on 26 July with wide spacing, the heads were frequently as large as in their original habitat. Of the 946 accessions screened, 320 samples had sweet stalks. They have good potential for development as dual-purpose (both forage and food) pearl millet cultivars.

The GRU evaluated 500 short-duration and large-grain types from Benin, Ghana, and Togo as a part of a multilocational evaluation in collaboration with NBPGR in Issapur and Jodhpur, and with the All India Coordinated Pearl Millet Improvement Project (AICPMIP) at Pune. Collaborative evaluations with both of these organizations were also carried out at ICRISAT Center.

Based on previous evaluations, suitable accessions were selected for four gene pools: short duration, high tillering, large spike, and large grain. About 1000 selected accessions for each gene pool were grown in isolation for random mating.

GRU staff sowed 3236 accessions of cultivated pearl millet and 85 accessions of other *Pennisetum* species for rejuvenation and seed increase In the Post-Entry Quarantine Isolation Area (PEQIA), 45 accessions of pearl millet and 35 accessions of wild species were grown

Table 2. Germplasm samples distributed by GRU, 1990.

Crops	ICRISAT Center	Within India	Other countries	Total samples
Sorghum	5 261	6 749	5 625	17 635
Pearl millet	814	2 864	657	4 335
Chickpea	3 791	1 554	1 306	6 651
Pigeonpea	1 979	3 094	490	5 563
Groundnut	1 846	1 432	1 315	4 593
Minor millets	nil	349	2 213	2 562
Total in 1990	**13 691**	**16 042**	**11 606**	**41 339**
Cumulative total to date	452 230	259 152	247 350	958 732

for quarantine inspection and seed multiplication.

Minor millets

The GRU added 164 new accessions of such minor millets as finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), and barnyard millet (*Echinochloa colona*) from India, the Maldives, Pakistan, Taiwan, and Zimbabwe, raising the total gene bank holdings to 7082.

With NBPGR collaboration, 23 accessions of finger millet, 19 of little millet, 9 of foxtail millet, and 6 of their closest wild relatives were collected in Orissa. A special attempt was made to collect panicles of finger millet free from blast disease (*Pyricularia* spp). The Unit supplied 2562 accessions to national programs in India, Korea, Nepal, Sudan, USA, Zambia, and Zimbabwe, and to the EARCAL Program in Kenya for testing and utilization in crop improvement programs.

Chickpea

Fifty-five chickpea accessions were added from India, Spain, Syria, Turkey, USA, and USSR, plus five more of unknown origin, raising the total chickpea accessions in the gene bank to 15 995. In addition, 133 accessions from Malawi and Myanmar were released by the Plant Quarantine Unit. A chickpea collection mission was organized in Myanmar during March in collaboration with the Agricultural Research Institute at Yezin. Myanmar chickpea material consists mostly of desi types diverse in plant height, growth habit, and seed size. Preliminary evaluation of 1315 accessions was carried out at ICRISAT Center. Joint germplasm evaluation was conducted at two locations in India—Akola and Kanpur—and several promising accessions were identified. In a replicated evaluation of 308 accessions from Madhya Pradesh, the top five seed yielders were ICC 14614, ICC 14627, ICC 14780, ICC 14860, and ICC 15129.

One dwarf mutant from ICC 14827, a landrace from Madhya Pradesh was identified. A highly desirable combination of fusarium wilt resistance and twin pod traits was found in ICC 12644, an Ethiopian landrace. Also identified were several genotypes with unique combinations of flower, stem, and seed color.

Pigeonpea

The GRU added 310 pigeonpea accessions to its world collection, raising its total to 11 482 from 54 countries. The new accessions are from the Central African Republic, India, Italy, Maldives, Thailand, Venezuela, and Zambia. A collection mission to Indonesia added 49 more landraces of cultivated pigeonpea and two wild relatives. These are now under quarantine observation.

Five hundred and four accessions were grown for characterization and rejuvenation. The Unit also grew 500 medium-duration accessions as part of the ICRISAT/NBPGR collaborative germplasm evaluation at ICRISAT Center and at Akola, Maharashtra. The 862 accessions raised for seed multiplication included 434 for long-term conservation. All the trials established well in spite of continual rains and high humidity which resulted in heavy incidence of pod borer despite regular spraying. Agronomists screened 1154 accessions and identified 58 accessions with high early vigor. Ninety accessions were identified as less sensitive to photoperiod.

New sources of high yield have been identified from the ICRISAT/NBPGR collaborative evaluation of medium-duration accessions at ICRISAT Center, Patancheru. Eight accessions produced grain yield greater than 2.5 t/ha. These will be further tested for confirmation.

In collaboration with Kenya's National Dryland Farming Research Centre and EARCAL in Kenya, GRU evaluated 435 accessions at Katumani and another 384 at Kampiyamave in Kenya. Three accessions (ICP 8006, ICP 11934, and ICP 12734) were identified as most promising in an elite germplasm yield trial at Katumani and these were recommended for on-farm trials in Machakos, Kenya. Characterization data of new accessions and the results of germplasm evaluation on 1000 medium-duration accessions have been computerized, and 5563 seed samples have been dispatched to scientists in 13 countries.

Groundnut

The GRU added 135 accessions from Cyprus, India, Indonesia, Malawi, Philippines, Togo, and USA, raising the total to 12 841 from 89 countries. The manuscript for a comprehensive **Groundnut Germplasm Catalog** has been finalized for editing and publication.

A total of 2694 accessions were grown at ICRISAT Center for confirmation of evaluation and characterization data. Of these, 839 were sown in replicated trials for agronomic evaluation and seed increase for long-term conservation. Under the ICRISAT/NBPGR joint evaluation project, 500 accessions were evaluated for 13 descriptors at Akola and ICRISAT Center. The Unit studied protein profiles of 23 wild species and their derivatives. White-seeded lines were observed to be highly susceptible to in vitro seed colonization by *Aspergillus flavus*, but no correlation appeared to exist between white seed color, seed rot, and aflaroot diseases.

Crosses with wild species were made to broaden the genetic base of groundnuts. The presence of barriers that impede such hybrids was detected while attempting these crosses.

GRU distributed 4593 accessions for utilization in breeding programs: 1846 to ICRISAT scientists, 1432 to other scientists in India, and 1315 to scientists in five other countries.

Gene bank and seed laboratory

The GRU processed 367 sorghum, 707 pearl millet, 1962 chickpea, and 664 groundnut accessions for long-term conservation at -20°C in sealed aluminum packets. The minimum number of seeds stored for each accession was 3000 for chickpea and groundnut, 5000 for sorghum, and 12 000 for pearl millet. Moisture contents of the seeds varied between 4% and 7%.

Viability tests were carried out on 116 sorghum, 3591 chickpea, and 475 groundnut accessions under storage for 5 years or more in medium-term conditions (4°C and 20% relative humidity). A total of 494 accessions with viability lower than 85% was identified for rejuvenation, including 3 sorghum, 363 chickpea, and 128 groundnut accessions.

Preliminary studies on seed maturity in relation to germinability, vigor, and longevity in pearl millet and sorghum showed that the optimal time to harvest seeds for conservation does not coincide with the occurrence of physiological maturity. In both these crops, seeds harvested 1-2 weeks after physiological maturity were found to have a longer storage life.


A.B Chitnis

Soviet delegates viewing GRU's pearl millet collection.

Human Resource Development Program (HRDP)

More than 600 scientists or technicians were nominated for long-term skill development programs at ICRISAT Center by Ministries of Agriculture, universities, or semi-arid tropics research or development programs. Of these, 165 were accepted. In addition, about 50 participated in regional human resource development activities in southern Africa and 70 others participated in SADCC/ICRISAT/INTSORMIL degree programs. The activities of postdoctoral fellows, research fellows, research scholars (MSc or PhD), national scientists, in-service trainees, and apprentices were coordinated by research program and HRDP scientists. Participants in study programs were sponsored by ICRISAT and other international organizations.

In-service training programs at ICRISAT Center

The intensive 8-week course in scientific English comprehension and usage at Osmania University was attended by 37 research scientists and technicians from 14 countries. Eighty-two nominees from 34 countries participated in rainy-season theoretical and practical field and laboratory training. They conducted 54 sorghum, 36 pearl millet, 51 groundnut, 20 pigeonpea, 4 maize, and 18 intercropping experiments. National scientists from Zimbabwe (12 weeks) and India (2 weeks) undertook short-term training in legume virology. Nine participants from five countries (Ethiopia, Malawi, Myanmar, Sri Lanka, and Vietnam) underwent 6-month postrainy-season crop improvement training programs with chickpea, pigeonpea, and groundnut projects. Figure 12 shows the geographic distribution and gender proportions of participants in HRDP's long-term programs.

In-service regional and national activities

One scientist from the national agricultural research system of Niger

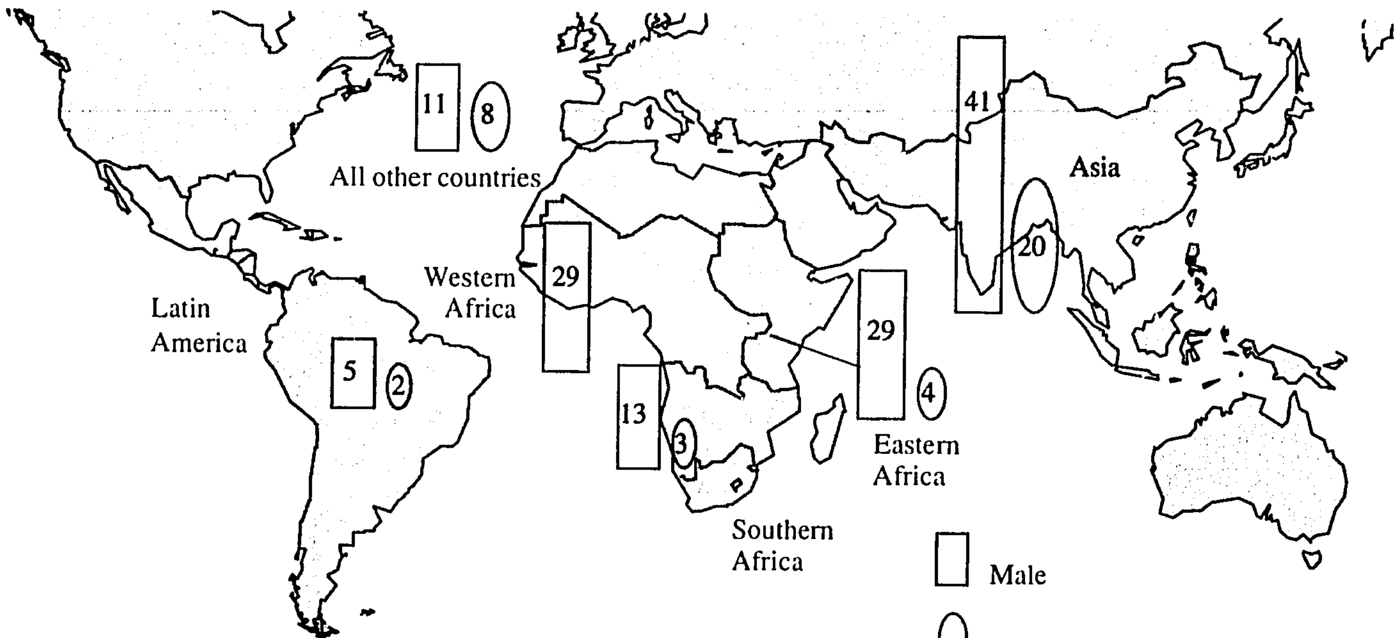


Figure 12. Participants in long-term programs, ICRISAT Center.

completed training in agroclimatology at the ICRISAT Sahelian Center, and scientists from Mexico, Nicaragua, and Panama completed 3-month programs in sorghum hybrid breeding methods at CIMMYT with LASIP staff.

Special national scientist skill development activities

A Mexican scientist studied sorghum breeding, hybrid seed production, and management techniques in January. Two other Mexican scientists, guided by LASIP scientists, examined food uses for sorghum in May. In-country programs accommodated 119 participants in skill development courses which were taught by ICRISAT and national program scientists (Table 3).

Postdoctoral fellowships

Postdoctoral Fellows from Argentina and France completed 2-year studies related

Table 3. In-country skill development activities, 1990.

Location	Dates	Activity	Leadership	Participants
Mexico	19-28 Mar	Sorghum production for bank assessor trainees	LASIP	28
Myanmar	22 Mar	Germplasm collection, preservation, and evaluation	ICRISAT	40
Nepal	7-25 May	Use of statistical packages for analysis and report preparation	ICRISAT	5
Sri Lanka	9-17 Jul	Legumes production	ICRISAT AVRDC Sri Lanka	24
Nigeria	2-8 Sep	Sorghum seed production and management	ICRISAT Nigerian seed producers	12
China	15-27 Oct	Legumes viruses—identification and detection	ICRISAT Peanut CRSP China	10
Total				**119**

AVRDC: Asian Vegetable Research and Development Center.
Peanut CRSP: Peanut Collaborative Research Support Program.

Table 4. Research Fellow study programs, ICRISAT Center, 1990.

Program/Discipline	Country	Program duration (weeks)
Cereals Program		
Millet Pathology	India (3)	6
Sorghum Physiology	Sudan	6
Sorghum Breeding	Mexico, Sudan	25
Sorghum Physiology	Sudan	9
Legumes Program		
Chickpea Breeding	India	5
Groundnut Breeding	Nigeria, Sudan	28
Legumes Agronomy	Pakistan, Philippines	11
Legumes Entomology	Ethiopia	8
Legumes Pathology	Ethiopia (2), Kenya, Sudan	29
Legumes Virology	India	2
Resource Management		
Agroclimatology	Nigeria, Ethiopia	4
Soil Physics	Sudan	12
Genetic Resources		
Germplasm Collection	Somalia	3
Crop Quality		
Food Quality Estimation	India (2)	1
Total		**149**

to utilization of tissue-culture techniques in cereals and identification of cereal viruses. A Ugandan Fellow studied agroforestry systems involving perennial pigeonpea.

Research fellowships

Scientists with MSc and PhD degrees from nine countries participated in a total 149 weeks of skill development (Table 4).

Research Scholars at ICRISAT Center

MSc and PhD thesis research was completed by five students from three countries and 20 are continuing their research.

Figure 13 gives the percentages of HRDP programs at ICRISAT Center.

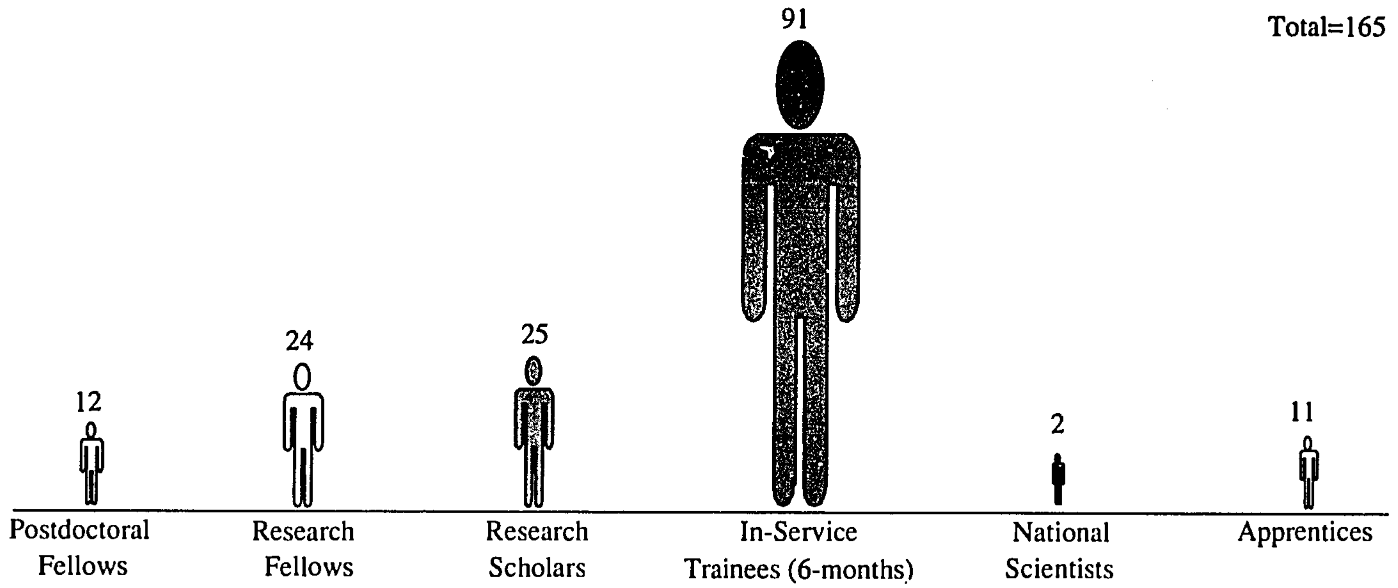
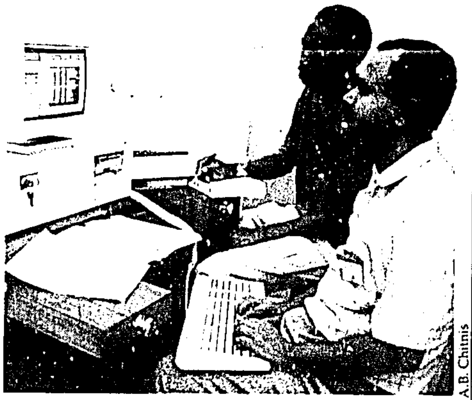


Figure 13. HRDP participants at ICRISAT Center, 1990.



A.B. Chitnis

A Somalian scholar conducts a literature search assisted by a Documentation Officer.

Research Scholar regional and national activities

A Malian PhD student completed thesis research related to soil fertility. University of Niamey students completed a study on growth analysis of pearl millet varieties and on soil chemical characteristics during the rainy season. A student from the University of Abidjan (Côte d'Ivoire) and a student from the Institut pratique de dévéloppment rural (IPDR) in Kolo, Niger, completed papers in crop physiology. Four other IPDR students completed field studies on crop improvement. A scientist from Niger's national program studied techniques related to the control of pearl millet stem borer, and a student from Niger completed his degree program on foliar diseases of groundnut in France. Four students from Germany studied with Resource Management staff.

The SADCC/ICRISAT/INTSORMIL degree programs included seven students from five countries who completed their BSc, MSc, or PhD degrees during 1990. SMIP scientists continue to guide four PhD and two MSc students from four countries in their thesis research projects. Ten undergraduate students from the University of Zimbabwe completed 3-month study papers with various staff and two Bulawayo Polytechnical Institute students were guided for 3 to 9 months in food technology studies. Ten BSc students completed papers and two BTech students studied with the Food Technology staff.

D.L. Oswalt

Research scholar from Sudan conducting entomology research in the greenhouse.

Apprenticeship activities

Three Indian apprentices completed 5-week training activities in editing and document production with Information Services staff. Self-supported undergraduates from the Netherlands, United Kingdom, and Germany studied chickpea breeding, legume entomology, agronomy, and soil science for up to 24 weeks.

Information Services

Information Services assists ICRISAT scientists in the exchange of technology by editing and publishing Institute-level publications and by creating and maintaining public awareness.

Editorial Committee Secretariat

The Division provides 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 multi-authored book chapters, achieve a high acceptance rate by publishers, and consequently obtain feedback from fellow scientists. During 1990 the Editorial Committee handled the review of 243 documents destined for publication.

Publications

Information Services published 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 the interested public. These publications comprised **ICRISAT Annual Report 1989, ICRISAT Research Highlights 1989**, and quarterly and half-yearly newsletters. Other publications were issued in the following categories: germplasm catalogs, plant material descriptions, books, research bulletins,

A B Chitnis

ICRISAT printers working on a four-color publication.

Creating graphics by computer.

information bulletins, conference/ workshop proceedings, bibliographies, newsletters, general audience publications, and audiovisual materials.

In 1990, the Division published, copublished, or reprinted a total of 93 items within these categories plus semiformal documents, representing an increase of more than 10% over 1989.

Support Services

During 1990, Information Services artists completed more than 1700 pieces of artwork, photographic staff handled 1649 assignments and processing jobs, and compositors created and processed 12 300 galley pages.

Distribution

Responding to requests from librarians in semi-arid tropical countries and from a range of partners who collaborate with the Institute in various ways, Information Services dispatched 96% of its priced publications (50 961 copies) free of charge. Such gratis distribution helps those who assist ICRISAT in the fulfillment of its mandated mission by providing ready access to the Institute's publications relevant to their work. Most of these Institute-level publications were produced in-house.

A senior Research Editor, on sabbatical leave, continued with external assistance the detailed task of overhauling, updating, and coding the Institute's mailing list and incorporating lists of program collaborators to ensure a better transfer of our technology.

Translation

The French Unit was redesignated the Foreign Language Unit reflecting an increasing responsibility for publishing in languages other than English. The Unit translated or edited 120 abstracts and papers for inclusion in the Institute's publications and assisted in producing 10 French editions.

The Unit also continued to provide translation services in Spanish and Portuguese with external assistance. Unit staff further enhanced the English/ French Lexicon, now containing about 5000 terms relating to semi-arid tropical agriculture, and collaborated with the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France, in preparing the copublication entitled **Manuel d'édition agronomique**.

New technology/skills enhancement

In response to a consultancy on publication production, Information Services took delivery of the selected PC-based MagnaFile system for electronic composition, supported by compatible software for desktop publishing. The installation was accompanied by the training of keyboard operators, and a senior staff member participated in a management training course organized by the Printing Industries Research Association in the UK. By the end of the year most production jobs were being handled via the new system and arrangements had been made for training the Division's artists and others in computer-assisted design techniques in a 16-day in-house consultancy.

The Division also arranged two small-group participatory seminars of 4 days each on scientific communication. The objective was to broaden Institute scientists' understanding of the range of skills required in writing articles for submission to journals, and in presenting information to peer audiences orally and in audiovisual mode. Postseminar questionnaires indicated considerable appreciation of the style and content of the seminars and the Division plans to present additional seminars for Institute scientists in 1991.

Newsletters

For the first issue of the Institute's quarterly newsletter in 1990 the title was changed from **At ICRISAT** to **SAT News**. It was felt the previous title implied an institutional focus, whereas the time seemed right to widen the scope and to encourage external contributions. The new newsletter was well received, one commentator remarking that "it is bright, cheerful, and well designed."

Progress Reporting and Public Awareness

The Division collaborated with consultants in creating a new design approach to ICRISAT publications when the third draft of the Institute's Strategic Plan **Pathways to Progress** was being prepared. Division staff put forward proposals for the new style and contents of this present report, and participated in discussions about improved collaboration with media staff worldwide under the auspices of the CGIAR's Public Awareness Association. The phased program aimed at enhancing such media contacts progressed well during the year, both within India and internationally. One effect of this work has been an increased demand for improved seeds derived from ICRISAT breeding material.

A member of staff from the Nitrogen-fixation by Tropical Agricultural Legumes Project, University of Hawaii, joined us on sabbatical assignment, primarily to help the Institute improve its range of public awareness documents and audiovisual aids.

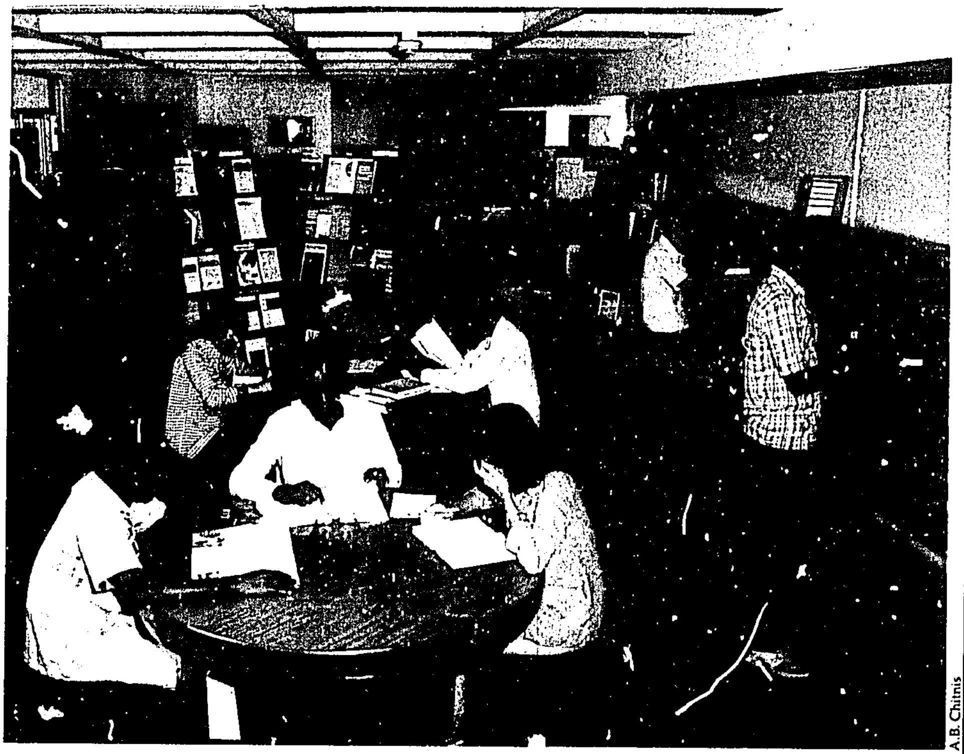
Library and Documentation Services

Library and Documentation Services plays an important role in serving the Institute's scientists as a center for world literature and information related to ICRISAT's mandate. These services are also available to other scientists.

The Division has three functional components: the Library itself, the Documentation Services Unit, and the Central Reprography Unit. The Division has a specialized information dissemination project called the Semi-Arid Tropical Crops Information Service (SATCRIS). SATCRIS is a database for information on the five crops mandated to ICRISAT.

Acquisitions

The Library is building a comprehensive document collection to meet the information needs of ICRISAT's scientists. Apart from conventional documents, efforts are made to acquire such nonconventional literature as technical reports, socioeconomic studies, and annual reports from various sources. During 1990 a total of 1682 documents were added to the Library.


A.B. Chitnis

The ICRISAT Center Library.

Document Delivery Service

More than 7545 requests for documents were entertained during 1990. Of these, the Selective Dissemination of Information (SDI) service alone provided copies of 4508 papers.

Semi-Arid Tropical Crops Information Service (SATCRIS)

The first phase of the SATCRIS project, started in 1986 with funding provided by the International Development Research Centre (IDRC), Canada, ended in 1990. A proposal for support of the second phase of this project has been submitted to IDRC for its consideration. The important features of the second phase include:

- development of nonbibliographic databases;
- development of an expert system to identify and control diseases of groundnut;
- development of a user-friendly interface to the SATCRIS database;
- strengthening of the information handling capability of the ISC library;
- distribution of subsets of SATCRIS database among national programs for use with Micro CDS/ISIS; and
- promotion of information services in Africa.

Selective Dissemination of Information (SDI)

This automated monthly information service was initiated in March 1988. Through it, scientists keep abreast of current literature of use to them. Current machine-readable data is matched against users' interest profiles and the output of relevant references is provided. The number of recipients added to this service during 1990 was 129. Of these, 40 were from 17 countries in Africa, 76 were from 7 countries in Asia, 7 were from the Americas, and 6 were from Europe. This service is now provided to a total of 356 users from 47 countries around the world. The distribution of SDI recipients is shown in Figure 14.

Database development

With the addition of 5663 records during 1990, the number of records in the SATCRIS database, has grown to 23 557. This database, maintained on MicroVax 3900, is built from the subset of data obtained in machine-readable form from two international databases: CAB International (CABI) and FAO's International Information System for Agricultural Sciences and Technology (AGRIS). Local input pertaining to the documents acquired by the ICRISAT library is also provided.

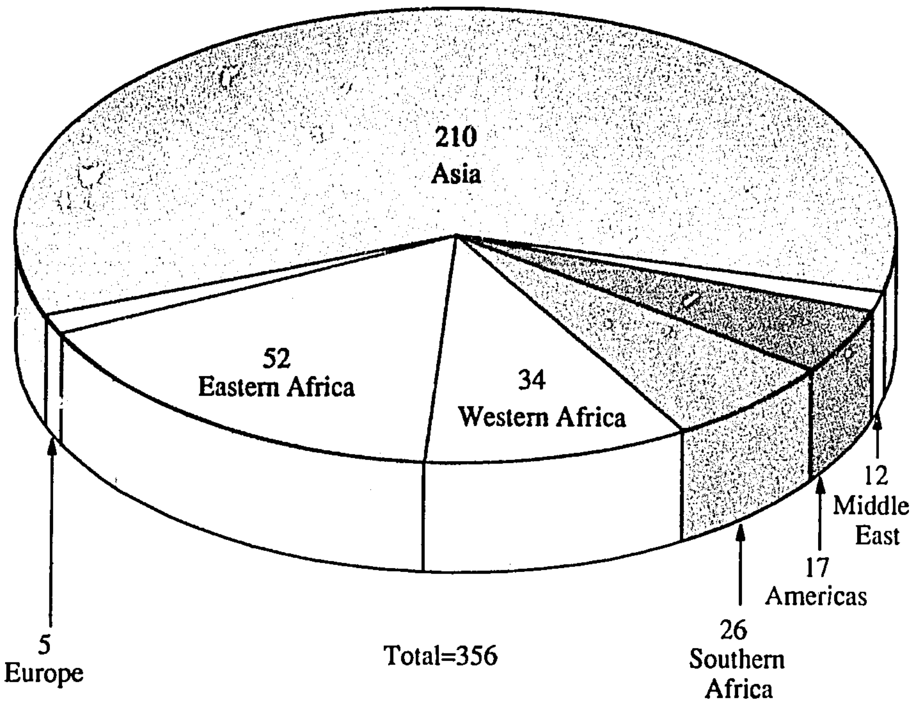


Figure 14. Recipients of SDI Service.

Literature search service

Users from within India accounted for most of the 390 literature searches carried out during 1990, followed by users from various countries in Africa. Other searches were carried out for users in North America, West Asia, and South and Southeast Asia.

Specialist abstracts services

Three specialist abstract services (Sorghum and Millets Abstracts, Chickpea and Pigeonpea Prompts, and Groundnut Prompts) were published by CABI in collaboration with ICRISAT as a part of the SATCRIS project. These services were provided free to 761 individuals and institutions in 45 countries of the semi-arid tropics.

Union catalog of serials holdings in the international agricultural research centers

In late 1988, work started on development of a machine-readable database. Acting on the recommendation of the CGIAR Meeting on Documentation and Information Services, a draft of the Catalog was completed during 1990. The Catalog includes 5401 entries from 14 centers. Its database was developed as a Micro CDS/ISIS application and has been provided to 40 institutions in 25 countries. Camera-ready copy of the Catalog was produced and sent for printing.

Input to the AGRIS and CABI databases

Items of 298 ICRISAT-generated conventional and nonconventional literature were added to the AGRIS database, and 97 items pertaining to nonconventional literature acquired by the Library were added to the CABI database.

ICRISAT Sahelian Center activities

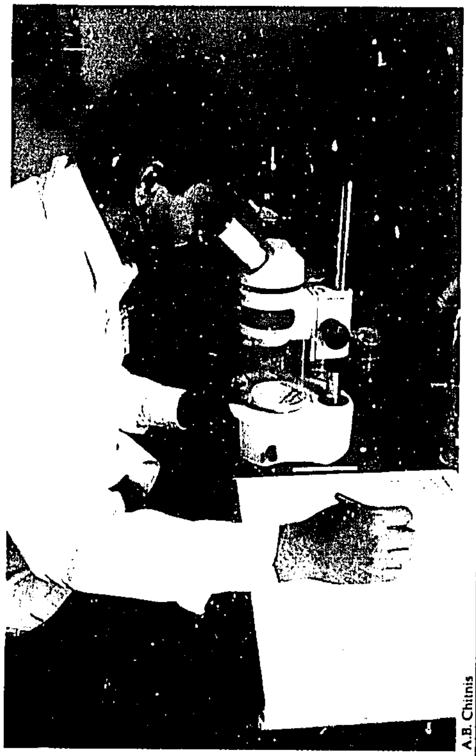
During 1990 the ISC Library added 542 documents to its collection. The number of journal subscriptions was 82. The Library provided copies of 20 000 pages of journal articles to scientists based in Kano (Nigeria), Bamako (Mali), and Sadoré (Niger). The circulation of the contents pages of the journals acquired in the ISC library generated demand of the photocopies.

SESAME, a database providing access to French literature on agriculture and rural development, was installed on CD-ROM. The database was provided by the Centre international de documentation en agronomie des régions chaudes.

Plant Quarantine Unit

The Plant Quarantine Unit provides support to ICRISAT's research programs by facilitating the free flow of germplasm in and out of India. During 1990, the NBPGR, India's plant quarantine seıvice, certified 50 262 seed samples of ICRISAT crops for export to 91 countries. NBPGR also released 1871 seed and plant samples of ICRISAT's mandate crops imported from 16 countries for ICRISAT experiments in India.

The Unit applies exclusionary procedures to protect agriculture in the importing countries in accordance with their specific regulations and conditions. The Unit carefully adheres to NBPGR regulations and safeguards concerning the release of imported seed and plant material to prevent entry of pests and pathogens that could infest, infect, or contaminate seeds. Seed and plant material for export is processed at ICRISAT Center, and clearance for incoming germplasm is obtained through NBPGR's Plant Quarantine Regional Station in Hyderabad.



A.B. Chitnis

Plant Quarantine technician checking germplasm suitability for export.

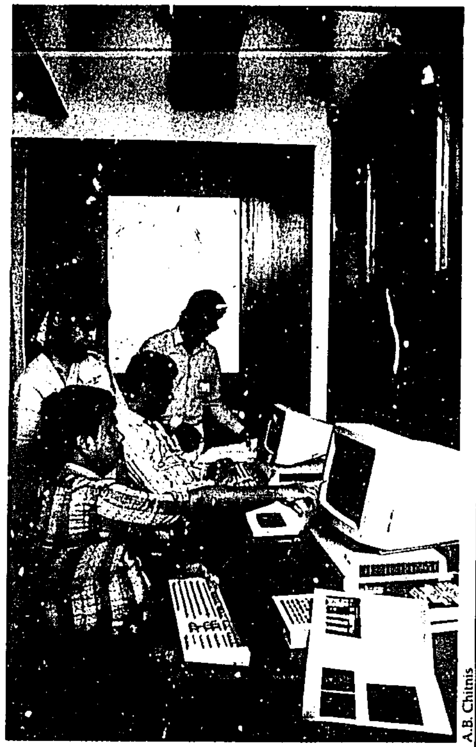
Statistics Unit

The Statistics Unit provides consultancy services to ICRISAT staff and scientists from collaborative projects at various stages of research, from planning experiments to processing the data and drawing inferences. The Unit delivers lectures to in-service trainees on the principles of experimentation and the use of statistical packages on the computer.

Consultancies with staff and collaborators during 1990 averaged over 70 per month. Two PhD students, one from the SADCC/ICRISAT Program and another from the University of Agricultural Sciences in Bangalore, were assisted in statistical analysis of data and interpretation of results.

Several data sets for various programs at ICRISAT Center were processed, and various computer programs for use by the plant breeders and other scientists were developed. ICRISAT statisticians compiled, tested, and modified a program used for the statistical analysis of interaction between genotype and environment developed by the Statistical Research Section of Agriculture, Canada. The Unit also developed an information retrieval system using dBase software.

Three consultant statisticians worked in the Unit for short periods to help the scientists in various topics. One staff member received training on microcomputer applications at Bonn, Germany, for a month. Staff members of the Unit also visited the National Grain Legume Improvement Program in Nepal and EARCAL in Kenya to conduct training on usage of statistical packages.



A.B. Chitnis

ICRISAT statisticians at work.

Appendices

Financial Highlights

Donor Contributions

	US $ (000)
African Development Bank	150
Asian Development Bank	230
Australia	642
Belgium	160
Canada/Canadian International Development Agency (CIDA)	1 795
China	30
Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)	389
European Economic Community	3 824
Finland	1 254
France	513
Germany	1 279
India	125
International Fund for Agricultural Development	98
Italy	944
Japan	3 005
Netherlands	1 055
Norway	701
Sweden	818
Switzerland	1 201
United Kingdom	1 697
United Nations Development Programme	1 623
United States Agency for International Development	6 340
World Bank	3 584
Complementary (Special Projects)	6 666
Total	**38 123**

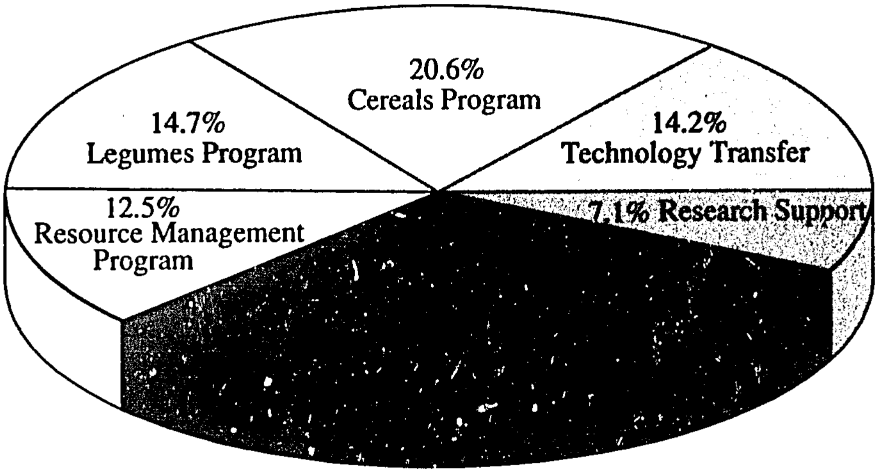


Figure 15. ICRISAT's resource allocations (core operations).

Balance Sheet (US $ 000)

	1990	1989
Assets	**96 460**	**90 872**
Cash and short-term deposits	8 621	10 331
Accounts receivable	11 136	9 282
Inventories	528	504
Prepaid expenses	702	469
Property, plant, and equipment	75 433	70 286
Currency translation adjustment (net)	40	0
Liabilities	**16 181**	**16 608**
Accounts payable and other liabilities	9 951	11 190
Overdrafts with banks	25	63
Accrued salaries and benefits	4 120	3 507
Payments in advance from donors	2 085	1 801
Currency translation adjustment (net)	0	47
Fund balances	**80 279**	**74 264**
Capital	75 433	70 286
Special purpose fund	231	180
Unexpended funds	4 615	3 798
Total liabilities and fund balances	**96 460**	**90 872**

A. F. FERGUSON & CO.

CHARTERED ACCOUNTANTS

ALLAHABAD BANK BUILDINGS

BOMBAY SAMACHAR MARG

BOMBAY 400 001

No. ACG/2113

March 19, 1991

The Governing Board,
International Crops Research Institute
for the Semi-Arid Tropics,
Patancheru (A.P.)

Dear Sirs,

Report on the Audit of the Financial Statements
for the year ended December 31, 1990

We have completed our examination of the books of account of the Institute for the year ended December 31, 1990 and enclose the Statement of Financial Position, Statement of Activity, Statement of Activity by Funding Source and Statement of Changes in Financial Position, duly signed by us under reference to this report.

2. Scope of Audit

Our examination of the above Statements included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. We have broadly reviewed the systems and procedures relating to accounting, internal control and maintenance of books and records. The audit was carried out in accordance with generally accepted auditing standards in India. Our examination was made primarily for the purpose of forming our opinion on the Financial Statements taken as a whole.

The reports on the accounts of the Institute's project in the Southern African Development Coordination Conference (SADCC) region, Zimbabwe, and the ICRISAT Sahelian Center, in Niamey, Niger, audited by other auditors, have been produced to us and have been considered in preparing our report.

3. Opinion

In our opinion, the Statement of Financial Position as on December 31, 1990, Statement of Activity, Statement of Activity by Funding Source and Statement of Changes in Financial Position for the year ended as on that date, present fairly, subject to and on the basis of the accounting policies set out in note 1 to the Financial Statements and read with the other notes thereon, the financial position of the Institute as on that date and the changes in its financial position for the year then ended, in conformity with consistently applied accounting principles. We further report that the above Statements are in accordance with the books and records of the Institute and the information and explanations furnished to us.

4. We record, with pleasure, our appreciation of the cooperation rendered to us by the Director General and the staff during the course of the audit.

Yours faithfully,

TELEPHONE: 286 3313 · TELEGRAMS: BALANCE, BOMBAY · TELEX: (011) 3824
BANGALORE · CALCUTTA · GOA · HYDERABAD · JAMSHEDPUR · MADRAS · NEW DELHI · PUNE
MIDDLE EAST: DUBAI, U. A. E. MUSCAT, OMAN

Institute Level Publications

Use the catalog codes (in parentheses) when ordering publications.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. ICRISAT research highlights 1989. Patancheru, A.P. 502 324, India: ICRISAT. 47 pp. (RHE 011)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. ICRISAT annual report 1989. Patancheru, A.P. 502 324, India: ICRISAT. 336 pp. (ARE 016)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Chickpea kabuli variety ICCV 2. Plant Material Description no.22. Patancheru, A.P. 502 324. India: ICRISAT. 4 pp. (PME 022)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Chickpea kabuli variety ICCV 5. Plant Material Description no.23. Patancheru, A.P. 502 324. India: ICRISAT. 4 pp. (PME 023)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Groundnut variety ICGV 87141 (ICGS 76). Plant Material Description no.24. Patancheru, A.P. 502 324. India: ICRISAT. 4 pp. (PME 024)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Groundnut variety ICGS 1 (ICGV 87119). Plant Material Description no.25. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. (PME 025)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Chickpea desi variety ICCL 80074 (ICCC 37). Plant Material Description no.26. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. (PME 026)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Groundnut variety ICGV 87187 (ICGS 37). Plant Material Description no.27. Patancheru, A.P. 502 324, India: ICRISAT. 4 pp. (PME 027)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Summary proceedings of the First ICRISAT Regional Groundnut Meeting for West Africa, 13-16 Sep 1988, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT. 264 pp. (CPE 062)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Chickpea in the nineties: proceedings of the Second International Workshop on Chickpea Improvement, 4-8 Dec 1989, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 412 pp. (CPE 063)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Summary proceedings of the First Consultative Group Meeting on the Host Selection Behavior of *Helicoverpa armigera*, 5-7 Mar 1990, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT. 40 pp. (CPE 064)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Industrial utilization of sorghum: summary proceedings of a Symposium on the Current Status and Potential of Industrial uses of Sorghum in Nigeria, 4-6 Dec 1989, Kano, Nigeria. Patancheru, A.P. 502 324, India: ICRISAT. 68 pp. (CPE 065)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Proceedings of the Fourth Regional Groundnut Workshop for Southern Africa, 19-23 Mar 1990, Arusha, Tanzania. Patancheru, A.P. 502 324, India: ICRISAT. 212 pp. (CPE 066)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. ICRISAT's contribution to pearl millet production. Patancheru, A.P. 502 324, India: ICRISAT. 8 pp. (GAE 024)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Vers une meilleure productivite du mil: Rapport de l'ICRISAT. Patancheru, A.P. 502 324, Inde: ICRISAT. 8 pp. (GAF 024)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Legumes entomology. ICRISAT Public Awareness Series. Patancheru, A.P. 502 324, India: ICRISAT. 2 PP. (PAE 001)

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Crop improvement in India: ICRISAT cultivars. ICRISAT Public Awareness Series. Patancheru, A.P. 502 324, India: ICRISAT. 8 pp. (PAE 002)

Maiti, R.K., Bisen, S.S. 1990. L'anatomie du mil (Pennisetum glaucum [L.] R.Br.). Bulletin d'information no.6. Patancheru, A.P. 502 324, Inde: International Crops Research Institute for the Semi-Arid Tropics. 24 pp. (IBF 006)

Nambiar, P.T.C. 1990. Nitrogen nutrition of groundnut in Alfisols. Information Bulletin no.30. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp. (IBE 030)

Nigam, S.N., Vasudeva Rao, M.J., and Gibbons, R.W. 1990. Artificial hybridization in groundnut. (Summary in Fr and Es) Information Bulletin no.29. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid tropics. 28 pp. (IBE 029)

Subrahmanyam, P., McDonald, D. 1990. La rouille de l'arachide. Bulletin d'information no 13. Patancheru, A.P. 502 324, Inde: International Crops Research Institute for the Semi-Arid Tropics. 20 pp. (IBF 013)

External Publications

Order reprints by JA or CP number.

Ae, N., Arihara, J., Okada, K., Yoshihara, T., and Johansen, C. 1990. Phosphorus uptake by pigeon pea and its role in cropping systems of the Indian subcontinent. Science 248:477–480. (JA 962)

Alagarswamy, G., Virmani, S.M., Godwin, D.C., and Singh, U. 1990. Evaluating fertilizer use strategies for sorghum - a systems approach. Pages 71–81 *in* Technology blending and agrarian prosperity (Verma, J.P., and Varma, A., eds.). New Delhi, India: Malhotra Publishing House. (CP 541)

Amin, P.W., Jain, K.C., Kumar Rao, J.V.D.K., Pawar, C.S., Jagdish Kumar, van Rheenen, H.A., and Faris, D.G. 1990. On-farm research on chickpeas and transfer of technology in India. Pages 329-335 *in* Chickpea in the nineties: proceedings of the Second International Workshop on Chickpea Improvement, 4–8 Dec 1989, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 570)

Anjaiah, V., Reddy, D.V.R., Manohar, S.K., Naidu, R.A., Nene, Y.L., and Ratna, A.S. 1989. Isolation and characterization of a potyvirus associated with bushy dwarf symptom in chickpea, *Cicer arietinum*, in India. Plant Pathology 38(4):520–526. (JA 869)

Appa Rao, S., Mengesha, M.H., Rajagopal Reddy, C., and Saideswara Rao, Y. 1990. Genetics of white sheath and bleached leaf mutants in pearl millet. The Journal of Heredity 81(2):159–162. (JA 873)

Awadhwal, N.K., and Smith, G.D. 1990. Performance of low-draft tillage implements on a hard setting Alfisol of the SAT in India. Soil Use and Management 6(1):28–31. (JA 806)

Awadhwal, N.K., and Takenaga, T. 1989. Development of a twin spinning-disc, knapsack sprayer. Journal of Agricultural Engineering 26(3):207–210. (JA 785)

Azam-Ali, S.N., Matthews, R.B., Williams, J.H., and Peacock, J.M. 1990. Light use, water uptake and performance of individual components of a sorghum/groundnut intercrop. Experimental Agriculture 26(4):413–427. (JA 959)

Azam Ali, S.N., Simmonds, L.P., Nageswara Rao, R.C., and Williams, J.H. 1989. Population, growth and water use of groundnut maintained on stored water. III. Dry-matter, water use and light interception. Experimental Agriculture 25(1):77–86. (JA 715)

Bandyopadhyay, R., Mughogho, L.K., Manohar, S.K., and Satyanarayana, M.V. 1990. Stroma development, honeydew formation, and conidial production in *Claviceps sorghi*. Phytopathology 80(9):812–818. (JA 931)

Bationo, A., Christianson, C.B., and Baethgen, W.E. 1990. Plant density and nitrogen fertilizer effects on pearl millet production in Niger. Agronomy Journal 82:290–295. (JA 1005)

Bidinger, F.R., and Parthasarathy Rao, P. 1990. Genetic and cultural improvements in the production of pearl millet. Pages 194–206 *in* Proceedings of the International Congress of Plant Physiology, 15–20 Feb 1988, New Delhi, India (Sinha, S.K., Sane, P.V., Bhargava, S.C., and Agrawal, P.K. eds.). Vol. I. New Delhi 110 012, India: Society for Plant Physiology and Biochemistry, Water Technology Centre, Indian Agricultural Research Institute. (CP 486)

Bidinger, F.R., and Raju, D.S. 1990. Effects of the d_2 dwarfing gene in pearl millet. Theoretical and Applied Genetics 79(4):521–524. (JA 946)

Bisht, V.S., and Nene, Y.L. 1990. Studies on survival and dispersal of pigeonpea *Phytophthora*. Indian Phytopathology 43(3):375–381. (JA 829)

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ICRISAT Governing Board - 1990

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Director, Agriculture Department
Asian Development Bank
Philippines

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Managing Director
Birrell Management
Australia

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Director, Plant Production and Protection Division, FAO
Italy

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Director, Institut de recherches agronomiques tropicales (IRAT)
France

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R and D Consultants
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Ministry of Agriculture
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India

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Department of Plant Breeding
University of Helsinki
Finland

Mamadou F. Traoré (*Mali*)
Conseiller Technique
Ministère de l'Agriculture
Mali

1. Ex-officio member.

ICRISAT Senior Staff
- as of 31 Dec 1990

(The countries of internationally recruited staff are italicized.)

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Samuel P. Ambrose, *India*, Assistant Director General (Administration) (*from Apr*)
Vishwa Shenoi, *India*, Assistant Director General (Liaison) (*from Aug*)
Bharati K. Patel, *Zambia*, Special Assistant to the Director General for Planning
B.C. Gamini Gunasekera, *Sri Lanka*, Advisor to the Director General for Donor Relations
Steven D. Goode, *USA*, Research Contracts Officer (*from Nov*)
Peter Reavey, *UK*, Special Assistant to the Director General for Educational Affairs
V. Balasubramanian, Senior Executive Officer (Director General's Office)
Joyce Gay, Senior Administrative Secretary to the Director General
V.S. Swaminathan, Senior Administrative Officer, Office of the Assistant Director General (Administration) (*on leave from May*)
D. Mitra, Fiscal Manager
A. Banerji, Assistant Manager, Fiscal (*until Dec*)
P.A.V.N. Kumud Nath, Senior Accounts Officer (*on leave from May*)
P.M. Menon, Personnel Manager (*from Aug*)
K.K. Vij, Assistant Manager (Administration) (*until May*)
N.S.L. Kumar, Senior Personnel Officer
P. Suryanarayana, Senior Personnel Officer
R. Vaidyanathan, Purchase and Stores Manager (*until May*)
P. Ram Reddy, Purchase and Stores Manager (*from Dec*)
C.R. Krishnan, Assistant Manager (Purchase and Stores)
K.P. Nair, Senior Purchase Officer (*on leave until Jan*)
D.K. Mehta, Senior Stores Officer
D.V. Rama Raju, Senior Purchase Officer
K.C. Saxena, Senior Stores Officer
A. Lakshminarayana, Senior Scientific Liaison Officer (Visitors' Services)
Deepak M. Pawar, Senior Scientific Liaison Officer (Visitors' Services) (*from Oct*)
K.K. Sood, Senior Security Officer
S. Krishnan, Manager, Delhi Office (*from Aug*)
K. Santhanam, Manager, Internal Audit (*on ad hoc assignment from Feb*)
A.N. Venkataswami, Senior Audit Officer (*from Apr*)
N. Surya Prakash Rao, Senior Resident Medical Officer

Cereals

Program Office

Johannes M.J. de Wet, *USA*, Program Director

Sorghum Group

John W. Stenhouse, *UK*, Principal Breeder
Lewis K. Mughogho, *Malawi*, Principal Pathologist
John M. Peacock, *UK*, Principal Physiologist
Kanayo F. Nwanze, *Nigeria*, Principal Entomologist
Chandra M. Pattanayak, *India*, Principal Coordinator CCRN
G. Alagarswamy, Physiologist
Belum V.S. Reddy, Senior Breeder
B.L. Agrawal, Breeder (*until Jun*)
P.K. Vaidya, Breeder (*until Mar*)
N. Seetharama, Senior Physiologist
Suresh Pande, Pathologist
Ranajit Bandyopadhyay, Pathologist
P. Soman, Physiologist (*on leave from Apr*)
S.L. Taneja, Entomologist
H.C. Sharma, Entomologist

Pearl Millet Group

John R. Witcombe, *UK*, Principal Breeder (*until Mar*)
Francis R. Bidinger, *USA*, Principal Physiologist
Stanley B. King, *USA*, Principal Pathologist (*on sabbatical leave until May*)
Eva Weltzien Rattunde, *Germany*, International Associate Scientist
K.N. Rai, Senior Breeder
B.S. Talukdar, Breeder
V. Mahalakshmi, Physiologist
S.D. Singh, Senior Pathologist
R.P. Thakur, Senior Pathologist

Cell Biology

Carlos S. Busso, *Italy*, Associate Principal Cell Biologist (*from Jul*)

EARCAL, Kenya

Vartan Y. Guiragossian, *France*, SAFGRAD/ICRISAT Coordinator for Sorghum and Millet, Eastern Africa
Samwiri Z. Mukuru, *Uganda*, Principal Sorghum Breeder

LASIP, Mexico

Compton L. Paul, *Guyana*, Team Leader and Principal Sorghum Agronomist
C. Thomas Hash, *USA*, Principal Sorghum Breeder
René Clará V., *El Salvador*, Sorghum Breeder

Legumes

Program Office

Duncan McDonald, *UK*, Program Director

AGLN

Donald G. Faris, *Canada*, Principal Coordinator
C.L.L. Gowda, Senior Breeder
P.W. Amin, Coordinator and Senior Entomologist, LEGOFTEN (*until Apr*)
Deepak M. Pawar, Senior Agricultural Officer, LEGOFTEN (*until Mar*)
C.S. Pawar, Entomologist, LEGOFTEN
J.V.D.K. Kumar Rao, Physiologist, LEGOFTEN (*at ICRISAT Center until Apr, in Gwalior from May*)

Crops Research

Shyam N. Nigam, *India*, Principal Groundnut Breeder (*on sabbatical leave until May*)
Hendrikus A. van Rheenen, *Netherlands*, Principal Chickpea Breeder (*on sabbatical leave from Nov*)
Rasiah P. Ariyanayagam, *Sri Lanka*, Principal Pigeonpea Breeder
Chris Johansen, *Australia*, Principal Agronomist
Osamu Ito, *Japan*, Principal Agronomist and Team Leader (*from Mar*)
Michel P. Pimbert, *France*, Principal Entomologist
John A. Wightman, *New Zealand*, Principal Entomologist
Nigel J. Armes, *UK*, Principal Entomologist, ICRISAT/NRI (*from Nov*)
Donald H. Smith, *USA*, Principal Pathologist (*from Oct*)
J. Philip Moss, *UK*, Principal Cell Biologist
D.V.R. Reddy, *India*, Principal Virologist
Nicholas Horn, *Netherlands*, Assistant Virologist
Said N. Silim, *Uganda*, International Associate Scientist (Physiology)
Ryoichi Matsunaga, *Japan*, Associate Principal Physiologist
Jagdish Kumar, Senior Chickpea Breeder
K.B. Saxena, Senior Pigeonpea Breeder
L.J. Reddy, Senior Groundnut Breeder
Onkar Singh, Chickpea Breeder
S.C. Sethi, Chickpea Breeder
K.C. Jain, Pigeonpea Breeder
S.C. Gupta, Pigeonpea Breeder
M.J. Vasudeva Rao, Groundnut Breeder (*until Jan*)
S.L. Dwivedi, Groundnut Breeder
S.S. Lateef, Senior Entomologist
G.V. Ranga Rao, Entomologist
M.P. Haware, Plant Pathologist
N.P. Saxena, Senior Physiologist (*on secondment from Nov*)
O.P. Rupela, Physiologist
K.R. Krishna, Physiologist
Y.S. Chauhan, Physiologist
V.M. Ramraj, Physiologist
R.C. Nageswara Rao, Physiologist (*on sabbatical leave from Sep*)
P. Subrahmanyam, Senior Pathologist (*until Sep*)
M.V. Reddy, Senior Pathologist
A.M. Ghanekar, Pathologist
V.K. Mehan, Pathologist
S.B. Sharma, Nematologist
D.C. Sastri, Cell Biologist
P.T.C. Nambiar, Cell Biologist (*until Apr*)

EARCAL, Kenya

Laxman Singh, *India*, Principal Pigeonpea Agronomist

ICARDA, Syria

K.B. Singh, *India*, Principal Chickpea Breeder

Resource Management

Program Office

John L. Monteith, *UK*, Program Director
R.S. Aiyer, Senior Administrative Officer

Agronomy

S.M. Virmani, *India*, Principal Agroclimatologist
Chin K. Ong, *Malaysia*, Principal Agronomist
David R. Butler, *UK*, Principal Microclimatologist
Merle M. Anders, *USA*, Principal Production Agronomist
Piara Singh, Soil Scientist
A.K.S. Huda, Agroclimatologist (*on sabbatical leave from Jan*)
A. Ramakrishna, Agronomist
Madhukar V. Potdar, Agronomist (*from Feb*)
Julius C.W. Odongo, *Uganda*, Visiting Scientist (*from Nov*)
S.K. Sharma, Senior Research Associate

Soil

John R. Burford, *Australia*, Principal Soil Chemist
Kofi B. Laryea, *Ghana*, Principal Soil Scientist
Donald F. Yule, *Australia*, Principal Soil Scientist, ICRISAT/QDPI
Keuk-Ki Lee, *Korea*, Principal Microbiologist
Adolf Schütt, *Germany*, Assistant Principal Engineer
K.L. Sahrawat, Senior Soil Scientist
T.J. Rego, Senior Soil Scientist
D.P. Verma, Soil Scientist, ICRISAT/IFDC (*on contract until Jun*)
Sardar Singh, Soil Scientist
Prabhakar Pathak, Agricultural Engineer
K.L. Srivastava, Agricultural Engineer (*on leave from Sep*)
R.C. Sachan, Agricultural Engineer (*until May*)
N.K. Awadhwal, Agricultural Engineer/ Soil Physicist (*on leave from Aug*)
Suhas P. Wani, Microbiologist (*on sabbatical leave until Nov*)

Economics

Rolf A.E. Müller, *Germany*, Principal Economist (*until Nov*)

Thomas S. Walker, *USA*, Principal Economist
Timothy G. Kelley, *USA*, Assistant Principal Economist
John M. Kerr, *USA*, Assistant Principal Economist
John H. Foster, *USA*, Visiting Economist (*from Sep*)
Meri L. Whitaker, *USA*, International Associate Economist (*from Nov*)
R.P. Singh, Economist

Support Programs

Computer Services

James W. Estes, *USA*, Head
S.M. Luthra, Manager
J. Sai Prasad, Assistant Manager
T.B.R.N. Gupta, Senior Programmer/ Analyst

Crop Quality Unit

R. Jambunathan, *USA*, Principal Biochemist and Program Leader
Umaid Singh, Biochemist
V. Subramanian, Biochemist

Electron Microscope Laboratory

A.K. Murthy, Senior Engineer

Farm Development and Operations

D.S. Bisht, *India*, Manager
Shiva K. Pal, Senior Plant Protection Officer
K. Ravindranath, Senior Engineer (Farm Machinery)
Marri Prabhakar Reddy, Senior Agricultural Officer
N.V. Subba Reddy, Senior Horticulture Officer
Ramesh C. Sachan, Senior Engineer (*from Jun*)
M.C. Ranganatha Rao, Senior Engineer

Genetic Resources Unit

Melak H. Mengesha, *Ethiopia*, Principal Germplasm Botanist and Program Leader
K.E. Prasada Rao, Senior Botanist
R.P.S. Pundir, Botanist
S. Appa Rao, Botanist
P. Remanandan, Botanist
A.K. Singh, Botanist (*from Aug*)
V. Ramanatha Rao, Botanist (*until Jul*)
Surendra Mohan, Senior Administrative Officer

Housing and Food Services

David A. Evans, *UK*, Head
Samiran Mazumdar, Assistant Manager (Food Services)
B.R. Revathi Rao, Assistant Manager (Housing)
D.V. Subba Rao, Assistant Manager (Warehouse)

Human Resource Development Program

D.L. Oswalt, *USA*, Program Leader
B. Diwakar, Senior Training Officer
T. Nagur, Senior Training Officer
S.K. Dasgupta, Senior Training Officer
Faujdar Singh, Training Officer

Information Services

J. Brian Wills, *UK*, Head
Susan D. Hall, *UK*, Research Editor (*on sabbatical leave from Sep*)
Eric M. McGaw, *USA*, Research Editor
Princess I. Ferguson, *USA*, Visiting Research Editor (*from Nov*)
S.M. Sinha, Assistant Manager (Art and Production)
D.R. Mohan Raj, Senior Editor (*until Jun*)
Jugu J. Abraham, Editor
V. Sadhana, Editor
Brij Bhushan Sahni, Editor (*on ad hoc assignment from Jun to Oct*)
Gopal Guglani, Senior Art Visualizer
T.R. Kapoor, Senior Supervisor (Composing)
A.N. Venkataswami, Senior Administrative Officer (*until Apr*)
P. Subrahmanyam, Senior Administrative Officer (*from May*)

Library and Documentation Services

L.J. Haravu, Manager (*on leave from Sep*)
P.K. Sinha, Senior Documentation Officer
P.S. Jadhav, Senior Library Officer
S. Prasannalakshmi, Senior Library Officer

Physical Plant Services

Vincent P. McGough, *UK*, Manager
D. Subramaniam, Chief Engineer
Sudhir Rakhra, Chief Engineer (Civil) (*until Apr*)
D.C. Raizada, Senior Engineer
N.S.S. Prasad, Senior Engineer
A.R. Dasgupta, Senior Engineer (*until Nov*)
A.N. Singh, Senior Engineer
S.P. Jaya Kumar, Senior Administrative Officer

Plant Quarantine Unit

N.C. Joshi, Chief Plant Quarantine Officer (*on ad hoc assignment*)
Upendra Ravi, Senior Research Associate
P. Subrahmanyam, Senior Administrative Officer (*until May*)

Radio Isotope Laboratory

S. Sivaramakrishnan, Biochemist

Statistics

Douglas R. Neeley, *USA*, Consultant Statistician

Western African Programs

ICRISAT Sahelian Center, Niger

Administration

Ronald W. Gibbons, *UK*, Executive Director, Western African Programs
Alieu M.B. Jagne, *Gambia*, Regional Administrative Officer
K.P. Nair, *India*, Regional Purchase and Supplies Manager
M.D. Diallo, *Guinea*, Regional Finance Officer
K.A. Moussa, *Niger*, Personnel and Transport Officer
G. Ouoba, *Burkina Faso*, Chief, Computer Services Unit

Research Programs

Pearl Millet

K. Anand Kumar, *India*, Principal Breeder and Team Leader (*on sabbatical leave from Aug*)
Shadrach O. Okiror, *Uganda*, Principal Breeder and Regional Trials Officer
Josef Werder, *Switzerland*, Principal Pathologist (*until Apr*)
Ousmane Youm, *Senegal*, Associate Principal Entomologist
Dale E. Hess, *USA*, Associate Principal Pathologist (*from Aug*)
P. Soman, *India*, Principal Agronomist
L. Marchais, *France*, Principal Geneticist (ORSTOM)
S. Tostain, *France*, Principal Geneticist (ORSTOM)

Groundnut

Bruno J. Ndunguru, *Tanzania*, Principal Agronomist and Team Leader
David C. Greenberg, *UK*, Principal Breeder (*until Mar*)
Farid Waliyar, *France*, Principal Pathologist

Resource Management

Charles Renard, *Belgium*, Principal Agronomist and Team Leader
Jonathan H. Williams, *Zimbabwe*, Principal Physiologist
Michiel C. Klaij, *Netherlands*, Principal Soil and Water Management Scientist (*on sabbatical leave from Sep*)
M.V.K. Sivakumar, *India*, Principal Agroclimatologist
Jojo Baidu-Forson, *Ghana*, Principal Economist
Rick J. Van Den Belt, *USA*, Principal Agronomist/Agroforester
A. Bationo, *Burkina Faso*, Principal Soil Chemist (IFDC)
B.R. N'tare, *Uganda*, Principal Cowpea Breeder/Agronomist (IITA)
Jane C. Hopkins, *USA*, Visiting Scientist (IFPRI)
J. Lambourne, *New Zealand*, Principal Animal Nutritionist, Special Consultant (ILCA) (*until Mar*)
M. Welte, *Germany*, Program Coordinator, University of Hohenheim
Jane Toll, *UK*, IBPGR Field Officer for West Africa
M. Powell, *USA*, Principal Agroecologist (ILCA) (*from Aug*)
B.D. Roxas, *Philippines*, Principal Animal Nutritionist (ILCA) (*until Sep*)
T.O. Williams, *Nigeria*, Principal Economist (ILCA) (*from Oct*)

Support Programs

Phillip G. Serafini, *USA*, Research Farm Manager (*until Aug*)
A.R. Das Gupta, *India*, Manager, Physical Plant Services
James D. Henry, *India*, Training Consultant, Physical Plant Services (*until Nov*)
Roger D. Stern, *UK*, Principal Statistician (*from Aug*)
Charles A. Giroux, *Canada*, Regional Information Officer
John Q.H. Nguyen, *USA*, Principal Training Officer

WASIP-Mali

Administration

K.V. Ramaiah, *India*, Principal Cereal Breeder and Team Leader
R. Vaidyanathan, *India*, Administrative Officer (*from May*)
K.R.C. Bose, *India*, Project Development Officer

Research

Melville D. Thomas, *Sierra Leone*, Principal Pathologist and SAFGRAD/ICRISAT Coordinator
S.N. Lohani, *Nepal*, Principal Breeder
Akinwumi A. Adesina, *Nigeria*, Assistant Principal Economist
P. Salez, *France*, Principal Agronomist (IRAT Team Leader)
A. Ratnadass, *France*, Principal Entomologist (IRAT)
C. Luce, *France*, Principal Breeder (IRAT)
G. Hoffmann, *France*, *Striga* Agronomist (CIRAD)

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Administration

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Research

D.S. Murty, *India*, Principal Sorghum Breeder
Ramadjita Tabo, *Chad*, Principal Agronomist
David J. Flower, *Australia*, Principal Physiologist

Mali Bilateral Program

S.V.R. Shetty, *India*, Principal Agronomist and Team Leader
Noel F. Beninati, *USA*, Principal Breeder (*until Sep*)

Southern African Programs

SADCC/ICRISAT Sorghum and Millets Improvement Program, Zimbabwe

Leland R. House, *USA*, Executive Director, Southern Africa, and Project Manager, SADCC/ICRISAT Sorghum and Millets Improvement Program
Samuel P. Ambrose, *India*, Regional Administrative Officer (*until Apr*)
Alfred Schulz, *USA*, Regional Administrative Officer (*from Jun*)
Anthony B. Obilana, *Nigeria*, Principal Sorghum Breeder
S.C. Gupta, *India*, Principal Forage and Millet Breeder
Walter A.J. de Milliano, *Netherlands*, Principal Cereals Pathologist
Mahmood Osmanzai, *Afganistan*, Principal Cereals Agronomist
Klaus Leuschner, *Germany*, Principal Cereals Entomologist
David D. Rohrbach, *USA*, Principal Economist
Henry Ssali, *Uganda*, Soil Scientist (IFDC)
Manel I. Gomez, *Sri Lanka*, Principal Food Technologist
Chimabu M. Matanyaire, *Zimbabwe*, Principal Station Management and Development Officer
Lovegot Tendengu, *Zimbabwe*, Regional Training Officer
Nurdin S. Katuli, *Tanzania*, Station Development and Management Officer
Emmanuel S. Monyo, *Tanzania*, Regional Pearl Millet Breeder
Nathaniel Mwamuka, Farm Manager
Richard Nxumalo, Accounts/Personnel Officer
Tenson Dube, Senior Research Technician (Sorghum)
Fungai Munaku, Senior Research Technician (Agronomy)
Murairo Madzvamuse, Laboratory Technician (Food Technology)
Sanders Mpofu, Senior Research Technician (Millet)

SADCC/ICRISAT Groundnut Project, Malawi

Gerhard Schmidt, *Germany*, Team Leader (*From Feb*)
Geoff L. Hildebrand, *Zimbabwe*, Principal Groundnut Breeder
Pala Subrahmanyam, *India*, Principal Groundnut Pathologist (*from Oct*)
V.S. Swaminathan, *India*, Administrative Officer (*from May*)

Postdoctoral and Research Fellows

Cereals

Fabrice Pinard, *France*, Postdoctoral Fellow
Michel Peterschmitt, *France*, Postdoctoral Fellow (*until Apr*)
Frauke Wehmann, *Germany*, Postdoctoral Fellow (*from May*)
José A. Sifuentes, *Mexico*, Postdoctoral Fellow (*from May*)
Alan Thomas, *UK*, Postdoctoral Fellow (*from Nov*)
Carlos S. Busso, *Italy*, Postdoctoral Fellow (*until Jun*)
Mohamed E. Abdelrahman, *Sudan*, Research Fellow (*Mar-May*)
Hector Williams A., *Mexico*, Research Fellow (*Aug-Nov*)
Mahmoud Fadl El Mula Ahmed, *Sudan*, Research Fellow (*from Nov*)
Abdelelah B.M. Hashem, *Sudan*, Research Fellow (*Jun-Sep*)

Legumes

A. Srinivasan, *India*, Postdoctoral Fellow
François X. Poul, *France*, Postdoctoral Fellow (*from Jul*)
Satoshi Tobita, *Japan*, Postdoctoral Fellow (*from Oct*)
Mohammed Iqbal Khan, *Pakistan*, Research Fellow (*until Feb*)
Felipa M. Taylan, *Philippines*, Research Fellow (*until Feb*)
Sylvester R. Boye-Goni, *Nigeria*, Research Fellow (*Aug-Nov*)
R.K. Gumber, *India*, Research Fellow (*from Nov*)
El-Gailani Abdalla, *Sudan*, Research Fellow (*Feb-May*)
Kamal Ali, *Ethiopia*, Research Fellow (*Nov-Dec*)
Tesfaye Beshir Mohamed, *Ethiopia*, Research Fellow (*until Jan*)
Githiri Stephen Mwangi, *Kenya*, Research Fellow (*Apr-Jun*)
Bekele Hunde, *Ethiopia*, Research Fellow (*Sep-Dec*)
Mohamed Elfatih Khalid Ali, *Sudan*, Research Fellow (*from Dec*)
Poonam Dhawan, *India*, Research Fellow (*Jul*)

Resource Management

Peter P. Motavalli, *USA*, Postdoctoral Fellow
Julius C.W. Odongo, *Uganda*, Postdoctoral Fellow (*until Nov*)
T. Bapi Reddy, *India*, Postdoctoral Fellow
Simane Belay, *Ethiopia*, Research Fellow (*until Jan*)
Salisu Abdulmumin, *Nigeria*, Research Fellow (*until Jan*)
Mekki A. Omer, *Sudan*, Research Fellow (*May-Aug*)

Crop Quality Unit

K. Achuta Rao, *India*, Research Fellow (*May*)
Vinod Kumar Chaturvedi, *India*, Research Fellow (*May*)

Genetic Resources Unit

Mohamed Mohamoud Farah, *Somalia*, Research Fellow (*from Oct*)

Acronyms

ACIAR Australian Centre for International Agricultural Research
AGLN Asian Grain Legumes Network
AGRIS International Information System for Agricultural Sciences and Technology (FAO)
AICORPO All India Coordinated Research Project on Oilseeds
AICPIP All India Coordinated Pulses Improvement Project
AICPMIP All India Coordinated Pearl Millet Improvement Project
AICRPDA All India Coordinated Research Project for Dryland Agriculture
AICSIP All India Coordinated Sorghum Improvement Project
APAU Andhra Pradesh Agricultural University (India)
AVRDC Asian Vegetable Research and Development Center (Taiwan)
AWHC available water-holding capacity
CCRN Cooperative Cereals Research Network (ICRISAT)
CGIAR Consultative Group on International Agricultural Research (USA)
CIDA Canadian International Development Agency
CILSS Comité permanent inter-Etats de lutte contre la sécheresse dans le Sahel (Mali)
CIMMYT Centro Internacional de Mejoramiento de Maíz y Trigo (Mexico)
CIRAD Centre de coopération internationale en recherche agronomique pour le développement (France)
CLAIS Comisión Latinoamericano de Investigadores en Sorgo (Guatemala)
CRIDA Central Research Institute for Dryland Agriculture (India)
CRSP Collaborative Research Support Program (USA)
DAE days after emergence
EARCAL Eastern Africa Regional Cereals and Legumes Program
EARSAM Eastern Africa Regional Sorghum and Millets Network
ESD extra-short-duration
FAO Food and Agriculture Organization of the United Nations
FDO Farm Development Operations (ICRISAT)
GIS Geographic Information System
GRU Genetic Resources Unit
GTZ Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
HATA houe à traction asine
HRDP Human Resource Development Program (ICRISAT)
IAR Institute of Agricultural Research (Nigeria)
IBPGR International Board for Plant Genetic Resources (Italy)
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)
ICIPE International Centre of Insect Physiology and Ecology (Kenya)
ICRAF International Council for Research in Agroforestry (Kenya)
ICRISAT International Crops Research Institute for the Semi-Arid Tropics (India)
IDRC International Development Research Centre (Canada)
IFDC International Fertilizer Development Center (USA)
IFPRI International Food Policy Research Institute (USA)
IIMI International Irrigation Management Institute (Sri Lanka)
IITA International Institute of Tropical Agriculture (Nigeria)

ILCA	International Livestock Centre for Africa (Ethiopia)
INRAN	Institut national de recherches agronomiques du Niger
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII International Sorghum/Millet Collaborative Research Support Program (USA)
IPDR	Institut pratique de développment rural (Niger)
IPM	integrated pest management
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (France)
IRHO	Institut de recherches pour les huiles et oléagineaux (France)
IRRI	International Rice Research Institute (Philippines)
ISC	ICRISAT Sahelian Center (Niger)
KARI	Kenya Agricultural Research Institute
LASIP	Latin American Sorghum Improvement Program (ICRISAT)
LEGOFTEN	Legumes On-Farm Testing and Nursery Unit (ICRISAT)
LSW	leaf surface wetness
NARS	national agricultural research system
NBPGR	National Bureau of Plant Genetic Resources (India)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
PCV	peanut clump virus
PEQIA	Postentry Quarantine Isolation Area (ICRISAT)
RFLP	restriction fragment length polymorphism
RMP	Resource Management Program (ICRISAT)
ROCAFREMI	Réseau ouest et centre africain de recherche sur le mil (WCAMRN)
ROCARS	Réseau ouest et centre africain de recherche sur le sorgho (WCASRN)
SADCC	Southern African Development Coordination Conference (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SATCRIS	Semi-Arid Tropical Crops Information Service (ICRISAT)
SDI	selective dissemination of information
SDP	short-duration pigeonpea
SMIP	Sorghum and Millets Improvement Program (SADCC/ICRISAT, Zimbabwe)
TSWV	tomato spotted wilt virus
UNDP	United Nations Development Programme
USAID	United States Agency for International Development (USA)
VAM	vesicular-arbuscular mycorrhizae
WANA	West Asia/North Africa
WASIP	West African Sorghum Improvement Program (ICRISAT)
WCAMRN	West and Central African Millet Research Network (ISC)
WCASRN	West and Central African Sorghum Research Network (WASIP-Mali)