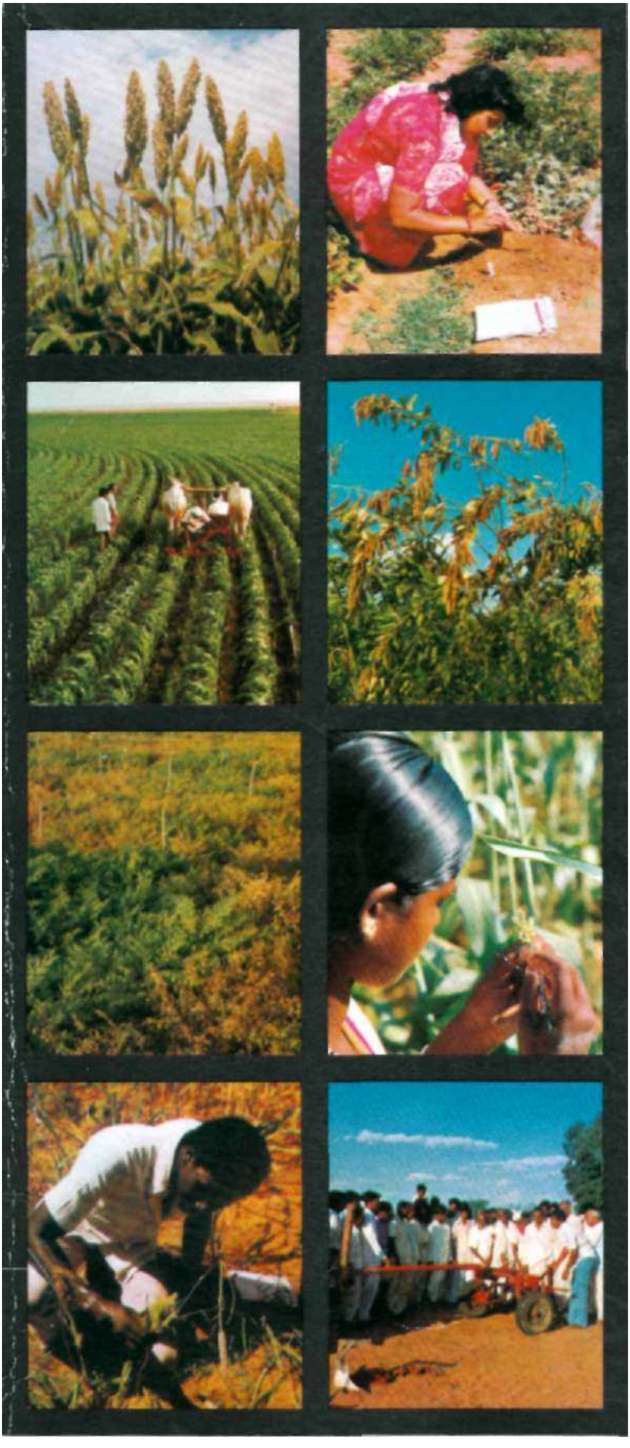

ICRISAT
ANNUAL REPORT
1977 - 1978

INTERNATIONAL
CROPS RESEARCH INSTITUTE
FOR THE SEMI-ARID TROPICS

ICRISAT
ANNUAL REPORT
1977-1978

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India

ICRISAT's Objectives

To serve as world center to improve the genetic potential for grain yield and nutritional quality of sorghum, pearl millet, pigeonpea, chickpea, and groundnut.

To develop farming systems which will help to increase and stabilize agricultural production through better use of natural and human resources in the seasonally dry semi-arid tropics.

To identify socioeconomic and other constraints to agricultural development in the semi-arid tropics and to evaluate alternative means of alleviating them through technological and institutional changes.

To assist national and regional research programs through cooperation and support and to contribute further by sponsoring conferences, operating international training programs, and assisting extension activities.

About This Report

This is the fifth annual report published by the International Crops Research Institute for the Semi-Arid Tropics. Printed for worldwide distribution, the report covers ICRISAT's development and activities from 1 June 1977 to 31 May 1978.

Detailed reporting of the extensive activities of ICRISAT's many research support units is beyond the scope of this volume, but a comprehensive coverage of ICRISAT's core research programs is included. Detailed annual reports have been prepared for limited distribution by each unit.

ICRISAT receives support from the Consultative Group on International Agricultural Research. The responsibility for all aspects of this publication rests with ICRISAT. Mention of particular pesticides, fungicides, herbicides, and other chemicals does not necessarily imply endorsement of or discrimination against any product by the Institute. The correct citation for this report is International Crops Research Institute for the Semi-Arid Tropics, 1978. *ICRISAT Annual Report 1977-1978,* Hyderabad, India.

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ICRISAT Governing Board

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Minister for Rural Development
Government of Senegal
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Senegal

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[a] Now Secretary for Economy & Planning, State of Sao Paulo, Brazil
[b] Deceased February 1979
[c] Now Head of ICRISAT's Genetic Resources Unit

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India

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ICRISAT Patancheru P.O.
Andhra Pradesh 502 324
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Dr. D.L. Umali (Member)
Assistant Director General, and
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Maliwan Mansion, Phra Atit Road
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[d] Now Secretary to the Government of India, Ministry of Agriculture and Irrigation
[e] Deceased January 1979

ICRISAT Personnel - 31 May 1978

Administration

L.D. Swindale, Ph.D., director
J.S. Kanwar, Ph.D., associate director
R.C. McGinnis, Ph.D., associate director
S.K. Sahgal, IAS, principal administrator (until Jul 1977)
B.F. Dittia, IAS, principal administrator (as of Oct 1977)
V. Balasubramanian, executive assistant to the director
S.K. Mukherjee, B.Sc. (Eng'g.), personnel manager
O.P. Shod, B.Sc, B.L., fiscal manager
R. Vaidyanathan, purchase and stores manager
R.G. Rao, records manager
Col. P.W. Curtis (Grad. IMA, Dehradun), security officer
R. Narsing Reddy, transport officer
S.B.C.M. Rao, B.Com., travel officer
B. Diwakar, Ph.D., scientific liaison officer (visitors service)
N. Rajamani, liaison officer, New Delhi office

Crop Improvement

Cereals

J.C. Davies, Ph.D., principal entomologist and leader
L. R. House, Ph.D., principal plant breeder (sorghum)
D.J. Andrews, B.Sc. (Hons.), D.A.S., D.T.A., principal plant breeder (millets)
F.R. Bidinger, Ph.D., principal physiologist
B.W. Hare, Ph.D., assistant plant breeder (millets) (until Feb 1978)
R.J. Williams, Ph.D., principal pathologist
Qaude Charreau, Ph.D., project leader, West Africa project, Senegal
A. Lambert, Ph.D., principal plant breeder, Senegal
R.T. Gahukar, Ph.D., principal entomologist, Senegal
C M. Pattanayak, Ph.D., principal plant breeder (sorghum) and team leader, Upper Volta
P.K. Lawrence, Ph.D., principal plant breeder (millets), Upper Volta
W.A. Stoop, Ph.D., principal agronomist. Upper Volta
J.A. Frowd, Ph.D., principal plant pathologist, Upper Volta
Ph.J. van Staveren, M.Sc, assistant agronomist, Upper Volta
S.A. Clarke, M.S., field trials officer, Mali
P.J. Serafini, M.S., field trials officer, Mali (as of Apr 1978)
B.B. Singh, Ph.D., principal plant breeder (millets), Niger
S.O. Okiror, Ph.D., principal plant breeder, Nigeria
N.V. Sundaram, Ph.D., principal plant pathologist, Nigeria
M.A. Faris, Ph.D., principal plant breeder (sorghum), Sudan
R.P. Jain, Ph.D., principal plant breeder (millets), Sudan
V.Y. Guiragossian, Ph.D., principal plant breeder (sorghum), Mexico (as of Oct 1977)
S.Z. Mukuru, Ph.D., principal plant breeder, (sorghum and millets), Tanzania (as of Sep 1977)
K.V. Ramaiah, Ph.D., plant breeder (sorghum)
Bholanath Varma, M.Sc, plant breeder (sorghum)
D.S. Murty, Ph.D., plant breeder (sorghum)
B.L. Agrawal, Ph.D., plant breeder (sorghum)
S.C. Gupta, Ph.D., plant breeder (millets)
K. Anand Kumar, Ph.D., plant breeder (millets)
B.S. Talukdar, Ph.D., plant breeder (millets)
K.N. Rai, Ph.D., plant breeder (millets)
K.E. Prasada Rao, M.Sc. (Ag.), botanist (genetic resources)
S. Appa Rao, Ph.D., botanist (genetic resources)
N. Seetharama, Ph.D., plant physiologist
G. Alagarswamy, Ph.D., plant physiologist
R.K. Maiti, Ph.D., D.Sc, plant physiologist
K.V. Seshu Reddy, Ph.D., entomologist
V.S. Bhatnagar, Ph.D., entomologist
K.N. Rao, Ph.D., plant pathologist

S.D. Singh, Ph.D., plant pathologist
R.P. Thakur, Ph.D., plant pathologist
R.V. Subba Rao, Ph.D., microbiologist
S. Krishnan, executive assistant

Pulses

J.M. Green, Ph.D., principal plant breeder (pigeonpea) and leader
A.K. Auckland, Ph.D., principal plant breeder (chickpea) (until Nov 1977)
K.B. Singh, Ph.D., principal plant breeder (chickpea) based in ICARDA, Syria (as of May 1978)
A.R. Sheldrake, Ph.D., principal plant physiologist (until Feb 1978)
W. Reed, Ph.D., principal entomologist
Y.L. Nene, Ph.D., principal pathologist
L.J.G. van der Maesen, Ph.D., principal botanist
P.J. Dart, Ph.D., principal microbiologist
D. Sharma, Ph.D., senior plant breeder (pigeonpea)
Jagdish Kumar, Ph.D., plant breeder (chickpea)
S. Sithanantham, Ph.D., entomologist (as of Sep 1977)
S.C. Gupta, Ph.D., plant breeder (pigeonpea) (as of Oct 1977)
K.B. Saxena, Ph.D., plant breeder (pigeonpea)
L.J. Reddy, Ph.D., plant breeder (pigeonpea)
B.V.S. Reddy, Ph.D., plant breeder (pigeonpea)
K.C. Jain, Ph.D., plant breeder (chickpea)
Onkar Singh, M.Sc. (Ag.), plant breeder (chickpea)
S.C. Sethi, Ph.D., plant breeder (chickpea)
C.L.L. Gowda, Ph.D., plant breeder (chickpea)
R.P.S. Pundir, M.Sc. (Ag.), botanist (genetic resources)
A.N. Murthi, Ph.D., botanist (genetic resources)
N.P. Saxena, Ph.D., plant physiologist
I.V. Subba Rao, Ph.D., plant physiologist
S.S. Lateef, Ph.D., entomologist
M.P. Haware, Ph.D., plant pathologist
M.V. Reddy, Ph.D., plant pathologist
J. Kannaiyan, Ph.D., plant pathologist
O.P. Rupela, Ph.D., microbiologist
J.V.D.K. Kumar Rao, Ph.D., microbiologist

Groundnuts

R.W. Gibbons, B.Sc. (Hons.), D.A.S., D.T.A., principal plant breeder and leader
W.C. Gregory, Ph.D., consultant
J.P. Moss, Ph.D., principal cytogeneticist (as of Mar 1978)
D.V.R. Reddy, Ph.D., senior plant pathologist
A.M. Ghanekar, Ph.D., plant pathologist
P. Subramanyam, Ph.D., plant pathologist
S.N. Nigam, Ph.D., plant breeder
V.R. Rao, Ph.D., botanist (genetic resources)
P.T.C. Nambiar, Ph.D., microbiologist
P.W.Amin, Ph.D., entomologist (as of Jul 1977)

Farming Systems

B.A. Krantz, Ph.D., principal agronomist and leader
J. Kampen, Ph.D., principal agricultural engineer (soil and water management)
S.M. Virmani, Ph.D., principal agroclimatologist
R.W. Willey, Ph.D., principal agronomist
L.P.A. Oyen, M.Sc, assistant agronomist
G.E. Thierstein, M.S., principal agricultural engineer (small implements development)
M.C. Klaij, M.Sc, assistant agricultural engineer (small implements development)
M.B. Russell, Ph.D., consultant, soil physics
F.P. Huibers, M.Sc, assistant agricultural engineer (soil and water management)
S.V.R. Shetty, Ph.D., agronomist
M.R. Rao, Ph.D., agronomist
Piara Singh, M.Sc, soil scientist
Sardar Singh, Ph.D., soil scientist
T.J. Rego, Ph.D., soil scientist
S.J. Reddy, M.Sc. (Tech.), D.A.S., agroclimatologist
M.V.K. Siva Kumar, Ph.D., agroclimatologist
J. Harikrishna, M.Sc, agricultural engineer
R.C. Sachan, M.Tech (Ag.Eng'g.), agricultural engineer
Harbans Lai, M. Tech., agricultural engineer
P. Pathak, M. Tech. (Ag. Eng'g), agricultural engineer
P.N. Sharma, M. Tech., agricultural engineer
R.K. Bansal, M.Tech., agricultural engineer

O.P. Singhal, Ph.D., agricultural engineer (as of May 1978)
M.S. Reddy, Ph.D., agronomist
M.Natarajan, Ph.D., agronomist (as of Jul 1977)
K.L. Sahrawat, Ph.D., soil chemist (as of Feb 1978)
S.K. Sharma, B.A., senior research technician

Economics Program

J.G. Ryan, Ph.D., principal economist
M. von Oppen, Ph.D., principal economist
H.P. Binswanger, Ph.D., principal economist
V.S. Doherty, Ph.D., principal social anthropologist
N.S. Jodha, Ph.D., senior economist
V.T. Raju, Ph.D., economist
S.L. Bapna, Ph.D., economist
B.C. Barah, Ph.D., economist

Biochemistry and Common Lab Services

R. Jambunathan, Ph.D., principal biochemist
Umaid Singh, Ph.D., biochemist
V. Subramanian, Ph.D., biochemist (as of Oct 1977)

Farm Services

E.W.Nmin, B.S. (Ag. Eng'g.), principal agricultural engineer.
D.S. Bisht, B.Sc. (Ag. & AH) (Hons.), senior engineer
B.K. Sharma, B.Sc. (Ag. Eng'g.), senior engineer
D.N. Sharma, B.Sc. (Ag.) Eng'g & Tech., senior engineer
S.N. Kapoor, M.Sc. (Ag.), senior engineer (as of Aug 1977)
S.K.V.K. Chari, M.Sc, electronics engineer
V. Lakshmanan, executive assistant
P.M.Menon, B.A., L.LB., executive assistant

Library and Documentation Services

T.C. Jain, M.Lib.Sci., librarian

Information Services

J.W. Spaven, B.S., head, information services (until Apr 1978)
G.D. Bengtson, B.S., research editor
S.M. Sinha, N.Dip. Com.Art, senior artist and printshop supervisor
H.S. Duggal, head photographer
Mira Shah, M.A. (French), French translator/ interpreter

Computer Services and Statistics

J.W. Estes, M.S., computer services officer
J.A. Warren, Ph.D., consultant
S.M. Luthra, B.Sc. (Hons.), M.Sc. (Operations Res.), assistant computer services officer
T.B.R.N. Gupta, B.Sc. (Jr. Cert. Agrl. Stat.), computer programmer
B.K. Chakraborty, M.Stat., Adv. Dip. Computer Science, computer programmer

Plant Quarantine

K.K. Nirula, Ph.D., plant quarantine officer

Fellowships and Training

D.L. Oswalt, Ph.D., principal training officer
A.S. Murthy, Ph.D., senior training officer

Physical Plant Services

N.N. Shah, Ph.D., project manager
F.J. Bonhage, construction supervisor
Sudhir Rakhra, B.E., senior engineer
B.H. Alurkar, B.E. (Civil), M.I.C.E. (Ind.), senior engineer
D. Subramanyam, B.E. (Elec.), senior engineer
S.K. Tuli, Dip. (Civil Eng'g), senior engineer
T.J. Choksi, B.E., L.LB., senior engineer
Manmohan Singh, B.E.F.I.E., senior engineer (as of Oct 1977)
J.K. Majumdar, B.C.E., senior engineer (as of Dec 1977)

Acronyms and selected abbreviations used in this Annual Report:

AGRICOLA	Agricultural On Line Access
AGRIS	Internationa] Information System for the Agricultural Sciences and Technology
AICMIP	All-India Coordinated Millets Improvement Project
AICORPO	All-India Coordinated Research Project on Oilseeds
AICRPDA	All-India Coordinated Research Project for Dryland Agriculture
AICSIP	All-India Coordinated Sorghum Improvement Project
ALAD	Arid Land Agricultural Development Program
APAU	Andhra Pradesh Agricultural University
BIOSIS	Bioscience Information Services
BTI	Boyce Thompson Institute
CAB	Commonwealth Agricultural Bureaux
CAS	Chemical Abstracts Service
CIAT	Centro International de Agricultura Tropical (International Center for Tropical Agriculture)
CIBC	Commonwealth Institute of Biological Control
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)
CNRA	Centre National de Recherches Agronomiques (National Agricultural Research Center)
CNRS	Centre National de la Recherche Scientifique (National Scientific Research Center)
COPR	Centre for Overseas Pest Research
CPPTI	Central Plant Protection Training Institute
CSIRO	Commonwealth Scientific and Industrial Research Organization
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (Brazilian Agricultural Research Institute)
FAO	Food and Agriculture Organization of the United Nations
FAO-AGRINDEX	A service of AGRIS (see AGRIS)
FSRP	Farming Systems Research Program
GAM	Groupe d'Amelioration des Mils (Millet Improvement Group)
GIET	Gram Initial Evaluation Trial
IAR	Institute for Agricultural Research
IARC	International Agricultural Research Center
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources
ICABN	International Chickpea *Ascochyta* Blight Nursery
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in Dry Areas
ICRRWN	International Chickpea Root Rots/Wilt Nursery
ICSN	International Chickpea Screening Nursery
IDRC	International Development Research Centre
HTA	International Institute of Tropical Agriculture
IPMAT	International Pearl Millet Adaptation Trial
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery
IPMSN	International Pearl Millet Smut Nursery
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (Institute for Tropical Crops Research)

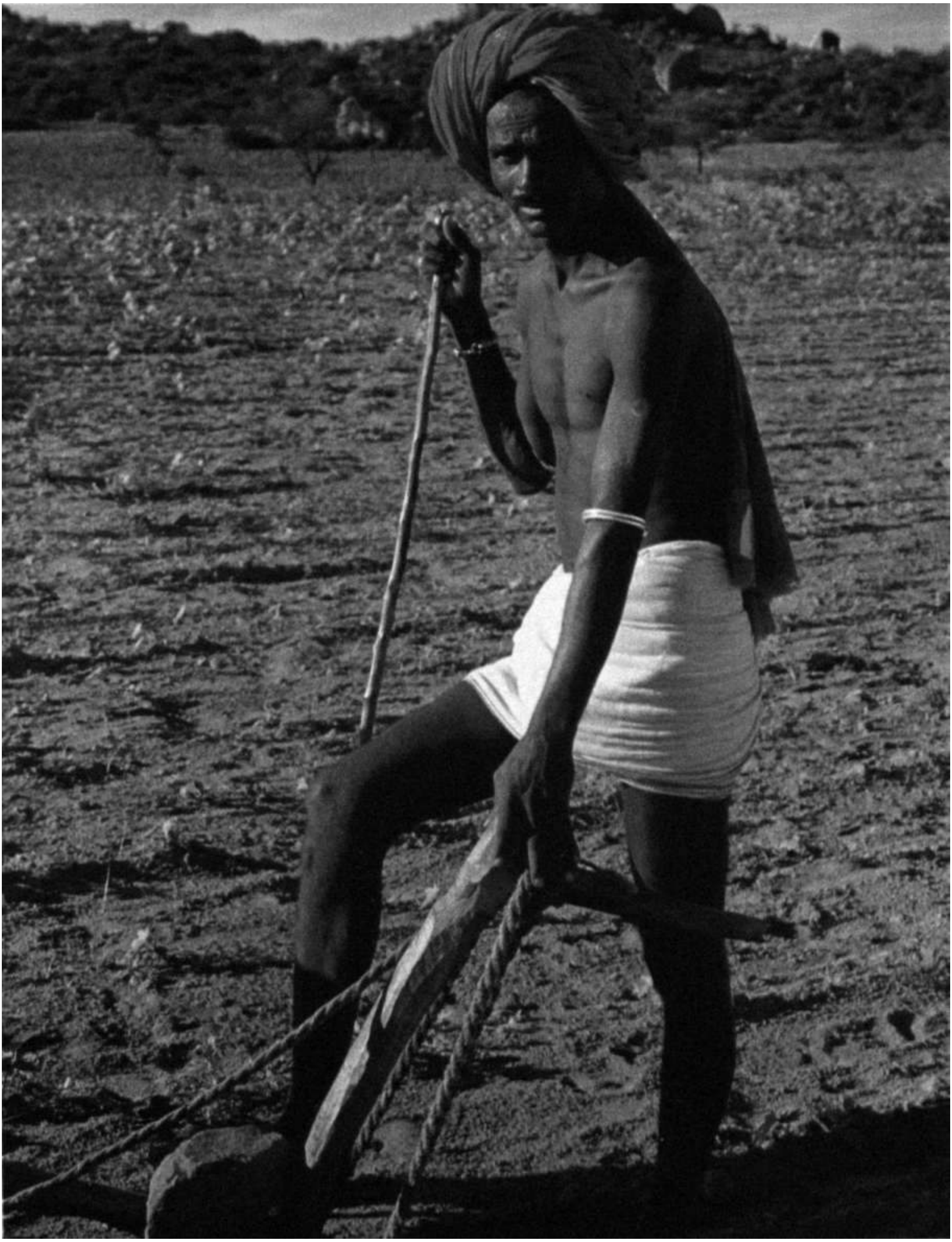
ISCRN	International Sorghum Charcoal Rot Nursery
ISDMN	International Sorghum Downy Mildew Nursery
ISGMN	International Sorghum Grain Mold Nursery
ISI	Institute for Scientific Information
ISLDN	International Sorghum Leaf Diseases Nursery
ISPYT	International Sorghum Preliminary Yield Trial
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya
NAL	National Agricultural Library
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (Overseas Scientific and Technical Research Office)
PEQIA	Postentry Quarantine Isolation Area
PMHT	Pearl Millet Hybrid Trial
PMST	Pearl Millet Synthetics Trial
RTI	Royal Tropical Institute
SEPON	Sorghum Elite Progeny Observation Nursery
SMIC	Sorghums and Millets Information Center
SSIE	Smithsonian Science Information Exchange
TPI	Tropical Products Institute
UNDP	United Nations Development Programme
UPN	Uniform Progeny Nursery
USAID	United States Agency for International Development
WRO	Weed Research Organization

Abbreviations:

BNV	bud necrosis virus
CLSV	chlorotic leaf streak virus
CMMV	cowpea mild mottle virus
CRISP	Crop Research Integrated Statistical Package
CSV	chlorotic spot virus
DAP	days after planting
DBC	dye-binding capacity
DM	downy mildew
FYM	farmyard manure
FSPS	full-sib progeny selection
GMS	gridded mass selection
HI	harvest index
HYV	high-yielding variety
ICCC	ICRISAT chickpea cultivar
ICPL	ICRISAT pigeonpea line
LAI	leaf-area index
LER	land-equivalent ratio
MAI	moisture availability index
PAR	photosynthetically active radiation
PMV	peanut mottle virus
RCB	Randomized Complete Block
RRPS	recurrent restricted phenotypic selection
RSTS/E	Resource Sharing Time Sharing/ Extended
SAT	semi-arid tropics
SDM	sorghum downy mildew
tswv	tomato spotted wilt virus

ICRISAT's Five Crops

Latin	*Sorghum bicolor* (L.) Moench	*Pennisetum americanum* (L.) K. Schum	*Cajanus cajan* (L.) Mill.	*Cicer arietinum* (L.)	*Arachis hypogaea* (L.)
English	Sorghum, durra milo, shallu, kafir corn, Egyptian corn, great millet, Indian millet	Pearl millet, bulrush millet, cattail millet, spiked millet	Pigeonpea, red gram	Chickpea, Bengal gram, gram, Egyptian pea, Spanish pea, chestnut bean, chick, caravance	Groundnut, peanut
French	Sorgho	Petit mil, millet, mil à chandelles	Pois d'Angole	Pois chiche	Arachide
Portuguese	Sorgo	Painço pérola	Guando, feijão-guando	Grão-de-bico	Amendoim
Spanish	Sorgo, zahina	Mijo perla, mijo	Guandul	Garbanzo, garavance	Mani
Hindi	Jowar, jaur	Bajra	Arhar, Tur	Chana	Mungphali



ICRISAT aims to help the small SAT farmer, tending his land within limited means.

Director's Introduction

This year we made good progress in our research, training, and cooperative programs. ICRISAT cultivars of pearl millet and chickpea were included in trials in India, and some sorghum cultivars in Upper Volta and pearl millet in the Sudan reached the stage of extension testing. These were the early results of our crop-improvement programs finding their way into national programs. In the next few years, increasing numbers of cultivars of all our crops will reach this stage of national testing. At the same time, our international adaptative trials and special breeding nurseries, containing materials resistant to major diseases, are being tested in an increasing number of locations around the world.

An ICRISAT millet breeder examines crop grown in Kamboinse, Upper Volta. ICRISAT has 18 scientists posted in nine countries of Africa, the Middle East, and Latin America.

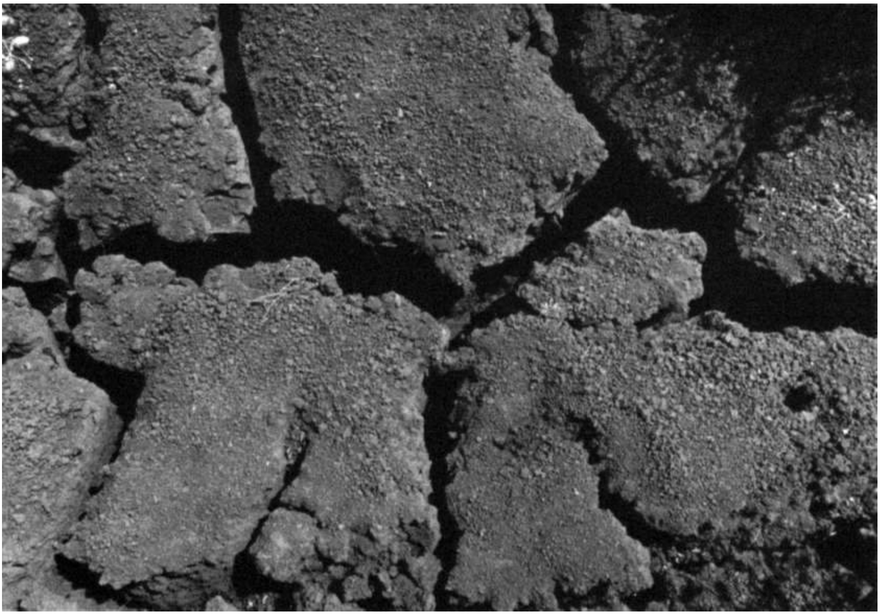
Semi-arid tropical ICRISAT Center wasn't so arid during the field tours of the 1977 International Pearl Millet Workshop. In addition to seeing breeding material in the field, visiting scientists got a good introduction to (wet!) Vertisols.

We had a very successful planning workshop for pearl millet improvement, to which 44 specialists came from many parts of the world. They discussed ways to improve this crop and helped us to decide on programs of research that would be of most assistance to them.

The results of our farming systems research on the deep black soils of India (Vertisols) have excited considerable interest. There is evidence that some of our concepts are already being tested independently in various parts of the country by agencies that have seen our work, became interested, and have decided to try it in their own way at locations of their choice. We agree that this work is now ready for wider testing, and have arranged with farmers in three of the villages—where our economists have been gathering data—to test the applicability of watershed-based farming systems technology to their conditions. This work will commence this year with the coming rainy season.

The numbers of our trainees and scholars continue to increase. This year, for the first time we had in-service trainees from Mauritania, Ghana, the Gambia, Tanzania, and Togo; research scholars from Ethiopia, Kenya, the Netherlands, UK, and the USA; and research fellows from Brazil, Senegal, Sri Lanka, and Thailand. Virtually every scientist at ICRISAT Center was involved in the training program. The individual treatment we are able to give to each trainee and scholar ensures that their time with us is used effectively.

Cracks that attract the soil scientist: ICRISAT research on the deep black soils of India (Vertisols) has generated considerable interest. The rainy season cropping is now ready for wider testing, along with studies of watershed-based farming systems technology.



Growing crops, planning and conducting research projects, presenting findings to colleagues, are all part of in-service training at ICRISAT. Trainees have come to ICRISAT from 26 countries. The newest of the in-service trainees are from Mauritania, Ghana, The Gambia, Tanzania, and Togo.

Development work on the ICRISAT Center research farm is near completion. We have a new set of research watersheds on the regional red soils of SAT India (Alfisols), constructed entirely by bullock-drawn equipment, which will be used in operational-scale research in cooperation with the All-India Coordinated Research Project for Dryland Agriculture. Some of our advanced lines of pearl millet and pigeonpea will be tested in intercropping situations in these watersheds. Development work has also been completed at the Kamboinse research farm of the National Agricultural Research Service of Upper Volta to provide sufficient field plots and office space for cooperative work between ICRISAT and Upper Volta scientists on sorghum and millet improvement.

The Indian Government agreed this year to an ICRISAT proposal to establish several substations in different parts of the country. The substations will enable us to extend the range of environments in which we work and increase the number of crop generations we can produce each year.

The ICRISAT Governing Board established a separate plant quarantine unit during the year, to give operational effect to the approval by the Government of India that permits ICRISAT to carry out all preclearance work on plant materials for export. In preparation for this year's planting season, we processed and cleared 59 584 shipments of seed to our cooperators all over the world. By doing the preclearance work at ICRISAT Center-under the supervision of the Government quarantine authorities who still are responsible for the issuance of the phytosanitary certificates—we removed a large burden of work from the Central Plant Protection Training Institute which had been handling this for us on an *ad hoc* basis.

Development work on the large complex of research fields and watersheds that constitute ICRISAT Center was brought nearer completion.

On-fieId discussion in progress at the fourth Annual International Chickpea Breeders" Meeting held 5-6 April 1978 at Haryana Agricultural University, Hissar, India. The University houses one of ICRISAT's four substations established in accord with the Government of India.

Dr. Melak Mengesha of Ethiopia and Dr. Ewert Aberg of Sweden completed their terms of service on the ICRISAT Governing Board. In recognition of their services in ICRISAT's formative years, the Board decided to continue their appointments until the Inauguration.

As the Institute grows, so do its linkages with national programs and individual research institutes. There is no large store of scientific information about our crops, particularly pearl millet, pigeonpea, and chickpea, as there is for maize and wheat, and ICRISAT must take the leadership in stimulating research to provide this information. With our sister IARC's, we have established important linkages. During the year we established an agreement with CIMMYT to utilize ICRISAT facilities in their regional maize program. With IITA we developed a contract through which ICRISAT has posted sorghum and millet breeders in Tanzania. We reached an agreement with ICARDA to locate a chickpea breeder at their headquarters in Aleppo, Syria, and to divide responsibility for chickpea improvement by region and type. Early this year, ICRISAT, IITA, CIAT, and ICARDA developed a joint program for grain-legume germplasm collection. The essence of the program is to make each center responsible for collecting, for the other centers, all grain-legume germplasm in its major geographic area of responsibility. Thus ICRISAT will look to CIAT for chickpea and pigeonpea collections in Latin America, and CIAT will look to us for *Phaseolus vulgaris* collection in Asia.

Packaging seeds for dispatch in ICRISAT's export certification quarantine lab. Cooperation with the Government of India in establishing a separate plant quarantine unit at ICRISAT Center streamlined preclearance work on export of plant materials, and made it possible for ICRISAT to expand its multilocational trials in other countries.

Getting a close look at ICRISAT's farming systems research are members of the stripe review team of the Technical Advisory Committee (TAC).

This year we participated in a stripe review by the Technical Advisory Committee (TAC) of farming systems research at the international agricultural research centers, and we are preparing for an in-depth five-year review of all our programs, also by TAC, to take place towards the end of 1978. As a consequence of these reviews and review preparations, we have reexamined our program goals and objectives. We are agreed that for the immediate future ICRISAT will concentrate its programs on the provision of stable high-yielding cultivars of sorghum, pearl millet, pigeonpea, chickpea, and groundnut, which are suitable for use under the resource conditions of the SAT and are particularly adaptable for the small farmer of limited means farming his land with few manufactured inputs and without the benefits of regular regional irrigation.

We take this opportunity to publicly acknowledge the help and assistance received during the year from the Governments of India and Andhra Pradesh, and the Governments of Senegal, Mali, Niger, Nigeria, Upper Volta and Sudan—countries in which our cooperative projects are located. We acknowledge also the support of our donors and the help and assistance of many scientists and scientific institutes around the world.

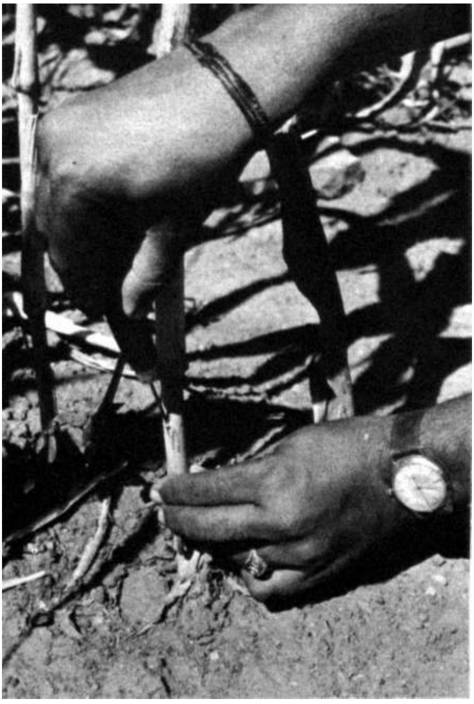
Research Highlights

Productive and collaborative research among scientists from various disciplines continued in all our programs, yielding useful results.

Sorghum

In sorghum improvement, three lines proved valuable in overseas and local trials. Rs1 x VGC was the best at two locations in Ethiopia and is being considered for further testing. Fast Lane R-101 was selected in Niger, Mali, and two locations in India—Sholapur and Rahuri—for inclusion in local programs. Fast Lane R-53 was the top yielder in an International Yield Trial, frequently outyielding the local check by a substantial margin.

"Toothpick" inoculation was successfully adapted for screening large numbers of sorghum lines for charcoal rot resistance.



A Sorghum Elite Progeny Observation Nursery of 72 entries was sent to nine countries in SAT, and from 8 to 35 entries were selected for incorporation into local programs.

A number of good-grain types, yielding 4 000 to 5 000 kg/ha (equal to or better than local checks) have been identified. Intensive screening of segregating generations resulted in 50 mold less-susceptible selections.

Some 1 338 grain samples were studied in the chapati lab, and 14 were found equal to the preferred local standard variety, M-35-1.

A total of 1 659 entries were screened for drought resistance in a late postrainy season sowing, and 152 were selected for further testing in several dry tracts of India.

A *Striga* nursery of 45 less-susceptible selections was sent to seven countries in Africa and eight locations in India. Thirteen cultivars were identified as promising. Host-parasite specificity was also identified.

An initial comparison was made of rainy season and postrainy season crops, with the following conclusions: i) temperature differences between the two seasons caused differences in crop-growth rates, but (where moisture was not limiting) not in crop dry-matter production, as the duration of crop growth was extended where growth rates were reduced (postrainy season); ii) dry-matter production during the postrainy season was directly related to crop water use, on both the dryland and the supplementally irrigated crops; iii) grain-yield reduction in the dryland postrainy season crop-compared to the supplementally irrigated crop-was mainly due to reduction in grain number, despite the fact that moisture deficit was more severe in the post- than in the preflowering period.

Trichomes, microscopic hairs on the leaves, were found to influence oviposition nonpreference of the shoot fly. The presence of trichomes has been associated with reduced egg laying. The correlation between trichome presence and no eggs laid was 0.82. The presence of trichomes is controlled by a single recessive gene. The effect of presence or absence of trichomes was followed up in a wider set of cultivars. Overall, the presence of trichomes resulted in 40 percent fewer deadhearts. The wide range of deadhearts in trichomed and nontrichomed lines, however, suggests that factors other than trichomes also affect the extent of shoot fly damage.

Cooperating scientists in Kenya examine a pest nursery distributed from ICRISAT. Four international pest-resistance nurseries in sorghum have been dispatched by ICRISAT to cooperators in nine countries.

Progress was made in screening and identifying sorghum cultivars for shoot fly, stem borer, midge, and earhead bug resistance. Methods of ensuring adequate pest challenge of breeders' material for shoot fly are now routine, and we are able to provide graded levels of shoot fly attack.

An effective artificial diet was developed for the stem borer *Chilo partellus,* giving 60 to 70 percent adult recoveries from very young larvae. Detailed work on stem borer pheromones was also done, in collaboration with the Tropical Products Institute, London.

Four international pest resistance nurseries were dispatched to cooperators in nine countries including India. A detailed list of the pests and their parasites and predators recorded from sorghum at ICRISAT Center was computerized and published.

A screening technique for midge resistance using mixed cultivars with varying flowering dates was tried. Studies on shoot fly and stem borer biology continued.

In pathology, nurseries were operated, as part of the cooperative international disease resistance testing programs, for grain mold, downy mildew (SDM), and leaf diseases of sorghum. Countries with test locations ranged from Senegal in the west to Thailand in the east, and from Pakistan in the north to Botswana in the south. Progress was made in the identification of stable low-susceptible entries. Breeders and pathologists jointly initiated a program to utilize identified low-susceptible lines for grain molds, and the pathologists moved closer towards an effective laboratory-screening technique to differentiate such lines.

A method was developed to enable the production of SDM conidial inoculum at any time of the day, instead of the 0200 to 0300 hr natural production. This enables inoculations to be made during the normal working day and facilitates easy study of sporulation and inoculation procedures.

The "toothpick" inoculation method was successfully adapted for use in the screening of sorghum for charcoal rot resistance. Using this method, 500 lines were screened and 28 apparently low-susceptible lines were identified.

Pearl Millet

Five downy mildew-resistant experimental cultivars developed at ICRISAT are now on test with the All-India Coordinated Millet Improvement Project (AICMIP), and one is in the prerelease stage.

ICRISAT hybrid ICH 105 continued to give high yields in its third year of testing by AICMIP, and three newer hybrids—ICH 154, ICH 162, and ICH 241—performed better than ICH 105 and appear to have more stable resistance to downy mildew.

Several promising synthetic varieties were identified; one of the best was ICMS 7703 — made from six lines, each from a different Indian x African cross—which gave good yields in India, Sudan, Upper Volta, and Senegal.

In results from 25 locations of the 1977 International Pearl Millet Adaptation Trial, ICH 118, IVS AX75 (variety), and ICH 107, gave the best yields.

When advanced generations of experimental varieties and individual progenies drawn from the composite breeding program were tested against parent stocks, no loss in yield was detected from generation advance.

Genotypes were found to vary greatly in their ability to take up nitrogen after flowering in low-fertility conditions, and this was strongly correlated with grain yield. Such differences were not detected in well-fertilized conditions.

A large number of protein analyses of seed from variety trials and germplasm grown in several environments have established that, up to 3 500 kg/ha (well above the average yields for SAT farmers), the relationship between protein content and yield in pearl millet, though negative, is weak ($r = -0.2$). Inbreds were identified which consistently gave 14 percent N (compared with average of 12%). At these yield levels, it will thus be possible to select concurrently for protein level and grain yield.

Comparisons of normal row planting and traditional West African hill planting with a range of plant types revealed no *cultivar* x *planting system* interaction and no differences in overall yield. Yield evaluations in a row-planting environment would therefore seem to be valid for hill planting.

New combinations generated from the variety-cross program were distributed to cooperating breeders in the form of a Uniform Progeny Nursery (UPN). This provides breeders access to new variability which they cannot generate themselves.

Pest problems on pearl millet were found to be

Experimental variety WC-C75, developed at ICRISAT from a composite originally from Nigeria, is in the prerelease stage after three years of yield testing in Indian national trials of AICMIP.

minimal, except for damage caused by the armyworm *Mythimna separata,* which caused severe defoliation locally. A list of the potential pests occurring on pearl millet—and of the parasites found on them—was published.

Five International Pearl Millet Disease Nurseries, two for downy mildew (DM) and one each for ergot, smut, and rust, were operated at more than 20 locations in several countries ranging from Senegal to India, and from Nigeria to Pakistan, in cooperation with scientists in national and regional programs.

In the International Pearl Millet Downy Mildew Nursery, grown at 18 locations in India and Africa, 9 entries out of 45 had mean infection-index values of less than 5 percent. Six of these, which also met the same criteria in the 1976 IPMDMN are now being used as parents in the breeding program. Through similar multilocational disease nurseries, lines have been identified with low susceptibility to ergot, smut, and rust.

At ICRISAT Center, the ICRISAT-developed infector-row system of screening for resistance to pearl millet DM was successfully operated on 6 ha in the rainy and postrainy seasons, enabling selection of DM-resistance sources in the population and hybrid programs and in new germplasm.

No seed transmission of pearl millet DM was detected when thoroughly dried and thoroughly surface-sterilized seeds from infected heads were grown in an environment free of external inoculum.

Excellent control of pearl millet DM was achieved with the new systemic fungicide

CGA 48'988 (Ciba Geigy Ltd., Basle, Switzerland) used as a seed dressing.

Pollination was discovered to have a major effect on pearl millet ergot. If protogynous heads were pollinated before or during ergot inoculation, little ergot developed. If inoculation occurred more than 16 hr ahead of pollination, severe ergot developed. Utilizing this new knowledge of the pollen-based escape mechanism, a more effective technique was developed for screening large numbers of millet lines for ergot resistance in the rainy and postrainy seasons.

The program for identification of resistance to pearl millet smut was moved to Hissar in northern India, a known smut hot spot.

Differences in crop growth between the rainy and postrainy seasons were found attributable to differences in radiation intercepted by the crop. Low night temperature during the vegetative stage in the postrainy season resulted in poor leaf-area development and the interception of only 26 percent of the total seasonal incident radiation. Despite this, grain yields were similar between the two seasons. The greater tillering stimulated by the cool temperature early in the season, and heavier grains resulting from higher radiation levels during grain filling in the postrainy crop, compensated for differences in total crop growth.

Although a number of easily measured seed and seedling characteristics were related to field measurements of seedling vigor, none of these was sufficiently highly correlated to replace field measurements. A simple visual-scoring system was devised, which gave correlations of the order of 0.8 to 0.9 of score and seedling dry weight and seedling leaf area. This system was found very effective in identifying differences in vigor among breeding lines and among population progeny in replicated tests. Better lines have been intercrossed; progenies selected for good seedling vigor are now ready for final evaluation.

One of the two ICRISAT chickpea lines advanced to the varietal yield trials of the All-India Coordinated Pulse Improvement Project, based on superior performance in the Gram Initial Evaluation Trial.

Wilt resistance in chickpea lines is identified through field screening at ICRISAT Center.

Pigeonpea

In the pigeonpea-improvement program, hybrids produced on male-sterile female parents appear promising; the best hybrid yielded 30 percent more than the highest-yielding cultivar at ICRISAT Center. Pilot crossing blocks indicated that economical production of hybrid seed on a commercial scale is feasible. Seed of male-sterile lines has been increased and will be available to local breeders for making hybrids in 1979.

Eight early maturing lines, two medium-duration lines, and one hybrid were entered in the All-India Coordinated Trials; all these lines were superior in yield in ICRISAT trials.

In international trials of short-duration vegetable types, superior performance of the new experimental lines was reported from Puerto Rico and Panama.

Resistance to wilt and to sterility mosaic was verified in a few pigeonpea lines.

Pot and field techniques for screening for resistance to *Phytophthora* blight were developed, and 28 resistant lines were identified.

Heritable differences in reaction to pod borer were demonstrated; varying levels of susceptibility, as well as different levels of ability to recover after severe damage, exist.

Large variation from field to field was found in pigeonpea rhizobia. *Rhizohium* numbers were very low in paddy soil and below 110 cm depth in other soils.

Rhizohium strains, competitive in nodulation with indigenous soil populations, were selected for an Alfisol.

Though yields were always lower in determinate cultivars, branch numbers did not differ in determinate and indeterminate cultivars.

Chickpea

In the chickpea-improvement program, five advanced breeding lines were entered in the Gram Initial Evaluation Trial of the All-India Coordinated Pulse Improvement Project. Two of these were advanced to coordinated yield trials because of their superior performance.

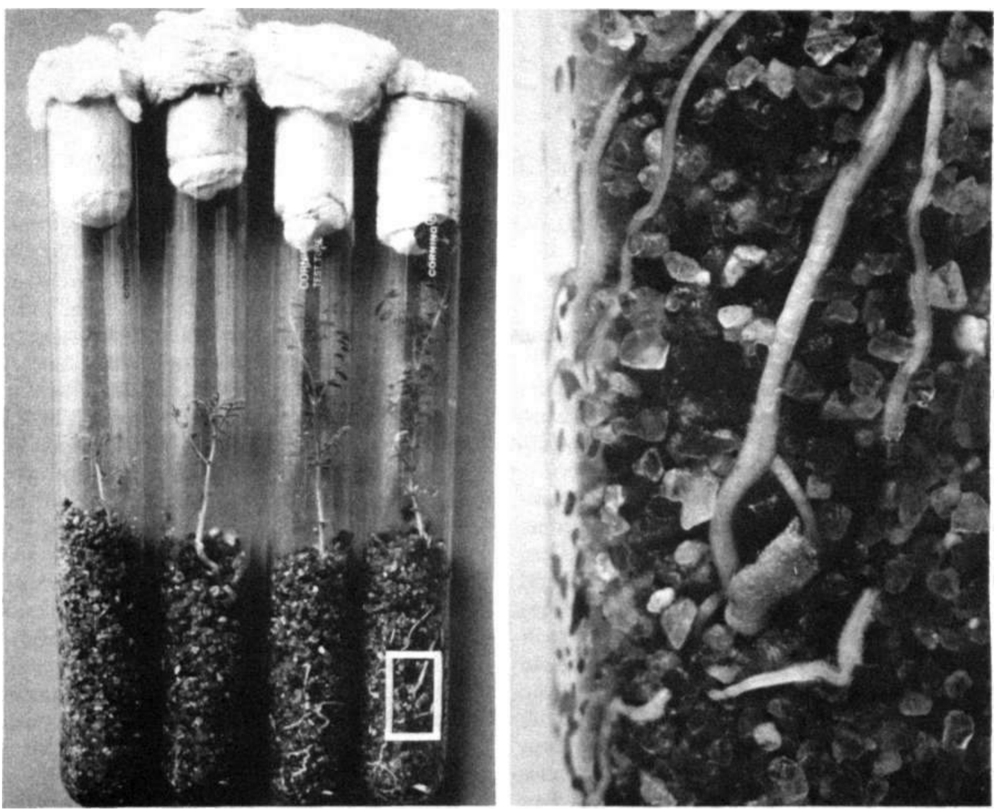
Field screening for wilt resistance was initiated; resistant plants and lines were identified in advanced breeding material. Laboratory methods correlated well with field results.

It was confirmed that powdery mildew is not seed-borne.

Twenty lines showing promise for stunt resistance were identified.

Among wild species, *Cicer judaicum* was found to be resistant to wilt.

A tube-culture method of plant infection was developed for estimating the populations of chickpea rhizobia in soil and inoculants. Enlarged photo on right is of the rhizobium boxed in white on the fourth test tube.



International disease nurseries containing promising lines for resistance to wilt/root rot and *Ascochyta* blight were initiated.

Distinct differences in susceptibility to pod borer damage were confirmed.

A tube-culture method of plant infection was developed for estimating the populations of chickpea rhizobia in soil and inoculants.

A method was established for identifying chickpea *Rhizobium* strains, using the "genetic fingerprint" of naturally occurring levels of resistance to 10 antibiotics.

The large variability in the germplasm for N_2-fixing symbiotic characters was confirmed.

Two chickpea cultivars cv G-130 at Hissar and cv 850-3/27 at ICRISAT Center gave stable yields, showing plasticity in yield over a wide range of plant populations (4 to 100 plant/m^2 at Hissar, and 15 to 100 plants/m^2 at ICRISAT Center).

Alleviation of temperature stress by shading in the reproductive period of growth did not increase chickpea yield at Hissar, but it increased yield at ICRISAT Center.

A general lack of response to soil-applied nitrogen and phosphorus was observed on heavy Vertisols at ICRISAT Center.

Groundnut

In the groundnut-improvement program, fertile, leaf spot-resistant lines were selected from hexaploids produced from crosses of *Arachis hypogaea* with wild species.

Two cultivars previously reported to be resistant to rust and two new cultivars confirmed as resistant by our groundnut pathologists were used in a hybridization program with 70 high-yielding parents. More than 12 500 pollinations were made, and by using vegetative cuttings to increase F_1 plants, large F_2 populations have been produced for screening for rust resistance in the 1978 rainy season.

Studies on longevity of spores of groundnut rust showed that they are short-lived under normal conditions, none surviving longer than 22 days. Spores could be stored for 120 days at —16 C with little loss in germination.

Two germplasm lines—NC Acc 17090 and EC 76446 (292)—were selected from among 6 000 lines as having better rust resistance than previously known sources.

Eight of the 13 wild species available at ICRISAT were found immune to rust.

Electronmicroscopy of infected groundnut tissues has provided the final proof that bud necrosis disease is caused by Tomato Spotted Wilt Virus. Several other crop plants are also hosts of TSWV, including mung bean (*Vigna radiata*) and urd bean (*Vigna mungo*).

Scirtothrips dorsalis and *Frankliniella schultzei* were shown to be vectors of TSWV, the causal agent of bud necrosis disease.

Clump virus, causing severely stunted plants with small green leaves, was detected in Punjab and Gujarat. The physical properties of the virus have been determined.

A total of 6511 germplasm lines have been introduced to ICRISAT since the inception of the program in 1976.

Farming Systems

In the farming systems research program, studies aimed at attaining better land and water use and increasing productivity of crops by utilizing improved technology were initiated on farms in three of the six SAT villages of India under study since 1975 by ICRISATs economics program. The All-India Coordinated Research Project for Dryland Agriculture and local agricultural universities are also participating.

A model was developed that permits effective estimation of photosynthetically active radiation from measured solar radiation.

Weekly rainfall data for 56 SAT locations in India were analyzed by the Markov chain method, and the initial and conditional rainfall probabilities published for the prerainy, postrainy, and dry seasons.

On deep Vertisols, the response to nitrogen fertilizer of sorghum intercropped with pigeon-

Sorghum/pigeonpea intercropping utilizes crop land more efficiently than either crop growing separately. Intercropping research is complex and difficult, but scientists believe it will provide a real payoff for SAT agriculture.

pea was shown to be virtually independent of population density (these ranged from 40% to 160% of the optimum).

Broadbeds in the Vertisols remained friable late into the dry season. Beds plowed easily after harvest of the postrainy season crop, thus facilitating early weed control, moisture conservation, and planting in dry soil just prior to the onset of the rains.

Linear programing demonstrated that the wheeled tool carrier, when used on the broadbed-and-furrow system, has a command area of about 15 ha in Vertisols. By spreading the cost of ownership over a large area through custom hiring or group action, cost per unit area can be kept low.

The value of "smother" crops like cowpea and mung bean in minimizing weed problems and increasing productivity was demonstrated.

It was confirmed that preemergence herbicides coupled with a later cultivation and/or hand weedings gave good results in double cropping deep Vertisols.

Sorghum/pigeonpea intercropping gave up to 100 percent the yield of sorghum and 70 percent the yield of pigeonpea, but a very inefficient period of growth—with less than 20 percent light interception—was indicated immediately after sorghum harvest. Further work is in progress, including selection of improved genotypes.

Pearl millet/groundnut intercropping confirmed yield advantages of up to 25 or 30 percent; a row arrangement of one millet: three groundnut gave the optimum balance of competition and maximum efficiency of resource use. Appreciable differences in genotype performance were observed for both crops.

While sorghum yields increased from application of practices such as use of improved varieties, management, and fertilization, the yield gain obtained by combining all three was considerably higher than the sum total of gains obtained over traditional practices when each of these was applied separately. The synergistic effect of all improved practices combined brought about a yield increase of 5 370 kg/ha, against a total gain of 3 640 kg/ha on their separate applications.

In cropping systems entomology, it was found that migration of *H. armigera*— which brought about disequilibrium in native biotic control agents—led to a rapid increase in larval populations which in turn caused heavy damage in intercropped pigeonpea and chickpea.

An improved understanding was obtained of the pest/parasite relationship which will enable us to predict the effects of these factors on cereal/pulse crop systems, particularly in inter- and mixed cropping.

Economics Program

In the economics program, studies of farmers' attitudes to risk in six villages of SAT peninsular India revealed that generally they are moderately risk averse when faced with choices which offer varying profits and risks. Small farmers do not seem to differ from large farmers in their risk attitudes. If this is a correct reflection of risk attitudes of SAT farmers in general, it suggests that separate technologies with different risk

Consumer preferences in terms of grain quality are found to influence market prices for the ICRISAT food grains in India.

characteristics for small and large farmers need not be developed. Instead, to ensure adoption of new technologies, institutional policies are required to give small farmers equal access to the credit and modern inputs which such technologies generally use.

Market prices were found to reflect consumer preferences, in terms of quality, for ICRISAT food grains in India. Such preferences are based on evident qualities such as color, mold infestation, or seed size, and on cryptic qualities such as dry volume, swelling capacity, and protein content.

Investments in improvements which facilitate agricultural market exchange have measurable payoffs. Using a theoretical model, the removal of restrictions on interregional exchange in India was found to cause aggregate food-grain production to increase. Positive effects of enhanced market exchange on productivity are brought about by relatively small changes in cropping patterns.

The density of traditional tank (small dam) irrigation systems in India was found to be primarily determined by geological and agroclimatic factors such as extent of granite substrata, humidity, soil moisture-holding capacity, and rainfall distribution. In the last two decades, the contribution of tank-irrigation systems to production in southern SAT India has become more unstable. This seems due mainly to increased siltation, less intensive water management, and increased climatic variability.

In low-wage environments such as in India, tractors have not had measurable effects on crop yields, cropping intensity, cropping patterns, or timeliness. Their main effect has been to displace labor and bullocks.

The Cereals

Sorghum (*Sorghum bicolor*)

Pearl Millet (*Pennisetum americanum* L.)

Sorghum and millet are the main cereal crops grown under the erratic climatic conditions of the SAT. The two crops occupy in excess of 70 million hectares, and form the staple cereals for many millions of people.

The quantum leaps seen in production of rice and wheat, brought about by high-yielding varieties and research-based technology, have in no way been matched by sorghum and pearl millet. Farm practices remain essentially as they have been for thousands of years. A world-wide effort in breeding superior varieties is just now getting under way, and much remains to be learned about the role of cultural practices in increasing yields of these cereals in the SAT. The two cereals can play major roles in feeding the underfed of developing nations if the total benefits of the agricultural sciences can be applied.

ICRISAT GOALS

Long-term benefits expected through ICRISAT's cereal programs include:

Consistent improvement in performance of sorghum and pearl millet over a wide range of environments throughout the SAT.

Genotypes that have higher yield potential than now found in cultivated varieties.

Improved resistance to insects, diseases, and other parasites.

Improved nutritional value, cooking quality, and palatability.

ICRISAT scientists are pursuing these goals at ICRISAT Center near Patancheru Village in Andhra Pradesh and at a number of other locations throughout India and the world. They have established communications with cereals breeders throughout the SAT so that exchange and evaluation of genetic materials can be thoroughly accomplished, and so that all may share in progress and approaches to problems. The emphasis is always on cooperation with scientists working in national programs.

ICRISAT CENTER

ICRISAT Center provides a wide range of environments for the development and testing of plant materials for the SAT. It has Alfisols and Vertisols and three growing-season environments. The rainy season, known locally as monsoon or kharif, occurs from June through September, and has long days until the September equinox. The postrainy season, known locally as postmonsoon or rabi and occupying the months of October through January, has little rainfall, is cooler, and has shorter days. Crops grown during the postrainy season rely on residual soil moisture or on irrigation. From February until the rains begin in June is the hot dry summer season. Temperatures at flowering time are very high during this season, and short-season crops may be grown if irrigation is provided. Certain areas of the Center are saline and others have impeded drainage, making it possible to evaluate plant performance under a variety of conditions as they exist in many areas of the SAT.

SORGHUM

Sorghum

Germplasm

COLLECTION AND MAINTENANCE

The total number of accessions available at ICRISAT Center increased to 15 304 with the addition of 267 new accessions released from the Postentry Quarantine Inspection Area (PEQIA). Regeneration of seed of 4 036 accessions was carried out; seed supplies of these accessions had dwindled to less than 30 g.

Planting was done in Alfisols in a 2.25-m row with a spacing of 75 cm by 15 cm. All collections were maintained by selfing from five to ten representative heads in each line.

New accessions totaling 267 were received from countries listed in Table 1.

EVALUATION

All new accessions not evaluated earlier were evaluated in postrainy season 1977 for plant height, days to 50 percent flowering, awning, midrib color, plant pigmentation, tillering, peduncle exsertion, earhead length and breadth, panicle type, glume color, and threshability. A total of 5 568 accessions from the World Collection (representing geographical regions) were screened for photosensitivity by planting in 1977 rainy (long day) season.

Screening for insect, disease, drought, and *Striga* resistance is being carried out. Details of the accessions screened are given in Table 2.

In addition, 2 854 accessions were supplied to sorghum breeding, biochemistry, physiology, and microbiology programs for use in their research projects.

DOCUMENTING AND PUBLISHING EVALUATION

Data tabulated for 7 114 IS numbers evaluated in postrainy season 1974 were computerized

Table 1. Sorghum germplasm lines received at ICRISAT Center during 1977-1978.

Country	Number
Bangladesh	1
Botswana	26
People's Republic of China	9
Ethiopia	14
Kenya	2
Niger	4
Philippines	5
Sri Lanka	2
Sudan	181
Taiwan	1
Upper Volta	3
USA	3
USSR	16
Total	267

Table 2. Accessions screened for insect, disease, drought, and *Striga* resistances at ICRISAT Center during 1977-1978.

Screened for	Accessions	Described by
Insect resistance	553	Entomology unit
Disease resistance	134	Pathology unit
Drought resistance	1 100	Physiology and Breeding units
Striga resistance	4 832	Sorghum Breeding unit
Total	6 619	

at the Information Sciences/Genetic Resources program of the University of Colorado, USA. The data were transferred to ICRISAT's computer and published in printout form. Data for the remaining IS numbers of the World Collection is being updated.

SEED DISTRIBUTION

In all, 72 consignments of germplasm involving 5 376 samples have been sent to scientists in India and other countries in response to requests (Table 3).

CLASSIFICATION

As per recommendation of the IBPGR advisory committee on sorghum and millets, the available World Collection has been classified according to Harlan and de Wet's new classification system. Panicle branches were collected for all the accessions and preserved as reference samples.

INTROGRESSION AND CONVERSION

The introgression and conversion project was initiated to make use *of* the genetic resources of sorghum by introgressing new germplasm from the collection into the adapted breeding material and to convert the tall photosensitive tropical germplasm into day-neutral on good agronomic background. Very desirable segregants with large head size and bold grain on a short insensitive background, from the F_3 and BC_t F_3 population of the crosses involving cv CSV-5 as the adapted cultivar and landraces from Ethiopia as exotic germplasm, were selected for testing in rainy season 1978. The single-cross F_1's between selected landraces from the germplasm and the adapted cultivars were planted to obtain F_2 seed. Under the conversion program, tropical sensitive landraces and dwarf insensitive parents 2219 B, 2077 B, and SC 108-3 were crossed in postrainy season 1977.

Breeding

POPULATION BREEDING

Our project on population breeding has been modified as we have gained experience. Effort is being concentrated on the Fast Lane 'R' and 'B,' Tropical Conversion, and Serere Elite

Table 3. Sorghum germplasm supplied to research agencies in India and other nations during 1977-1978.

Institution	Location	Entries
		(no)
INDIA:		
Agricultural College	Bapatla, A.P.	13
Pioneer Seed Company	Hyderabad, A.P.	78
AICSIP, Rajendranagar	Hyderabad, A.P.	199
Department of Genetics, Osmania University	Hyderabad, A.P.	23
Indian Agricultural Research Institute	New Delhi	1 108
ICAR Research Complex	Goa	5
Gujarat University	Ahmedabad, Gujarat	12
Gujarat Agricultural University	Navsari, Gujarat	13
UAS/KDDC Fodder Project	Bangalore, Karnataka	92
University of Agricultural Sciences	Bangalore, Karnataka	42

Continued

Table 3 *Continued*

Institution	Location	Entries
Agricultural Research Station	Bijapur, Karnataka	8
College of Agriculture	Dharwar, Karnataka	38
Punjabrao Krishi Vidyapeeth	Akola, Maharashtra	185
Maharashtra Agricultural University	Parbhani, Maharashtra	4
Agricultural Research Station	Ratnapur, Orissa	20
Rajasthan College of Agriculture	Udaipur, Rajasthan	41
Tamil Nadu Agricultural University	Coimbatore, Tamil Nadu	73
Sugarcane Breeding Institute	Coimbatore, Tamil Nadu	7
Cotton & Millet Experiment Station	Kovilpatti, Tamil Nadu	1 024
R.B.S. College	Agra, UP.	58
Chandra Shekhar Azad University of Agriculture & Technology	Kanpur, U.P.	35
G.B. Pant University of Agriculture & Technology	Pantnagar, U.P.	124
OTHER NATIONS:		
CSIRO	Australia	160
Bangladesh Agricultural Research Institute	Dacca, Bangladesh	15
Est. Exp. Universitaria	Cochabamba, Bolivia	27
Ethiopian Sorghum Improvement Project	Ethiopia	429
Fachbereich 16 Dor Universitat	West Germany	1
Crops Research Institute	Ghana	16
FAO	Rome, Italy	55
Kenya Agriculture & Forestry Research Organization	Kenya	20
IRAT	Mali	8
P.i. de la Station de Sotuba	Bamako, Mali	8
C1MMYT	Mexico	277
University of Papua	Papua New Guinea	53
Department of Plant Breeding & Genetics, University of Agriculture	Pakistan	32
Mayaguez Institute of Tropical Agriculture	Puerto Rico	27
Universite Nationale du Rwanda	Rwanda	91
ICRISAT Cooperative Program	Senegal	15
Agricultural Research Corporation	Sudan	10
Crop Development Division	Tanzania	304
Tropical Products Institute	London, UK	100
Department of Agriculture & Horticulture, University of Reading	UK	5
Hawaiian Agronomics Company (International)	USA	42
Purdue AID Sorghum Project	Indiana, USA	100
Texas A&M University	USA	148
Embassy of the USSR in India	Leningrad, USSR	225
Department of Agriculture, Government of Yemen	Sana'a, Yemen Arab Republic	6

populations at ICRISAT Center. Most of the populations under selection have attained fairly high levels of grain yield with reasonably acceptable grain color and food-quality requirements. Mass-selection procedures will be used.

Some of the pure-line derivatives from early cycles of improvement are now contributing to breeding programs in the SAT. The current emphasis is on integrating elite-population breeding materials with sources of resistance to important diseases and pests.

International Sorghum Preliminary Yield Trial-1 (ISPYT-1)

This trial, consisting of 56 promising derivatives from different populations, including five checks, was distributed to 18 locations in the semi-arid tropics (Table 4).

Table 4. Locations of the International Sorghum Preliminary Yield Trial-1.

Country	Locations
	(no)
India	5
Senegal	
Upper Volta	
Mali	2
Nigeria	
Sudan	
Ethiopia	2
Botswana	
Pakistan	2
Thailand	2

The data on grain yield was available only from four locations; performance of selected entries is presented in Table 5. Many lines performed better than did the varietal checks and a few entries performed better than the hybrid check, CSH-6. Fast Lane 'R' 53 produced the highest mean yield of 4 919 kg/ha as compared to 4 734 kg/ha of cv CSH-6. Six entries performed better than the highest-yielding varietal check NE-830 x 705, a derivative from SC-108, and as many as 25 lines produced a higher grain yield than cv CSV-4—a released variety in India.

Twelve entries at ICRISAT Center and one entry in Botswana were significantly superior in grain yield; in the Sudan eight entries were numerically better than the local check. In Ethiopia, where trial conditions were excellent, Rs_1 x VGC, Fast Lane 'R' 101, Bulk 'Y' 31, and Rs/R-20 performed very well. The cross was the most outstanding entry at both test locations and has been selected for inclusion in national trials. Another entry, FLR-101, performed well in dry areas of Mali and Thailand, and in Rahuri and Sholapur in India. At ICRISAT Center, 23 lines were superior to the improved local check, cv CSV-4. Seven were superior to the check cultivar in Botswana and 14 were superior in Ethiopia.

Populations in the S_2-testing Phase

S_2 progeny-evaluation trials were conducted for four populations—Rs/R, Rs/B, Tropical Conversion, and Serere Elite—on low fertility (20 kg N, 20 kg P, per ha) Alfisols and high fertility (150 kg N, 80 kg P_2O_5, per ha) Vertisols at ICRISAT Center and at cooperative centers in Sudan and Upper Volta. (Trials were also sent to Ethiopia and Thailand.)

Yield data were received from the Sudan and Upper Volta (Table 6).

Comparison of mean yields of populations with the mean yields of checks indicated that the populations have satisfactory yield levels and that Rs/R and Rs/B populations have better yield potential than the Tropical Conversion and Serere Elite populations. The latter two populations will henceforth be advanced by mass selection at ICRISAT Center.

Rs/R population. This population was originally developed at Serere (Uganda). After its introduction to ICRISAT in 1973, two cycles of S1 selection were completed. The population progeny trial consisting of 170 S_2 entries was conducted in 1977 in Ouagadougou, Upper Volta; Wad Medani, Sudan; ICRISAT Center, India; Khon kaen, Thailand; and Kobo and Nazareth in Ethiopia. The material performed

Table 5. Performance of promising derivatives of populations at one Indian and three African locations in the International Sorghum Preliminary Yield Trial-1 (ISPYT-1), 1977.

Pedigree	Grain yield and rank[a]					Mean	
	India[b]	Sudan[b]	Upper volta[b]	Botswana[b]	Mean	50% flow-ering	Height
						(days)	(cm)
FLR-53 (late)	5 187 (2)	7 041 (13)	3 616 (4)	3 833 (5)	4 919 (1)	65	161
FLR-53 (early)	3 707 (19)	7 686 (7)	3 710 (3)	3 233 (13)	4 584 (3)	69	168
US/R-408	4 213 (9)	7 984 (3)	2 632 (18)	3 100 (16)	4 482 (4)	61	188
US/R-591	4 773 (3)	7 826 (5)	2 545 (21)	2 733 (22)	4 469 (5)	61	168
US/R-408	3 773 (16)	8 710 (1)	2 431 (26)	2 733 (21)	4 412 (6)	64	177
FLR-101	3 920 (13)	6 845 (17)	2 946 (10)	3 867 (4)	4 395 (7)	66	151
FLR-53	5 573 (1)	6 750 (20)	2 243 (32)	2 267 (38)	4 208 (9)	65	190
US/R-408	3 640 (21)	7 167 (12)	2 444 (25)	3 567 (7)	4 205 (10)	62	178
Bulk 'Y'-1667	3 347 (29)	6 689 (21)	2 103 (38)	4 667 (1)	4 202 (11)	71	204
FLR-101	3 893 (14)	7 684 (8)	2 491 (23)	2 600 (26)	4 167 (12)	69	186
Bulk 'Y'-1670	2 583 (36)	8 088 (2)	2 980 (8)	2 700 (4)	4 155 (13)	63	167
PP5	3 400 (27)	6 812 (18)	2 699 (16)	3 600 (6)	4 128 (14)	72	167
Diallel Pop-1898	3 747 (18)	7 763 (6)	2 404 (28)	2 433 (31)	4 087 (15)	69	186
Rs_1 × VGC	4 427 (6)	7 870 (4)	1 741 (44)	2 300 (35)	4 085 (16)	69	193
CHECKS:							
CSH-6	4 760 (4)	6 907 (15)	3 770 (2)	3 500 (8)	4 734 (2)	60	170
CSV-4	3 707 (19)	6 250 (31)	2 109 (37)	2 533 (28)	3 560 (26)	71	137
NES-830 × 705	4 160 (10)	6 281 (30)	3 147 (6)	3 433 (9)	4 255 (8)	70	145
Local	3 533 (23)	7 341 (9)	4 808 (1)	3 300 (10)			
C.V.(%)	19	14	32	22			
L.S.D. (0.05)	1 261	1 790	1 505	1 150			

[a]Based on 7.5 m^2 area and two replications. Yields in kg/ha; number in parenthesis indicates ranking.
[b]Hyderabad, India; Wad Medani, Sudan; Ouagadougou, Upper Volta; Gaborone, Botswana.

Table 6. Mean grain yield of the populations tested daring 1977.

Population	Mean grain yield over all lines tested[a]			mean over locations
	India[b]	Sudan[b]	Upper Volta[b]	
	(kg/ha)			(kg/ha)
Rs/R	3 449 (2 513)[c]	4 914 (5 266)	3,152 (3 478)	3 838
Rs/B	3 117 (2 793)	3690 (3 464)	2 748 (3 258)	3 185
Tropica] Conversion	2 682 (2 400)	2 392 (2 487)	2 595 (2 624)	2 712
Serere Elite	3 174 (3 077)	2 676 (2 815)	2 574 (3 109)	2 802

[a]Size of plot was 7.5 m^2.
[b]ICRISAT Center, India; Wad Medani, Sudan; Ouagadougou, Upper Volta.
[c]Values in parenthesis are the means of four checks.

well at most locations. Data on grain yield is available from three locations. Mean grain yield of S_2 lines ranged from 2 317 to 5 067 kg/ha, with a population mean of 3 838 kg/ha, indicating a good scope for selection. Twenty-six lines were selected on the basis of overall performance for reconstituting the population. In addition to these, 11 promising lines from previous cycles were included. In order to diversify the population for different resistance and quality traits, the reconstituted population has been crossed to new sources of resistance to *Striga*, grain mold, shoot fly, stem borer, and midge.

Many good-looking plants were selected at each location. At ICRISAT Center, 80 plant selections have been advanced to the S_3 generation. In Ethiopia, 16 and 18 lines were selected at Kobo and Nazareth, respectively, and will be advanced by pedigree selection.

Rs/B population. The population, originally developed at Serere, Uganda, was introduced to ICRISAT in 1973. Since then, two cycles of S_1 selection have been completed. Two hundred S_2 lines from the Rs/B population were tested at the same locations as the Rs/R (except in Thailand). The performance of the population was satisfactory at most locations. Grain yield over three locations ranged from 1 545 to 5 104 kg/ha. There was good variability for height and maturity. On the basis of overall performance, 35 lines were selected for recombination. Mean grain yield of the selected lines was 3 605 kg/ha, that of the entire population was 3 185 kg/ha.

A number of individual plant selections were made at each location. At ICRISAT Center, 83 plants were selected, and in Ethiopia many plants from 12 entries were selected. These plants are being advanced by the pedigree-breeding method. At the same time, these lines were test-crossed to the cytoplasmic A-lines to evaluate them for nonrestoration of male fertility.

Populations in the Random Mating and Preliminary Selection Phase

Populations have been divided so that only half of them are involved in multilocation S_2 testing in any one year. (Populations in the off-year were the US/R, US/B, and West African Early. The Fast Lane 'R' and 'B' populations were included in this set, but will not be propagated at ICRISAT by mass selection.) The US/R and US/B populations have been out-crossed to a source of grain mold resistance. The West African Early composite was formed from photosensitive material, but now contains many good early selections with bold pearly white seeds and tan plants. S_2's have been selected for multilocation testing in 1978.

New Populations

Several new populations are in the development stage, but have not yet reached S_2 testing. The Indian diallel initiated in 1974 will be ready for Si testing in 1978 and the early and mid-late populations, initiated as part of an effort to better serve some of the different climatic situations in SAT, are being developed. An Indian Synthetic was synthesized, using 10 adapted lines selected for their good crossing performance and without incorporating male sterility. All possible F_1's were made and the F_1's again intercrossed, using bulk pollen. In 1977 a few very promising lines were selected for inclusion in a preliminary yield trial. It is now planned to introduce genetic male sterility into this population.

Evaluation of Population Derivatives as Seed Parents in Hybrids

An effort to identify potential B-lines was made by making 605 test crosses onto A-lines. A high proportion of entries from B-line composites have been found to produce male-sterile hybrids.

DEVELOPMENT OF HYBRIDS

Hybrids have greater yield potential than varieties and hybrid yields are more likely to be sustained under harsh SAT conditions. In view of the increased interest expressed by some African nations, ICRISAT is increasing its efforts to identify good seed parents for hybrids. The available seed-parent lines have a limited range of maturity and most are poor in grain quality and resistance to diseases and pests. Hence the best maintainer lines were crossed to suitable source material. In the future, the desirable types will be selected from segregating populations and test-crossed to identify the maintainer.

It is also equally important to have good pollen parents (R-lines) for the production of hybrid seeds. Therefore, promising lines were selected from various projects in sorghum breeding. Nearly 400 experimental hybrids were evaluated in postrainy season 1977. The selected hybrids will be further tested. In addition, 1511 lines from the nursery of the late Dr. Karper of Texas A & M University, in the United States, were evaluated.

BREEDING FOR POSTRAINY SEASON SORGHUM TYPES

Approximately 40 percent of the sorghum area in India is sown in the postrainy season months of September and October, when the moisture supply is receding and temperatures are lower. Progress in breeding sorghum types for this situation has been limited.

A number of germplasm lines selected from postrainy season 1977 were crossed to dwarf, early, and high-yielding lines. Breeders are working with physiologists in an investigation of the effects of temperature, day length, and moisture. Highly significant *genotype x sowing date* interactions were noted, indicating that genotypes differ in their adaptation to temperature and day length.

GRAIN QUALITY

High-yielding genotypes which flower earlier than farmers' types frequently mature during late rains and become subject to complex grain-deterioration problems such as i) susceptibility of the grains to parasitic molds (*Curvularia* and *Fusarium*); ii) pigmentation and grain weathering; iii) loss of seed viability; and often have poor food quality. The market value of grain depends upon its quality. ICRISAT sorghum breeders are concerned about these problems and have succeeded, in collaboration with cereal pathologists, in identifying good sources of mold resistance. Some 7 000 crosses were made between mold-resistant, good-grain quality, and high-yielding varieties. Twenty percent of these were selected after critical evaluation and their segregating F_2 populations screened under natural conditions for plants good in agronomic characters with "clean" grains. Visual selection in the field for various physical grain-quality attributes is supported by laboratory measurement of grain size, weight, density, corneousness, hardness, and water absorption. In collaboration with sorghum pathologists, more than 5 000 progenies of early segregating generations were artificially inoculated with mold (Table 7); about one-tenth of these with good quality grains showed a reduced susceptibility to mold (Table 8). Ten percent of the less mold-susceptible selections had a score of 2 on a scale of 1 to 5 (increasing order of infection), and grains of these were again inoculated, incubated, and

Table 7. **Early generation breeding material evaluated for grain molds at ICRISAT Center, 1977-1978.**

Generation	Progenies
	(no)
F_1	6 988
F_2	592
F_3	2 119
F_4	1 576
F_5	770

Table 8. Less mold-susceptible selections obtained in rainy season 1977 from F_3, F_4 and F_5 progenies after inoculation with *Curvularia* and *Fusarium.*

Origin		Score 2	Score 3	Total
Single crosses	(71)	34	330	364
Double crosses	(23)	—	49	49
Three-way crosses	(28)	16	58	74
Total		50	437	487

evaluated for relative fungal infection in the laboratory. Several selections seemed to be relatively resistant, and parents such as IS-2328, IS-9530, IS-9327, CS-3541, E35-1, SC-108-3, SC-423, CS-3687,2219B, and 2KX-2 were found to be useful in breeding for mold-free plants.

Development of a mold-resistance composite is under way and recurrent selection for grain mold resistance will be performed in this population very soon. Preliminary studies on the inheritance of resistance to the fungi *Curvularia* and *Fusarium* indicate that it is probably polygenic and that additive gene action is predominant, while partial dominance for susceptibility cannot be ruled out.

Grain-yield tests were carried out at ICRISAT Center on 210 F_5 bulks from the mold-resistance crosses and several entries produced 4 000 to to 5 000 kg/ha. Some of the more promising selections are listed in Table 9, along with grain yield and flowering data.

Sorghum Elite Progeny Observation Nursery (SEPON), 1977

Seed of 72 elite selections in the F_5 generation was supplied to cooperators in the SAT in the form of a nursery labeled SEPON. Comments of cooperators and scores for grain molds, yield, and adaptation revealed that many of the lines exhibited satisfactory to good performance in comparison with local checks across locations. Number of entries selected in various locations is listed in Table 10. Notable among the entries which performed well across locations are derivatives from crosses between SC-108, a line from the Texas A & M University in the USA, and CS-3541, a variety released in India.

SEPON-1978, consisting of 46 selections in F_5 and F_6 generations, has been supplied to 18 locations in the SAT.

FOOD QUALITY

Several cooperators in the SAT were asked to provide information about the popular modes of sorghum grain consumption in their regions, along with details of preparation of the recipe, specific grain-quality requirements, and the grain types preferred for a particular recipe. Nearly 90 percent of the sorghum-food grain consumption in the SAT can be broadly classified into five preparations: i) unleavened bread (chapati); ii) leavened bread (injera, khisra, tortilla); iii) thin or thick gruel/porridge (To, tuwo, cous cous, bogobe, ugali, kali); iv) boiled sorghum (from whole grain pr coarse pieces after removal of the pericarp); and v) beer.

Sorghum flour is frequently mixed fifty/ fifty with wheat or maize flours in various preparations.

Selection for Food-quality Parameters

The selection criteria exercised by breeders in most of the regions where sorghum is a staple food are in general white or yellow grains of bold size with corneous endosperm. However, all such grains do not produce the required

Table 9. Performance of some elite F_5 bulks from *adapted* x *mold-resistant* crosses, rainy season 1977.

Origin	Pedigree	Days to 50% flowering	Grain yield[a]
		(days)	(kg/ha)
ENTRIES:			
Expt 31/38	(SC-108-4-8 x CS-3541)-14	64.6	4 258
Expt 31/26	(SC-108-3 x CS-3541)-3	60.3	4 008
Expt 31/11	(0222 x CS-3541)-10	58.6	4 160
Expt 31/36	(SC-108-3 x CS-3541)-11	62.3	4 098
Expt 32/22	(10262 x CS-3541)-12	62.0	4 648
Expt 32/28	(10680 x CS-3541)-7	60.3	4 506
Expt 32/12	(9954 x CS-3541)-10	59.6	4311
Expt 32/17	(0222 x CS-3541)-20	60.0	4444
Expt 33/21	(SC-108-3 x CS-3541)-29	64.0	4 844
Expt 33/23	(SC-108-3 x CS-3541)-38	65.0	4417
Expt 33/26	(SC-108-4-8 x CS-3541)-15	63.3	4 257
Expt 33/32	(SC-108-4-8 x CS-3541)-32	56.6	4 586
Expt 33/39	(SC-108-4-8 x CS-3541)-54	58.3	4 951
Expt 33/36	(SC-108-4-8 x CS-3541)-40	62.0	4 239
Expt 33/37	(SC-108-4-8 x CS-3541)-47	60.6	4 746
Expt 33/58	(SC-108-4-8 x CS-3541)-56	65.3	4 622
CHECKS":			
Expt 32/72	CSH-6	53.0	4 853
Expt 32/69	SPV-104	64.0	4080
Expt 32/74	USV-2	58.6	4 088
Expt 33/68	CS-3541	65.0	3 822
Expt 33/70	SC-108-3	62.0	3 813

[a]Size of plot was 7.5 m^2.

[b]Checks were present in all experiments and reported values are from the experiments in which their performance was at their best.

C.V. Days to 50% flower: 2.80, 2.21, and 2.67 for experiments 31, 32, and 33 respectively.

C.V. Grain yield (kg/ha): 18.64, 15.18, and 17.75 for experiments 31, 32, and 33 respectively.

food satisfactorily. Therefore, breeders are trying to test and rank grain samples from their elite material in terms of suitability to make a recipe, and to identify the properties or parameters that need improvement. Simple laboratory techniques to evaluate grain samples for chapati suitability were standardized and a range of farmer types, improved varieties, hybrids, and breeding stocks were studied for 14 attributes. Variety M35-1 was used as a standard and all other samples were compared with it. Two hundred of these samples were studied in more detail in randomized and replicated experiments, including evaluation by taste panels. The broad range of variation for grain and food quality attributes in some of the varieties is presented in Tables 11 and 12. Fourteen lines from breeding stocks were found to be comparable to cv M35-1 in chapati quality. Parameters essential in chapati

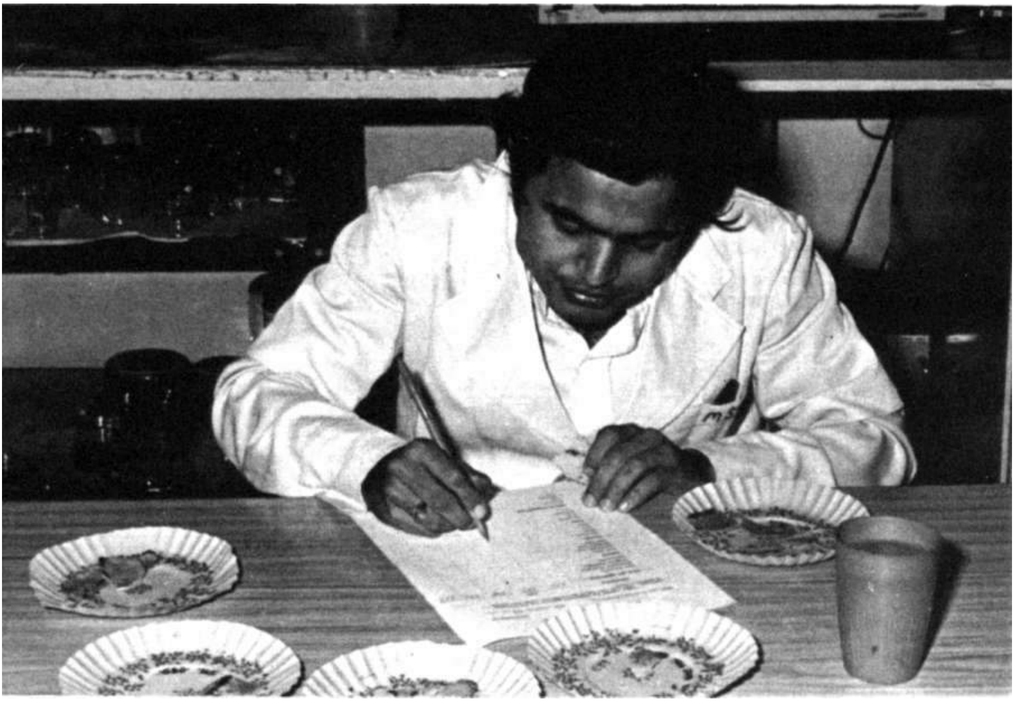


Figure 1. Samples of chapati—a popular sorghum dish—are studied. Simple laboratory techniques have been standardized at ICRISA T to evaluate grain samples for chapati suitability.

Table 10. Sorghum Elite Progeny Observation Nursery-1977 (SEPON). Overall performance across locations.

Location	Lines despatched	Lines selected
	(no)	(no)
Upper Volta	72	21
Niger	72	35
Senega]	72	22
Mali	20	8
Kenya	72	17
Thailand	72	8
Tanzania	70	11
Mexico	33	31
India	72	13

quality evaluation are under investigation. Similar studies and analyses for recipes for To and injera will be carried out in collaboration with our cooperators in Africa.

Improvement for Lysine

Breeding is being carried out using two high-lysine sources; one involves the Ethiopian *hl* gene, the other is an induced mutant, P-721. After several generations of selection, no high-lysine progenies with plump seed were found in selections in which the Ethiopian *hl* gene was the sole high-lysine parent. However, a fair number of plump-seeded high-lysine progenies have been identified in crosses that included cv P-721 as a second high-lysine parent. In these lines, high protein (13-15%) is often associated with high lysine (2.4-2.6% of the protein). However, environmental variation can change these levels rather drastically. For example, in an environment where available soil nitrogen is low, both protein and lysine (as % of protein) can drop to near normal levels.

BREEDING FOR PEST RESISTANCE

Breeding for resistance to the three major pests of the SAT—stem borer, shoot fly, and midge—continued. Four populations were advanced, one for resistance to each pest, and one for combined resistance to the three. After intercrossing pest-resistant lines three times, four separate population bulks were prepared and tested under high insect pressure in screening nurseries during the rainy season. The combined-pest population bulk was tested in each screening nursery and the individual pest bulks in their respective screening nurseries. Interestingly, the combined-pest population showed better resistance to shoot fly than did the population bred for shoot fly alone. Sibbing was done between resistant sterile and fertile plants in order to maintain sterility in the populations. Based on agronomic eliteness and the resistance of male and female plants, a number of sibs in each population were selected. These sibs were recombined further during the

Table 11. Grain quality properties of diverse grain types of sorghum.

	Grain					
Genotype	Color[a]	Corneousness[b]	100-grain weight	Breaking strength	Density	Water absorption/ 5hr
			(g)	(kg)		(%)
M-35-1	5Y 8/3	3	3.450	7.08	1.241	20.46
Surat-1	5Y 8/3	3	4.650	6.19	1.230	31.63
PJ 24K	5Y 8/3	3	4.987	7.22	1.260	28.24
Mothi	5Y 8/2	2	3.535	9.63	1.240	25.34
IS-1584	2.5Y 7/6	4	3.011	5.26	1.200	33.51
M-6058	2.5Y 8/6	4	6.922	7.70	1.184	18.45
BG 30	2.5Y 6/4	3	5.161	7.04	1.227	32.41
IS-9985	10YR 5/4	3	6.186	10.90	1.217	31.02
E-35-1	5Y 8/3	1	3.773	14.58	1.240	27.16
1S-2328	5Y 8/3	2	3.183	12.36	1.283	28.95
M-35088	2.5Y 8/4	1	3.781	10.53	1.242	30.23
M-32282	5Y 8/2	2	3.562	12.85	1.209	28.07
H1-52	2.5Y 8/3	3YE	4.090	7.70	1.267	26.62
CE 90-16-3	5Y 8/2	3	3.281	8.63	1.208	30.78
2 KX 6-2	5Y 8/2	3	2.390	7.29	1.229	32.71
P-721	5Y 8/2	5	2.510	6.81	1.130	32.66
CSH-6	5Y 8/3	3	3.460	8.87	1.260	20.75
M-35420	5Y 8/2	Waxy 3	2.616	10.37	1.230	29.16
M-36410	5Y 8/3	2	3.812	9.10	1.219	23.18
M-35082	5Y 8/3	2	3.104	9.53	1.240	27.89

[a]Color was compared with Munsell's Soil Color Charts.
[b]Corneousness was scored on a 1 to 5 scale, in the order of decreasing desirability.

Table 12. Food quality properties of diverse grain types of sorghum.

Genotype	Dough			Chapati					
	Water for dough	Kneading quality*	Rolling/ spreading	Color[a]	Taste[c]	Texture[a]	Flavor[b]	Keeping quality[c]
	(ml)		(cm)					
M-35-1	26.11	1.0	23.70	5Y 8/3	1.33	1.50	1.00	1.50
Surat-1	25.47	1.5	21.50	SYR 7/2	2.00	2.10	2.00	2.00
PJ 24K	25.93	1.0	21.50	2.5Y 7/2	2.50	1.87	1.87	2.00
Mothi	26.51	1.0	22.35	5Y 8/3	1.25	1.75	1.50	2.00
IS-1584	23.13	1.0	21.32	5Y 8/3	3.33	2.87	1.83	3.00
M-6058	29.53	2.0	21.46	5Y 7/2	3.40	3.10	2.40	2.25
BG 30	25.21	1.5	21.26	5Y 7/4	2.93	2.81	2.50	3.50
IS-9985	25.31	2.0	19.22	5YR 5/2	3.56	3.06	2.50	4.00
E-35-1	26.74	1.0	22.45	5Y 8/3	2.16	2.33	1.67	2.00
IS-2328	26.19	1.3	22.63	5Y 8/3	2.16	2.66	1.66	3.75
M-35088	29.60	1.5	22.00	2.5Y 8/2	3.50	3.00	1.00	4.50
M-32282	25.87	1.0	21.70	5Y 8/2	1.66	2.25	1.00	3.25
H1-52	24.39	1.0	22.96	2.5Y 7/2	2.50	2.75	2.12	2.75
CE 90-16-3	27.50	1.3	22.00	5Y 8/2	2.65	2.45	1.50	3.00
2 KX 6-2	25.81	1.0	22.35	5Y 8/3	2.93	2.87	1.87	3.25
P-721	25.67	3.0	18.13	2.5Y 7/2	2.67	3.67	3.33	4.00
CSH-6	25.16	1.0	22.37	5Y 8/3	1.50	2.25	2.50	3.00
M-35420	20.93	1.0	23.17	5Y 8/3	2.33	1.66	1.33	2.50
M-36410	28.67	1.0	22.00	5Y 8/2	1.31	1.75	1.00	1.62
M-35082	25.27	1.0	22.21	5Y 8/3	1.60	1.80	1.60	2.00

[a] Color was compared with Munsell's Soil Color Charts.
[b] Kneading quality and flavor were scored on a 1 to 3 scale, in the order of decreasing desirability.
'Taste, texture, and keeping quality were scored on a 1 to 5 scale, in the order of decreasing desirability.

postrainy and summer seasons. These populations will be developed and improved. A number of selections from each population were made and their resistance confirmed during the postrainy season.

Development of three elite populations with multiple resistance—one for low-rainfall and one for high-rainfall situations and a third for high-elevation areas—was started. A number of top crosses were made during the rainy and postrainy seasons and advanced to F_2 in the postrainy and summer seasons. Parents were selected from the best sources of resistance for all three insect pests and from populations with adaptation to these environments. The development of sidecars to five advanced populations (FLR, FLB, Rs/R, Rs/B, and new good-grain) was stopped and useful selections directed into the development of these elite multiple-resistant populations for specific areas.

Pedigree breeding was used in a substantial effort to strengthen source material and to incorporate resistance into elite agronomic types. A large number of entries was identified, screened, and selected for resistance to each insect. Selected segregating breeding materials, which incorporated the best sources of resistance, were screened under heavy insect pressure.

Other entries were screened with natural pressure and selected for useful agronomic characteristics.

During the postrainy season, about 3 300 undamaged plants were identified in the shoot fly-screening nursery. Plants were examined for incidence of egg laying and presence or absence of trichomes. About 40 percent were identified as possible escapes. Based on these results, approximately 20 percent of the plants showed oviposition nonpreference and about 25 percent showed resistance due to antibiosis. About 15 percent of the plants did not fit into any category.

For shoot fly resistance, 3 457 segregating progenies were evaluated in the screening nursery in the rainy and postrainy seasons. A large number (about 3 500) of agronomically good and resistant plant selections, showing both primary and secondary resistance mechanisms, was made. Primary resistance mechanisms refer to antibiosis and oviposition preference and the secondary resistance mechanism refers to recovery—i.e., the main stem is killed, but a crop develops from tillers. Nearly 1 300 crosses were made with the best shoot fly-resistant sources and advanced. Seed of more than 1 100 agronomically superior crosses was harvested for further screening and testing.

Successful screening for stem borer *(Chilo)* resistance during the postrainy season necessitates protection from the shoot fly. For this reason, work on *Chilo* resistance is best done in the rainy season. During rainy season 1977, about 212 segregating progenies were screened against *Chilo;* 159 plants were selected. A limited number of entries was selected as source material for stem borer resistance and nearly a thousand crosses were made.

Selection of useful source material for midge resistance was attempted. AF-28, a line from Brazil, has been found to be the most resistant and stable source[1]. DJ-6514 (India) and S-Girl-MR-1 (USA) were observed to have good levels of resistance. A large number of crosses (1 087) was prepared, advanced, and 930 agronomically superior crosses were harvested.

[1] Personal communication from M.A. Faris, ICRISAT sorghum breeder in Sudan.

STRIGA RESISTANCE

During the 1977-1978 report year, considerable progress was made in understanding resistance mechanisms, identifying resistant varieties, and utilizing them in the program of breeding for resistance to *Striga.*

Screening for Low Stimulant Production

During the year, 4 901 lines were screened (Table 13) and 245 low-stimulant lines identified. Screening work undertaken at ICRISAT and Weed Research Organization (WRO) indicated that in the material tested, there were no low-stimulant lines available for *S. densiflora* (India), *S. hermonthica* (Abu-Naama, Sudan), or *S. asiatica* (South Africa). *S. asiatica* of India and *S. hermonthica* from Samara, Nigeria appear to be similar in terms of their reactions to a particular stimulant.

Screening for Antihaustorial Factors

These factors operate after germination of the

Table 13. Low-stimulant sorghum lines identified in *Striga-germination* trials (Jul 1977 Jan 1978, ICRISAT Center).

Material	Number screened	Low-stimulant lines	
		(no)	(%)
Sorghum germplasm	4 750	243	5.12
Collection from Sangli[a]	81	0	0.00
Disease nursery	30	1	3.33
Parbhani Striga trial[a]	40	1	2.50
Total	4 901	245	

[a] Sangli and Parbhani are villages in the State of Maharashtra, India.

Striga seeds, but before the resulting *Striga* plants become established on roots of the host plant. Resistance factors known to operate during this stage are mechanical and chemical in nature.

Twenty-five cultivars- ranging from completely resistant to susceptible—were screened microscopically by ICR1SAT sorghum physiologists for root characters, specifically thickening of the endodermal cell wall, presence of silica crystals in these cells, and thickening of pericyclic cells. It was noted that all resistant cultivars have these mechanical barriers, but not all cultivars with these characteristics are resistant to *Striga.*

The above technique does not take into consideration the effect of chemicals on resistance. A laboratory technique to determine the Sriga-penetration index was developed; this procedure recognizes the effects of chemical resistance, although it does not identify them. The procedure is as follows:

i) Sorghum seedlings are grown on moist filter paper and the root growth monitored for 15 days (1- to 15-day-old roots);
ii) ready-to-germinate *Striga* seeds are inoculated on root regions of different ages;
in) susceptible host-root exudate or synthetic stimulant is applied to germinated *Striga* seeds; and
iv) after 7 to 10 days, the stage of establishment of the *Striga* seedlings on the roots of the host plant is determined by counting the number of *Striga* seedlings attached to the host roots and the number of successful penetrations. The *Striga*-penetration index is calculated as the ratio between the number of attached and the number of penetrated haustorn on the host xylem vessels.

This technique was used first with two varieties, N-13 (resistant) and CSH-1 (susceptible). N-13 and CSH-1 were roughly equally susceptible up to 6 days of age (Fig 2), but later on N-13 became highly resistant to *Striga* parasitization, whereas CSH-1 continued to show susceptibility, even up to 15 days. It is hypothesized that N-13, in the field, can escape

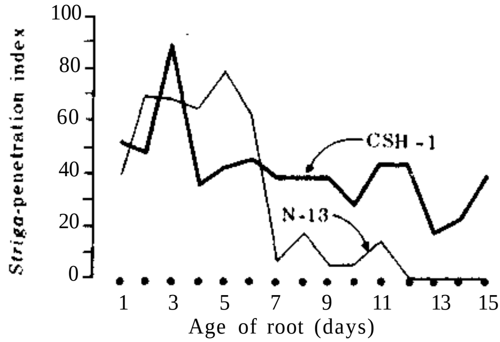


Figure 2. Striga-penetration index of two sorghum varieties, N-13 and CSH-1, as determined by a laboratory teehnique developed at ICRISAT Center, 1977-1978.

because of the short period of root susceptibility, whereas with CSH-! the susceptible period is prolonged, making it more vulnerable to parasitization.

A similar study involved nine resistant and nine susceptible cultivars, but a significant difference in *Striga*-penetration index was not observed in the two groups. Additional studies are under way.

Field Testing

Details of 13 selected promising cultivars, based on 1977 multilocation testing, are presented in Table 14. It is clear that host-parasite specificity for *Striga* parasitization exists and resistance to *S. asiatica* in India did not correlate well with resistance to *S. hermonthica.* There also appears to be race physiologic specificity in *S. hermonthica,* varying with location. In Sudan, *S. hermonthica* appears to be a "superior strain", that is, no cultivars so far tested have been found to be resistant. However, "tolerance" in cv IS-4202 and IS-9985 was striking as their grain yields were greater than the local susceptible check. Cultivar SRN-4841 (IS-8686) was resistant in all locations, except for the one in Sudan.

Inheritance of Low Stimulant Production

The inheritance of low stimulant production

Table 14. Information about sorghum cultivars with promise for resistance to *Striga*.

	Field testing						
	Striga hermonthica		*Striga asiatica*			Stimulant reaction	
Cultivar	Sudan	Cameroun	Ethiopia	Bhavanisagar	Akola	(*S. asiatica*)	Yield[a] (kg/ha)
NIGERIA:							
SRN-4841 (IS-8686)	x x[b]	x[c]	X	X	X	Low	2 160
INDIA:							
16-3-4	X X	X X	X		X	Positive	1 960
IS-2203	X X	x x	X	X	X	Positive	1 910
IS-6942	X X	X X	X	X	X	Positive	1 810
IS-4242	X X	X X	X	X	X	Positive	1 730
N-13	X X	X X	X	X	x	Positive	1 640
IS-4202	X X	X X	XX	X	X	Positive	2 270
SUDAN:							
IS-9985	X X	XX	XX	X	X	Positive	2 200
INDIA.							
SRN-4310A (1S-4025)	X X	X X	XX	X	X	Low	1 960
NJ-91515	X X	X X	XX	X	X	Positive	1 950
IS-5218	X X	X X	XX	X	X	Positive	1 730
SUDAN:							
SRN-6838A	X X	X X	XX	X	X	Positive	1 580
INDIA:							
IS-5603	X X	X X	XX	X	X	Positive	940
Swarna (Check)	X X	X X	XX	XX	X X	Positive	1 830

[a] Yield is an average over Sudan, Cameroun, and Ethiopia. Yield was taken from the center row of three-row planting 3 m in length, 25 cm between rows.
[b] x x = Susceptible (*Striga* count > 10% of susceptible check).
[c] x = Resistant (*Striga* count < 10% of susceptible check).

was studied in F_3 seedling progenies of several crosses, and detailed segregation ratios were obtained in only two (Table 15). The ratios obtained clearly show that the low stimulant production to the ICRISAT Center strain of *S. asiatica* is controlled by a single recessive gene, designated sal.

Genetics of field resistance is being worked out. Preliminary results indicate that it may be controlled by only a few genes.

Table 15. Segregation pattern in F_3 and backcross (BC_1F_2) seedling progenies of two crosses.

Cross	Stimulant positive	Low-stimulant production	Total	Ratio expected	x^2 Based on 3:1 ratio)	Probability
	(no)	(no)	(no)			
CROSS I:						
Swarna x SRN-6496F_3	71	24	95	3:1	0.25	0.50-0.75
Swarna (Swarna x SRN-6496) BC_1F_2	44	3	47	1:0		
SRN-6496 (Swarna x SRN-6496) BC_1F_2	11	6	17	1:1	1.47	0.10-0.25
CROSS II:						
Swarna x Framida-F_3	73	28	101	3:1	0.399	0.50-0.75
Swarna (Swarna x Framida)-BC_1F_2	20	0	20	1:0	-	
Framida (Swarna x Framida)BC_1F_2	3	9	12	1:1	3.00	0.05-0.10

Breeding

In transferring the resistance into elite agronomic background, emphasis is given to both traditional and composite approaches.

Pedigree program. There are three aspects in this program—i) strengthening of resistance *per se* by intercrossing different resistant cultivars (Unit I); ii) transferring resistance into elite agronomic backgrounds (Unit II); and iii) simultaneously incorporating resistance to other traits, such as shoot fly, etc. (Unit III).

During postrainy season 1977, 971 crosses were made in Unit 1,2967 in Unit II, and 423 in Unit III. All were advanced to F_2 and several promising selections were made during the 1978 rainy season.

Composite approach. A composite is being developed involving parents with different resistance mechanisms and those which are resistant to *S. asiatica* and *S. hermonthica.* Several crosses were made onto the genetic male steriles ms_3 and ms_7; and one backcross to the few best resistant cultivars was effected. If resistant agronomically elite lines become available in 1978 testing, it is planned to effect a second backcross to incorporate this material into the composite before beginning random mating.

BREEDING FOR CHARCOAL ROT RESISTANCE

Charcoal rot, caused by *Macrophomina phaseolina* (Tassi), Goid is recognized as a serious disease of dryland sorghums. Losses from this disease are increasing in India and several African countries (Ethiopia, Tanzania, Upper Volta); and is of concern in Mexico and Colombia. It is considered to be the most serious disease of sorghum in Nicaragua. In view of this, a project in cooperation with sorghum pathologists was initiated in 1977.

Developing source material. In postrainy season 1977, a range of sorghum lines were assembled and screened (Table 16) against charcoal rot using the "toothpick" method of inoculation. Based on the absence of soft stalk and no nodal crossing by the pathogen, 51 lines were found to be promising. These lines are being screened for confirmation of resistance.

Breeding. In anticipation of the results from screening, some crosses were made. In summer 1978, the F_1's were advanced to the F_2 stage. These will be selected for agronomic suitability and screened for resistance to charcoal rot.

Once the resistance in the selected lines is confirmed, studies of the inheritance of charcoal rot resistance will be undertaken.

BREEDING FOR DROUGHT RESISTANCE

Problems associated with breeding for "drought resistance" are receiving increased attention, especially for the low rainfall areas (650 mm or less) where stress may occur intermittently in the life of the plant, or plants may grow essentially on residual moisture (as in the postrainy season in India). Generally, the drier areas are also associated with hotter climates. Evaluation under field conditions may be relevant for both moisture and temperature stress. It is expected that seed or seedling tests will supplement field testing. Work on this project, in cooperation with sorghum physiologists, was initiated in rainy season 1977.

Table 16. Materials screened for charcoal rot resistance.

Material	Lines: Tested	Lines: Selected
	(no)	(no)
B-lines	15	0
Elite lines from populations	14	0
Elite lines from mold resistance project	81	6
Shoot fly-resistant lines	10	0
Striga resistant lines	3	0
Tetraploid sorghum	1	0
Midge-resistant lines	4	1
Downy mildew-resistant lines	4	1
Promising lines from drought screening	76	11
Karper's nursery	264	25
Grain grasses	30	5
Suspected charcoal rot-resistant lines	15	2

Screening. Each cycle of screening consists of testing germplasm and breeders' lines under imposed drought conditions at a single location (ICRISAT Center), then at several locations in India, followed by international testing. In the postrainy season 1977, a range of lines drawn from germplasm and other disciplines (Table 17) were tested by sowing on Alfisols late in the season (18 Nov). Irrigation was suspended after three initial irrigations, including that at the time of sowing. The interval between two irrigations was 13 days.

Selection was based primarily on yield/plot. After discard of the less-vigorous, lodged lines, 152 of the lines remained. The "drought resistance" of these selections will be confirmed by further testing. The initial screening test revealed that such traits as emergence rate, seedling vigor, plant height at 50% flowering and/or at stress initiation, waxiness, and rolling of the leaf and number of green leaves at physiological maturity should be further explored. These studies will enable us to develop source material.

Breeding. Breeding activities will be concerned with the crossing of drought-resistant types with agronomically good lines. The segregating generations will be screened under moisture stress. Selection will be used in attempts to bring together the favorable alleles of various traits.

Physiology

POSTRAINY SEASON SORGHUM CROP

The postrainy or *rabi* season is a major cropping

Table 17. Lines evaluated and selected for drought resistance.

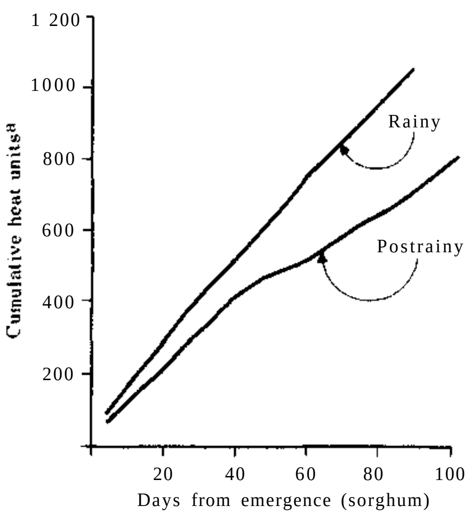
	Lines	
	Tested	Selected
	(no)	(no)
COUNTRY:		
Pakistan	11	1
Botswana	16	1
Afghanistan	4	0
Turkey	1	0
Niger	23	4
Mali	60	8
Chad	60	10
Tanzania	23	3
Upper Volta	120	5
Yemen	21	4
Nigeria	251	38
Ethiopia	168	11
Sudan	317	48
PROMISING LINES[a]:		
Charcoal rot program	17	0
Indian Adaptation	24	4
Grain grass	26	0
Mold project	66	4
Physiology	16	0
Populations	144	8
Karper's nursery	39	3

[a] Cross discipline cooperation.

season for sorghum in many areas of India. Progress in breeding high-yielding cultivars for this season had lagged behind that for the rainy season; it has proven difficult to identify lines with consistently better performance than that of the Maldandi types traditionally grown by Indian farmers. The postrainy season differs from the normal rainy season in two major ways: i) cooler average temperature (due to much lower minimum temperature), especially during the latter part of the season, and ii) a high probability of moisture stress during the grain-filling period, as the crop is grown almost entirely on stored soil moisture.

We have used data gathered in our 1977-1978 cooperative experiments with the soil physics and agroclimatology subprograms to attempt to estimate the importance of these two factors on crop yields during the postrainy season. The comparison involved three crops: a normal rainy season crop, a supplementally irrigated postrainy season crop, and a normal (nonirrigated) postrainy season crop. Temperature effects were estimated from the differences in the rainy and irrigated crops and moisture effects from the comparison of the irrigated and nonirrigated crops.

Temperature differences between the two seasons are summarized (Fig 3) as the rate of heat unit accumulation during crop growth. Heat units (daily summation of the number of degree by which the mean temperature exceeds 15° C) have been shown to be a major controlling factor in the rate of crop growth and development. A comparison of crop-growth



[a]Daily summation of the number of degrees by which the mean temperature exceeds 15°C.

Figure 3. Heat-unit accumulation in the rainy and postrainy seasons at ICRISAT Center, 1977.

rates (Fig 4) and heat-unit accumulation (Fig 3) indicates that crop-growth rates for the postrainy season fell below those of the rainy season crop at approximately 40 days after emergence, when the rate of heat-unit accumulation significantly differed from that of the rainy season. The reduced growth rate in the postrainy season crop was balanced, however, by a corresponding increase in total length of growing season. As a result, the total dry-matter accumulation in the supplementally irrigated postrainy season crop exceeded that of the rainy season crop.

The irrigated postrainy season crop outyielded the rainy season crop, largely as a result of a much higher individual grain weight (Table 18). Part of the difference in grain size may be due to cultivar differences, but in the main it seems to be the result of the much longer grain-filling period required during the postrainy season (40 days vs 31 days in the rainy season), a result of the temperature differences

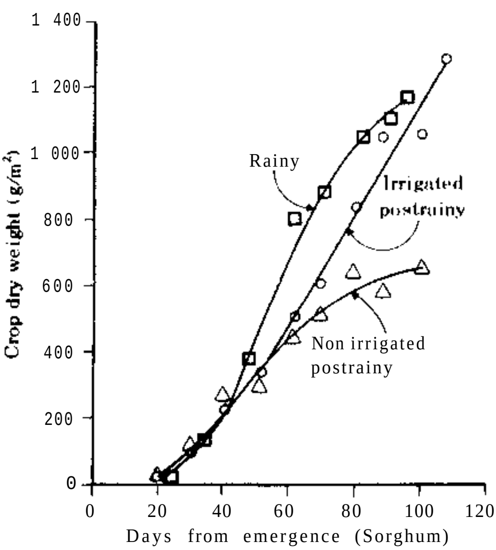


Figure 4. Crop-growth rates of sorghum growing in rainy season and in nonirrigated and supplementally irrigated postrainy season plantings at ICRISAT Center, 1977.

between the two seasons during this period. (Mean temperature during the grain-filling period in the rainy season was 25.3°C, compared to 21.7°C for the postrainy season.) This difference in length of the grain-filling period more than compensated for a smaller grain number (Table 18) in the postrainy season crop.

These results suggest that the cooler temperatures of the postrainy season, while causing reduced crop-growth rates, were not a limitation to crop yield in an adapted cultivar, for this season at least.

The comparison between the irrigated and nonirrigated crops clearly indicates that moisture was a major limitation to crop growth and yield in the latter. Growth rates of the two crops were similar until about 50 days after emergence (Fig 4), when soil moisture became no longer adequate to meet the full evaporative demand on the crop (see Environmental Physics, pp 180). From this point, the growth rate of the nonirrigated crop declined, and final dry-matter production and grain yield were of the order of 45 to 50 percent that of the supplementally irrigated crop (Table 18). For both crops, the rate of dry-matter production was directly related to evapotranspiration (Fig 5), providing clear evidence that available moisture was the major determinant of yield in the normal postrainy season crop.

Although the main moisture deficit occurred after flowering in the nonirrigated crop, the major reason for the yield difference in the irrigated and nonirrigated crops was the difference in grain numbers, determined before flowering (Table 18). The nonirrigated crop was quite efficient at filling the grains it produced. Dry-matter production after flowering in the nonirrigated crop was only of the order of 1 500 kg/ha, suggesting that a significant portion of the grain yield was filled by translocation of carbon assimilated prior to flowering.

These data indicate that breeding of postrainy. season cultivars should be carried out under conditions which emphasize i) ability to maintain maximum growth under receding soil-moisture conditions, which are inadequate to meet full potential evapotranspiration, and ii)

Table 18. Yield and yield-component comparison, rainy and postrainy seasons 1977, at ICRISAT Center.

	Rainy season	Postrainy season	
		Irrigated	Nonirrigated
Cultivar	CSH-6	CSH-8	CSH-8
Grain yield (kg/ha)	4 750	5 490	2 520
Total dry matter (kg/ha)	11 700	12 900	6 600
Grains (1 000/m^2)	21.4	16.4	9.8
100-grain weight (g)	2.01	2.98	2.29
Days to flowering	59	63	63
Grain-filling period (days)	31	40	38

ability to make maximum use of available carbohydrate reserves for grain filling.

ROLE OF TRICHOMES IN SHOOT FLY RESISTANCE

In an earlier survey of the anatomy of leaves of a number of lines with known resistance or susceptibility to the sorghum shoot fly, leaves of many of the resistant lines were found to possess trichomes. Trichomes are microscopic hairs projecting from the surfaces of the leaf.

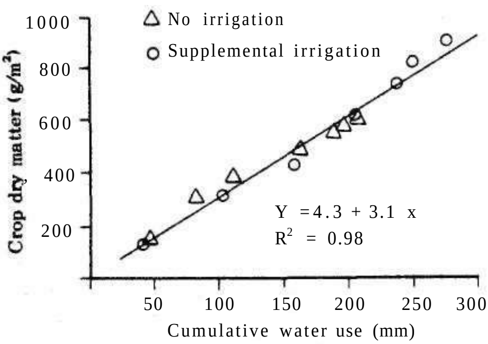


Figure 5. Relationship between cumulative water use and cumulative dry-matter production in sorghum growing on nonirrigated and supplementally irrigated plots at ICRISAT Center, postrainy season 1977.

Figure 6. Stomata, guard cells, and trichomes on 14-day-old sorghum leaf. Trichomes are arranged in alternate rows along the epidermis.

Their length ranges from 30 to 50 microns and they vary in density from 0 to more than 45 per mm^2 of leaf surface (Fig 6). The initial observation indicated that the presence of trichomes seems to discourage oviposition by the shoot fly.

We carried out a preliminary study of the relationship between the presence or absence of trichomes and the degree of susceptibility of the sorghum plant to shoot fly attack; and are working to determine why the presence of trichomes may be conferring a measure of resistance. The first study was carried out in collaboration with cereal entomologists, utilizing 76 lines of diverse origin representing a range of resistance and susceptibility to the shoot fly. Distribution of the percent plants with deadheart (main shoots killed by shoot fly) were significantly different in the trichomed and nontrichomed lines (Fig 7). Average percent deadhearts in the trichomed lines was only 60 percent that of the nontrichomed lines, and of the 12 lines with less than 20 percent deadhearts, 10 were trichomed. The data also indicated that susceptibility varies considerably in both groups, suggesting that factors other than presence of trichomes may be involved.

In an experiment designed to determine how trichomes might be affecting resistance, we followed egg laying and the appearance of deadhearts plant-by-plant on a daily basis in

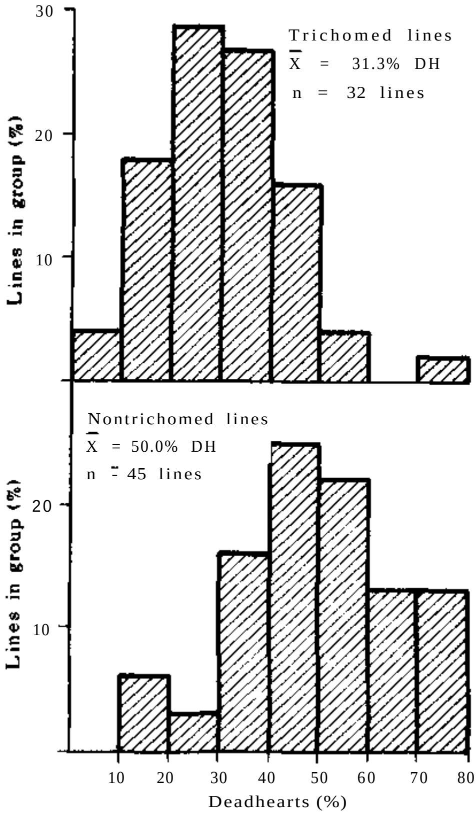


Figure 7. Differences in frequency distribution of percent sorghum plants with deadhearts in trichomed and nontrichomed lines. Mean values for the two classes are significantly different ($p < 0.001$).

4 trichomed and 11 nontrichomed lines. In the nontrichomed lines, the percentage of plants involved was higher and deadhearts appeared sooner than on the trichomed lines (Fig 8). These differences persisted over a 28-day period. In either group, however, egg laying was essentially completed by Day 12 and deadheart counts had reached near maximum by Day 22.

Differences in deadheart percentages (77% on nontrichomed and 27% on trichomed) were related to both the greater percentage of nontrichomed plants with eggs (Fig 8) and the greater number of larvae surviving.

Entomology

Observations on pest incidence and damage levels on standard cultivars of sorghum continued in an unsprayed area of ICRISAT Center. Levels of the important species—shoot fly, stem borer, and midge—were low. The sporadic pest, *Mythimna separata,* caused severe defoliation of sorghum. A detailed list of pests and their parasites recorded on sorghum at ICRISAT Center was computerized and published.

Shoot Fly Biology

Identification of shoot fly species bred from sorghum showed that the dominant species was *Atherigona soccata;* this confirmed previous observations (Table 19). We were able to use the newly discovered character for identifying female *A. soccata* for the first time and the backlog of identification of stored specimens from bred and trap-collected specimens is yielding valuable information.

In all, a total of 10 species of shoot fly have now been bred from sorghum, but from 3 years' data it is clear that more than 98 percent of the flies bred are *Atherigona soccata.* Other species are of negligible importance.

Table 19. Dominant species of *Atherigona* and *Acritochaeta* bred from sorghum, January 1976 to May 1977.

	Males	Females	Total
Atherigona:			
A. soccata	740	1052	1792
A. falcata		6	6
A, eriochloae	4	1	5
A. approximata	1	0	1
Others	1	1	2
Acritochaeta:			
A. orientalis	3	3	6
Total	749	1063	1812

Table 20. Catch of male *Chilo partellus* over 21 nights with various loadings of major pheromone (Z_{11}-16 CHO).

Loading/vial	Moths trapped
(µg)	(no/night)[a]
800	10.2
400	9.8
200	11.5
100	13.7
50	14.1
Virgin female	15.2
Control	0.4

[a]Mean number per trap; three replicates.

Table 21. Effect on catch of male *Chilo partellus* of different ratios of major/minor pheromone at a 7:1 ratio and various loadings for 14 nights, and with minor pheromone removed for a further 7 nights.

Loading/vial	Moths trapped 14 nights	7 nights
(µg)	(no/night)[a]	(no/night)[a]
125 (109.5/15.5)	9.9	12.1
250(219.0/31.0)	7.9	6.5
500 (437.5/62.5)	6.3	2.4[b]
1 000 (876.0/124.0)	5.6	2.7
2 000 (1 752.0/248.0)	5.5	2.4
Virgin female	41.6	28.2
Control	2.1	1.7

[a]Mean number per trap; three replicates.
[b]Minor pheromone retained

square design reduced coefficients of variability considerably.

A series of trap designs were tested, and a simple funnel design may be of use for monitoring stem borer catches on farmers' fields. In routine monitoring at 14 sites at ICRISAT Center, it was clearly demonstrated that catches were greatest near sorghum fields and that it was possible to detect, by the catch of adult moths about 2 weeks after the first significant rainfall (Fig 10), the rain-induced pupation of larvae which had carried over the summer season. Comparison of catches of moths at light, by use of virgin females and pheromone traps, is being done. In general, catches with day-old virgin females were better than those with pheromones—up to 100 per night per trap in the postrainy season were common. In one experiment comparing virgin females with the synthetic pheromone, 202 males were caught in a single trap; the pheromone trap contained only 145 males. Height of trap was important-most moths were caught at 0.75 m above ground level; catches at the 3-m height were negligible.

Screening for Pest Resistances

Further screening for shoot fly resistance was carried out on germplasm lines and on breeders' material. It is now possible to subject material under test to varying levels of attack, using a combination of cultural and fishmeal/interlard methods. Shoot fly oviposition levels as high as 95 percent were obtained in field screening. A list of lines with useful attributes was published and many of these were multiplied for use in breeding programs and for use by scientists attempting to ascertain reasons for the resistances observed.

Table 22. Effect on catch of male *Chilo partellus* of different ratios of major/minor pheromone at 200 µg loading for 21 nights.

Ratio Z_{11}-16:CHO/Z_{11}-16:OH	Moths trapped
	(no/night)[a]
100:0	19.8
56:1	22.2
28:1	19.7
14:1	20.5
7:1	21.4
3.5:1	19.3
0:1	1.7

[a]Mean number per trap; three replicates.

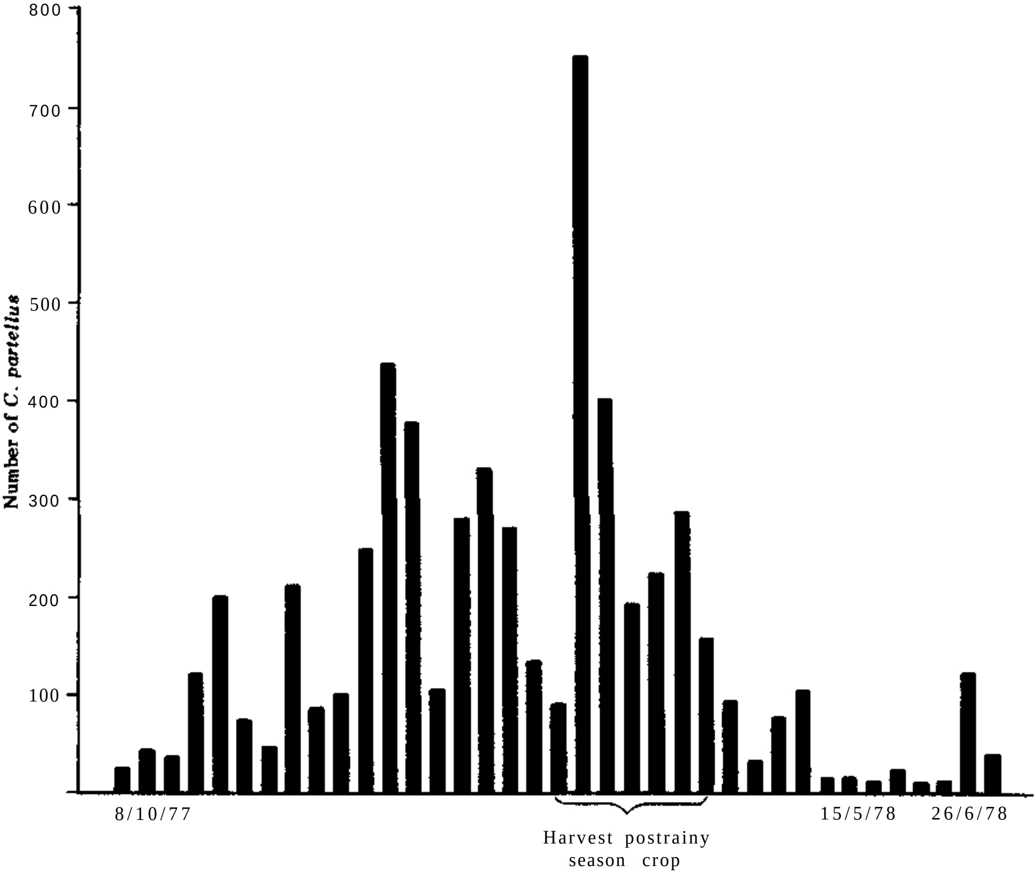


Figure 10. Total weekly catch of Chilo partellus *at 14 pheromone traps at ICRISAT Center (Oct 1977 to Jun 1978).*

As a result of expansion of the facilities for artificially rearing *Chilo,* screening was intensified. The CIMMYT "bazooka" technique for introduction of larvae into whorls was modified. Using finger millet as a carrier, it was found possible to introduce five to seven larvae into each sorghum plant quickly and efficiently. Infestation was carried out 28 days from emergence of the crop. About 1 800 plants per hr can be treated by one worker. A number of useful tines, some of them also possessing some resistance to shoot fly, were identified.

A fortuitous attack of *Calocoris angustatus* enabled readings to be obtained on 9 400 lines of germplasm material sown for other purposes. Just more than 100 lines were selected for further examination; these showed a range of maturities and head characteristics and are to be tested further in the 1978 season.

Pest Nurseries

Four nurseries—for shoot fly, stem borer, midge, and mixed species—were distributed to cooperators in nine countries. Preliminary results show that several of the lines selected have broad-based resistance and will be of use to breeders overseas.

Pathology

Major emphasis continued to be directed at the identification and utilization of stable resistances to grain molds (*Fusarium* spp., *Curvularia* spp., and *Phoma* sp.), sorghum downy mildew (SDM) (*Peronosclerospora sorghi*), several leaf diseases (anthracnose—*Colletotrichum graminicola,* leaf blight—*Helminthosporium turcicum,* sooty stripe—*Ramulispora sorghi*), and charcoal rot (*Macrophomina phaseoiina*). For some of these diseases, rapid progress has been made in the identification and utilization of effective resistance-screening techniques, and effective cooperative international resistance-screening networks have been developed to test the stability of identified resistances. For other diseases, progress has been less rapid and screening techniques are still under review.

GRAIN MOLDS-RESISTANCE SCREENING

At ICRISAT Center

Field screening. About 5 ha was used to screen several thousand entries which included new germplasm, lines selected during the previous year, and breeding progenies from the crosses between the grain mold low-susceptible lines and elite good-grain lines. Severe grain mold was promoted by early planting and by the use of sprinkler irrigation during the grain-filling period. In the breeding progenies, no single line was uniformly resistant to molds, but 564 single heads with little or no mold were selected. These were multiplied in postrainy season 1977 for retesting by laboratory screening in summer season 1978, and in field screening during rainy season 1978.

Laboratory screening. Field screening permits only one screening in a year, and its success depends on the weather during the critical flowering period. In an attempt to make screening independent of season and local weather conditions, we experimented with laboratory screening procedures.

The technique finally adopted was to incubate sorghum grain in petri plate moist chambers at 25°C for 4 to 7 days, with alternating 12-hr light and dark periods. The blotters in the petri plates were moistened with 0.4% 2,4-D solution to inhibit seedling development. Grain used, from the postrainy season harvest, appeared clean and mold free. After incubation, many samples appeared severely molded while others had little mold growth. It thus appears that seed infection of susceptible lines occurs even in the dry-season crop, although the molds are expressed only when humidities are high.

Selections from rainy season 1977 were increased in postrainy season 1977 and were screened in the laboratory during summer season 1978. Not one of the 659 entries given 4 days' incubation was free from grain mold, but 77 entrier were rated as $\leqslant 2$ by visual scoring. After 3 more days' incubation—i.e., 7 days' total incubation—14 lines were rated as $\leqslant 2$. Results of the laboratory screening will be compared with field reactions of the same lines during rainy season 1978. If the correlations between laboratory and field reactions are meaningful, we will have a most useful method for speeding up selection for grain mold resistance.

Multilocational Testing

The first International Sorghum Grain Mold Nursery (ISGMN) was tested cooperatively in 1976, and although no line was found highly resistant to grain molds at all locations, certain entries appeared to be generally less susceptible than others. Interest was expressed in continuing this cooperative international screening process, and in 1977 two groups of entries were tested under the ISGMN program. For those locations where main-season planting occurs during January through March, an Early Season ISGMN (ES-ISGMN), consisting of 22 entries was provided. For the majority of the cooperative locations in India and West Africa, planting takes place during the June-July period and these locations were provided with a 30-entry Main Season ISGMN (MS-ISGMN) which included 15 entries in common with the ES-ISGMN. Complete data from all locations have been published in the Report of the 1977 International Sorghum Grain Mold Nursery (ICRISAT, 1978). Mean rankings of the entries in the ES-ISGMN and MS-ISGMN for each of three mold-assessment parameters are presented in Tables 23 and 24, together with the mean number of days to flowering.

In the ES-ISGMN, 6 entries appeared among the best 10 for all infection parameters, and the best lines were relatively early flowering.

In the MS-ISGMN, field grain mold-rating averages varied from 1.6 to 4.4, and eight entries had ratings of 3 or less at all locations (Large glume-7, IS 2261, IS 9225, IS 3443, IS 2328, IS 2327, E-35-1, and IS 2583). Nine entries had a mean field grain mold rating of 2 or less, but eight of these entries took more than 70 days to flower, whereas of the nine most affected entries (average more than 3) eight flowered in 66 days or less (the correlation coefficient of mean days to flowering and mean field rating is - 0.772). Thus there is probably an element of escape in

Table 23. Rank values of 22 entries in the 1977 ES-ISGMN for three grain-mold parameters[a] and days to flowering (DTF) based on averages over several locations.

Entry	Field Rating	Lab Rating[b]	Lab Ranking	DTF
IS 9225	3	2	1	91
IS 2328	2	1	4	86
IS 2327	1	5	3	87
IS 9504	4	6	2	86
IS 5246	8	3	5	103
IS 1545	9	4	9	99
E 35-1	6	11	13	90
IS 9331	5	19	7	96
IS 3443	7	13	15	86
CS 3541	18	8	8	90
IS 1087	14	10	11	87
IS 9533	10	16	10	91
IS 9521	12	17	6	100
IS 2435	11	15	12	93
IS 2261	15	9	14	84
IS 9327	13	12	18	95
IS 9544	17	7	19	94
IS 2583	20	14	17	88
IS 9468	16	18	20	99
IS 179	19	20	16	89
BY x IS 511[c]	21	21	22	78
PP2B x 11167[c]	22	22	21	91

[a]Field-rating ranks based on data from five locations. Lab-rating and lab-ranking ranks based on data from three locations.

[b]Based on estimation of % molded surface of individual grains.

[c]Susceptible checks.

Table 24. Rank values of 30 entries in the 1977 MS-ISGMN for three grain-mold parameters and days to flowering (DTF) based on averages over 12 locations.

Entry	Field Rating	Lab Rating[b]	Lab Ranking[a] (visual)	DTF
IS 2327	6	1	1	77
IS 2261	2	5	3	72
IS 2328	5	2	4	76
Large Glume-7	1	6	5	76
IS 14332	8	4	*2*	68
E-35-1	7	3	6	80
IS 9225	3	8	11	75
IS 2435	10	7	8	80
IS 3443	4	11	12	79
IS 2583	9	13	9	72
CS 3541	17	9	10	73
CSH-6	20	10	7	65
IS 5246	13	14	13	79
IS 15788	12	18	14	74
IS 1087	19	12	15	70
IS 1545	18	17	16	74
Large Glume-3	15	16	21	67
LG Selections-1	14	19	19	65
27006-10	11	21	22	64
IS 9521	21	15	20	65
G 69-1-3	23	20	18	58
CSH-5	24	22	16	73
IS 179	25	24	23	66
27006-43	16	23	24	60
IS 2404	22	25	25	62
NP x EL-18-2	28	26	26	62
G 81-111	27	27	27	60
A 4186	26	28	28	65
BY x IS 511[c]	29	29	30	63
PP2B x IS 11167[c]	30	30	29	60

[a]Based on eight locations only. Visual inspection of general moldiness.
[b]Based on estimation of % molded surface of individual grains.
[c]Susceptible checks.

the lower mold values of the later-flowering entries. Entry IS 14332, however, combined early flowering (68 days) with good performance (overall fifth) and thus is probably the most valuable entry in the trial. (Differences in flowering tune of the same entries in the ES-ISGMN and MS-ISGMN are probably due to the high altitudes and low night temperatures found at several of the ES-ISGMN locations.) Seven entries (IS 2327, IS 2328, IS 2261, IS 14332, E-35-1, Large glume-7, and IS 2435) appear in the best ten for all three parameters.

In 1977, as in 1976, no entry was highly resistant to grain molds at all locations, but several appeared to consistently develop less mold than the others. Of the seven entries in the best ten for all the three infection parameters, four (IS 2327, IS 2328, E-35-1, and IS 2261) were also regarded as the best 1976 entries under severe mold conditions in West Africa. IS 9225 is another entry which performed well in both years. Thus, across locations, these entries have been consistently less molded for two consecutive seasons. Progeny from crosses among these lines, and between them and agronomically elite lines, will be available for testing in 1978.

SORGHUM DOWNY MILDEW

Inoculation Technique Studies

Conidial production. The first requirement of a resistance-identification program is a reliable and meaningful screening technique. For SDM, reliance on oospores in a "sick plot" has many drawbacks and several methods of inoculations with conidia have been examined. Large quantities of conidia were needed at a more appropriate time than that during which they naturally mature (0200 to 0400 hr). It was found that leaves that have received 6 to 8 hr daylight (they need more time in overcast cloudy weather than in sunny weather), and which are then maintained at 20°C in dark moist chambers, produce abundant conidia which mature in 7.5 to 8 hr after start of incubation. It is convenient to harvest infected leaves between noon and 1300 hr and to inoculate between 2000 and 2100 hr. Conidia can, however, be produced whenever they are needed by manipulation of light and temperature in incubators; for example, leaves collected at 1700 hr are placed in the moist chambers at 20°C in an incubator programmed to remain at 20°C for 7.5 hr and then to cool to 5°C, which enables harvest of conidia at any time they are required on the subsequent morning. Leaves can also be harvested at 1700 hr, maintained under flourescent lighting overnight, moist-chambered at 20°C at 0900 hr the next morning, and the conidia can be harvested for inoculation after 1700 hr.

Inoculation method and age of plants. Several ways of exposing sorghum seedlings of various ages to conidia of *P. sorghi*—including injection deep into the whorl, direct spray, exposure to older conidia-producing infected plants, and injection of conidia into the collar region—were examined.

Germinating DMS 652 seedlings (20 and 36 hr after placement of seed in moist chambers at 30°C) were sprayed with conidial suspension and planted in pots after 3,6, and 9 hr of postinoculation incubation. The percent systemic infection was reduced with increased pre- and post-inoculation incubation (Table 25).

In a staggered-planting pot experiment with cv DMS 652, sorghum plants of six ages were inoculated by injection of a conidial suspension into the whorls. The greatest infection developed in the plants youngest at inoculation (Table 26), but the level of infection (37%) was not as high as expected. These data add to the existing evidence that the younger the plant when exposed to conidia, the greater the probability of systemic infection.

Inoculation of ISDMN entries. In late 1977, the 25 entries in the 1977 International Sorghum

Table 25. Systemically SDM-infected DMS-652 sorghum plants 28 days following planting.

	Infected plants[a]		
	Postinoculation time		
Preinoculation time	3 hr	6 hr	9 hr
	(%)		
20 hr	65	49	32
36 hr	35	33	24

[a]Germinating seeds, after incubation at 30°C for 20 or 36 hr, were sprayed with *Peronosclerospora sorghi* conidia and then continued in incubation for 3, 6, or 9 hr prior to planting.

Table 26. Systemic infection by SDM 28 days following inoculation with conidial suspensions.[a]

Age of plant at inoculation	Systemic infection 28 days after inoculation
(days)[a]	(%)
5	37
10	24
15	13
20	10
25	11
30	11

[a]Plantings were made sequentially so that plants of all ages were inoculated on the same date.

Downy Mildew Nursery were inoculated by injection of conidial suspensions deep into the whorls of seedlings 5 days after emergence. Very high levels of infection were obtained on several cultivars which consistently are much more resistant when exposed to natural inoculum pressure at Indian SDM hot-spot sites, such as Dharwar and Mysore. Cultivars varied greatly in the degree of difference between SDM-infection levels from the artificial and natural inoculations, indicating the possibility of different types of resistance. These results highlight the importance of determining effective inoculum concentrations and inoculation methods in order to avoid failure to recognize useful field resistance.

The International Sorghum Downy Mildew Nursery (ISDMN)

The 25-entry 1977 ISDMN was sent to cooperators at five locations in India and to cooperators in Botswana, Malawi, and Niger. Results were received from the Indian locations and from Botswana. Entry QL-3 remained free from systemic and local lesion symptoms at all locations for the second successive year. An additional six entries (SC-120-14, CSV-4, IS 5273, CSV-5, Uch V-1, and IS 173) had less than 10 percent SDM in all replications at all locations, except at ICRISAT Center where injection of conidia deep into the whorls of young seedlings produced higher infection on several entries than did exposure to inoculum at known hot-spot sites (Table 27). The 1978 ISDMN will be expanded to include test locations in the Americas.

LEAF DISEASES

International Sorghum Leaf Disease Nursery (1SLDN)

The International Sorghum Leaf Disease Nursery (ISLDN), a cooperative international program for the identification of stable resistance to several important sorghum leaf diseases, was initiated in 1976. The initial nursery included participation of cooperators at nine locations in three countries in Asia and Africa; in 1977, several more cooperators participated and results were reported from 13 locations in seven countries. The locations were diverse in distance, elevation, latitude, and disease pressure. The high-elevation locations in Ethiopia and Kenya appear to require a different set of entries than do locations in India and West Africa.

In India and West Africa, sooty stripe, anthracnose, blight, and zonate leaf spot were the most common diseases and hot-spot locations were identified. Apparent differential reactions for blight and anthracnose need further examination.

Entry IS 7254 performed well at most locations, and was also the best entry in the 1976 ISLDN. However, it was somewhat later in flowering than most of the entries (Table 28). On the other hand, cv IS 10240 and IS 10262 were relatively early flowering and they were close to IS 7254 in overall superior performance.

CHARCOAL ROT-RESISTANCE SCREENING

During the 1977 postrainy season, 508 sorghum lines selected on the basis of their eliteness for various characteristics were field screened for reaction to charcoal rot at ICRISAT Center. Between 20 and 34 plants of each entry, in a

Table 27. Downy mildew infection indices of 25 sorghum entries at six locations in the 1977 International Sorghum Downy Mildew Nursery.

Entry	ICRISAT Center		Dharwar		Mysore		Digraj	Coimbatore		Botswana	
	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 1	Rep 2	Rep 1	Rep 2
	(%)										
QL-3	0	0	0	0	0	0	0	0	0	0	0
Uch V-1	0	7.8	0	3.4	2.6	3.3	1.9	2.2	1.6	0	0
SC-120-14	30.6	43.8	0	9.8	4.4	4.2	0	0	0	0	0
CSV-4	10.5	2.6	4.0	4.3	4.1	5.1	0	1.5	3.1	0	0
IS 2042	12.5	19.7	0	4.5	10.1	5.1	0	4.2	1.8	25[a]	0
IS 5273	13.0	6.6	8.6	4.4	6.8	6.1	0	1.3	0	0	0
IS 173	19.4	17.2	0	4.2	7.0	9.6	0	1.7	6.0	0	6.9
Uch V-2	35.5	23.7	10.8	2.1	6.9	3.9	0	4.3	1.4	0	0
CSV-5	23.7	29.8	7.0	8.6	3.6	2.5	2.3	3.7	3.9	0	0
IS 3799	26.2	52.6	11.1	7.9	9.2	6.7	0	1.7	1.4	0	0
SC-110-14	72.4	40.4	10.0	12.3	4.7	8.9	4.6	6.5	4.2	0	0
SC-414-12	68.8	59.5	16.1	18.0	8.1	2.6	2.8	8.0	1.4	0	0
SC-239-14	25.0	43.1	18.0	20.6	6.5	2.5	6.6	1.9	1.9	0	0
SC-170-6-17	70.3	73.5	17.9	15.8	2.9	5.3	3.4	5.0	8.0	0	0
SC-120-6-88	72.6	37.5	6.8	27.0	2.2	1.8	7.1	10.7	5.8	0	0
IS 3164	44.3	51.3	6.1	11.2	10.8	9.5	9.9	4.0	12.5	4	51.5[a]
SC-108-14	47.4	35.5	2.9	12.5	2.5	15.3	20.8	8.0	4.3	0	0
TAM 2566	53.6	44.1	15.6	6.1	25.8	7.8	0	5.5	10.6	0	0
SC-173-12	81.7	63.8	35.5	22.7	11.0	6.5	3.2	0	2.7	0	0
TAM 428	43.8	42.2	22.9	25.0	31.3	9.4	9.2	5.9	3.3	0	0
SC-175-14	28.3	81.7	22.2	27.8	39.7	15.8	3.6	8.9	7.8	0	0
IS 2918	58.3	36.1	34.5	25.5	28.9	15.2	6.5	10.8	8.1	34.6[a]	0
NSA 440-12	76.7	67.3	34.0	63.3	68.1	31.1	26.2	6.1	13.5	29.7	26.0
CSV-2	82.9	69.4	62.0	80.6	91.1	93.8	20.8	13.3	13.9	85	100
DMS 652	78.4	96.3	90.7	82.1	89.9	91.7	40.6	26.7	36.6	71.9	83.8
Location Mean	42.4		18.7		16.8		6.8	5.9			

[a] The major discrepancies between replicates of these three entries indicate a possible error in recording or in the original seed packeting. Cultivar IS 2042 is included in the 1978 ISDMN, so its reaction at Gaborone can be re-examined.

Table 28. Flowering data and maximum reactions of 28 entries to seven leaf diseases[a] at various locations in the 1977 ISLDN.

Entry	MDTF[b]	Rough	Rust	Zonate	Sooty	Blight	Anth.	Grey
IS 7254	84	1	1	2	3	2	4	3
IS 10240	64	1	1	2	2	3	5	5
IS 10262	58	1	1	3	2	2	5	5
IS 4150	72	2	1	1	2	3	4	5
IS 2223	69	1	1	2	4	2	5	4
BY x Entol.	69	1	2	2	4	4	2	5
CS 3541	65	1	2	1	3	3	4	4
IS 10264	60	1	1	2	3	3	4	5
IS 3390	57	4	1	3	2	5	2	5
BY x GPR 165-2	61	1	1	2	3	4	5	5
TAM 428	64	1	1	2	3	4	4	5
IS 2550	66	1	1	2	4	3	4	5
SC 110-14	61	1	2	3	3	2	4	5
IS 7322	85	2	2	3	2	4	3	5
R 55 DX	55	1	1	3	3	4	4	5
Sel. 512	70	1	2	3	3	4	5	5
IS 4277	55	1	3	3	3	2	5	5
IS 8171	71	1	-[c]	2	4	3	4	5
BY x Pickett	61	1	2	3	3	3	3	5
BY x GPR 165-1	61	1	2	3	3	3	4	5
IS 643	55	1	4	2	4	3	5	5
IS 73	55	1	3	5	2	5	4	5
CSV-2	63	1	1	3	4	3	4	5
BY x GPR 165-3	61	1	4	4	3	3	4	5
555	74	3	4	1	5	3	3	5
IS 856	56	1	5	4	3	5	4	5
IS 6848	58	1	5	4	4	3	5	5
H-112	58	1	4	3	5	5	5	5

[a] Rough leaf spot, rust, zonate leaf spot, sooty stripe, anthracnose and grey leaf spot.
[b] Mean number of days to 50% flowering.
[c] No data available.

single row without replication, were inoculated 2 weeks after flowering with toothpicks carrying the charcoal rot pathogen. Irrigation was not provided after the majority of the lines had reached the boot-leaf stage.

Three infection parameters were measured: i) the condition of the stalk around the inoculation point (if destroyed, will give a soft-stalk feeling when stem is squeezed between thumb and forefinger); ii) number of nodes crossed with visible symptoms of the disease; and iii) length of stem over which symptoms are visible. Lines without soft stalks, without nodes crossed, and with a mean symptom spread of no more than 5 cm were classed as apparently resistant. Table 29 shows the number of apparently resistant lines among the various groups of materials screened.

Table 29. Classification of lines screened for charcoal rot resistance using toothpick inoculations in postrainy season 1977.

Identity of the material	Lines screened	Lines selected[a]
	(no)	(no)
B-lines	15	-
Lines from populations	16	-
Lines from mold-resistance breeding project	74	4
Shoot fly-resistant lines	12	-
Striga-resistant lines	6	-
Tetraploid sorghum lines	2	-
Midge-resistant lines	4	1
Downy mildew-resistant lines	4	1
Lines from AICSIP trials	20	-
Promising lines from drought screening and germplasm	61	3
{Carper's Nursery (Texas, USA)	264	19
Grain-grass sorghum breeding material	30	-
Total	508	28

[a]Based on absence of soft stalks, absence of infection crossing the nodes, and no more than 5 cm of stem showing any discoloration.

In this first large-scale field screening for charcoal rot resistance at ICRISAT Center, techniques for charcoal rot promotion were satisfactory. Because of the influence of soil moisture and temperature on sorghum susceptibility to charcoal rot, it will be important to replicate entries in advanced screening of selected entries.

Although there is a reasonable correlation between the three infection parameters (Table 30), it seems useful to continue to take all three and to assess susceptibility on the combination of the three when dealing with elite material. For large-scale screening of source material and breeding progenies, where numbers preclude such detailed scoring, the use of the soft-stalk parameter alone will enable a rapid primary screen.

Table 30. Correlation coefficients between three charcoal rot-reaction parameters.

Soft stalk value	1		
Nodes crossed/ plant (no)[a]	0.76	1	
Length of spread (cm)[a]	0.80	0.70	1

[a]Mean values.

As with several sorghum diseases, care must be taken to fully appreciate the confounding nature of different flowering dates. In charcoal rot screening, lines of similar maturity should be grouped to facilitate initiation of moisture stress at the correct physiological stage (boot-leaf).

In order to widely test the stability of resistant materials and to distribute resistant lines to interested breeders and pathologists, an International Sorghum Charcoal Rot Nursery (ISCRN) program will be initiated in 1978 with 30 entries tested at a few locations in India and Africa.

Microbiology

Twenty-eight of 334 field-grown sorghum lines tested had high nitrogenase activity associated with their roots (equivalent to more than 100 ug N fixed/15-cm diameter core per day). The active lines came from India (12 of 104 tested), West Africa (6 of 36), East and Central Africa (5 of 63), South Africa (6 of 29), USA (2 of 39), Thailand (1 of 2) and Japan (1 of 3). However, 167 lines stimulated nitrogenase activity >25ug N/core per day which was more than twice the mean activity of soil cores without plant roots (range 0-10ug N/core per day). Some 15 lines have been consistently active in three or more seasons. However, they are not consistently active on each assay occasion during the season.

Nitrogen fixation associated with sorghum was correlated with soil moisture, with increased activity in wet soil. Little activity is detected until plants are about 30 days old, with most consistent activity detected from the panicle emergence stage to the milky grain stage.

Activities vary a great deal over seasons and from field to field. The large differences obtained in three Alfisol fields in postrainy season 1977 are plotted in Figure 11. Field P6 and the nursery were within 100 m of each other, but the nursery had received fertilizer at the'rate of 60 kg N/ha

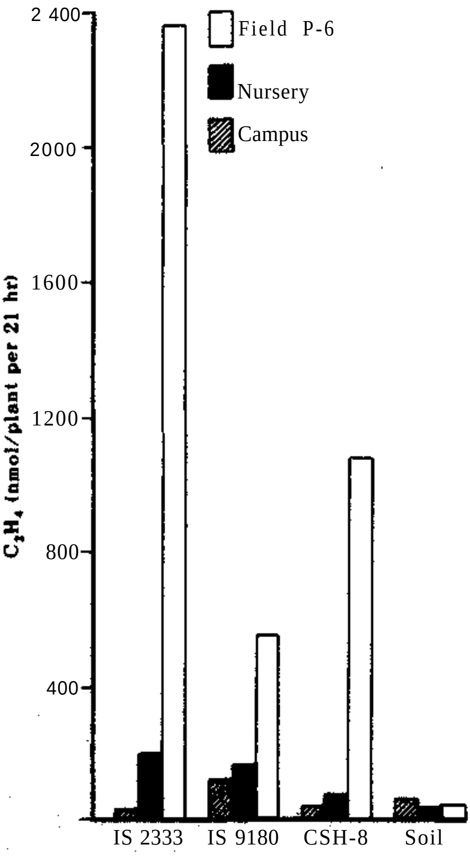


Figure 11. Nitrogenase activity in three sorghum lines and noncropped soil at three locations, ICRISAT Center, post-rainy season 1977.

at sowing, as against only 20 kg N/ha applied to the other fields. Least activity was found for plants grown in fields such as ST2 North, in which neither sorghum nor millet had recently grown, suggesting that the presence of the cereal may build up the soil population of N_2-fixing bacteria over time. If this is so, for sorghum grown in new fields inoculation with N_2-fixing bacteria may enhance subsequent N_2-fixation associated with the crop. Within one field, we have not observed significant effects of N fertilizer on activity, but this may have been because activity of plants even in unamended plots was low. However, for the active line IS-2333 grown in an Alfisol or a vermiculite/ sand mixture in pots, addition of fertilizer at the rate of 100 kg N/ha inhibited activity as compared to the 0 or 20 kg N/ha treatments.

During the rainy season, blue-green algae are. sometimes present as a crust on the soil surface. Nitrogenase activity of these algal mats ranged from 24 to 119 mg N fixed/m^2 per day, compared with only 0.5-1.6 mg N/m^2 per day for surface soil without visible algal growth. Activity is only present when the soil surface is moist, and the cover is not present over the entire soil surface. It may reach up to 29 percent of the surface area. Activity also declines rapidly as the soil surface dries out. However, N_2-fixation of this order could contribute significantly to the soil N balance.

Bacteria with nitrogenase activity were isolated from roots of sorghum which had been surface sterilized for 15 min in 1% chloramine T, suggesting that nitrogen-fixing bacteria are within the root tissues. Of the 100 isolates with nitrogenase activity obtained from different roots, 22 were highly active N_2-fixers in culture media containing either sucrose or malate as the carbon source. At least six different types of organisms are present; *Azospirillum-likc* isolates were obtained only from the roots of the hybrid CSH-5 and *Sorghum halepense,* but were not apparently a major component of the N_2-fixing populations within the root tissues.

Large increases in dry-matter production and N uptake have been obtained for CSH-5 plants grown in vermiculite in pots, following inoculation with a crude enrichment culture obtained from the roots of Napier bajra *(Pennisetum americanum* x *P. purpureum).* In 49 days, about the same amount of dry matter was produced by these inoculated plants and noninoculated plants receiving the equivalent of 120 kg N/ha; this was nearly three-fold the dry matter produced by noninoculated plants receiving no N fertilizer.

Looking Ahead in Sorghum Improvement

Immediate future plans in breeding include i) studying of the yield potentialities of selected germplasm lines; ii) attempting to further understand the effects of moisture and temperature on plant performance; and iii) selection from segregating populations of types adapted to the postrainy season.

Germplasm. Emphasis will be given to the collection of germplasm from countries not adequately represented in the World Collection.

We hope to maintain 500 g pure-seed samples of all accession collections, spontaneous collections, conversion collections, and 2-kg samples of named cultiyar and genetic-stock collections.

In collaboration with other disciplines, we want to expand screening for insect, disease, *Striga,* and drought resistances.

Physiology. A series of joint investigations with the breeding and entomology subprograms on trichomes are under way; these include the inheritance of trichomes, the utility of direct selections for the presence of trichomes, the effects of trichome density versus the simple presence or absence of trichomes, and the relationship between trichomes, shoot fly resistance, and glossy light green leaf color in the seedling.

Further investigations of crop growth in the postrainy season are in progress, focusing on the magnitude of genotype and environment interactions and the water relations of postrainy crops. *Genotype* and *environment* interactions are the focus of a major rainy season study; *environment* in this work represents the level of a range of management factors provided to the crop.

Microbiology. We plan to characterize the nitrogen-fixing bacteria associated with sorghum and determine, for sorghum growing in pot culture and in the field, responses to inoculation with these.

A long-term nitrogen-balance experiment with eight sorghum genotypes has been started, to provide an estimate of N_2-fixation in the field. We will attempt to measure N_2-fixation in the field *in situ* by enclosing the plant tops and part of the root system in gas-tight chambers, to follow the effect of photosynthesis on nitrogenase activity measured by acetylene reduction, as well as by $^{15}N_2$ uptake.

PEARL MILLET

Pearl Millet

Germplasm

COLLECTION AND CLASSIFICATION

To the already existing 5 048 accessions of pearl millet, 914 accessions were added this year. ICRISAT conducted expeditions in India and collected 366 and 200 landrace accessions, respectively, from Rajasthan and Tamil Nadu. Collection made by FAO-ORSTOM in Africa and processed through quarantine include 220 accessions from Niger and 108 from Nigeria (Table 31). Three species of *Pennisetum,* yet to be identified, were received.

After preliminary evaluation, it was possible to group the collection from Rajasthan into eight distinct types and the collection from Tamil Nadu into seven distinct types.

MAINTENANCE AND EVALUATION

To multiply seed during the first grow-out at ICRISAT, the "cluster-bagging" method was found to be very convenient. Using this method, 1 629 accessions were multiplied during the postrainy season. For the evaluation of pearl millet germplasm, a standard list of descriptors and descriptor states was proposed in terms of which 1 829 new accessions were evaluated for various agro-morphological characters during the rainy season. From the new collection, 223 accessions were selected on the basis of geographic origin and particular ecotype and added to the existing working collection. In addition, 511 accessions were screened against downy mildew, ergot, and smut. Selfed seed of 460 accessions were sent to various institutions in India and abroad (Table 32).

Table 31. Pearl millet germplasm accessions, June 1977 May 1978

Source	Entries
Rajasthan, India	366
Tamil Nadu, India	200
Australia	1
Niger	220
Nigeria	108
Senegal	4
USA	7
USSR	8

Breeding

Recurrent selection in composite populations and the variety-cross approach receive equal emphasis in ICRISAT's pearl millet breeding program. Several types of material, including hybrids, synthetics, experimental varieties, and inbreds, as well as an array of breeding lines, were generated and distributed to cooperating breeders in various countries during the past year. These materials were tested multilocationally and in disease nurseries to ensure the stability of performance and resistance to major diseases, particularly downy mildew.

SOURCE MATERIAL

Continuous progress in a crop-improvement program lies in effectively utilizing the genetic diversity of the species. In the source-material project, selected germplasm accessions, as well as source populations created by breeders outside ICRISAT, are maintained and utilized.

The working collection, consisting of 340 lines from diverse geographical regions, has been examined extensively for various characteristics. An enormous variability exists in this collection, and data gathered has been processed, in the form of a catalog, by the Genetic Resources Communication, Information, and Documentation System, University of Colorado, USA. These accessions have been crossed to adapted lines, and progenies selected for use in the hybrid as well as the variety-cross program.

Landrace varieties and "shibras" (*Pennisetumamericanum* Spp. *Stenostachyum*—natural

Table 32. Millet germplasm lines supplied to research agencies in India and other nations, 1977-1978.

Institution	Location	Entries
INDIA:		
Andhra University	Waltair, A.P.	13
Nagarjuna University	Nagarjuna Sagar, A.P.	4
All-India Coordinated Millet Improvement Project	Aurangabad, Maharashtra	7
All-India Coordinated Millet Improvement Project	Pune, Maharashtra	230
Mahatma Phule Krishi Vidyapeeth	Rahuri, Maharashtra	15
Agricultural Research Station	Ratnapur, Orissa	19
Punjab Agricultural University	Ludhiana, Punjab	30
Agricultural Research Station of Durgapura	Jaipur, Rajasthan	58
Tamil Nadu Agricultural University	Kaveripatnam, Tamil Nadu	2
Tamil Nadu Agricultural University	Madurai, Tamil Nadu	2
Indian Grassland and Fodder Research Institute	Jhansi, U.P.	2
Chandra Shekhar Azad University of Agriculture & Technology	Kanpur, U.P.	30
G.B. Pant University of Agriculture & Technology	Pantnagar, U.P.	5
OTHER NATIONS:		
Port Dauphin, S.A.	Port au Prince, Haiti	3
Kenya Agriculture and Forestry Research Organisation	Nairobi, Kenya	20
Weed Research Organisation	Oxford, UK	4

hybrids of cultivated and wild species) collected in West Africa in 1975 were released from quarantine in 1977. Shibras are cross-fertile with cultivated varieties, and will be examined for earliness and resistance to diseases and drought.

Ex-Bornu, one of the nine source populations maintained in this project, is a population from Nigeria which has shown wide adaptation, good yields, and disease resistance in many trials. Of the 447 S_3 progenies planted over three locations in rainy season 1976, 17 were chosen for assembling synthetics. The F_1's between these lines (136 crosses in all combinations) were evaluated for yield, downy mildew resistance, and other desirable characters in rainy season 1977. Sixty-seven entries had head yields above the mean of the experiment (4052 kg/ha); of these, 33 were significantly superior to hybrid checks ICH 105 and BK 560 (up to 6 280 kg/ha, 6 to 43% above the checks). With these, we are attempting to develop three synthetics and a breeding population.

The four 1RAT West African populations (3/4 Souna, 3/4 Ex-Bornu, 3/4 Heine Kheiri, and Saria synthetic) represent further sources of variability in a dwarf d_2 background. Using individual plants from S_2 progenies, 1 042 crosses were made to male-sterile lines of the A_1 system to assess the frequency of maintainer/restoration alleles in these populations. Evaluation of the resulting test crosses indicated 39 percent were fertile, 16 percent being sterile, and the remaining crosses were partially fertile.

A large number of F_2 populations generated from crosses between source material and Indian inbreds were grown at Hissar in northern

India and at ICRISAT Center in 1977. From these populations, 2 823 individual plants were chosen for evaluation as F_3 progenies in rainy season 1978.

Progenies derived from source populations proved to be valuable sources of disease resistance (Table 33). Screening at Hissar identified two progenies of Ex-Bornu free from smut, even under bagging. Progenies from other source populations were found to have low incidence of downy mildew and ergot.

Fifteen downy mildew-resistant lines from the 1976 International Pearl Millet Downy Mildew Nursery (IPMDMN) and the 1977 Pre-IPMDMN were intercrossed in all combinations in summer 1978; the resulting F_1's will be planted in downy mildew nurseries at ICRISAT Center and Samaru, Nigeria, to form a "downy mildew resistant-source population."

COMPOSITE BREEDING

Intrapopulation improvement by recurrent selection continued in 13 composites, one less than the total number in 1976. Two phenotypically similar composites (Senegal Dwarf Composite and GAM 73) had been merged into a single group. By onset of postrainy season 1977, three composites had completed three cycles of selection, nine composites had completed two cycles of selection, and the newly-developed composite had gone through a single cycle. Selection is effected through testing from 225 to 315 progenies at three to five locations with one replication in the downy mildew nursery. Beginning from 1977, composite progenies were also tested with the assistance of the ICRISAT breeders in West Africa. For the cycle completed in 1977, 21 to 28 progenies per composite were selected for recombination, the selection differential for mean grain yield was about 29 percent. Recombination was done in the downy mildew nursery and involved only disease-free plants.

To assess the achievement in selection in these composites, comparisons of C_0 to C_1 bulks were made in four composites and C_0 to C_2 in two composites. Though the differences were not significant statistically, an average of 2.8 percent gain in seed yield per year was recorded—the best being 9.4 percent. Selection was effective in reducing plant height and increasing the level of downy mildew resistance. Progeny testing in the more advanced cycle in these composites showed no reduction in variability for yield,

Table 33. Reaction of source population progenies to diseases.

Population	Smut[a]			Downy mildew[b]			Ergot[c]		
	Total screened	< 10%	10-20%	Total screened	<10%	10-15%	Total screened	< 20%	20-30%
	(no)			(no)			(no)		
Ex-Bornu	188	7	18	10	4	2	–	–	–
3/4 Souna	25	1	–	6	2	1	267	9	30
3/4 Ex-Bornu	35	–	1	3	1	–	152	4	16
3/4 Heine Kheiri	–	–	–	–	–	–	55	2	5

[a] Infection index; advanced smut-screening nursery, Hissar, northern India, rainy season 1977.
[b] Percent infected plants; pre-IPMDMN average over four locations in India and West Africa, rainy season 1977.
[c] Infection index; preliminary ergot-screening nursery, ICRISAT Center, rainy season 1977.

indicating that the selection methods being employed have not rapidly diminished the potential for improvement.

At ICRISAT, the advanced cycle bulks of composites are not visualized for release (except to breeders); the practical products are experimental varieties and individual best progenies generated in each cycle of selection. An experimental variety is formed by combining five to eight progenies with outstanding performance in a certain test location (location-specific experimental variety), or on the average overall locations (across-locations experimental variety).

Composite products tested at several locations in India and Africa in 1977 included 20 experimental varieties and 81 best progenies. Eight experimental varieties were equivalent in yield to the hybrid check ICH 105 (2 360 kg/ha), and most were superior in downy mildew resistance. Four experimental varieties—SSC-H-76, MC-P76, WC-B76, and RF-A76-were selected for further testing; the former two were also entered in the All-India Coordinated Millets Improvement Project (AICMIP) trials to be conducted in 1978. The four ICRISAT experimental varieties in the AICMIP trials in 1977 did well; WC-C75 ranked first and was recommended for prerelease and minikit demonstrations; IVS-A75 and MC-C75 were promoted to the Advanced Pearl Millet Population Trial.

Of the 81 best progenies tested, 50 gave the same yield levels as the hybrid check BK 560 (2 710 kg/ha), and the majority recorded a lower incidence of downy mildew. Fourteen progenies were selected for advanced testing in the Elite Variety Trial in 1978.

A trial to assess inbreeding depression in experimental varieties and individual progenies, in general, showed no evidence of yield loss due to generation advance. Yield of SYN-1 averaged 4.6 percent more than SYN-0, indicating that yield loss does not necessarily occur in pearl millet varieties generated from a few or even single composite progenies as a result of generation advance during seed increase.

A dwarf-sidecar program was initiated in 1976 to convert seven tall (normal) composites with plant heights ranging from 170 to 230 cm to their dwarf d_2 versions, using largely GAM 75 (below 140 cm) as the dwarfing-gene donors. Two backcrosses have been completed, and the third and final backcross is planned for 1978.

In the interpopulation-improvement project, primarily aimed for the production of hybrids, the first cycle of reciprocal full-sib recurrent selection has been completed in one complementary composite pair—1B and 1R. The parental progeny pairs of the best full-sib hybrids identified during the first selection cycle are being developed and evaluated as potential parents (Fig 12). Another pair of complementary composites—2R and 2B—are in the second random-mating stage, and will also be improved by reciprocal full-sib recurrent selection.

Based on a diallel study of 16 ICRISAT composites, two additional complementary pairs (GAM 75 and 3/4 Ex-Bornu, and Serere Composite-2(M) and Nigerian Composite) were selected for interpopulation improvement. The first pair will be improved by reciprocal full-sib method, whereas the reciprocal inbred-tester method will be used for the second pair.

COMPARISON OF POPULATION IMPROVEMENT METHODS

In order to provide pearl millet breeders with information on the relative values and efforts involved in different methods of recurrent selection, a 6-year study was initiated in 1976 to compare four principal methods of recurrent selection—gridded mass selection (GMS), recurrent restricted phenotypic selection (RRPS), full-sib progeny selection (FSPS), and S_2 progeny selection (S_2PS). The World Composite, a composite with wide genetic variability for several important characters, was chosen for this study. The first cycle of S_2PS and second cycle of the other three methods were completed in rainy season 1977. An initial comparison is planned for 1979.

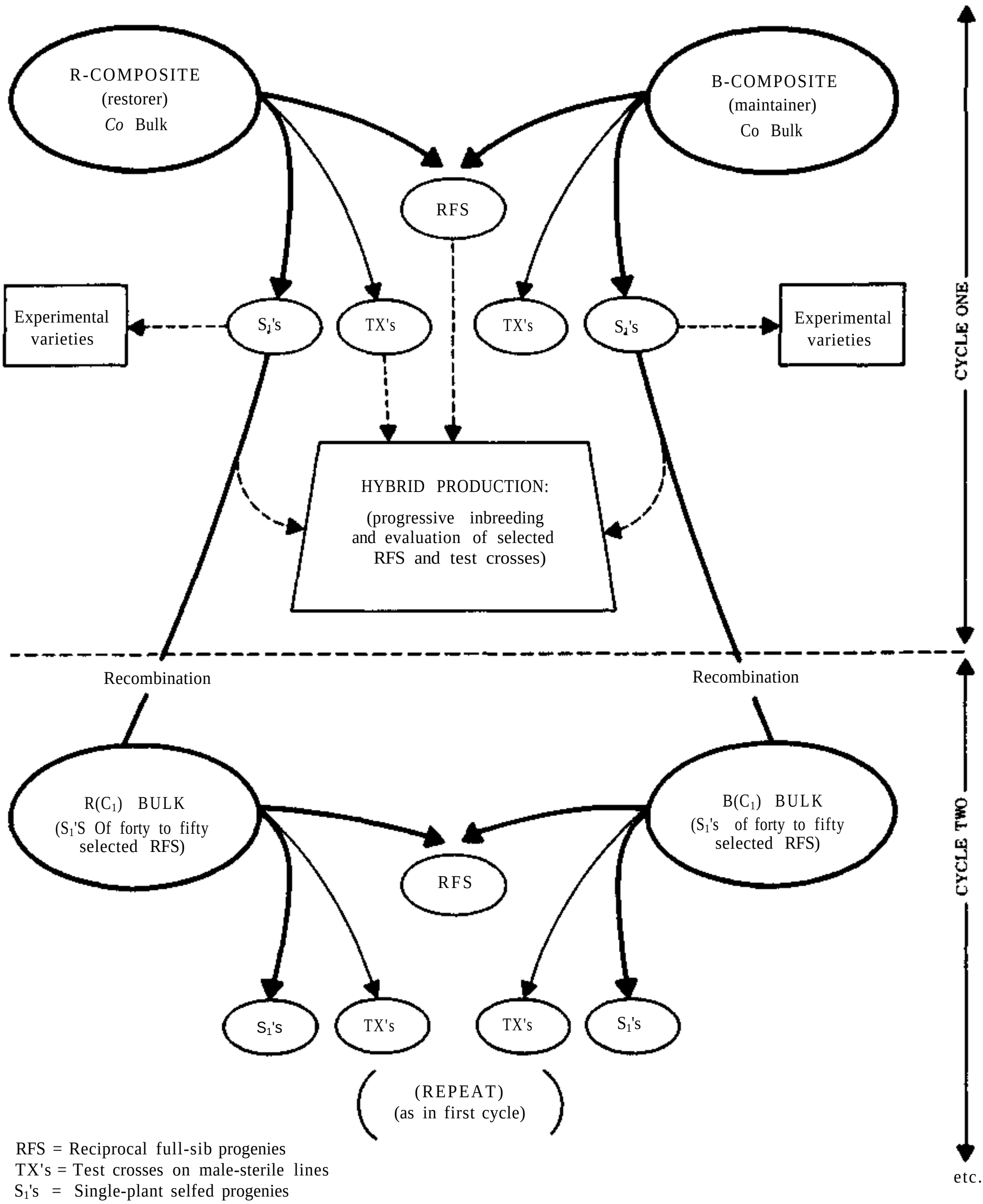


Figure 12. Generalized scheme of interpopulation improvement in pearl millet.

VARIETY CROSSES AND SYNTHETICS

This project represents much of the "conventional" breeding approach, in which inbreds or partially inbred lines are generated by crossing complementary inbreds or varieties followed by pedigree selection for two or three generations. The lines so generated are evaluated for *per se* performance, for use in synthetics, and for potential as hybrid parents. Selected lines with a range of diversity are distributed to cooperating breeders annually in the form of Uniform Progeny Nurseries, providing a continuous supply of useful clear-cut variability to national programs.

In rainy season 1977, 126 new F_1's and 223 F_2 populations were grown at ICRISAT Center; an additional 169 F_2's from crosses between good agronomic lines and downy mildew-resistant sources were grown at Hissar in northern India. Individual plant selections were made from the F_2 populations for testing as F_3 lines in the subsequent generation. Potential segregates have been obtained largely from crosses having *Indian x African* parentage. At Hissar, emphasis was on selection for resistance to smut and downy mildew as well as other desirable agronomic characters. A selected group of F_2 populations were also supplied to ICRISAT breeders at Samaru, Nigeria, and Kamboinse, Upper Volta. In more advanced progeny nurseries, 4 424 progenies were grown at ICRISAT Center and two other Indian locations, of which more than 3 000 plants were selected for further advance.

F_3 and F_4 Uniform Progeny Nurseries (271 F_3's and 126 F_4's) were sent to five cooperators in four countries and seven cooperators in six countries, respectively. Ten F_3's and 21 F_4's were identified as having good potential across locations.

Fifty-seven inbreds were tested in two yield trials at several locations in India and Africa in 1977. Two inbreds (ICMI 7616 and ICMI7549) gave yields (2 415 and 2 374 kg/ha respectively) equal to the hybrid check BK 560 (2 254 kg/ha). A number of inbreds showed low levels of downy mildew at all locations.

In a synthetic trial initiated in 1977, seven new ICRISAT synthetics were tested at five locations In India and Africa along with the best experimental varieties and hybrids, which were included as checks. Two synthetics (ICMS 7703 and ICMS 7704) gave high yields across locations, and were superior to the highest-yielding hybrid check BK 560-230 (Table 34). These two synthetics were made up from inbreds that performed well in multilocational tests.

HYBRIDS

The hybrid program is directed towards the development of parents for high-yielding disease-resistant hybrids. Inbreds or partial inbreds generated from the recurrent-selection, source-material, and variety-cross projects are routinely tested for their potential as hybrid parents.

Three stages are involved in identifying superior hybrids. Initially, test crosses are evaluated in single plots at ICRISAT Center. Selected hybrids were entered in the second stage—the initial hybrid trial—which was a replicate trial at several locations including the DM nursery. Hybrids which display high yield potential, show stability across environments for yield and downy mildew resistance, and are agronomically satisfactory, move forward to the third (the advanced) stage of testing at a larger number of locations, including African locations critical for identification of stable disease resistances. The best hybrids from the advanced trial are more intensively evaluated in the International Pearl Millet Adaptation Trial and national testing programs.

One third-stage hybrid trial (PMHTI) and two second-stage trials (PMHT 2 and 3) were grown at several locations and in DM nurseries in India and Africa in 1977. Seed parents included 111 A, 5054A. and 5141 A, while restorer lines were Indian and African inbreds, composite progenies, and newly developed progenies from *Indian* x *African* crosses.

In PMHT 1, hybrid BD 763 from Indian Agricultural Research Institute, New Delhi, was the top-yielding entry which gave high yields

Table 34. Grain yields and downy mildew incidence of selected synthetics in PMST 1, 1977.

Entry	Grain yield				DM incidence	
	ICRISAT Center[a]	Hissar, India	Bambey, Senegal	Mean[b]	ICRISAT Center	Bambey, Senegal
	(kg/ha)				(%)	(%)
ICMS 7703	3 791	3 905	1 797	2 597	8	6
ICMS 7704	3 203	3 272	1 976	2 551	0	29
BK 560-230[c]	2 923	2 219	2 001	2 190	8	15
ICMS 7705	2 259	2 442	1 302	1943	10	0
PSB 7	2 424	2 971	1 180	1 913	8	
Mean (20 entries)	2410 ±271	2 710 ±225	1509 ±711	1968 ±195	NA"	NA
L.S.D. (0.05)	776	645	2 034	549		

[a]The plots at ICRISAT Center had received 80 kg P_2O_5 and 150 kg N per ha.
[b]Mean yield over five locations.
[c]Highest-yielding hybrid check.
[d]Not averaged.

in all locations except at Samaru, Nigeria, where a high incidence of downy mildew was recorded. Thirteen ICRISAT hybrids gave yields greater than BK 560-230 (2 087 kg/ha), of which four (ICH 163, 118, 117, and 175) were moderately resistant to downy mildew, both in India and Africa (Table 35). All hybrids in this trial were susceptible to ergot and showed moderate resistance to smut. Of 60 ICRISAT hybrids evaluated in PMHT 2 and 3, 25 performed well and were selected for the third-stage trial.

An additional 1 569 test crosses using four male-sterile lines of the A_1 system (111A, 5054A, 5071A-P23, and 5141A) were evaluated at ICRISAT Center in 1977. Of these, 234-involving mainly progenies from variety crosses —were retained for second-stage testing.

New seed parents are being developed by converting good maintainer lines into male steriles, extracting superior lines from existing seed parents by plant-to-plant crossing between the maintainer lines and their corresponding male-sterile counterparts, and incorporating downy mildew resistance into a male-sterile line using a resistant maintainer mutant induced by irradiation. Some of these lines are being evaluated for combining ability and stability of sterility.

International Cooperation

NETWORK OF BREEDING CENTERS

ICRISAT's African programs in Senegal Upper Volta, Niger, Nigeria, and Sudan now have a millet breeder posted in each location. In India, ICRISAT breeders also operate cooperative breeding nurseries in the north (at Hissar, 29°N) and in the south (at Bhavanisagar, 11 °N) and work with scientists of the AICMIP. Between India and West Africa, the main flow of early generation breeding material is between the core program at ICRISAT Center and Kamboinse in Upper Volta (Fig 13). Other national and ICRISAT programs in Africa can draw on Kamboinse for breeding material, but will be included in cooperative multilocational

Table 35. Grain yields and disease incidence of selected hybrids in PMHT 1 (1977).

Hybrid	Pedigree	Grain yield[a]	DM incidence ICRISAT Center	DM incidence Samaru, Nigeria	DM incidence Kamboinse, Upper Volta	Ergot score,[b] Kamboinse	Smut score,[b] Kamboinse
		(kg/ha)	(%)	(%)	(%)	(1-5)	(1-5)
BD 763	5141A x D763	3 029	0	45	6	5.0	2.0
ICH 165	111A X SC14(M)	2 579	0	9	9	4.5	2.5
1CH 118	111A x Souna B	2 449	2	7	18	5.0	2.0
ICH 117	111A x 1/2HK	2 300	6	5	14	5.0	2.0
ICH 175	5040A x EB 70-1	2 102	1	22	21	5.0	2.0
BK 560-230	5141A x K560-D230	2 087	10	72	34	5.0	2.0
Mean (30 hybrids)		2213 ±175	4	38	20	4.7	2.1
L.S.D. (0.05)		491					

[a]Mean yield over six test environments.
[b]Score of 1 = low incidence; 5 = high incidence.

yield trials. In 1977, we received seed from breeding material sent in 1975 to Upper Volta and selected for two cycles there. We expect to find these materials much improved for downy mildew, smut, and grain mold resistance.

INTERNATIONAL TRIALS

Twenty pearl millet genotypes—experimental and commercial hybrids, synthetics, experimental varieties, and populations from several origins—were tested in the Third International Pearl Millet Adaptation Trial (IPMAT-3) sent out in 1977 to 60 locations in 24 countries. Results were received from 30 locations in 7 countries of which 29 locations reported grain-yield data.

The highest mean grain yield over all entries (2 888 kg/ha) was recorded at Anand, India, and the lowest (341 kg/ha) at Ouahigouya, Upper Volta, with the mean over all locations of 1 634 kg/ha. The highest-yielding entry over all locations was ICRISAT hybrid ICH 118 (1 917 kg/ha) and lowest was KB 436 (1 277 kg/ha). At only 10 of the 29 locations did the local check of commercial hybrid give the highest yield. The top grain yields at individual Indian locations ranged from 888 kg/ha (PHB 14 at Jaipur) to 3 988 kg/ha (PSB 8 at Ludhiana).

Mean and rank for grain yield of each entry over all locations (29), locations in India (21), and locations in West Africa (7) are presented in Table 36. The trial mean yield over Indian locations was 1 808 kg/ha and over West African locations was 1 072 kg/ha. The entries that performed well across locations were the hybrids ICH 118, BD 111, ICH 107, and experimental varieties SSC-C75 and IVS-A75. Over locations in India, grain yields of the top performing hybrids (BD 111, ICH 118, ICH 107, and PHB 14) and of the top-performing experimental varieties (SSC-C75, IVS-A75, and LC-C75) were not significantly different. Hybrid ICH 118, experimental varieties IVS-A75 and WC-C75, populations Ex-Bornu and World Composite, and local checks performed well over African locations; these five entries have been bred using totally or partly African germplasm.

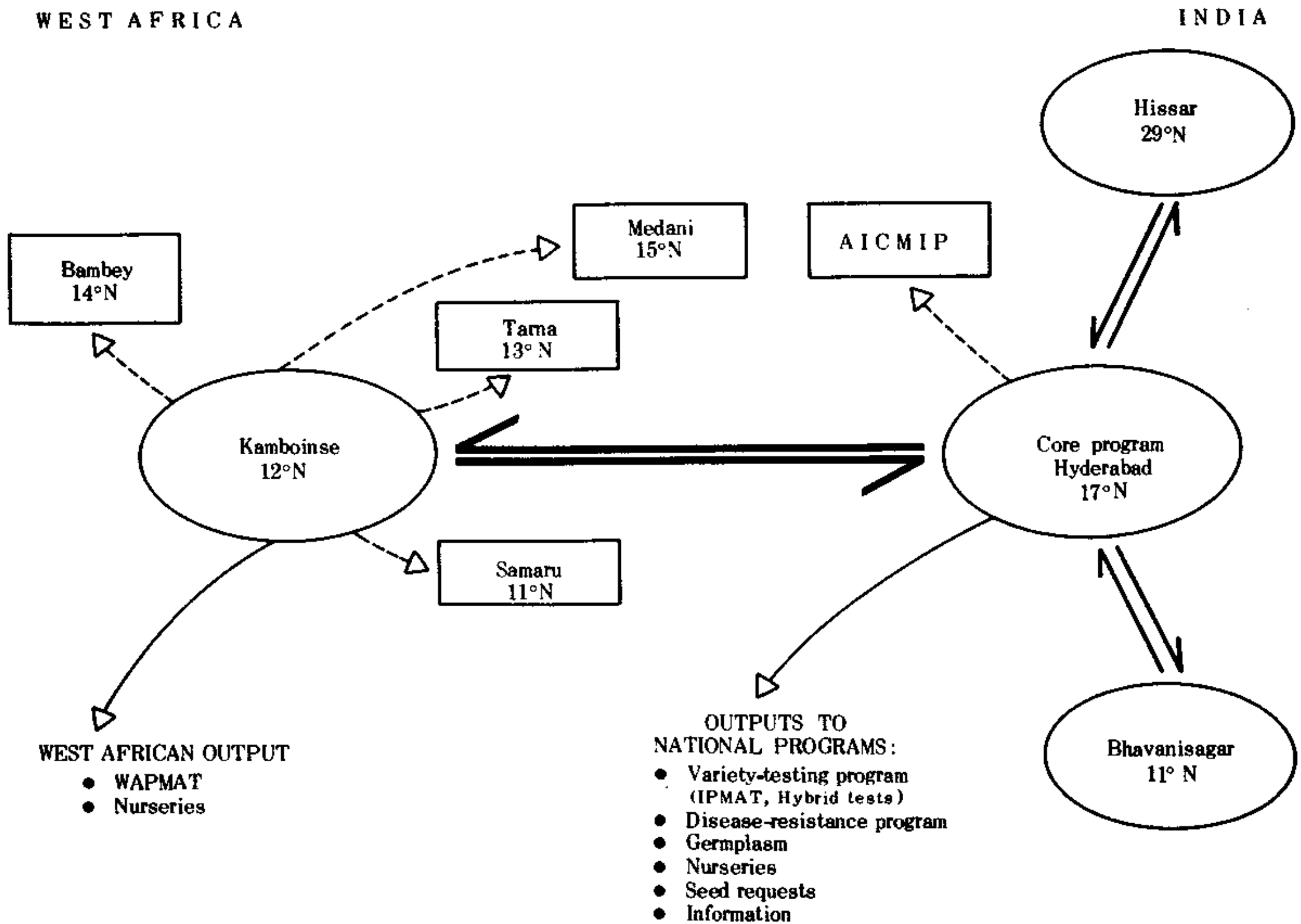


Figure 13. ICRISAT pearl millet multilocational breeding.

Table 36. Mean grain yield of IPMAT-3 entries over all Indian and West African locations, 1977.

Entry No.	Entry	Mean over all locations (29) Yield (kg/ha)	Rank	Mean over Indian locations (21) Yield (kg/ha)	Rank	Mean over West African locations (7) Yield (kg/ha)	Rank
1.	3/4 Ex-Bornu	1369	18	1487	19	901	17
2.	3/4 Souna	1279	20	1375	21	894	18
3.	PSB-8	1562	15	1 784	14	902	16
4.	ICS 7605	1 588	14	1 757	15	1083	12
5.	Ex-Bornu (C_2)	I 748	9	1896	9	1 323	3
6.	World Composite	1 763	7	1 905	8	1 281	5
7.	PHB-14	1774	6	1992	5	991	15
8.	NHB-3	1 374	17	1 631	17	707	19
9.	BD 111	1874	2	2 059	1	1 151	8
10.	ICH 107	1 810	5	2 029	4	1 176	7
11.	ICH 108	1663	12	1 862	10	1004	14
12.	ICH 118	1917	1	2 045	2	1 502	1
13.	ICH 190	1 627	13	1 802	13	1 112	10
14.	WC-CX75	1 706	10	1 852	11	1 267	6
15	NC-SX75	1 539	16	1 672	16	1 089	11
16.	IVS-AX75	1817	4	1989	6	1 284	4
17.	SSC-CX75	1828	3	2 031	3	1 130	9
18.	LC-CX75	1704	11	1912	7	1048	13
19.	KB-436	1277	21	1477	20	671	20
20.	CO-6	1336	19	1 601	18	584	21
21.	Local Check	1753	8	1 818	12	1420	2
	Mean (kg/ha)	1 634		1 808		1072	
	S.D.	±48		±56		±91	
	L.S.D. (0.05)	133		157		252	
	C.V. (%)	27.45		24.95		38.92	

Rank correlations between entry mean yields over all locations, over locations in India, and over locations in West Africa were all positive and high (0.65 to 0.91), indicating similar relative performances of entries in India and Africa.

Contrasting responses of entries to downy mildew were obtained between locations in India and West Africa, confirming the results of IPMAT-2 in 1976. Cultivars ICH 118 and ICH 190 consistently had low incidence of downy mildew both in India and in Africa, indicating that these two hybrids possess a relatively "stable" resistance.

Several other multilocational trials of composite progeny and products, inbreds, synthetics, and hybrids were also grown by cooperators in India and other countries. Distribution of these trials in 1977 is shown in Table 37.

In 1977, ICRISAT contributed 18 entries to the AICMIP National Yield Trial. The experimental variety WC-C75 and hybrid ICH 105, entered in the initial trials in 1976, were promoted to the respective advanced trials. Three new hybrids (ICH 110, ICH 118, and ICH 190) and three new experimental varieties (IVS-A75, MC-C75, and SSC-C75) were accepted for initial trials, and 10 elite restorers were included in the parental trial.

Variety WC-C75 ranked first in grain yield among the varieties tested over 27 locations in the Advanced Population Trial, its mean yield of 1631 kg/ha was only 9 percent less than the mean of the best hybrid check (BJ 104, 1794 kg/ha). This variety also recorded the highest fodder yield (8 988 kg/ha; trial mean was 6 859 kg/ha) in the trial. Experimental varieties MC-C75 and IVS-A75 performed well in the Initial Population Trial, and were promoted for advanced testing in 1978.

Nutritional Quality

ANALYSIS OF BREEDING MATERIAL

During 1977, analysis for protein content was carried out in entries of IPMAT-3 (three locations), advanced hybrid trials, synthetic trial, and AICMIP's Advanced Hybrid and Initial Population Trials.

Grain yield and protein content of IPMAT-3 entries grown in three locations are presented in Table 38. Though grain yields of the entries varied substantially, the range of protein content was rather narrow. Hybrid BD 111 from IARI, New Delhi, showed a consistently high protein content at all three locations. The correlation coefficients between grain yield and protein content were negative but low (—0.15 to —0.50), indicating a weak relationship between yield and protein content. Similar results were obtained for the analysis of entries in the advanced hybrid and advanced synthetic trials and the two AICMIP trials. These results

Table 37. Locations at which pearl millet breeding trials were grown in 1977.

Country	Composite progeny	Composite bulks	Experimental varieties	Best progenies	Inbreds	Synthetics	Advanced hybrids	Total
India	3	1	1	-	-	-	1	6
Pakistan	-	-	1	-	-	-	-	1
Niger[a]	2	1	1	-	-	1	-	5
Nigeria[a]	2	-	1	-	-	-	1	4
Senegal[a]	2	-	1	-	-	1	-	4
Sudan[a]	-	-	1	-	-	-	-	1
Upper Volta[a]	9	1	1	1	1	-	1	14
								35

[a] ICRISAT breeders in the international program.

Distribution of Seed Material

During 1977-1978, 2 177 seed lots of breeding and source material, consisting of inbreds, restorers, hybrids, synthetics, population progenies, and experimental varieties were distributed to breeders in 21 countries.

Table 38. Grain yield and protein content of IPMAT-3 (1977) entries grown at ICRISAT Center and Hissar.

Entry	ICRISAT (HF)[a] Yield	ICRISAT (HF)[a] Protein	ICRISAT (LF)[b] Yield	ICRISAT (LF)[b] Protein	Hissar, INDIA Yield	Hissar, INDIA Protein
	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)
World Composite	3 454	10.6	1 569	11.6	3 313	11.5
KB 436	2 195	11.9	975	13.2	1914	13.3
PHB 14	2 179	12.5	1 316	13.0	3 319	13.3
ICH 190	1 149	12.0	1098	11.9	2 026	12.7
ICH 118	3 551	11.7	1945	12.0	3 088	11.9
SSC-CX75	2 694	11.1	2 103	12.3	3 164	12.2
NHB-3	2 981	10.5	1022	12.5	2 476	12.5
3/4 Ex-Bornu	2217	10.6	1 233	11.0	2 517	11.4
PSB 8	2 636	10.3	1 325	12.8	2 800	12.3
WC-C75	2 976	11.7	1587	12.3	2 786	12.3
CO-6	2 629	10.3	1 855	11.8	2 500	12.6
3/4 Souna	2 316	12.0	1 044	11.8	2 139	12.5
ICH 108	2 302	12.1	1925	12.3	2 125	12.8
Ex-Bornu (C_2)	3 485	11.3	1643	11.4	3 172	11.1
NC-Dx75	3 482	10.0	1478	11.4	2918	12.7
ICS 7605	3 261	9.5	1 627	10.7	2 787	11.0
IVS-A75	3 482	10.0	1636	11.4	2 910	11.5
ICH 107	3 053	11.6	1 797	12.2	3 239	12.7
BD 111	1555	15.0	1 723	13.4	3 852	13.0
LC-CX75	2 725	10.7	1645	12.0	2 859	12.6
Local check	1811	11.1	1035	13.2	2 902	13.1
Mean	2 615	11.3	1 504	12.1	2 800	12.3
C.V. (%)	16.2	6.3	27.3	5.6	18.5	5.8
L.S.D. (0.05)	701	1.2	679	1.1	857	1.2
Range: Min	1 149	9.5	975	10.7	1914	11.0
Max	3 551	15.0	2 103	13.4	3 852	13.3

[a] High fertility (120 kg N, 60 kg P_2O_5, per ha).
[b] Low fertility (20 kg N, 20 kg P_2O_5, per ha).

indicated that with the yield levels obtained from these advanced products (about 2 000 kg/ha), about 170 to 250 kg/ha of protein could be harvested from pearl millet.

Fractionation of Pearl Millet Protein

Protein fractionation of grain samples from five millet genotypes (three hybrids, one experimental variety, and one composite) grown in four locations revealed that albumin and globulins accounted for about 22 to 28 percent of total nitrogen, while 22 to 35 percent were prolamin and prolamin-like fractions which are poor in lysine, and 28 to 32 percent were glutelin and glutelin-like fractions.

An interesting observation emerging from this study is that hybrid ICH 105 consistently recorded a low prolamin content across locations, suggesting the possibility of having high lysine content. In fact, the analysis showed a higher mean lysine content for 1CH 105 than for other genotypes (Table 39).

Physiology

SEASONAL DIFFERENCES IN CROP GROWTH

Although yield levels of pearl millet grown during the summer season (Feb-Apr) and during the rainy season (Jun-Sep) are generally comparable, there are evident differences in the way the crop grows during the two seasons, particularly in the early stages of growth. These differences were investigated in order to develop information on how the crop responds to seasonal differences and to evaluate the possibility of *cultivar* x *season* interactions in breeding materials. The experiment involved a number of cultivars, but the data presented here is only for the AICMIP hybrid BJ 104.

Seasonal Differences

The summer season differs from the rainy season mainly in terms of temperature (Fig 14). Minimum temperatures during GS_1 (Growth Stage-1, the period from emergence to floral initiation) were considerably cooler in the summer season, averaging 17.9°C, compared to 22.5°C in the rainy season. Mean maximum temperatures during the GS_1 and GS_2 stages (from floral initiation to flowering) were not different between the two seasons; but during the GS_3 (grain-filling) stage were considerably higher (35.5°C) in the summer season than in the rainy season (28.9°C).

The two seasons also differed in day-length, during the preflowering periods. In the preflowering period of the summer crop, days were about 12 hours long; those in the equivalent part of the rainy season were about 13.5 hours in length. Despite the longer days during the early part of the rainy season, average daily incoming radiation was less (432 ly/min) than early in the summer season (483 ly/min) because of the cloud cover present during the rainy period.

Crop Phenology

The time to floral initiation (GS,) was considerably shorter in the summer season, as initiation occurred earlier in the shorter days of

Table 39. Lysine content (g/100 g protein) of five pearl millet genotypes grown at 1CRISAT Center, Hissar, and Bhavanisagar, India in 1977.

Location	Genotype				
	PHB 14	BK 560	ICH 105	VVC-C75	Ex-Bornu
ICRISAT (HF)[a]	2.41	2.41	3.15	2.82	2.70
ICRISAT (LF)[b]	2.61	2.53	2.84	2.86	2.84
Hissar	2.56	2.78	2.94	2.81	2.68
Bhavanisagar	2.61	2.64	2.96	2.59	2.75
Mean	2.55	2.59	2.97	2.77	2.74
Range	2.41-2.67	2.41-2.78	2.84-3.15	2.59-2.86	2.68-2.84

[a] High fertility (120 kg N, 60 kg P_2O_5 per ha).
[b] Low fertility (20 kg N, 20 kg P_2O_5 per ha).

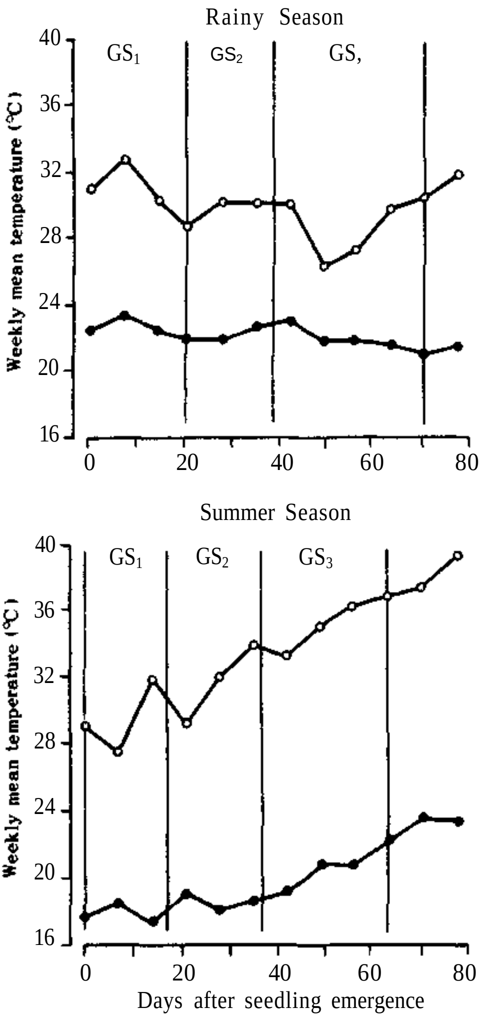


Figure 14. Weekly mean minimum and maximum temperatures for rainy season 1977 and summer season 1978 at ICRISAT Center. Growth stage: GS_1—seedling emergence to floral initiation; GS_2—floral initiation to flowering of main panicle; and GS_3-flowering of main panicle to maturity of main panicle.

summer than in the longer days of the rainy season (Table 40). Combined with the cooler night temperatures of the summer season, this early initiation resulted in the accumulation of only half of the heat units (daily summation of the number of degrees by which the daily mean exceeds 17°C) during the GS_1 stage. As crop growth is proportional to heat units, rather than to day length, dry-matter production (Table 40) and leaf-area index (Fig 15) developed during this period were much less in the summer than in the rainy season.

The length of the two remaining growth stages (GS_2 and GS_3) appear to be controlled by the accumulation of a characteristic number of heat units, which was nearly identical in the two seasons. This is particularly evident in the GS_3 period, where higher daytime temperatures resulted in an overall shortening of the period by 5 days, as the required number of heat units were accumulated in 25 days in the summer compared to 30 days in the rainy season.

The cooler temperatures during GS_1 produced an additional difference between the two crops—a substantial increase in tiller numbers. Although a relatively high percentage of these did not produce grain (Table 41), those that did resulted in an increase in the length of the tiller maturity period (between main stem panicle maturity and maturity of the tillers) (Table 40). Because of this, the overall season length (in terms of days and/or heat units) was similar for both seasons. The distribution of days and heat units over the different growth stages was quite different, however.

Crop Growth

The effects of cooler temperatures on leaf-area expansion during the GS_1 period in the summer season crop persisted throughout the entire season (Fig 16). Maximum leaf-area index (LAI) in the rainy season crop reached 2.9 compared to only 1.7 in the summer season crop. Cumulative radiation interception was estimated from LAI, using data developed by Peter Gregory and Geoffrey Squire of the University of Nottingham. The rainy season crop intercepted 65 to 70 percent of the incident radiation at peak LAI; the summer crop intercepted only 40 to 43 percent during the equivalent period. Integrated values for total seasonal interception were 42

Table 40. Comparison of length of growth stage, heat units, and dry-matter accumulation during rainy season 1977 and summer season 1978, ICRISAT Center, (cv BJ 104).

Growth stages	Length		Heat Units[a]		Dry wt accumulated	
	Rainy season	Summer season	Rainy season	Summer season	Rainy season	Summer season
	(days)	(days)	(no)	(no)	(g/m^2)	(g/m^2)
GS_1	22	17	217	111	37	10
GS_2	18	20	160	155	248	155
GS_3	30	25	250	256	310	235
Tiller maturity	9	19	82	253	55	175
Season total	79	81	709	775	650	575

[a]Daily summation of the number of degrees by which the mean temperature exceeds 17°C.

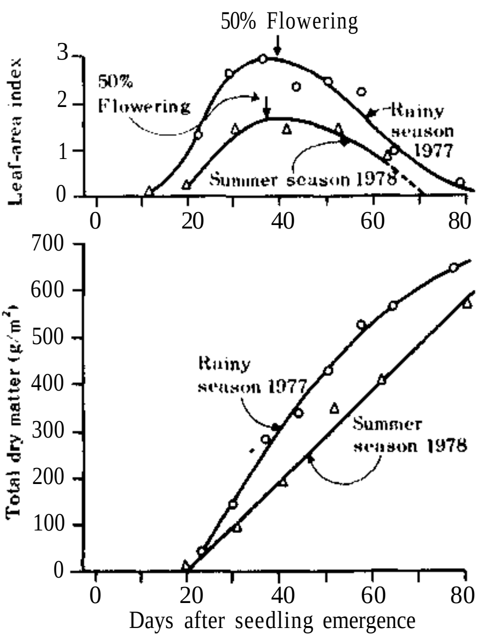


Figure 15. Total crop dry matter and leaf-area index in pearl millet cv BJ 104 grown at ICRISAT Center during the rainy season 1977 and summer season 1978.

Table 41. Yield and yield components of cv BJ 104 for rainy season 1977 and summer season 1978 at ICRISAT Center.

	1977 Rainy season	1978 Summer season
Tillers (no/m^2)	66	85
Heads (no/m^2)	39	43
Grains (no x $10^3/m^2$)	51.0	48.7
1000-grain wt (g)	4.9	5.3
Grain dry wt (g/m^2)	249	257
Harvest index (%)	38	45

and 26 percent of total incident radiation, or 11.6 and 8.6 $kcal/cm^2$, respectively, for the rainy and summer season crops.

Rates of crop dry-matter accumulation were different in the two seasons, particularly from 20 to 50 days after emergence; the rates of leaf-area expansion were also different between the two crops (Fig 16). Dry-matter production in both crops was similarly and closely related to estimated intercepted radiation (Fig 16) indicating that differences in crop-growth rates

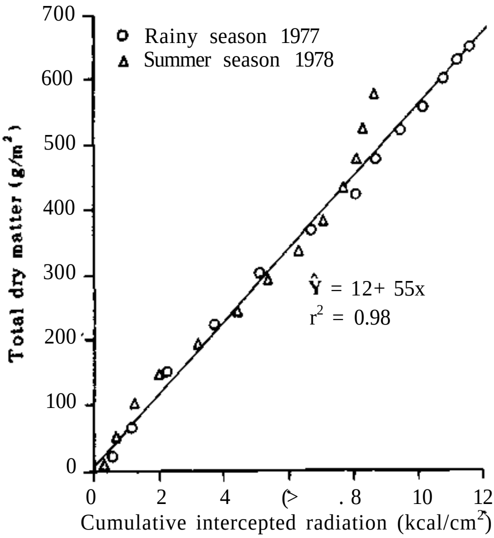


Figure 16. Total crop dry matter produced by cv BJ 104, plotted as a function of cumulative radiation interception during the rainy and summer seasons at lCRISAT Center.

between the two seasons were mainly a function of differences in LAI. Ultimately then, differences in crop-growth rates were due to the cooler temperatures and shorter days of the GSj period of the summer season, which greatly reduced leaf-area development during that period.

Grain Yield

Grain numbers per panicle were less in the summer crop than in the rainy season crop (reflecting the lesser overall crop growth prior to flowering in the summer season), but grain numbers per unit area occupied by the crop were only slightly less, because of the greater number of panicles produced in the summer crop (Table 41). Grain size (1000-grain weight) was slightly greater in the summer season, probably reflecting the greater radiation levels during the grain-filling period of this season. As a result, grain yields were similar in the two crops (Table 41), as generally observed in previous seasonal yield comparisons.

Importance of Favorable Environment

The experiment clearly points out the importance of favorable environmental conditions during the early growth stage of pearl millet. The potential for subsequent leaf-area development, radiation interception, and dry-matter production are clearly dependent upon growth prior to floral initiation.

There was, however, no correspondence between radiation interception or growth prior to flowering and grain numbers. The fact that the summer season crop produced a nearly equivalent number of grains with only slightly more than 50 percent of the leaf-area index of the rainy season crop, suggests that the latter was operating well below maximum efficiency in grain production.

Short-season millets are recognized as inherently less efficient in intercepting incoming radiation than are the longer-season cereals, such as sorghum and maize, because their preflowering growth period is not long enough to develop as large a leaf-area index. From the above data, it appears that the efficiency of use of intercepted radiation needs to be further investigated in pearl millet.

SEEDLING VIGOR

Crop establishment and early crop growth are major problems in pearl millet. Mineral nutrient and carbohydrate reserves available for early growth are, in comparison to other cereals, considerably less in millet. Because of its small seed size, the crop is more dependent upon favorable seedbed conditions for vigorous early growth. There is, however, considerable genetic variability in pearl millet for rates of early seedling growth; it would be desirable to breed for improved seedling vigor if reliable techniques were available for selection.

We have evaluated a number of simple methods for the measurement of seedling vigor. Two criteria were used in the evaluation: i) ability to measure genetic differences with a high degree of precision, and ii) strong correlation to measured seedling growth under field conditions. A number of simple laboratory tests (seed weight, seedling growth in petri dishes, weight of seed reserves mobilized for seedling growth) were effective in distinguishing differences among cultivars. Attempts to corre= late these measurements to seedling vigor under field conditions (estimated by seedling dry weight at 15 days after emergence) were not promising. Correlations were significant but weak (values in the range of 0.4 to 0.6), and it was concluded that these laboratory measurements could not be used as a substitute for direct field measurements.

Attempts to develop a visual-scoring system for use with field-grown materials were more successful. It was found that by using a relative scale for scoring—that is, adjusting the extremes of the scale to the extremes of vigor present in the material being scored—genotype differences could be rapidly and reliably assessed (Fig 17). Correlations of score to measured seedling dry weight were quite good (Fig 18). The choice of a relative rather than an absolute scoring system results in a normal distribution of scores, permitting direct statistical analysis of data; and the precision of such a system is sufficient to statistically distinguish the better lines (Table 42).

Entomology

Pest problems on pearl millet were minimal in the year, except for damage caused by the armyworm, *Mythimna separata,* which caused severe defoliation locally. There was some damage to breeders' material by root grubs.

Destructive sampling of a plot of pearl millet (cv ICH 105) sown in an unsprayed area showed that pest levels were low throughout the season. Only 3 percent of the plants were laid on by shoot fly, *Atherigona approximata,* and incidence of the two lepidopterous stem borers *Chilo* and

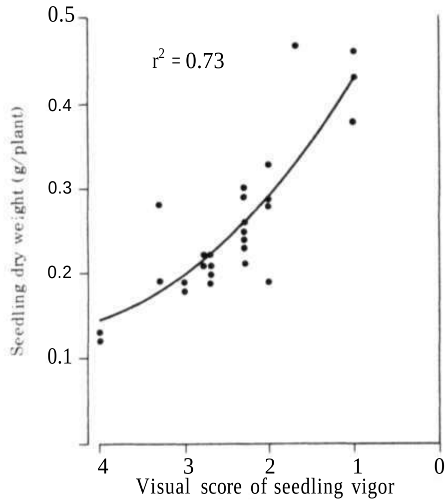


Figure 18. Relationship between the visual score for vigor and seedling dry weight at 15 days in pearl millet.

Figure 17. Differences in seedling vigor in pearl millet, 15 days after emergence. Visual-score Classes 2 and 4.

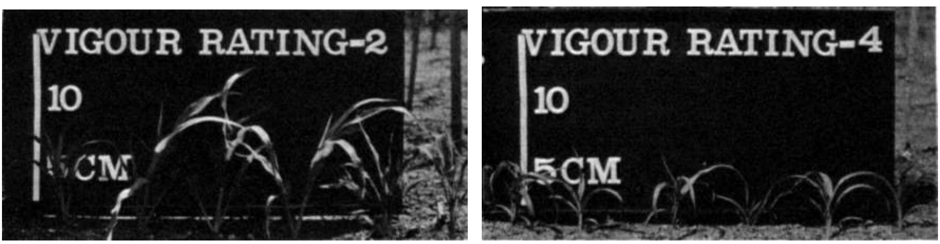


Table 42. Visual scoring for seedling vigor in pearl millet at ICRISAT Center, rainy season 1977.

	Intervarietal synthetic S_1 trial	AICMIP Advanced Hybrid Trial
No. of entries	315	22
Mean score	2.8	2.6
Range	1.0-5.0	1.7-3.7
L.S.D. (0.10)	0.9	0.8
F ratio (entry)	2.66**	2.44**
C.V. (%)	19	13

(**P<.01)

Sesamia was less than 1 percent. Other minor pests included *Calocoris angustatus, Oxycarenus* sp., *Heliothis armigera,* and various Meloids.

A list of the potential pests occurring on pearl millet was published, along with a list of the parasites found on them.

An extensive survey to locate sources of off-season carryover of pest species was made in the environs of ICRISAT Center. Pearl millet, irrigated from wells, was found on limited hectarages. This crop was more heavily attacked by *A. approximata* than was the main season crop—12 to 13 percent of the plants had deadhearts. Almost all the flies (97% of the males) bred from deadhearts were of the named species. The only other species recorded was *A. soccata.*

Pathology

Identification and utilization of resistance to downy mildew (DM) *(Sclerospora graminicola),* ergot *(Claviceps fusiformis),* smut *(Tolyposporium penicillariae),* and rust *(Puccinia penniseti)* continued to be major activities in ICRISAT's pearl millet pathology program. In addition, studies were undertaken to fill in gaps in the knowledge of the biology and epidemiology of these diseases.

DOWNY MILDEW

Resistance Screening at ICRISAT Center

About 7 000 pearl millet breeding lines, test hybrids, and germplasm entries were screened for DM resistance in a 6-ha screening nursery during the rainy season and about 3 000 were screened in a 4-ha nursery during the postrainy season, utilizing the ICRISAT-developed "infector-row" system for inoculum provision (ICRISAT, 1976-1977 Annual Report). In this cooperative effort with plant breeders, at least one replication of all breeding trials was tested for DM resistance in the rainy season. Resistant plants were selfed and the selfed seed resown in the DM nursery during the postrainy season for further selection, and recombination of selected lines. By exerting high pressure for DM resistance in both the selection and recombination phases of the population-improvement projects, DM-susceptible populations were rapidly converted to DM-resistant populations, and DM-resistant populations were maintained (Table 43).

In addition to the ICRISAT breeding material, entries from five trials of AICMIP were screened in the DM nursery. Hybrids which appear equally resistant under low inoculum pressure in breeders' plots and farmers' fields gave widely differing DM reactions under high inoculum pressure in the DM nursery (Table 44).

Muitilocational Screening

In an attempt to identify stable DM resistance, an international cooperative screening program has been established in which resistant materials identified in the ICRISAT Center DM-screening nursery are exposed to many populations of *S. graminicola* under a wide range of environments. The program has two component nurseries—the pre-IPMDMN of about 150 entries which is tested at a few key DM hotspot sites in Africa and India, and the IPMDMN

Table 43. Advance in DM resistance in four pearl millet populations in three seasons through selection and recombination under high DM pressures.

	Season		
	Rainy 1976	Postrainy 1976	Rainy 1977
World Composite:			
Total (no)	234	35	228
< 5% DM (%)	82	69	83
Late Composite:			
Total (no)	270	38	278
< 5% DM (%)	33	66	72
Super Serere Composite:			
Total (no)	270	52	222
< 5% DM (%)	12	46	78
GAM 75:			
Total (no)	256	21	198
< 5% DM (%)	0	24	77

Table 44. Downy mildew incidence in five pearl millet hybrids in several trials in the ICRISAT screening nursery, rainy season 1977.

Hybrid	Trials	Range	Mean
	(no)	(%)	(%)
ICH 105	4	0.0-6.9	2.7
BK 560-230	4	22.4-29.1	25.5
PHB 14	6	22.8-46.5	30.6
BJ 104	7	27.7-57.1	41.9
NHB 3[a]	8	84.9-97.3	93.1

[a]Known high-susceptible indicator line.

of 45 entries that have successfully come through the pre-IPMDMN screening, which is tested at about 25 locations in eight countries in Africa and Asia (Fig 19) through the valuable participation and assistance of scientists in national programs.

The 1977 pre-IPMDMN. A total of 133 entries were sent to cooperators for testing at Kamboinse, Upper Volta; Kano, Nigeria; Hissar and Mysore, India, and at ICRISAT Center. Results were received from four locations. One entry, EB-74-75-1, was DM free at all locations, 22 entries had less than 10 percent DM at all locations, and 32 entries had less than 15 percent DM at all locations. These 32 entries will be moved into the 1978 IPMDMN.

The 1977 IPMDMN. The 45-entry 1977 IPMDMN was sent to cooperators at 24 locations in eight countries. Results were received from five locations in West African countries and from 11 locations in India. Two entries, SDN 503 and 700251, had DM infection-index values of less than 10 percent at all locations, and another nine entries (P-7, P-10, 700651, 700516, Ex-Bornu, SDN 347-1, 114-1-R, ICH 190, and Tulaja local) had less than 10 percent

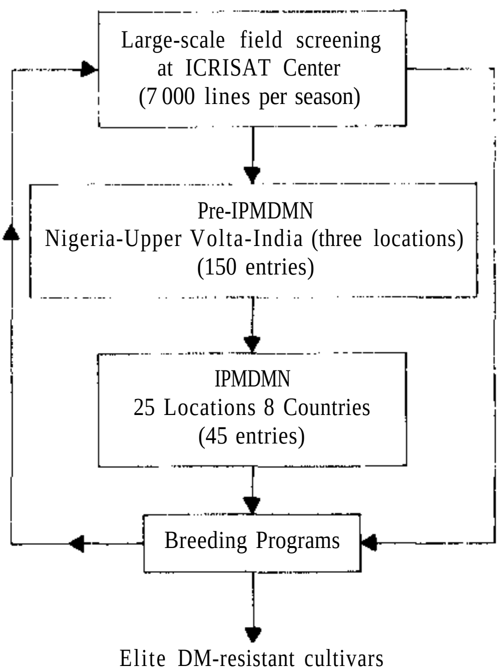


Figure 19. Summary of pearl millet DM screening activities in the ICRISAT cereal pathology program.

DM infection indices at 15 of the 16 locations. DM reactions of four of the best 1977 IPMDMN entries at the four most severe DM pressure locations were compared with the all-entry means and a moderate susceptible line (Fig 20). Nine of the best 10 entries originate from West Africa or are based on West African parents, and six of the best 10 were among the best ten 1976 IPMDMN entries (Table 45).

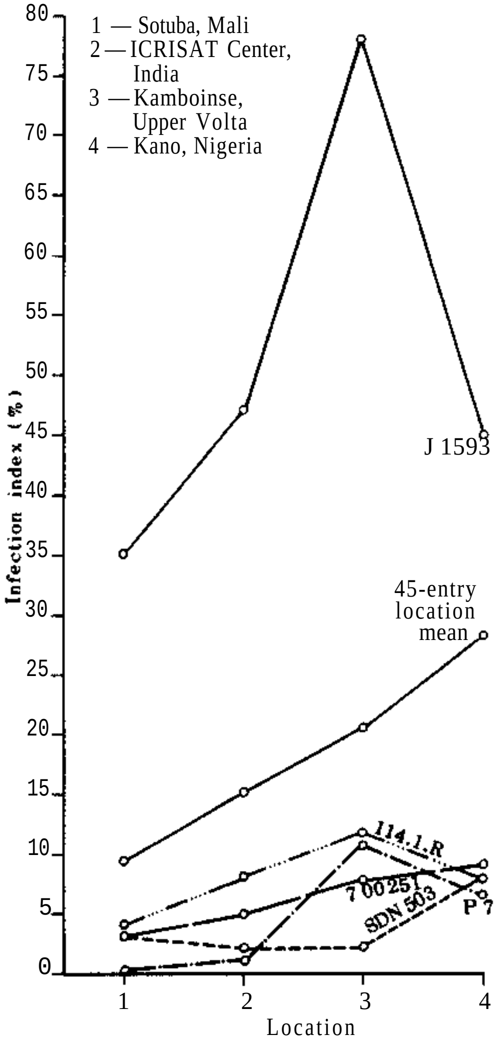


Figure 20. Performance of selected 1977 IPMDMN entries at four locations in India, Mali, Nigeria, and Upper Volta.

Alternative Control

During postrainy season 1977, the new Ciba Geigy systemic fungicide CGA 48'988 (RIDOMIL) was tested as a seed dressing for the control of pearl millet downy mildew in the DM-screening nursery. Two formulations (WP 10 and WP 25) were used with three application methods: i) Dusting—dry seeds were thoroughly shaken with the fungicide (8 g product/kg seed); ii) Soaking—seeds were stirred for 4 hr in aqueous fungicide suspension (8 g product/liter water/kg seed) and were then removed from the suspension and allowed to dry at room temperature: iii) Sticking—seeds were stirred in a methyl cellulose-fungicide suspension (8 g product/750 ml 1% methyl cellulose/kg seed) until they were thoroughly coated, and were then removed from the suspension and allowed to dry. The treated seeds were maintained at 20°C in an incubator overnight and were hand-planted the following day.

Plants grown from treated seed (treated plots) had significantly less DM and gave significantly more grain yield than did the check plots (Table 46). There was little DM in the treated plots until after 30 DAP. Mean grain yield from the treated plots was more than double that of the check plots.

The level of control was attained in spite of the severe inoculum pressure in the DM nursery. It is likely that a fungicide will be even more effective in plantings without continual inoculum supply from nontreated infector rows.

Seed-transmission Investigations

Mycelial detection. The following technique was developed to detect mycelium in pearl millet seeds. Seed harvested from partially infected inflorescences of the pearl millet hybrid NHB 3 was sundried, threshed, and freed of all glumes and debris. Five g of the seed was soaked in 100 ml of 10% sodium hydroxide containing 0.05% trypan blue at about 75°C for 20 min, after

Table 45. Downy mildew incidence and infection indices of selected entries in the 1976 and 1977 IPMDMN trials.

	1977[a]			1976[b]	
	Incidence		Infection index	Infection index	Rank
	30 days[c]	Final			
	(%)				
SDN 503	1.2	2.7	1.3	0.5	2
P-7	1.5	2.7	1.7	2.7	7
700251	1.7	2.6	1.8	1.4	4
Ex-Bornu	1.9	4.2	2.4	-	-
ICH 190	3.1	3.7	2.7	-	-
700651	3.3	4.6	3.0	0.5	1
SDN 347-1	2.3	4.3	3.0	2.7	8
700516	1.6	4.1	3.0	1.3	3
J 1593	25.4	35.4	27.9	30.7	46

[a]16 locations.
[b]14 locations.
Incidence (%) 30 days following planting.

Table 46. Downy mildew incidence 18, 31, 54, and 64 days after planting (DAP): DM infection indices 64 DAP, and grain yield in pearl millet cv NHB 3 grown from seed treated with two formulations of CGA 48'988 and from nontreated seed.

Treatment	Formulation	Incidence at DAP 18	31	54	64	Infection index	Yield
		(%)					(kg/ha)
Dust[a]	WP 25	0	0.3	12.8	23.8	12.5	1 350
Soak*	WP 25	0	0	17.3	27.5	16.2	1 357
Stick'	WP 25	0	1.8	16.7	28.5	18.0	1 102
Dust	WP 10	0.5	4.3	18.4	29.4	20.1	1 120
Soak	WP 10	0	2.2	23.9	31.2	20.8	1 313
Stick	WP 10	0	1.3	27.1	44.5	29.1	1 138
No treatment	-	15.0	44.6	55.7	65.8	59.5	800
L.S.D. (0.05)		2.4	7.9	11.9	15.2	12.2	277

[a]Seeds shaken with dry fungicide (8 g product/kg seed).
[b]Seeds stirred for 4 hr in aqueous suspension (8 g product/liter water per kg seed).
[c]Seeds stirred until well coated in methyl cellulose (MC)-fungicide suspension (8 g product/750 ml 1% MC per kg seed).

which the container was incubated at 55 to 60°C for 60 min. Following incubation, the seeds were tipped into a plastic sieve (0.5-mm mesh) and washed for 3 min in running tap water with continuous stirring with a fine brush. The washed seeds were boiled in lactophenol for about 3 min and then suspended in fresh lactophenol for observation. The cleared stained seeds were observed with a stereoscope, using dark-field illumination. In a small proportion of the seeds, blue-stained *Sclerospora-type* mycelium was clearly visible in a net around the scutellar region.

The technique is rapid (seed is ready for observation in less than 90 min), reliable, and as the seeds are not fragmented it allows accurate quantification of seed infection. An additional advantage of the nonfragmentation is the capability to accurately determine location of mycelium within the seed.

We have used the described technique on more than 20 seed samples from partially infected inflorescences and found that mycelial infection generally occurs in 1 to 3 percent of the seed, though one sample had no mycelium and two samples had higher levels (up to 10%). In none of the samples was the mycelium detected within the embryo.

Callus culture. In experiments at ICR1SAT Center, more than 2 000 calli were developed on modified-White's and Murashige and Skoog's medium from seed harvested from partially infected inflorescences. Dry mature seed was surface-sterilized in 0.1% mercuric chloride for 5 min prior to planting in the media. In no case did *Sclerospora*-type mycelium develop.

Grow-out tests. In a cooperative project with scientists at the quarantine department at the Royal Botanic Gardens, Kew, England, about 1 900 plants of DM high-susceptible 7042 were grown from dry surface-sterilized seed harvested from partial green ears (2.8% of seed carried *Sclerospora*-type mycelium) and no plant was detected with DM symptoms.

ERGOT

Pollination Effects on Ergot Susceptibility

Pollination of inflorescences of three male-sterile lines before or at the time of inoculation with *C. fusiformis* conidia reduced ergot to a low level and pollination 16 hr after inoculation resulted in significantly reduced ergot in comparison with inoculated nonpollinated checks (Table 47). As pollen germinates much more rapidly than *C. fusiformis* conidia, and as pollination induces rapid stigma withering, it seems likely that the pollination effect on ergot occurs through the reduction or removal of the infection path—the stigmas. The discovery of the pollination-based escape mechanism has major implications for resistance screening and cultural control measures. All heads to be inoculated should be bagged at the boot-leaf stage so that they emerge in a pollen-free environment and can thus be inoculated before they are pollinated. A possible cultural control measure, indicated by the results, is the planting of a cultivar that sheds pollen early with an

Table 47. Ergot-infected florets[a] in inflorescences of three male-sterile pearl millet lines subjected to various pollination (poll) and/or inoculation (inoc) treatments[b] in two experiments.

	Experiment 1		Experiment 2	
Treatment*	5141-A	111-A	111-A	5054-A
	(%)			
No inoc, no poll	<1	<1	0	0
Inoc, no poll	86	65	60	60
Poll, no inoc	0	<1	0	0
Poll 24 hr before inoc	2	3	2	3
Poll 8 hr before inoc	<1	<1	3	8
Poll immediately after inoc	3	4	3	1
Poll 16 hr after inoc	8	21	7	11
L.S.D. (0.05)	4	9	6	7

[a]Mean of 20 inflorescences per datum.

[b]Single-operation treatments and the first of double-operation treatments were done at the maximum fresh-stigma flowering stage.

ergot-susceptible hybrid, so that the synchronous protogyny in the hybrid coincides with pollen shedding in the cultivar. This possibility is now being evaluated in our program.

Resistance Screening and Development

At ICRISAT Center. Ergot-resistance screening at ICRISAT Center during 1977 was divided into two phases: i) Initial screening, in which 10 randomly selected heads in a single 5-m row of each entry were bagged at the boot-leaf stage and dip-inoculated in a honeydew-conidial suspension at the protogyny stage and were then rebagged, and ii) Advanced screening, in which entries selected during the initial screening phase were retested, with 20 plants per entry inoculated.

During rainy season 1977, 489 breeding lines were inoculated in the initial screening phase. Only one entry, 3/4 S-217-2-3, had less than 10 percent ergot infection index and another 15 lines had no more than 20 percent. Seed from these inoculated and "selfed" heads were carried forward for subsequent retesting.

Advanced screening was carried out on 109 pearl millet lines selected during initial screening in 1976. High levels of ergot occurred on some heads in all lines, and individual heads with low or no ergot infection in relatively less susceptible lines were selected for further testing. As the 1976 initial screening was done on open heads, with the opportunities for operation of the (then unknown) pollen-based escape mechanism, it is not surprising that most of them gave at least some plants which were highly susceptible when tested by the technique that does not permit the pollen-based escape mechanism to function. The occurrence of variability in ergot reactions among plants in a line is consistent with the outcrossing nature of this crop.

In an attempt to concentrate ergot-resistance genes and generate lines with higher degrees of resistance, more than 200 crosses were made among lines identified as relatively less susceptible. The progeny will be carried forward under heavy ergot pressure and the head-to-row procedure will be followed for several generations.

Multilocational testing. An International Pearl Millet Ergot Nursery (IPMEN) was initiated with cooperatorsat 11 locations in five countries. No line was identified with a high degree of ergot resistance at all locations, but five lines [SC-2(M)5-4, J 2238, SC-l(S4)27-2, J797-1, and Ex Bouchi 700638-3-2] had relatively less ergot at most locations. As the products of the improved screening at ICRISAT Center become available, the IPMEN entry performances are expected to improve.

SMUT

The smut resistance-screening work was conducted at Hissar in northern India during rainy season 1977. There, bagging plants at the boot-leaf stage promotes severe smut in susceptible cultivars. Of 541 lines screened at Hissar during 1977, 2 lines (EB 132-2 and EB 237-3-1) were smut free, and 9 had infection indices of less than 10 percent. Single-head selections were made for further testing in 1978.

The first International Pearl Millet Smut Nursery (1PMSN) was tested by cooperators at two West African and two Asian locations. The best five entries were IP 2253, J-6, ND 2282-79-1, 700130, and J 1999. The best selections made at Hissar in rainy season 1977 will be tested in the 1978 IPMSN.

RUST

Progeny for 113 rust-free plants, identified during the 1976 postrainy season germplasm grow-out, were tested for rust susceptibility at Bhavanisagar during rainy season 1977 and at ICRISAT Center during postrainy season 1977. Rust severity ranged from 0 to 65 percent at Bhavanisagar and from 0 to 100 percent at ICRISAT Center. One entry, IP 537-B, was rust free at both locations, 6 entries had a maximum rust score of 5 percent, and 24 entries had no more than 10 percent rust in any replication at either location. The best lines will go

Figure 21. *Inoculating a pearl millet plant in screening for resistance to smut.*

into an International Pearl Millet Rust Nursery in 1978.

Seventy-four lines selected during screening at ICRISAT Center from 1974 through 1976 were tested at six locations in India in a co-operative trial with national program scientists. Eight entries had no more than 10 percent rust at any location, but some entries had distinct differential reactions among locations.

Microbiology

Of 142 pearl millet lines examined for their ability to stimulate nitrogen fixation by bacteria associated with their roots, activity was detected in 107 lines. Of these, 10 cultivars (Table 48) were particularly active in our core assay of roots and associated soil (for details see ICRISAT Annual Report 1976-77, p 43), with fixation rates of more than 100 ug N/core per day. Of 52 lines tested over three to five seasons,

Table 48. Millet lines with high N_2-ase activity.

		N_2-ase activity (µg N/core per day)	
Cultivar	Origin	Mean[a]	Range
IP 2787	Chad	559	17-1586
J 1279	India	326	8 1571
GAM-73	Senegal	246	60-370
PIB-155	India	235	0-872
PHB-12	India	205	1-858
HB-3	India	143	2-401
J 88	India	114	0-539
Ex-Bornu	Nigeria	105	9-252
Sauna D_2 x Ex-Bornu-2	ICRISAT selection Sauna D_2 from Senegal[b]	103	57-167
IP-2789	Chad	102	0-271

[a]Measured by acetylene-reduction assay over 24 hr, of an 18 cm diam x 22 cm deep core of roots plus soil taken over the crown of the plant. Values mean of five cores.
[b]Cross made at Institute for Agricultural Research, Samaru, Nigeria.

13 had activity greater than 25 µg N/core per day in at least three seasons and two lines (GAM-73 from Senegal and IP-2788 from Chad) had more than 50 µg N/core per day.

Activities varied a great deal from season to season, and from field to field. The most consistent activity was obtained for an irrigated summer planting in 1977 when more than 75 percent of the 123 assays (each the mean of five cores) were active (>25µg N/core per day), representing 55 of the 78 millet lines tested. The best rainy season activity was in 1976, when 42 percent of the 157 assays had activity, representing 46 of the 96 entries tested. The least activity occurred in summer season 1978 in a field, probably growing millet for the first time, where only 5 percent of the 625 assays were active.

In our acetylene-reduction assay of cores containing roots and soil, the nitrogenase activity measured is usually linear over the first 24 hr, with little or no lag in the onset of ethylene production (Fig 22), suggesting that we are not inducing activity by our assay procedure.

Several minor millets including *Eleusine coracana, Setaria italica, Panicum* spp. *P. miliaceum* stimulated N_2-fixation over several seasons. Cultivars of *S. italica* had activity in four out of five seasons. Several tropical grasses belonging to genera *Brachiara, Cenchrus, Chloris, Cymbopogon, Dicanthium, Euchlaena, Panicum, Pennisetum, Setaria, Sorghum* were grown without addition of any nitrogen fertilizer over 19 months in an observation garden which is irrigated in the dry season. Thirty-four out of 48 entries were very active in stimulating N_2-fixation (Table 49). The activity was associated with the crown of the plant and with more distal roots so that virtually the whole sward area could be considered active. The nitrogen content of the top 30 cm of soil was 0.064% N, and in the 30-90 cm zone it was 0.03%. The dry-matter yields, particularly of Napier bajra, a cross between *Pennisetum americanum* and *P. purpureum,* have been quite spectacular (Table 50). For one Napier bajra entry, we calculate that over 77 tons/ha of dry matter have been removed, including 514 kg N. The uptake of nitrogen by some of these entries has been greater than what would normally become available from mineralization of organic matter, even at the rate of 5 percent per annum. There is sometimes evidence of nitrogen deficiency when compared with N fertilized plants close by. However, such observations suggest that these plants are either extraordinarily efficient in taking up available nitrogen from the soil or perhaps they are also stimulating a significant level of nitrogen fixation.

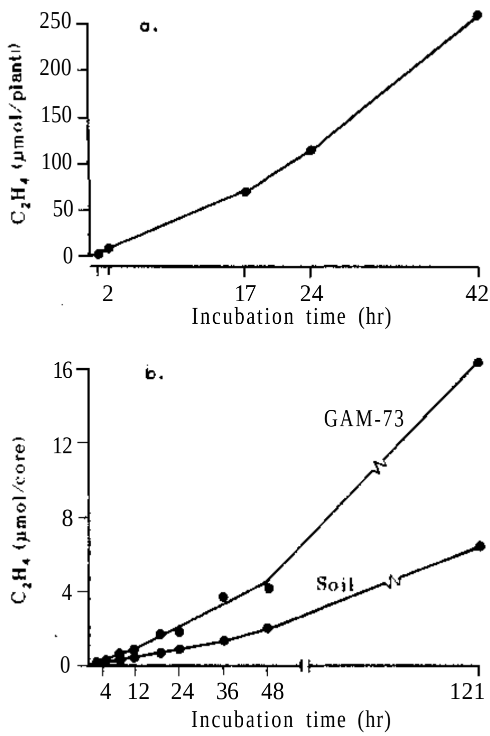


Figure 22. Nitrogenase activity associated with: a) core, 28 by 48 cm, of soil containing roots of Pennisetum purpureum *Pusa Giant Napier; and b) cores, 15 by 20 cm, containing soil alone, and soil with roots, of a GAM 73 millet plant 86 days old. In both cases, above-ground parts of the plants were removed just prior to taking the cores.*

Table 49. Tropical grasses with high N_2-ase activity.

	Number of Cores/ plant*	N_2-ase activity[b] µg N/plant per day
Cenchrus ciliaris (Buffei grass)	7	209
Cenchrus setigerus	7	1380
Chloris gayana (Rhodes grass)	17	202
Coix lactyma	7	234
Cymbopogon citratus (lemon grass)	30	894
Dicanthium annulatum	15	285
Panicum antidotale	38	492
P. ciliaris	6	417
Pennisetum clandestinum	1	67[c]
P. hohenackeri	3	267
P. mezianum (4 n)	8	88
P. orientate	7	94
P. purpureum	27	1 760
P. purpureum (Pusa giant napier)	37	2 435
P. americanum x *P. purpureum* (Napier bajra)	3	1 789
P. setaceum	8	100
P. squamulatum	21	158
P. villosum	7	521
Setaria sphacelata	3	1 354
Sorghum halepense	23	1 747

[a] 15 cm diam x 22 cm deep core of roots plus soil.
[b] Estimated from acetylene reduction over 24-hr assay period.
[c] Plant produces a sward from runners. Activity for one 15 cm diam core only.

Bacteria capable of fixing nitrogen were isolated not only from rhizosphere soil and root surfaces of pearl millet and related *Pennisetum* species, but also from roots of field-grown plants surface sterilized, suggesting that bacteria are also present within the root tissue. Thirty of the 118 cultures with nitrogenase activity, isolated from pearl millet roots in N-free media, were active N_2-fixers in standard culture media. A similar proportion of active isolates (120 out of 316) was obtained from the roots of other *Pennisetum* species and grasses. *Azospirillum-like* organisms were isolated from roots of *P. americanum x P. Purpureum* crosses.

Table 50. Dry-matter production and N uptake by *Pennisetum* species 19 months after sowing.

	Dry-matter production (kg/ha)[a]	Nitrogen uptake (kg/ha)[b]
Pennisetum americanum x *P. purpureum* (Napier bajra)	77 100	514
P. purpureum (Pusa giant napier)	47 600	311
JVM-1	25 800	249
P. squamulatum	38 300	277
P. purpureum x *P. squamulatum*	20 300	148
P. purpureum	36 500	243
P. mezianum (4 n)	27 300	180
P. setaceum	18 300	123
P. hohenackeri	16 500	117
P. villosum	14000	87
P. clandestinum	10 800	76
P. orientate	7 500	49

[a] Estimated from data for two row plots, net harvest area 6 m^2, cut three times.
[b] From Kjeldahl N analyses of plant tops at each cut.

Looking Ahead in Pearl Millet

Work will continue on developing high-yielding hybrids, synthetics, and experimental varieties, keeping a continuous inflow of genetic diversity both from new germplasm introductions and recently developed breeding material, particularly those generated in Africa. The resistance

Figure 23. Large amounts of dry matter have been produced by Pennisetum *spp. without nitrogen fertilization in an Alfisol under irrigation.*

to downy mildew, ergot, and smut already identified will be incorporated into high-yielding lines. Useful characteristics relating to the use of pearl millet in intercropping, to seedling vigor, fertilizer response, and to grain quality will, as they become available, also be incorporated into breeding material.

Microbiology. Our efforts will be concentrated on measuring the amounts of nitrogen involved in these systems, using $^{15}NO_3$ and $^{15}N_2$ and starting initially with pot and lysimeter balance studies. We then plan to determine the nitrogen balance for millet production in field studies in several locations in SAT India and West Africa.

We wish to gain a better understanding of the variability in nitrogenase activity. Does it reflect host genetic differences, microorganism-distribution patterns in the field, or artifactual variability associated without assay method?

We will isolate organisms from different locations for use in our inoculation experiments. A great deal of work needs to be done to ensure that inoculation responses can be obtained and that our inoculation methods are reliable.

Active lines identified in germplasm screening and from crosses which we make will be tested in different locations.

species, and the provision of seed from the ICRISAT collection for evaluation and use in programs of colleagues everywhere.

To increase, through breeding, the ability of genotypes to produce higher yields, optimum protein content and quality, and characteristics favored by the consumer.

In its management of the germplasm collections and genotypes resulting from its work, ICRISAT intends to continue its cooperation with plant breeders in all national and regional pulse-improvement programs, hoping to provide superior genetic materials for the use of others who are attempting to develop tailor-made lines needed for conditions in a specific location. The segregating of genotypes with a wide diversity of genetic characters, plant architecture, physiological attributes, and insect and disease resistance is a major goal.

ICRISAT CENTER

ICRISAT Center is the major research facility of the Institute. Located near the village of Patancheru on the highway between Hyderabad and Bombay, the facility includes two major soil types found in the semiarid tropics. The red soil (Alfisol) is light and droughty; the black soils (Vertisols) have a great water-holding capacity. The availability of these two soil types provides an opportunity to conduct selection work under conditions representative of many areas of the SAT. Three distinct agricultural seasons—rainy, postrainy, and hot dry summer-characterize the area. The rainy season, also known as monsoon or kharif, usually begins in June and runs into September; more than 80 percent of the annual rainfall occurs during these months. The postrainy season of October through January, also known as postmonsoon or rabi, is dry and cool; days are short. From February until the rains begin again is the summer season, hot and dry, with daily temperatures between 36° and 43°C.

Chickpeas are planted in October or November and grow on residual soil moisture; only one generation per year is grown. June and July are the months in which pigeonpeas are planted; they grow throughout the season and on into the postrainy season without irrigation. An additional generation of early maturing types is planted at ICRISAT Center in December and grown with irrigation so as to provide an additional generation for the breeding program.

PIGEONPEA

Pigeonpea

Germplasm

COLLECTION

Within India, collections were made in the western Himalayan foothills, the southern parts of the Western Ghats, Assam, Uttar Pradesh, and Gujarat. A total of 197 accessions of pigeonpea were obtained, mainly from farmers' fields. Of the 120 pigeonpea samples collected earlier in Kenya, 62 received clearance from quarantine. Samples were obtained from Burma (17), Venezuela (15), Nepal (9), Pakistan (8), and Nigeria (7). The collection now houses 5 971 accessions.

Of *Atylosia,* pigeonpea's wild relative, 29 samples were found, including *A. mollis.* Several *Rhynchosia* species, which are also closely related to pigeonpea, were added to the collection.

EVALUATION AND REJUVENATION

A total of 1 016 lines were grown in 1977 and data on morphoagronomic characters recorded. Maintenance of *the* outcrossed population as collected was attempted, instead of purifying the accessions as inbred lines. Selfed-seed obtained from about 30 plants of each collection were bulked to constitute the next generation. Seed supplied against requests is from open pollination because of limited selfed-seed. Part of the collection is rejuvenated during the postrainy season, when the plants are much smaller and can be bagged entirely with muslin; all seeds then obtained are selfed.

In addition to the standard evaluation, the following special evaluations were carried out.

Photosensitivity. To classify germplasm into the four photoperiod-response groups identified at ICRISAT Center, about 500 accessions were screened during 1976-1977, by sowing on 14 Nov and 14 Dec 1976 and on 14 Feb 1977. In 1977-1978, 1 335 accessions were screened. We will screen each year until we have these data on all entries in the germplasm bank.

Seed-viability tests and seed-coat study. Germination of seed of five cultivars of pigeonpea from the 1974-1975 harvest, stored in three types of seed containers, at normal room temperature (24 37°C) and in an air-conditioned room (14-18°C), was tested after 6, 12, 22, and 40 months of storage. Seed of all cultivars stored at ambient room temperature showed a marked reduction in germination, when compared to that of seed stored in the cooled room.

With regard to containers (cloth bags, paper bags, and plastic bottles) tested, a marked decrease in germination percentage was noted after 40 months of storage at room temperature (Fig 24). Seeds stored in paper bags gave the highest germination. However, the differences among containers under cool-storage conditions were negligible. This experiment indicates that it is not desirable to store pigeonpea in cloth bags and plastic containers for more than a few months when cold-storage facilities are not available. Paper bags are dependable if seed is protected from bruchids and other pests.

Seed stored for 40 months with naphthalene balls (very effective against bruchids) produced normal plants when grown out. Slightly reduced initial seedling vigor, observed after 40 months' storage in comparison with 6 months of storage, can probably be ascribed to age. Germination and emergence were equivalent to that of the fresh samples.

DOCUMENTATION

Data on 4 490 lines evaluated in previous years were entered into the computer. It was decided not to publish a catalog of the entire collection; instead specialized listings based on user needs will be supplied on request.

SEEDS SUPPLIED TO OTHER AGENCIES

A total of 758 lines were supplied to 18 research agencies in India, and 71 lines were supplied to 4 agencies in other countries (Table 51).

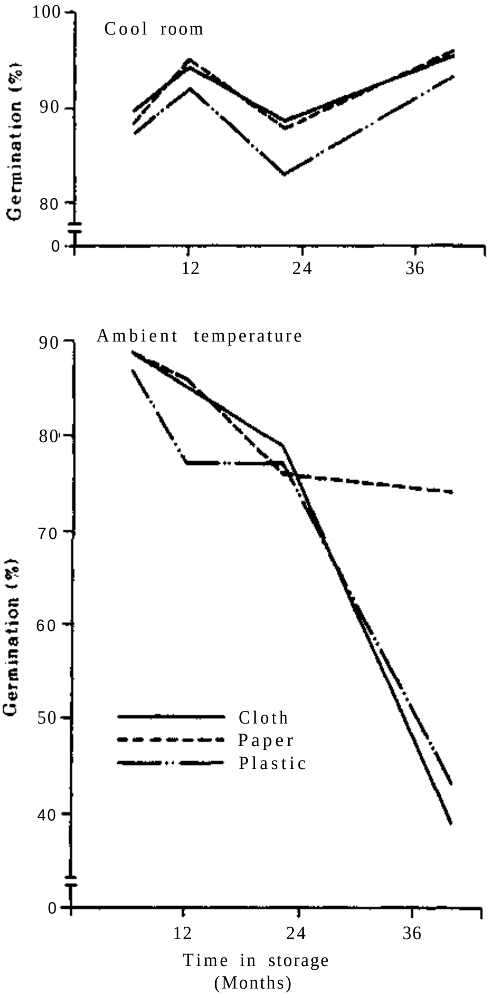


Figure 24. Average germination of five pigeonpea cultivars after storage at ambient and at cool temperatures in paper bag, cloth bag, or plastic bottle.

Breeding

Pedigree selection for locally adapted types of medium maturity at ICRISAT Center, early maturity at Hissar, and of late types at Gwalior continued. Advancing of bulk populations with mass selection for maturity and yield is in progress at all three locations. Male sterility was introduced into some of the bulk populations to increase crossing among plants. In addition to the above breeding procedures, which will result in pure lines and improved populations, the breeding of superior F_1 hybrids for farmer use received additional emphasis. The major emphasis is on increasing yield of grain types (those producing dry grain for use as dhal—dehulled split grains), but we are also selecting specifically for vegetable types with large grain for use as green peas.

There has been a continuing interest in India in developing a pigeonpea-wheat rotation, involving short-season pigeonpea. There is need in several areas of the SAT for additional legume crops, that produce high yields in a short period of time, for animal as well as human food. In many such areas, machinery is available for wheat production that could serve for mechanized pigeonpea production.

The University of Queensland, Brisbane, Australia, initially studied pigeonpeas as a forage crop, and more recently has developed suitable agronomic practices, using a conventional photoperiod-sensitive line for mechanized grain production. From the first material supplied by ICRISAT, University scientists selected an off-type plant, some of the progeny of which have proved to be photoperiod insensitive. To strengthen research on short-season photoperiod-insensitive pigeonpeas, a formal relationship between ICRISAT and the University of Queensland was developed during the year.

Following identification of the off-type plant in 1976, S_1-derived families have been advanced to the S_3 generation. At 28°S, this material flowers within approximately 60 days, regardless of planting date, and growth-cabinet studies suggest it is insensitive to photoperiods up to 16 hours.

A bulk population of the insensitive material was evaluated at various densities for September and January plantings, and the September

Table 51. Pigeonpea germplasm lines supplied to research agencies in India and other nations during 1977-1978.

Institution	Location	Entries
INDIA:		
Jawaharlal Nehru Krishi Vishwa Vidyalaya	Jabalpur, Madhya Pradesh	169
Medium Research Station, University of Agricultural Sciences	Gulbarga. Karnataka	156
Department of Botany, Kakatiya University	Warangal, Andhra Pradesh	82
Department of Plant Breeding & Genetics, C.S. Azad University of Agriculture & Technology	Kanpur, Uttar Pradesh	76
Redgram and Soybean Improvement Scheme, Agricultural Experiment Institute	Vayalogam, Tamil Nadu	60
Banaras Hindu University	Varanasi, Uttar Pradesh	48
Department of Botany, Osmania University	Hyderabad, Andhra Pradesh	42
Department of Agricultural Botany, University of Agricultural Sciences	Bangalore, Karnataka	34
University of Udaipur	Udaipur, Rajasthan	15
Department of Plant Breeding, G.B. Pant University of Agriculture & Technology	Pantnagar, Uttar Pradesh	15
Department of Plant Breeding, Assam Agricultural University	Jorhat. Assam	15
Pulses and Oilseeds Research Station	Berhampore, West Bengal	10
Department of Entomology, Agricultural Research Station	Badnapur, Maharashtra	10
Agricultural Research Station	Parbhani. Maharashtra	5
Agricultural Research Station, University of Udaipur	Durgapur, Jaipur, Rajasthan	3
Pulse Research Station	Nayagarh, Orissa	3
Indian Grassland & Fodder Research Institute	Jhansi, Uttar Pradesh	2
Agricultural College, A.P. Agricultural University, Rajendranagar	Hyderabad, Andhra Pradesh	1
OTHER COUNTRIES:		
Gene Bank, Institut fur Pflanzenbau and Sastgutforschung	Braunschweig-Volkenrode (FAL), Federal Republic of Germany	40
Plant Quarantine, Kenya Agricultural & Forestry Research Organization	Nairobi, Kenya	20
M/s Macondray & Company, Inc.	Manila, Philippines	6
Welfare Missionary	Apia, Western Samoa	5

planting was ratooned at 12 cm following harvest in January. Seed yields were high (Table 52) in the planted and ratooned crops. Low-, density plots yielded as well as high-density plots in the ratoon, and different plant types were identified. In a separate December planting, individual lines have yielded up to 4 600 kg/ha on the first harvest in small plots, and yields greater than 3 000 kg/ha were common.

MATURITY CLASSIFICATION

With the wide range of maturity in pigeonpea, which is important in adaptation of cultivars to

Table 52. Mean seed yield of photoperiod-insensitive pigeonpea at various densities in 25-cm rows at Redland Bay (28°S), Queensland, Australia.

		Seed yield		
Sowing date	Density	Planted	Ratooned	Total
	(plants/ha)	----------------	(kg/ha)	----
26 Sep 1977	100 000	I 320	2400	3 720
	200 000	1970	2 620	4 590
	300 000	2 130	2 460	4 590
	400 000	2 580	2 710	5 290
	500 000	2 630	2 450	5 080
9 Jan 1978	100 000	1610	-[a]	–
	200 000	2 180	-	-
	300 000	2 670	-	–
	400 000	2400	-	-
	500 000	2 890	-	-

"Not available.

agroclimatic areas and agronomic systems, we have found it useful to develop a scale of maturity classes. This is based on days to 50 percent flowering at ICRISAT Center, and some reference cultivars for each maturity group have been identified (Table 53). Reference to maturity groups is made in several instances in this report.

CULTIVAR PURIFICATION

One consequence of the partial crossing typical of pigeonpea is continuing heterozygosity in breeding lines and cultivars. We undertook to purify some existing cultivars in order to have stable genotypes that can be maintained. One question was the possible effect of reducing heterozygosity on the vigor of the cultivar. After five generations of selfing (three generations of plant to row followed by two of bulk selfing of rows), we compared the yields of the original cultivars with derived selfed lines. Figure 25 plots the distribution of yields of derived inbred lines of cv Pant A-3 in relation to the check cv. In only one of seven cultivars tested were derived inbred lines significantly higher yielding than the original cultivar, indicating in general no advantage or disadvantage for either a pure line or partially heterozygous cultivar for yielding ability in a single environment. Eight of the inbred lines have been entered in the All-India Coordinated Trials. The multilocation data will

Table 53. Maturity classification of pigeon peas grown at ICRISAT Center.

Maturity Group	Days to 50% flowering	Reference cultivars
0	<60	Pant A-3
I	61- 70	Prabhal, Pant A-2
II	71- 80	UPAS-120, Baigani
III	81- 90	Pusa Ageti, T-21
IV	91- 100	1CP-6
V	101- 110	No. 148, BDN-1
VI	111- 130	ICP-1,6997, ST-1,C-11
VII	131-140	HY-3C, 7035
VIII	141 - 160	7065,7086
IX	Above 160	NP(WR)-15, Gwalior-3, NP-69

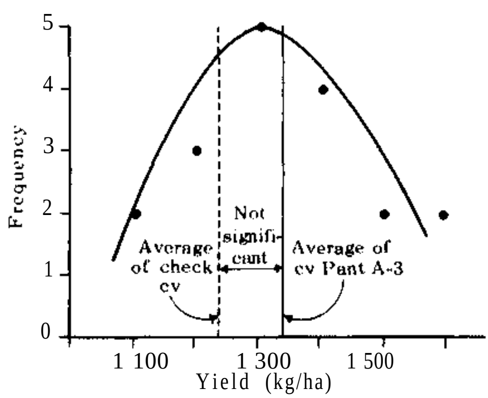


Figure 25. Relative yield performance of 18 selfed lines of cv Pant A-3 and two check cultivars. Seed of Pant A-3 was from the breeder and a bulk maintained at ICRISAT Center.

be of interest in making a preliminary assessment of the relative stability of inbreds and open-pollinated cultivars.

MULTILOCATION TESTING

High-yielding lines from our breeding program are entered under ICPL (ICRISAT pigeonpea line) designations in the Indian trials. In order to evaluate new lines as thoroughly as possible before offering them for national trials, we seek the cooperation of local breeders in screening advanced lines. Breeders in five countries have accepted from 19 to 33 promising advanced lines for initial evaluation over locations in 1978.

HYBRID PIGEONPEA

The success of hybrids in any crop depends upon the presence of sufficient hybrid vigor and the availability of an economical hybrid-seed-production system. Our studies on hybrids in previous years indicated the presence of sufficient heterosis to warrant its exploitation; last year we reported the availability of genetic male sterility. Plants carrying the male-sterile gene in the homozygous-recessive condition are easily identified by their white translucent anthers. For our first test of hybrids with male-sterile female parents, 15 elite lines were crossed by hand pollination with two male-sterile stocks, MS-3A and MS-4A. We compared the yield performance of the hybrids and their pollen parents in intercropping trials with sorghum. The best hybrid, MS-3A x ICP-7118 (C-11), yield 31.5 percent more than did the best cultivar (C-11) in the experiment. Seeds of this hybrid were produced in a winter planting and it is being tested at 10 locations in the All-India Coordinated Trials.

PHYTOPHTHORA STEM BLIGHT

Blight reaction of parents, F_1, and F_2 populations indicated that the resistance of cv BDN-1 to the ICRISAT isolate was controlled by a single dominant gene. Detailed studies on the inheritance of resistance against different isolates and the allelic relationship of the genes in the different resistant parents are in progress.

VEGETABLE-TYPE PIGEONPEA INTERNATIONAL TESTS

A vegetable-type pigeonpea nursery of 38 entries was sent to 16 locations in 11 countries; results were received from only 6 countries. Seven entries, in spite of very early maturity (up to 32 days earlier than the earliest check), outyielded the late-maturing local checks.

This year, two sets of replicated international trials-VPPIT-1 (early) and VPPIT-2 (medium maturity)—were sent to 15 locations in eight countries.

INTERGENERIC HYBRIDIZATION

Attempts have so far been made to cross six diverse pigeonpea cultivars with eight different species of *Atylosia A. lineata, A. sericea, A. scarabaeoides, A.albicans, A. trinervia, A. cajanifolia, A. platycarpa,* and *A. volubilis.* The *A. platycarpa* and *A. volubilis* could not be crossed with any of the six pigeonpea cultivars. The intergeneric hybrids were backcrossed to their respective pigeonpea parents as the recurrent parents. Interspecific crosses of *A. lineata* with *A. scarabaeoides* and *A. albicans* and of *A. sericea* with *A. scarabaeoides* were successful.

F_2 data from crosses of different pigeonpea cultivars x *A. scarabaeoides* indicated that characters of *Atylosia* are governed by either one or two major genes. Hairiness of pods was controlled by a single dominant gene in ICP-6915 x *A. scarabaeoides.* The glabrous pod character of pigeonpea (allelic to hairiness) was inhibited by a gene present in the *Atylosia* parent in ICP-6997 x *A. scarabaeoides.* In both the above crosses the nonpersistent strophiole character of pigeonpea, a major character on the basis of which the two genera have been separated taxonomically, was suppressed by an inhibitory gene of the *Atylosia* parent. In the crosses of *A. scarabaeoides* with cv ICP-6915 and 7035, the mottled seed-coat character of *Atylosia* was controlled by two complementary genes and in the cross with ICP-6997 it was controlled by duplicate genes with the double-recessive giving non-mottled seeds. Joint segregation studies indicated that hairy pods and strophioled seeds arc linked.

Physiology

GROWTH ANALYSIS

Determinate vs indeterminate cultivars. Dry-matter accumulation, yield, and yield components of determinate and indeterminate cultivars in three growth-duration classes (early, medium, and late) were studied. At flowering, plant height, leaf number per plant, and dry weight progressively increased in cultivars of later maturity (Fig 26). The determinate and indeterminate cultivars did not differ in branch number per plant, but yields were always lower in the former. Early cultivars gave lower yields than did cultivars of medium and late maturity.

Growth and development of postrainy season pigeonpeas. In areas where winter temperatures are not too low, postrainy season pigeonpeas are an attractive possibility. Lower temperatures during the early period of growth inhibit the rate of dry-matter accumulation and the short-day sensitivity results in early initiation of reproductive growth. These two factors limit per-plant productivity, but the harvest index is higher than in a full-season crop. With increased population density, yields are as high as, or even higher than, the full-season crop (Table 54).

With the reduced crop duration in the postrainy season resulting from short-day sen-

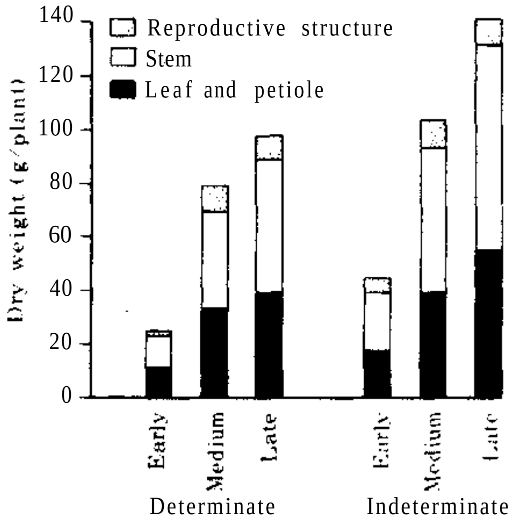


Figure 26. Dry-matter distribution at flowering in early, medium-, and late-duration pigeonpea at ICRISAT Center, rainy season 1977.

Table 54. Average performance of cultivars of different maturity in full-season (rainy season) and postrainy season plantings.

Cultivars	Days to maturity		Grain yield		Harvest index	
	R[a]	PR[a]	R	PR	R	PR
	(no)	(no)	(kg/ha)	(kg/ha)	(%)	(%)
Early	144	130	938	915	26	33
Medium	190	130	1.454	1 254	27	35
Late	210	153	651	1 188	25	29

[a] R = rainy season; PR = postrainy season.

sitivity of pigeonpea, medium and late cultivars become early and early cultivars become extra early. The earlier cultivars have least leaf area and less total dry-matter production.

Time of sowing had a marked effect on the performance of postrainy season crops. September sowing was found to be the best. Also, there was a positive response to increasing plant density. Yields decreased with progressively later dates of plantings, irrespective of plant density. Thus, early sowing and increased plant density optimize yield. Harvest index did not change with dates of sowing from September through November.

Yield of the postrainy season crop was not increased by a single irrigation in either the vegetative or the reproductive stage. Yields increased when the crop was irrigated in both the vegetative and the reproductive stages of growth. One possible explanation is that a single irrigation was not sufficient to join the top wet zone to the deeper moisture-charged zone and was therefore ineffective.

Source-sink relationship. Last year we hypothesized that partial leaf removal under conditions of limiting water supply improved the water status of the remaining leaves on the plants (because of reduced total transpiration), and thus increased the efficiency of photosynthesis of the remaining green tissues. This apparently explained why the ill effects of defoliation were not directly proportional to the degree of defoliation.

To check this hypothesis, we applied this year a defoliation treatment with and without irrigation. We found no interaction of defoliation and irrigation treatment, suggesting our hypothesis was incorrect. We have not identified the specific mechanism that provides compensation for defoliation. Such factors as uniformity of light distribution on the remaining green tissues (leaves, stem, and pods) and/or remobilization of photoassimilates from other parts of the plant may account for the compensation.

Response to nutrients. Soil applications of 200 kg N/ha on deep Vertisols increased dry-matter production, but not grain yield, in 1976 (Table 55). Total uptake of nitrogen increased in the 200-kg treatment, mostly because of more dry matter in plant parts other than the grain. The crop receiving no additional nitrogen removed 5.5 kg P/ha at a dry-matter production level of 6 015 kg/ha.

The effect of foliar fertilizations with urea, in combination with P, K, and a growth regulator (oc naphthylacetic acid) was investigated this year. There were responses to urea alone and to urea in combination with other treatments, but the yield increases were not significant.

Ratooning in pigeonpeas. Ratooning has been demonstrated to be an effective and useful means of exploiting the perenniality of pigeonpea by extending the grain yields of the full-season crop. Experiments were continued on means of increasing the efficiency of ratooning. On a light Alfisol of low water-holding capacity, a single irrigation after the first harvest almost doubled the ratoon yield. One irrigation was not effective on Vertisol, because of its high water-holding capacity.

The best time to take the first harvest was investigated in relation to the second harvest and total yield. Early harvesting at physiological maturity decreased the first-harvest yield; yields progressively increased with delay in harvesting up to full maturity. The first and second flush could be harvested together to reduce the total cost of harvest. However, such

Table 55. Grain yield and N and P uptake response in pigeonpea growing on a deep Vertisol receiving 200 kg N/ha at ICRISAT Center, 1976.

Nitrogen application	Plant part	Weight	Uptake N	Uptake P
(kg/ha)		(kg/ha)	(kg/ha)	(kg/ha)
0	Grain	1 007	34.7	2.9
	Total dry weight	6015	82.2	5.5
200	Grain	1 072	38.8	
	Total dry weight	8 593	124.4	

Figure 27. Experiments on increasing the efficiency of ratooning—regrowing from stubble —in pigeonpea continued at ICRISAT Center on irrigated and nonirrigated Vertisols.

a practice decreased yield, primarily because of the shattering of pods from the first flush. To overcome the problem, shatter-resistant cultivars would be needed.

Ratooning tends to increase the sensitivity of cultivars to diseases and may result in buildup of both insect pests and disease. There is often a reduction in plant stand in the ratoon crop, especially where *Fusarium* wilt is present in the soil.

Waterlogging. Temporary waterlogging occurs in the wet season and severely affects plant stands and, in consequence, yields. Facilities for creating waterlogged conditions were developed last year and found to be very effective for screening limited numbers of cultivars. Six days of waterlogging were required to induce waterlogging symptoms in plants in either the preflowering or postflowering stages.

A modification of this screening method to permit handling of more lines was tested this year. Material was grown in earthen pots immersed in ponded water for 6 days, starting 6 weeks after sowing. However, this method gave very inconsistent results.

Soil salinity. Some of the areas under pigeonpea cultivation are either saline or alkaline in nature. Differential cultivar reaction to these adverse conditions appears to exist. Cultivaral differences in response to salinity were tested by using graded levels of salts ($NaCl:Na_2S0_4:CaCl_2$ in 7:1:2 meq ratios). Germination was delayed with increasing levels of salinity of mixed salts up to 100 meq/kg soil. Clearcut differences were visible between the tolerant and susceptible cultivars at a salt concentration of 20 meq/kg soil.

Ovule abortion—a limitation to maximum yield. We reported last year that the potential seed number, as determined by ovule number per carpel at flowering, is never realized. Earlier studies indicated that soon after fertilization the developing ovules stimulate development of the pod wall and of the partitions which form the locules. Abortion of an ovule at an early stage results in the development of no locule, but the locule develops when abortion of an ovule is delayed. An estimate of the potential seed in a pod can be made by counting the number of ovules (by dissecting flowers), and abortion estimated by counting seeds at harvest.

This year, ovule abortion ranged from 0 to 5.5 percent in different cultivars. During 1975, ovule abortion was as high as 32 percent. Differences in ovule abortion from year to year are likely related to climatic conditions.

Positive correlations between 100-seed weight and number of ovules, locules, and seeds per pod suggest no limitation of photoassimilate transport to developing pods. If such a limitation exists, there would be a negative correlation between seeds per pod and 100-seed weight.

Entomology

SURVEY OF INSECT PESTS ON PIGEONPEAS

In India alone, more than 200 insect species have been reported to damage pigeonpea, but most of these are sporadic and localized in importance. Insects feed on the crop from the seedling stage, but early leaf and bud damage appears to have little effect on later growth and grain yields. Even if the first flush of flowers or pods is destroyed by pests, a second flush will be produced if soil moisture and climatic conditions are favorable. We are thus not too concerned about leaf, bud, and early flower damage caused by insects, given the tremendous compensatory capability of this crop, but real losses to insect pests clearly occur, particularly in pods found to be damaged at harvest. Thus, our surveys in India concentrate upon sampling the farmers' crops at or near maturity and we record the percentage of damage in pods on the plants at that time. Results from 3 years of such surveys are summarized in Table 56. Damage by lepidopteran pod borers, mostly *Heliothis armigera*, is of greatest importance in the south, whereas podfly, *Melanagromyza*

Table 56. Percentage of pigeonpea pods damaged by insect pests in farmers' fields in northern, central, and southern India, based on surveys conducted by ICRISAT, 1975-1978.

	North (n=161)[a]	Central (n= 136)	South (n = 218)
	(%)		
Lepidopteran borers:	16.7	24.5	30.8
Podfly	20.8	24.1	3.4
Hymenoptera	0.1	3.2	1.4
Bruchids	0.4	1.1	5.2

[a] Number of fields surveyed.

obtusa, is of more importance in central and northern India.

HOST-PLANT RESISTANCE

Progress was made with the methodology of screening for host-plant resistance in the past season. The initial testing is of unreplicated small plots; from these we reject those that are clearly more susceptible, or yield less, than the checks. Subsequent testing is of larger plots with replication. In this way, we have screened the germplasm and some breeding material, and found consistent differences among cultivars in susceptibility to losses caused by lepidopteran pod borers, podfly, and other pests. In the 1977 season, very heavy *H. armigera* infestations completely destroyed the first crop on some of the trials, but the second flush from these was harvested and substantial differences in the ability to recover noted.

For the more-advanced stage evaluation, the use of balanced lattice-square designs with 16 entries and five replicates was tested. The results obtained from one such trial (Table 57) show encouragingly low coefficients of variation. The lattice design gave up to 80 percent increased efficiency over a randomized-block design. The characters selected for in the previous year were generally evident in the results of this year's trial, particularly for lepidopteran borer susceptibility, and so provided encouragement for the continuation of such work.

Attempts to transfer pest resistance from the *Atylosia* spp. to pigeonpea continued. We have found that *A. scarabaeoides* has some antibiosis and a pod wall barrier that limits *H. armigera* infestation (Fig 28). The transfer of these characters into a useful pigeonpea type will not be easy, but we have initiated work to attempt such a transfer. From the F_2 populations of five crosses of diverse pigeonpea parents with *A. scarabaeoides,* the least-susceptible F_2 plants were intermated in an attempt to accumulate a high frequency of resistant genes.

A few F_7 derivatives of T-21 x *A. scarabaeoides* were found to be less susceptible to *Heliothis.* These lines were crossed with six standard pigeonpea cultivars and the segregating material is being screened.

Populations of pests and their natural enemies are monitored throughout each year, not only

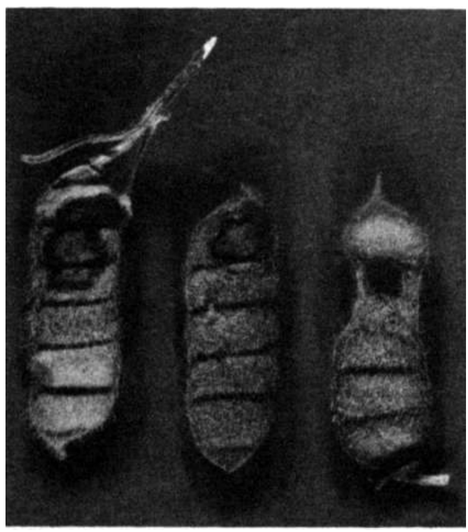


Figure 28. Pods of A. scarabaeoides *scarified by* H. armigera. *The outer pod wall is damaged, but the seeds are not affected because they are protected by a hard inner pod wall.*

Table 57. Insect damage and yield of pigeonpea selections screened for susceptibility to lepidopteran borer and podfly damage in a five-replicate balanced lattice-square design trial in the pesticide-free area at ICRISAT Center, 1977

Selection	Characters 1977[a]	Pod damage (mean %) Borers	Podfly	Yield
		(%)	(%)	(g/m^2)
PPE-37-3	LB, LPf, HY	35.1	13.8	15.4
ICP-4745-8-E 14	LB, HY	50.2	12.2	5.6
PPE-39-1	LB, LPf, HY	50.6	7.0	11.4
ICP-830-2-E-16	LB	54.1	12.1	7.2
NP(WR)-15	HPf	44.8	7.6	9.8
ICP-4745-4-E7	HB, LPf	61.3	4.1	4.1
PPE-37-1	LB, LPf	44.4	7.7	3.2
ICP-4745-6-E10	LB, HY	51.0	9.4	11.2
PPE-36-1	LB	29.0	18.3	17.9
ICP-830-2-E-17	LB, HY	58.7	4.5.	4.5
PPE-38-2	LB, LPf, HY	32.9	19.9	12.8
ICP-6840-E1	LPf	57.0	8.2	5.5
ICP-7050	HB, Check	77.2	2.8	2.1
PPE-38-1	LB, LPf	36.2	12.2	11.8
HY-3C-E25-E13	HB, HPf	69.5	5.5	2.6
ICP-7176-18-E2	LB	49.8	4.5	3.3
S.E. of mean ±		3.15	0.08[b]	1.45
L.S.D. (0.05)		9.1	0.7	4.2
C.V. (%)		14.1	21.0	40.4

[a] Characters noted for these selections in 1976-1977, LB = Low borer damage; HB = High borer; LPf = Low podfly; HPf = High podfly; HY = High yield.

[b] Arcsin $\sqrt{\%}$ transformations used for analysis. Mean values presented are actual percentages.

in the pigeonpea crop, but also on alternative crop and weed hosts. We have been experimenting with traps and techniques, to reduce the work involved in such monitoring.

In cooperation with the Tropical Products Institute, London, we have been testing synthetic pheromones of *H. armigera* for attracting male moths to traps. The pheromones tested to date, as well as virgin female *H. armigera*, have not proved effective attractants during the main infestation season, but we intend to continue with this study and are supplying pupae to TPI for further testing and synthetic pheromone development.

Male moths of two other lepidopteran pests on pigeonpea—the leaf webber, *Eucosma critica*, and the pod borer, *Exelastis atomosa*—were found to be strongly attracted to sticky traps containing virgin females (Fig 29). Such traps are now being used for monitoring populations of these pests in and around our fields. After *H. armigera, E. atomosa* is the most important pod borer in India.

Attempts to develop traps for podfly, based upon pheromonal or chemical attraction, have not been successful so far, but after testing several colors, surfaces, orientations, and heights of traps, white sticky surfaces placed

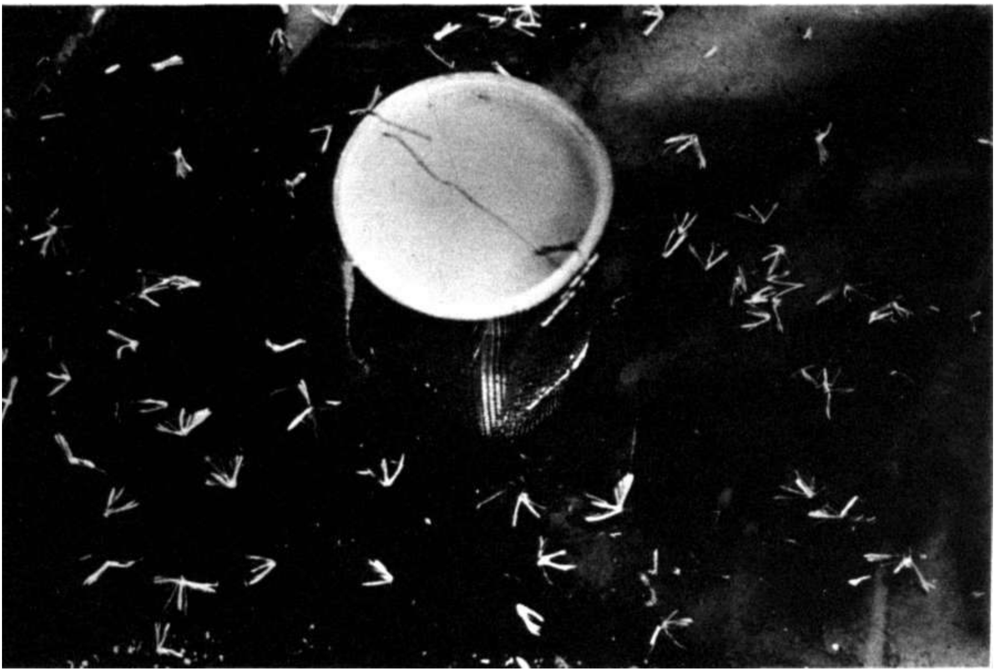


Figure 29. Plume moth (Exelastis atomosa) *males caught on a sticky surface surrounding caged virgin female moths.*

vertically at 1.5 m from the ground were found to be optimum for catching podfly adults.

POD WASHING AND PODFLY INCIDENCE

An attempt was made to increase the podfly incidence in some plots by spraying yeast and honey solutions on plants, as such treatments were known to attract some Diptera. In that test, plants were sprayed with water as a control treatment, but these developed the greatest podfly infestation.

Based on this surprising result we ran a series of tests in which podfly infestations on branches and plants sprayed with water were compared with those on nonsprayed controls. There was a measurable increase in podfly infestation in water-treated pods, but with substantial differences among cultivars (Table 58). Initially, we thought the water attracted the egg-laying podfly, but differences in egg laying in washed and nonwashed pods were found even when podflies were caged on the branches. This has led us to consider the possibility of the presence of a water-soluble exudate on the young pods that is a deterrent to egg laying. Clearly, such a factor would be of importance in podfly host-plant-resistance studies and the effect of rain at podding time may well be an important factor.

PEST-MANAGEMENT STUDIES

As a prelude to pest-management developments, the effects of differing cultural practices on pest populations are being studied in pesticide-free areas and in sprayed fields. Plant-spacing

Table 58. Effect of washing flowering terminals of pigeonpea with water on the number of eggs laid by four pairs of *M. obtusa* (podfly), caged on each terminal for three days following treatment.

Pigeonpea cultivar	Eggs per terminal		S.E. (Mean)
	Not washed	Washed	
	(no)[a]	(no)[a]	
Pusa Ageti	0.3	3.5	±2.49
T-21	2.0	19.5	±4.59
ICP-1	0.4	4.9	±1.34
ICP-6915	6.1	9.6	±4.83
NP(WR)-15	0.8	1.4	±0.75

[a] Mean number.

trials showed a considerable increase in *H. armigera* larvae per unit area with closer spacing. The closer spacing was found to give reduced yields in the nonsprayed area, in contrast to the results obtained where pesticides were used to reduce pest populations (Table 59).

POLLINATION STUDIES

Pigeonpea is known to have a considerable incidence of outcrossing, most or all of which is caused by insects. This factor is of particular interest in breeding trials where cross-pollination is often regarded as a nuisance that has to be overcome by the use of bags or cages for selfing, and in the F_1 hybrid-seed-production plots where insects bring pollen to male-sterile plants. To assist in the pollination studies, two experts from Rothamstead Experimental Station worked at ICRISAT Center in November 1977. Experiments with the honey bee. *Apis Indica* (*cerana*), showed that these small insects were unable to trip and feed on pigeonpea flowers; they are of no use as pollinators of this crop. We also obtained further evidence that thrips rarely, if ever, cross-pollinate even though they can move from plant to plant and carry pollen on their bodies.

Pathology

SURVEYS

In 1975, we started roving surveys in cooperation with agricultural universities in different states of India, and to date have surveyed five states. This year, we surveyed 136 locations in 40 districts of Madhya Pradesh. The average wilt incidence in the state was only 5.4 percent, but the range in farmers' fields was from nil to 96 percent. Average incidence of sterility mosaic was 3.6 percent, with the range in farmers' fields from nil to 99 percent. *Phytophthora* blight was observed in northern India, although its incidence in farmers' fields was low. This disease is most damaging during long wet spells.

Pigeonpea-growing countries in Central and South America and Malaysia were surveyed and the following diseases observed:

Puerto Rico : Rust, unidentified mosaic, yellow mosaic, Witches' broom, *Phytophthora* blight. None was serious.

Dominican Republic : Witches' broom, rust, *Phytophthora* blight. Witches' broom was serious.

Table 59. Effect of spacing -and pesticide use on *H. armigera* populations and yields of pigeonpea at ICRISAT Center, rainy season 1977.

	Larvae	Yield
	(no/m^2)	(kg/ha)
Pesticide-free:		
Close spacing	64.4	303
Normal spacing	35.9	379
Wide spacing	22.1	272
Pesticide-treated:		
Close spacing	27.7	826
Normal spacing	15.7	800
Wide spacing	11.2	655

Trinidad : Rust, Phoma canker, Collar rot (*Selerotium rolfsii*), mosaic (similar to the one seen in Puerto Rico). Rust was most common; other diseases were frequently observed; little disease problem in farmers' backyard crops.

Venezuela : Rust and leaf spots. Rust was common but not damaging.

Panama : Seed/seedling rots, bacterial blight, rust, Witches' broom, sclerotial (not *Selerotium rolfsii*) disease. No disease was serious.

Malaysia : Aerial blight (*Rhizoctonia solani*), leaf spots, mosaic similar to that observed in Puerto Rico and Trinidad. Aerial blight was serious.

WILT (*FUSARIUM UDUM*)

Loss estimation. It is generally presumed that every wilted plant represents a total loss. Since there is partial wilting in many plants, and increasing wilt incidence in the flowering and podding stages, we estimated loss in yield in plants which wilted at different stages. Average data for 2 years are presented in Table 60.

Loss was almost complete when wilt occurred at or prior to the early pod stage. Even when pods were full and plants close to harvest, the loss was around 30 percent in wilted plants. More than 70 percent of the seed produced by wilted plants was normal, and when the wilt was delayed, the percentage of normal seed produced was essentially equal to the percentage produced on healthy plants.

Systemicity of the fungus. Five completely wilted plants of three cultivars (Sharda, BDN-1, ICP-6997) were selected and samples were taken for fungus isolation at 15-cm intervals from root tip to the top. *Fusarium udum* was isolated from tap root, lateral roots, collar region, main stem, branches, leaflets, petioles, rachis, pedicel, and pod hulls. It was not isolated from flowers or seeds, but could be detected as a surface contaminant on nonsurface-sterilized seed.

Survival. To find out how long *F. udum* survives in pigeonpea stubble, an experiment was initiated in November 1974. Stubble (the plant's root system with about 15 cm of the above-ground stalk) of naturally infected plants was obtained, weighed, and buried in earthen pots 35 cm in diameter. Two sets were prepared, one with black (Vertisol) and the other with red (Alfisol) soil collected from ICRISAT Center.

Table 60. Grain yield loss in pigeonpea (cv Sharda) as influenced by stage at which wilt occurred.[a]

Stage at which Plants wilted	Yield	Actual loss of yield	Loss of yield	Seed condition Normal	Seed condition Wrinkled
	(g/plant)	(g)	(%)	(%)[b]	(%)[b]
Prepod	0.05	57.05	99.92	-	
Early pod	0.71	56.39	89.80	72.80	27.20
Pod-fill	6.35	50.75	88.85	86.01	13.99
Pod maturity	18.84	38.26	67.18	85.94	14.06
Preharvest	40.46	16.64	29.58	85.88	14.12
Healthy (check)	57.10	0.00	0.00	87.69	12.31

[a]Average grain yield from a total of 40 plants in 1976 and 1977 tests.
[b]By weight.

Sixty pots, 30 with each soil type, were prepared and buried so that the top of the pots was flush with the ground surface. Stubble from six pots (three Vertisol, three Alfisol) was removed after every 6 months, weighed, and checked for the survival of *F. udum.*

We were able to detect *F. udum* in stubble fragments from Vertisol up to 30 months and from Alfisol up to 36 months; none was found in later observations.

Screening. It took some time to develop a good sick plot, so we could not initiate dependable field screening until the 1976 season. In that year we concentrated on screening (i) cultivars claimed to be resistant, and (ii) lines identified as resistant to another important disease, sterility mosaic. We have been discarding susceptible segregants and selfing individual resistant plants to fix wilt resistance in a homozygous condition, and now have promising lines which come from both the sources indicated above.

At this stage we feel reasonably confident about the performance of the following lines when grown as annual (without ratooning)— ICP-8859, 8860, 8861, 8862, 8863, 8864, 8865, 8868, and 8869. ICP-8861, 8862, and 8869 are also resistant to sterility mosaic.

These lines still give a very small percentage of wilted plants, indicating that they are still segregating, or that lines are being fixed with "threshold" levels of susceptibility. The lines listed above have been sent to several locations for wilt screening.

STERILITY MOSAIC

Epidemiology. Among cultivated crops, pigeonpea has been found to be the only host of sterility mosaic and its mite vector, *Aceria cajani.* We have found six species of *Atylosia (lineata, platycarpa, sericea, albicans, scarabaeoides,* and *cajanifolia),* wild relatives of pigeonpea, to be susceptible to sterility mosaic. *A. scarabaeoides* and *A. cajanifolia* were also found to be colonized by the vector. Since *A. scarabaeoides* is widely prevalent in pigeonpea-growing areas, it could be serving as a reservoir for the causal agent and the vector during the off-season.

Ringspot symptoms. Some lines exhibiting localized reaction to the disease (ring spots) were identified; they were found to flower normally and appeared to suffer no yield loss. These lines are considered tolerant and are expected to serve as good sources of resistance in the breeding program, in addition to the apparently immune sources already identified.

PHYTOPHTHORA BLIGHT

Pot screening. We have standardized a pot-screening procedure that is working quite well. Test cultivars are planted in nonsterilized Alfisol in earthen pots (Fig 30) along with susceptible check cv HY-3C. When 5 to 10 days old, the seedlings are treated with an inoculant made from a culture of isolate P_2, taken at ICRISAT Center. Symptoms usually appear within 48

Figure 30. Pot screening technique for evaluating Phytophthora blight resistance in pigeonpea requires maximum of 20 days from emergence, as against a full season for field screening. Correlations of results of pot vs field screening are high.

hours; final observation is taken 10 days after inoculation. Field screening requires an entire season. Pot screening has proved extremely satisfactory, and correlation with field-screening results is excellent.

Field screening. During the year we screened more than 1 000 germplasm accessions, breeding material, and 35 entries in the All India trial.

We have identified 28 resistant lines/cultivars: ICP 28, 113, 213, 214, 339, 580, 752, 913, 914, 934, 1088, 1090, 1120, 1123, 1149, 1150, 1151, 1258, 1321, 1529, 1535, 1570, 1950, 2376, 3753, 6974, 7065, and 7182.

Among *Atylosia* species, *sericea* and *platycarpa* have been found to be resistant.

Existence of physiologic races. When we inoculated the 28 lines resistant to the ICRISAT isolate of *Phytophthora* with an isolate from Kanpur, we found all susceptible. An isolate from New Delhi caused mortality of a certain percentage in each of the 28 lines. This indicates the existence of physiologic races.

Microbiology

RHIZOBIUM POPULATION IN SOIL

The numbers of *Rhizobium* of the cowpea group which nodulate pigeonpea were estimated in some Alfisol and Vertisol fields at ICRISAT Center. Generally, Alfisols contained more rhizobia than the Vertisols; 5 of 15 Vertisol fields examined on one occasion had fewer than 100 rhizobia per gram of soil. In Alfisols, the population was generally more than 10^4 and could be as high as 10^6 rhizobia per gram of soil.

In both soil types, the number of rhizobia beyond a depth of 110 cm declined to fewer than 100 per g of soil. Such low numbers would make it difficult for pigeonpea to nodulate at these depths.

In paddy fields, the population was very low, less than 100 per g of soil. It appears that continuous cultivation of paddy has an adverse effect on *Rhizobium* survival, as there were more rhizobia in a field under paddy for 2 years than one under paddy for 6.5 years. The population was invariably less in a field with standing paddy than in a paddy fallow. Virtually no rhizobia were observed at a depth of 40 to 50 cm in a standing paddy field. This suggests that if pigeonpea or other members of the cowpea-inoculation group of legumes are planted after a paddy crop, they should be inoculated in order to ensure adequate nodulation.

RHIZOBIUM STRAIN SELECTION

We continued to isolate rhizobia from selected fields. After testing and authentication, they were added to our culture collection, now containing about 300 *Rhizobium* cultures for pigeonpea. Most were found to be fast growers and, unlike other cowpea-group strains, able to grow readily on glucose peptone agar. In Leonard jar trials on pigeonpea, the strains varied in nodulation pattern and effectiveness in nitrogen fixation. When pigeonpeas growing in pots containing an Alfisol were inoculated with 15 promising strains, 6 increased growth over noninoculated controls, indicating that they were both effective and competitive with the native soil *Rhizobium* population in that soil. These are now being tested in field trials.

N SUPPLY TO PIGEONPEA

We repeated our examination of the N supply to pigeonpea by comparing the growth and nitrogen-uptake responses of cv ICP-1 to fertilizer additions of 0,20, and 200 kg N/ha. In Vertisols, the 20- and the 100-kg applications (first dressing of the 200-kg N treatment) stimulated plant growth up to 65 days after sowing, but neither *Rhizobium* inoculation nor N application had an effect on plant dry matter and grain yield at maturity. The 100-kg application inhibited initial nodulation and N_2-fixation.

EFFECT OF N SUPPLY ON N_2-ASE ACTIVITY

The 20- and the 200-kg applications stimulated plant growth in an Alfisol, and although 100 kg N inhibited nodulation and nitrogenase activity at 25 days after planting, there was little apparent effect at 45 and 60 days after planting. At 90 days (10 days after the second 100-kg application), however, nitrogenase activity was much reduced, presumably in response to the N fertilizer addition.

Nitrogenase activity per plant in Alfisols was much greater than in Vertisols in both seasons (Fig 31). There was much greater activity in the 1977 season, probably a response to the differing rainfall pattern. Activity declined after 90 days, and virtually ceased at 120 days. Cultivar ICP-1 reaches 50 percent flowering at around 115 days and matures at about 165 days, so little N_2 fixation was detected during the grain-filling stage. Again, in the Vertisols, many nodules were damaged by insect larvae. However, final grain yields in 1977 were higher in Vertisols (mean 1 194 kg/ha) than in Alfisols (mean 928 kg/ha).

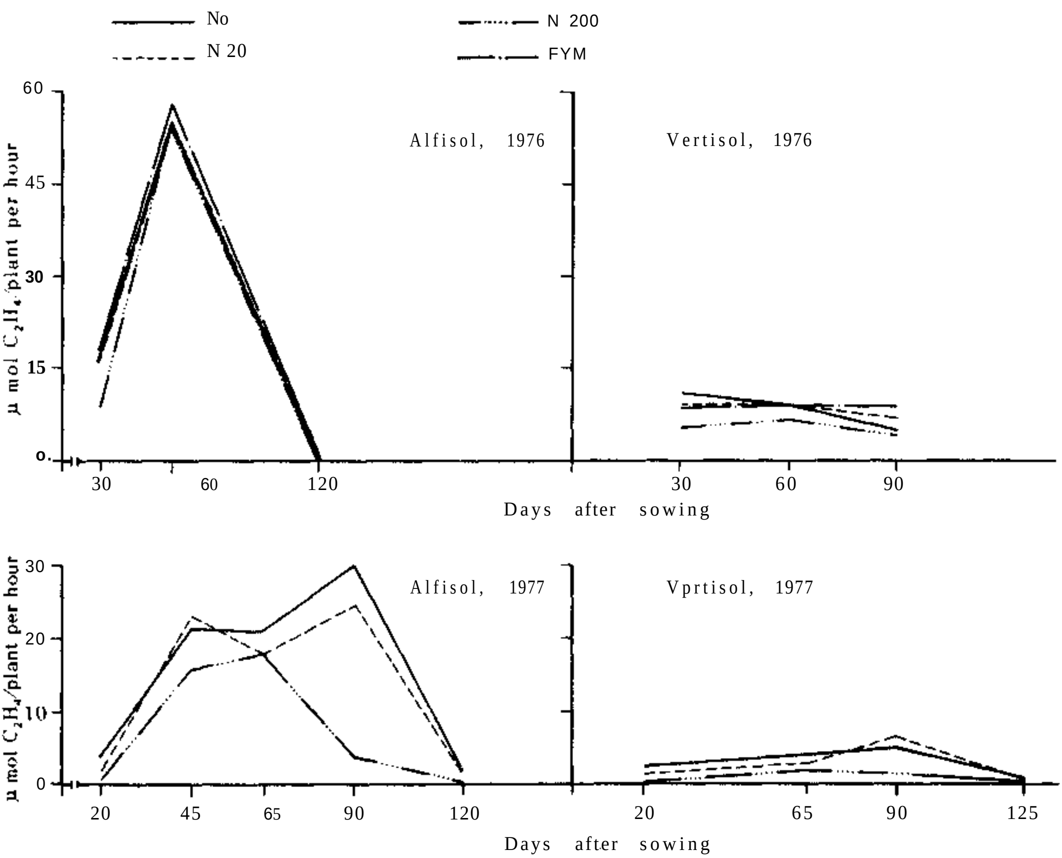


Figure 31. N_2-ase activity in pigeonpea cv ICP-1 growing on Alfisols and Vertisols at ICRISAT Center, rainy seasons 1976 and 1977, with fertilizer applications of 0, 20, and 200 kg N/ha. In 1976, N_2-ase activity in Alfisols with applications of 0 and 20 kg N/ha was almost identical. In 1977, one-half of the 200-kg applications was made at sowing and the remainder when the plants were 80 days of age.

Periodicity of N_2-ase activity. Using the acetylene-reduction assay on plants grown in pots, we found a marked diurnal periodicity in activity of 50-day-old plants, with activity increasing rapidly from 0800 until 1400, then declining until 1800, and remaining at a low level until sunrise next day. This indicates a close relationship between current photosynthesis and N_2-fixation.

N_2-ase activity of root samples. For nodulated roots, maximum specific activity was observed in the initial 30 minutes of incubation, with a slight decline thereafter with activity continuing for 4 hours. Washing excised nodulated roots did not change specific activity, while washing and blotting significantly reduced activity—perhaps because of damage to the fragile connection between nodule and root. In assays of pigeonpea, it is virtually impossible to extract roots from the growing medium without detaching some nodules. Excised nodules had less activity than nodulated roots. Leaving excised nodules in air for 45 minutes before assay did not alter their specific activity, and activity at 60 minutes actually increased. Thus, although N_2-ase activity of detached nodules and nodulated roots of pigeonpea declines after they are taken from the soil, the decline is small during the first hour. Because pigeonpea nodules are often taken from deep in the soil, an hour may be required for their recovery, but our results suggest that this delay will have relatively little effect on nitrogenase activity.

NODULATION OF GERMPLASM LINES

Nodulation characteristics of 500 germplasm accessions collected from different regions of the world were examined in an Alfisol. There was more than a threefold range among entries for nodule number and weight per plant, number of damaged nodules, and shoot and root weight. The 110 parents used by pigeonpea breeders in the crossing program were also examined. At 25 days after planting there was a similarly large range in response among entries (Table 61).

Table 61. Range of symbiotic characteristics in 110 entries in the pigeonpea crossing block at ICRISAT Center, measured 25 days following planting.

Character	Range[a]
Nodule number	6.7-37.8
Nodule weight (mg/plant)	9-55
N_2-ase activity:	
µMolC_2H_4/plant per hr	1.1-11.3[b]
µMolC_2H_4g/nodule per hr	65-565[b]
Shoot weight (mg/plant)	383- 1 408
Root weight (mg/plant)	38-185

[a]Means of 30 plants.
[b]Means of 20 plants.

Nutritional Quality

Screening for protein percentage in pigeonpea germplasm was continued. Whole-seed samples of 2 433 germplasm lines were analyzed by the Technicon auto analyzer. Protein content (N x 6.25) in these samples varied between 16.5 and 26.5 percent.

Protein content in many dhal (dried split seeds) samples of intergeneric material involving pigeonpea and *Atylosia* species was also determined. Earlier we reported that some of the derivatives of pigeonpea x *Atylosia* spp. were high in dhal percent. This year's analysis of five *Atylosia* species showed that *A. albicans* and *A. sericea* are high in dhal protein (30%).

Comparison of amino acid profiles of two pigeonpea cultivars, Pant A-2 and Baigani, and three species of *Atylosia* (*sericea, scarabaeoides,* and *albicans*) revealed no important differences in the essential amino acids. Seed proteins of pigeonpea and *Atylosia,* and their hybrid derivatives, were separated into salt-, alkali-, and alcohol-soluble fractions. Major differences were not observed among these lines in the concentration of any of these fractions. Further, sodium dodecyl sulphate polyacrylamide gel electrophoresis of salt-soluble proteins in these lines revealed no significant differences in their electrophoretic patterns.

TOTAL SULPHUR AND SULPHUR AMINO ACIDS IN PIGEONPEA

Total sulphur in 24 genotypes was determined by the turbidimetric procedure and by Leco sulphur analyzer. Results obtained by these two procedures were highly correlated. Total sulphur estimated by the turbidimetric method varied from 0.129 to 0.816 percent in the sample, while Leco sulphur analyzer values ranged between 0.147 and 0.194 percent. Methionine content in these samples was estimated by bioassay using *Leuconostoc mesenteroides,* and it ranged between 0.84 and 1.13 percent of the protein content.

Looking Ahead in Pigeonpea Improvement

Additional germplasm will be collected in Bangladesh, Australia, and various parts of India. Collecting in Africa will be done on a cooperative basis. We expect to publish a revision of the taxonomy of *Cajanus* and *Atyhsia* in 1979.

Short-term plans in breeding include a general distribution of seed of male-sterile lines for increase by local breeders and for production of hybrids involving locally adapted cultivars as male parents. Multilocation testing will be expanded since new breeding lines, in grain and vegetable types, are available. Agronomic studies with cv adapted in the African SAT will be encouraged.

Physiological investigations will be concentrated on innovative production systems, responses to and screening for reaction to salinity and waterlogging, and production inputs. Means of shortening the growth cycle for rapid-generation turnover will be investigated.

Entomological investigations will be extended to include multilocation tests for host-plant resistance and ecological studies away from ICRISAT Center. Pest-management systems will be tested in cooperation with national programs.

Disease-screening methods will continue to be refined, and cooperative screening will be expanded. The investigation of races of the various pathogens will be intensified. Development of lines with multiple-disease resistance will be emphasized.

Response to *Rhizobium* inoculation will be tested over a number of sites. We expect to cross high- and low-nodulating lines to start genetic studies and breeding for improved nodulation, and will add to our techniques the use of ^{15}N for estimating N fixation.

CHICKPEA

Chickpea

Germplasm

COLLECTION

With the addition of 155 accessions from Gujarat, the ICRISAT chickpea collection now numbers 11 198 entries. Collection trips abroad included Turkey, Syria, Pakistan, and Afghanistan. Seed of wild species was not collected from the Taurus mountains in Turkey, but information which may assist future expeditions was gathered. In Afghanistan a few areas in the Samangan and Balkh provinces were covered, and 13 samples collected. Of the 13 samples collected in Pakistan, 8 were cleared for postentry quarantine isolation.

EVALUATION AND REJUVENATION

Evaluation and rejuvenation were carried out as usual. Full data on the morphoagronomic characters of 3 085 entries were obtained and prepared for computerization. Data for 10 842 entries evaluated one to three times during previous years were entered in the computer storage and retrieval system. A complete catalog will not be published, but computer printouts listing accessions with requested characters or combinations will be supplied on request. A summary publication describing the collection is being prepared.

SEED VIABILITY

Germination is tested four times a year to monitor loss of viability of seed stored in various seed containers at room temperature and cooled (<15°C) conditions. Results with five cultivars stored for 18 months after harvest (Table 62) revealed that:

i) There was no appreciable difference in germination of seeds of cv BEG-482, P-3090, and Hima stored in plastic bottles or paper packets at the cool temperature, but seed of cv L-550 (Kabuli) and Kaka (black-seeded) in packets lost considerable viability,

ii) There was no appreciable difference in germination percentage of seed stored in air-tight plastic bottles at the two temperatures, except in cv P-3090. However, seeds of all five cultivars stored in paper packets at room temperature lost their viability, almost completely.

These data are in marked contrast with those recorded with pigeonpea, where paper packets afforded a good means of storage. A contributing factor may be the nature of the seed coat of chickpea, which is more permeable and so more vulnerable to humidity changes.

INFLUENCE OF NAPHTHALENE ON GERMINATION AND GROWTH

Tests carried out on seeds stored with naphthalene balls for 3 years in plastic bottles proved that this was not harmful to the seeds. Doubts had been created when small chickpea samples, sown for rejuvenation in pots, had poor emergence and stunted growth. This is now considered to have been due to phytotoxicity of the sterilized soil, since subsequent tests with ordinary soil did not show this effect. Stunted growth was also produced by placing naphthalene balls in the soil below the seeds. Under wet conditions, naphthalene is toxic to the growing plant; in storage it is an excellent deterrent against pests.

WILD *CICER* SPECIES IN THE COLLECTION

Annuals	Perennials
C. bijugum	*C. anatolicum*
C. chorassanicum	*C. floribundun*
C. cuneatum	*C. graecum*
C. echinospermum	*C. isaurkum*
C. judaicum	*C. microphyllum*
C. pinnatifidum	*C. montbretii*
C. reticulatum	*C. pungens*
C. yamashitae	*C. rechingeri*

Table 62. Viability of seed of five chickpea cultivars (1977 harvest), after 18 months' storage under various conditions.

Treatment	BEG-482	P-3090	L-550	Hima	Kaka
	Germination (Nov 1978) (%)				
Cool storage temperature:					
Air-tight plastic bottle + Napthalene	100	98	100	100	96
Air-tight plastic bottle w/o Napthalene	100	100	100	100	94
Simple lid plastic bottle w/o Napthalene	96	92	98	100	56
Paper packet + Napthalene	96	92	50	100	20
Paper packet w/o Napthalene	100	92	54	100	24
Average	98.4	94.8	80.4	100.0	58.0
Room temperature:					
Air-tight plastic bottle + Napthalene	90	82	94	98	92
Air-tight plastic bottle w/o Napthalene	100	84	100	NA[a]	96
Simple lid plastic bottle w/o Napthalene	100	68	100	100	92
Paper packet + Napthalene	2	0	0	0	0
Paper packet w/o Napthalene	10	0	0	0	0
Average	60.4	46.8	58.8	49.5[b]	56.0

[a] Data not available.
[b] Average of four treatments.

Of the wild species, only *C. reticulation* hybridizes readily with *C. arietinum.* This species was found to be resistant to *Ascochyta* blight. It was crossed with cv G-130, JG-62, and P-5462, and F_2 and BC_1 were produced. The harvested seeds were handed over to pathologists for screening against blight.

SEED SUPPLIED AGAINST REQUESTS

A total of 1 267 samples were furnished (Table 63), 227 to 8 institutions in India, and 990 to 10 institutions outside of India.

Breeding

ICRISAT Center near Hyderabad (17°32'N) lies south of the main latitudes of chickpea culture in India (23° to 29°N) and internationally. Consequently, plant breeding and testing was started in 1975 at the Haryana Agricultural University at Hissar in northern India, and has progressively expanded. Close collaboration in chickpea improvement with ICARDA was formalized. The programs were integrated in 1978, and an ICRISAT breeder is now based at ICARDA. As a result of these arrangements, more effective coverage of chickpea improvement is now possible. The major emphasis is on early desi types at ICRISAT Center, late desi and kabuli types at Hissar, and kabuli types at ICARDA.

Chickpeas give very poor yields when planted later than October in the northern Indian belt. During the 1977-1978 season, we initiated a project for breeding cultivars adapted to late planting. We intend to screen germplasm lines to identify genotypes adapted to late planting for use in that breeding program.

In the investigation of new plant types.

Table 63. Chickpea germplasm lines supplied to research agencies in India and other countries during 1977-1978.

Institution	Location	Entries
INDIA:		
Department of Plant Breeding, Punjab Agricultural University	Ludhiana, Punjab	71
Department of Plant Breeding, Banaras Hindu University	Varanasi, Uttar Pradesh	61
Department of Genetics and Plant Breeding, Haryana Agricultural University	Hissar, Haryana	50
Departments of Genetics and Botany. Osmania University	Hyderabad, Andhra Pradesh	40
Department of Plant Breeding, G.B. Pant University of Agriculture and Technology	Pantnagar, Uttar Pradesh	23
Indian Agricultural Research Institute	New Delhi	18
Department of Genetics, Chandrasekhar Azad University of Agriculture and Technology	Kanpur, Uttar Pradesh	9
Department of Botany, Punjabrao Krishi Vidyapeeth	Akola, Maharashtra	5
OTHER COUNTRIES:		
Division of Genetics, National Institute of Agricultural Sciences	Hiratsuka, Kanagawa 254, Japan	500
Crop Development Center, University of Saskatchewan	Saskatchewan. Canada	300
Estacion Experimental Sociedad Nacional de Agricultura	Fundo la Vega, Huelguen Paina, Chile	100
Department of Agronomy, University of Florida	Florida, USA	33
Kenya Agricultural and Forestry Organization	Nairobi, Kenya	20
The International Center for Agricultural Research in Dry Areas (ICARDA)	Aleppo, Syria	11
Rangpur Dinajpur Rehabilitation Service	Lalmanirhat, Rangpur, Bangladesh	11
M/s Macondray & Co., Inc.	Manila, Philippines	10
Projet Tapis Vert	Niamey, Niger	3
Agriculture Research Institute	Wagga Wagga, Australia	2

crosses have been made between medium-height compact F_4 lines and high-yielding cultivars in an effort to improve the potential for pod-set in the tall lines.

SELECTION AMONG CROSSES

In the absence of adequate information on the breeding value of parents, large numbers of crosses have been made using parents selected on ecogeographical diversity and possession of complementary or specific characteristics. An early generation estimate of usefulness of the crosses would permit discard of unpromising material.

Of 217 crosses grown in a replicated F_1 trial in 1975-1976, we chose five high-, five medium-, and five low-yielding crosses for yield estimates in subsequent generations. These crosses were chosen on mean yield of F_1. However, since mean yield and heterosis of the F_1's were associated ($r = +0.74$), these groups of crosses also reflect differences in heterosis. The crosses were evaluated as bulk F_2's in 1976 and F_3 performance was determined in 1977, using a bulk population and a sample of 60 F_2-derived lines per cross. Seed yield and rank for each cross in each generation are presented in Table 64.

There was considerable shifting of rank of the crosses in the different generations. This could indicate either that the F_1 mean had relatively low predictive value for subsequent generations or that substantial *cross* x *environment* interaction occurred, or both. There was relatively close association of seed yield in the F_1 and F_2 (r = + 0.62) and the F_2 and F_3 bulk (r = + 0.79) generations, but not between the F_1 and F_3 bulk generations (r = +0.41). The low correlation (r = +0.41) of the yields of the F_3 bulk and F_3 progeny tests suggests that the lines might have been a select, rather than a random, group. However, F_3 tests were on poor irregular soil, and yield levels were very low.

The mean yield of the high and medium crosses was greater than that of the low group in all generations (Table 64), and discard of the low group on F_1 performance would have eliminated none of the top five crosses in any generation.

This suggests that limited selection among crosses may be practiced effectively by discarding crosses with low yield in the F_1 generation. However, most crosses should be evaluated

Table 64. Mean yield and ranks of crosses in the high, medium, and low F_1-yield groups in F_1, F_2, and F_3 generations.

	F_1		F_2		F_3 bulks		F_3 progeny mean	
Cross	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
	(g/plant)		(kg/ha)		(kg/ha)		(kg/ha)	
HIGH:								
1 JG-39 x P-436	50.00	1	2 367	3	1 034	1	1 100	2
2 P-502 x BG-1	44.52	2	1 987	5	902	3	970	5
3 T-3 x L-532	43.88	3	1 647	10	435	13	473	15
4 T-3 x P-4357	43.33	4	1 853	8	631	11	1 003	3
5 T-3 x NEC-721	42.66	5	1 960	6	625	12	510	13
Mean	44.88	3.0	1 963	6.4	726	8.0	811	7.6
MEDIUM:								
6 P-861 xT-103	34.66	6	2400	2	938	2	477	14
7 P-502 x P-514	34.66	7	2 427	1	805	6	1 217	1
8 P-861 x Pant-104	34.66	8	1927	7	878	5	873	7
9 T-3 x T-103	34.53	9	2 260	4	895	4	567	11
10 P-648 x P-1243	34.46	10	1 693	9	649	10	977	4
Mean	34.59	8.0	2 141	4.6	833	5.4	823	7.4
LOW:								
11 Ceylon-2 x P-662	21.33	11	1 613	13	411	14	733	9
12 P-648 x G-543	20.66	12	1 620	11	702	8	700	10
13 JG-39 x Pant-102	20.33	13	1 526	14	753	7	903	6
14 Ceylon-2 x NEC-835	19.50	14	1 320	15	325	15	510	12
15 JG-39 x P-3172	19.00	15	1 567	12	681	9	837	8
Mean	20.16	13.0	1 529	13.0	465	10.6	736	9.0

as bulk F_2 or F_3's, preferably in multilocation trials, in breeding for high yield.

OPTIMUM PLOT SIZE

Because of limitations on resources, experimental design inevitably involves a compromise between the precision of the estimate desired and the number of entries in the trial. Precision of the estimate will vary, depending on the type of character observed. Therefore, we conducted an experiment to determine for seed yield the minimum plot size compatible with an acceptable level of precision.

The trial involved two desi (cv H-208, Pant-102) and two kabuli (cv L-550, NEC-1646) entries. Six plot sizes were tested; 3 m and 6 m long (2.5 m and 5.5 m harvested, respectively) with one, two, or three rows per plot. Interrow spacing was 30 cm. The trial was grown at 1CR1SAT Center and at Hissar in 1975 and 1976. The design was a split-split plot with four replications, having cultivars as main plots, row length as subplots, and row number as sub-subplots.

Significant differences existed among genotypes, row lengths, and row numbers in each year/location combination. In general, mean seed yield increased as plot size decreased, indicating a positive bias on yield estimation from small plot sizes. Further, the coefficient of variation (C.V.%) was greatest for the smallest plot size (2.5 m by one row, 0.75 m^2) and least for the largest plot (5.5 m by three row, 4.95 m^2) in all cases. There was a progressive reduction in C.V.% as plot size increased (Fig 32).

For the International Trial series, we have recommended that 1.5 m^2 be harvested per plot. The range and mean C.V.% for these trials (Table 65) are similar for the two years, and the means are similar to our experimental estimate.

These data indicate that adequate precision can be obtained in some cases, using a 1.5-m^2 harvested area. However, on average a plot size of about 3 m^2 appears necessary to attain acceptable precision (say, 20% C.V.), and this will be recommended for future regional and international trials.

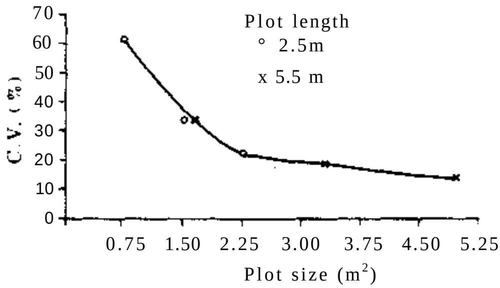


Figure 32. Relationship of C. V. (%) to plot size in chickpea trials, 2 years and two locations.

DISEASE RESISTANCE

Breeding for resistance to *Fusarium* wilt, *Ascochyta* blight, and stunt is in progress. We have started a limited-generation backcross program to transfer wilt resistance to a number of high-yielding desi and kabuli cultivars.

The *Fusarium* wilt-sick plot at ICRISAT Center became available for the first time in 1977. All advanced generation lines (F_5 to F_7) and F_2 to F_4 breeding material, involving one or more resistant/tolerant parent(s), were evaluated. Early and virtually complete mortality of a susceptible check, cv JG-62, in every third ridge indicated that the plot provided a relatively uniform challenge, so that surviving material probably possessed resistance.

Table 65. Coefficient of variation (%) in International Chickpea Cooperative Trials with 1.5-m^2 plots.

Tests	No.	C.V. Range	C.V. Mean
		(%)	(%)
1975-1976 ICCT	15	15-62	31.7
1976-1977 ICCT-D	25	16-58	32.0
Experimental estimate			33.9

PERFORMANCE OF ICCC LINES IN INDIAN COOPERATIVE TRIALS

In the 1976 season, 100 early and 100 late-maturing advanced breeding lines were evaluated at 11 and 13 regional sites respectively in India as part of the International Chickpea Screening Nursery (ICSN). These lines were derived from crosses made in 1973, which were grown as F,'s in the off-season in Lebanon. Selections were made in the F_2's at ICRISAT Center, and F_4's were grown at ICRISAT Center and Hissar in 1975 following an off-season F_3 nursery in Lebanon. Promising F_4 lines were bulked and entered in the ICSN in 1976.

Based on the performance in the Indian trials, five lines were identified as having high yield potential. These are as follows:

ICCC No.	Pedigree	Cross
1	7310-26-2-B-BP	H-208 x T-3
2	7332-7-2-B-BH	H-208 x F-370
3	73111 -8-3-B-BH	850-3/27 x H-208
4	7310-3-2-B-BH	H-208 x T-3
5	73219-2- 1-B-BH	F-404 x H-223

These five lines were offered for testing in the Gram Initial Evaluation Trial (GIET) of the All-India Coordinated Pulse Improvement Project during the 1977 season.

INTERNATIONAL COOPERATION

In 1977, we intensified our efforts in international cooperation. Our objectives are as follows:

i) Strengthening of national and regional programs.
ii) Supplying of cultivars, segregating populations, and advanced breeding lines with special characteristics (disease resistance, high yield, high protein, etc.) to cooperators.
iii) Identification of differences among lines in adaptation regionally and internationally.
iv) Promotion of international cooperation through personal visits, conferences, and information exchange.

Following integration of the ICRISAT and ICARDA chickpea-improvement programs in 1978, it is intended that ICRISAT will coordinate the international tests and nurseries of desi types, and ICARDA will coordinate the kabuli trials and nurseries.

The third international trials and nurseries were sent to 64 cooperators in 26 countries. Ten different trials/nurseries were made available. The results of these trials will be compiled in a separate report. In response to requests, we sent 780 parent lines, 377 segregating bulks, and 1 264 advanced generation lines to 36 individual scientists in 10 countries.

Two years of results for the international trials are now available and published. Substantial *entry* x *location* interaction was apparent in each year, and there was considerable reordering of rank for the entries common to both years. This suggests that chickpea genotypes may exhibit specific differences in adaptation and that development of broadly adapted genotypes may be difficult. This aspect will be examined in more detail following completion of the third international trial series.

The fourth International Chickpea Breeders' Meet was organized by ICRISAT in April 1978 at Haryana Agricultural University, Hissar. Thirty-six scientists from six countries participated and made selections from ICRISAT breeding plots. ICRISAT scientists visited 22 locations in six countries during 1977 and 1978, and 21 scientists visited our plots at ICRISAT Center. Active cooperation continued with the All-India Coordinated Pulse Improvement Project, involving exchange visits, workshops, and cooperative trials.

Physiology

COMPARATIVE DRY-MATTER PRODUCTION, YIELD, AND YIELD COMPONENTS

Yields of chickpeas are greater at higher latitudes in India than at ICRISAT Center near Hyderabad. To compare growth duration.

yield, and yield components, chickpeas were grown at two locations in India: at ICR1SAT Center (17°32'N, 78°16'E, altitude 542 m) and in northern India at Hissar (29°10'N, 75°44'E, altitude 221 m). The duration of the vegetative growth at Hissar is on average longer by about 40 days and total growth duration by about 80 to 85 days. As reported in the 1976-1977 Annual Report, the plants continued growing vegetatively at Hissar because of abortion of flowers at the low temperatures prevailing during the early flowering stage. The reproductive period was only slightly longer at Hissar (Table 66).

The longer growth duration at Hissar results in the development of many more nodes, almost twofold increase in grain yield, and threefold increase in total dry-matter production. Relatively, there is greater increase in total dry-matter production than in grain yield at Hissar, resulting in a harvest index lower by about 10 percent that at ICRISAT Center. The dry-matter productivity per day is substantially higher at Hissar, but the grain yield per day is similar at the two locations.

Table 66. Differences in growth duration, growth, yield, and yield components of chickpea in India (average of two cultivars, 850-3/27 and JG-62) at ICRISAT Center and at Hissar, 1977.

	ICRISAT Center	Hissar
Vegetative period (days)	49	76
Period of ineffective flowering	-	48
Reproductive period (days)	41	48
Growth duration (days)	90	172
Nodes/plant	167	346
Dry matter (kg/ha)	2 072	6 176
Yield (kg/ha)	1 166	2 395
Harvest index (%)	50	40
Dry matter (kg/day)	22	36
Yield (kg/day)	12	14

EFFECTS OF SHADING

We reported in 1976-1977 that at ICRISAT Center the yield of chickpeas increased with shading from 50 percent flowering until harvest. Similar shading experiments were conducted at Hissar during 1976-1977 and 1977-1978 but at that location, shading did not increase yields.

During 1976-1977, shades were placed horizontally above the crop canopy upon initiation of pod-set and were kept in position until harvest. The shades were not put up at flowering because of the long lag between first flowering and pod-set. Though the plants were in the reproductive stage of growth, they were not setting pods and continued to grow vegetatively. A reduction of 20 to 22 percent of full sunlight during this period resulted in a decline of about 23 percent in yield. Temperatures during this period (first week of Feb) were not rising, and perhaps for this reason the expected benefit of shading did not accrue.

During 1977-1978, shading was delayed until 26 March when temperatures had begun to rise (Fig 33), about 25 days after initiation of effective podding. Shading was continued until harvest (20 Apr), i.e., for 24 days. The object was to determine if the bad effects of high temperature during pod-filling were alleviated by shading. Reduction in photosynthetically active radiation (PAR) up to 55 percent of full sunlight did not result in any significant decline in yield. However, yield was reduced when PAR was reduced by 84 percent by shading the crop with thick cloth.

SOURCE-SINK RELATIONSHIPS

Effects of defoliation. It seemed likely that environmental conditions during growth and development would affect the response to defoliation. Two environments were provided by adjusting the date of sowing (normal and late planting) at ICRISAT Center. Material planted on both dates was subjected to progressively increasing degrees of defoliation. In this experiment, the response to defoliation was not influenced by the date of planting, thereby suggesting that climatic conditions during the period of treatments were much less important than the

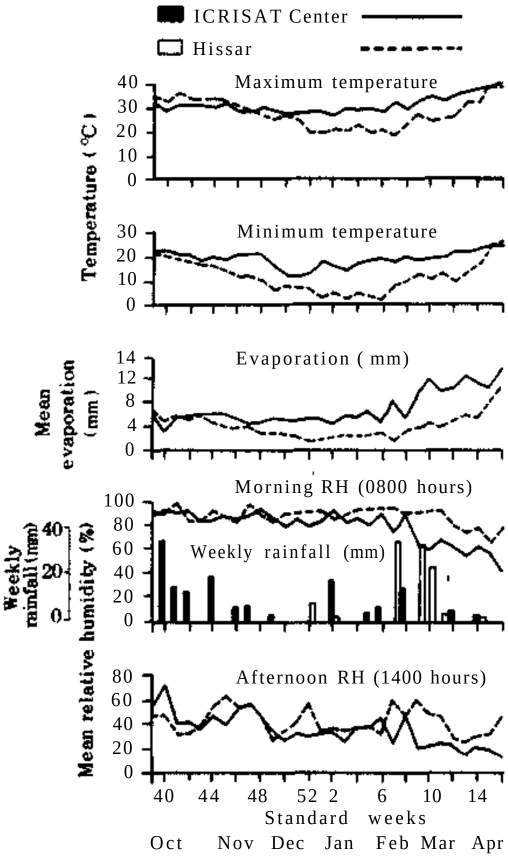


Figure 33. Maximum and minimum temperatures, mean evaporation, morning and afternoon mean relative humidity, and weekly rainfall at Hissar and ICRISAT Center during postrainy (rabi) season 1977.

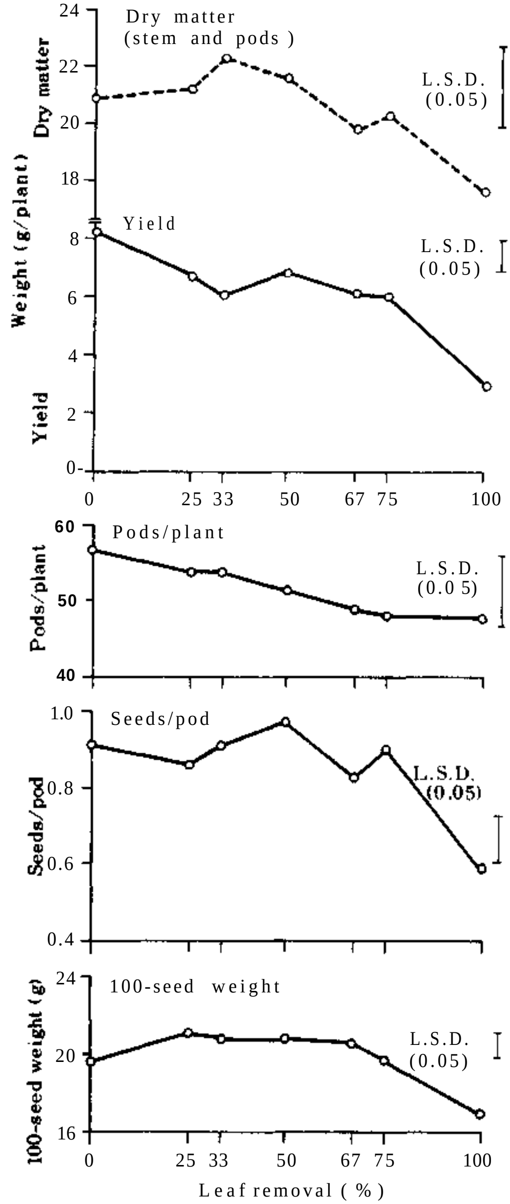


Figure 34. Effect of defoliation from flowering until harvest on total dry matter, yield, pod number per plant, seed number per pod, and 100-seed weight of chickpea growing at Hissar, 1977.

response to defoliation. The overall response to defoliation was similar to that reported last year. The dry matter in stems and pods (which was taken instead of total dry matter because of differential leaf removal in different treatments) decreased with defoliation but drastically only in total (100%) defoliation.

The studies were extended to Hissar in 1977. The results (Fig 34) were very similar to those observed at ICRISAT Center. The dry matter in pods and stems declined significantly only in those plants with complete defoliation. Progressively increasing degrees of defoliation decreased grain yield, but the decrease was not proportional to the degree of defoliation. With complete defoliation from flowering until harvest, about 35 percent of normal grain yield was produced, presumably by stem and pod photosynthesis and photosynthates that are remobilized from stems. The yield component affected was pods per plant; 100-seed weight and seeds per pod decreased only with complete defoliation.

Effect of flower removal. The same question was asked as in the defoliation study: whether different environmental conditions associated with different times of planting would affect the response to flower removal. This was investigated this year at ICR1SAT Center. There was no effect of date of planting (normal and late) on the response to different flower-removal treatments. The results on flower removal are in fair agreement with those reported last year.

There was no decline in yield when 33 percent of the flowers were removed from initiation of flowering until harvest. Yield declined only by 22 percent when 75 percent of the flowers were removed throughout the reproductive period, suggesting a remarkable ability to compensate for the loss in potential sinks.

In response to partial flower removal, total dry matter production declined, but substantial reduction occurred only at 67 percent flower removal and above. Grain yield did not decline up to 33 percent flower removal, but declined thereafter (Fig 35). As observed in the leaf-removal treatments, the component of yield that was affected was pods per plants; seeds per pod was not affected and 100-seed weight increased in flower-removal treatments.

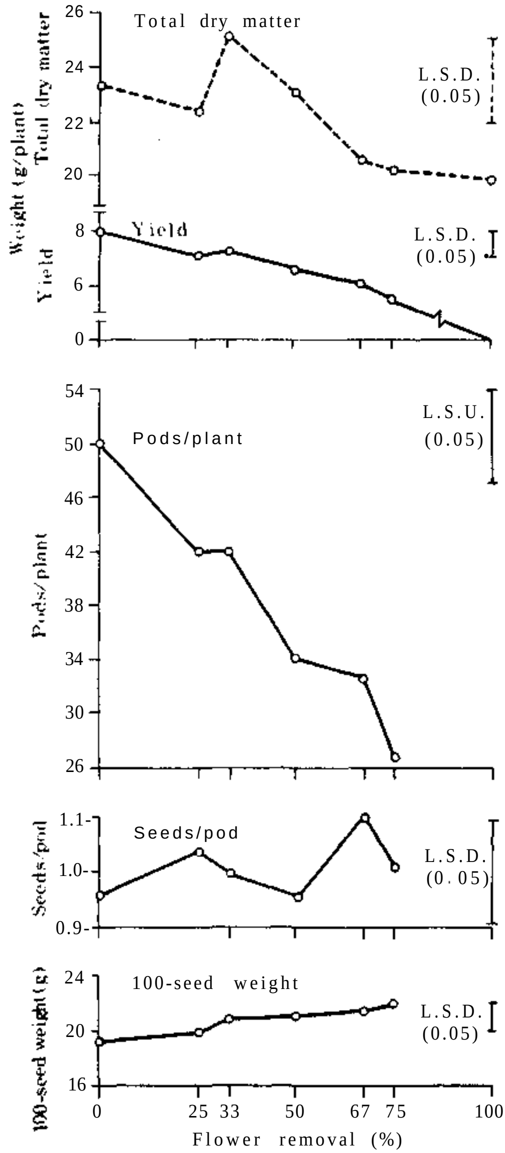


Figure 35. Effect of flowerremovalfrom flowering until harvest on total dry matter, yield, pod number per plant, seed number per pod, and 100-seed weight of chickpea growing at Hissar, 1977.

RESPONSE TO CULTURAL PRACTICES

To exploit the full genetic potential of a species, optimum cultural conditions are needed. Studies in this direction have been in progress since the beginning of the chickpea physiology program.

Response to plant population. Chickpeas in general seem to produce quite stable yields over a range of populations. This was mentioned in our previous report as "plasticity." The plasticity depends, *inter alia,* upon the location and the choice of cultivar.

At Hissar we found that cv G-130, a high-yielding cultivar of that region, produced almost the same yield at plant populations ranging from 4 to 100 plants/m^2.

At ICRISAT Center, two cultivars were tested in a spacing and time-of-planting trial. Cultivar 850-3/27 was completely plastic over the range of populations studied (1 to 100 plants/m^2) in the October planting (all yields were low), but responded to increased population in the November planting. Cultivar JG-62 responded to increasing plant density in a linear manner in the mid-October planting, while in the mid-November planting the response was curvilinear. The optimum population was between 60 and 80 plants/m^2.

These studies indicate the importance of genetic differences in plasticity that exist among cultivars.

Uptake of nutrients and response to fertilizer application. Balance sheets of N and P are worked out each year. On an average at ICRISAT Center, a 1 500-kg grain crop (with total dry matter of 2 600 kg/ha) removes 58 kg N and 5 kg P/ha. At Hissar, a 3 400-kg grain crop (7 000 kg total dry matter) removes 143 kg N and 10 kg P/ha in its total dry matter. The removal of P seems to be exceptionally low.

Graded levels of N, up to 100 kg N/ha, in the form of ammonium sulphate were applied to the soil in 1975-1976. The experiment included a treatment of farmyard manure (FYM) at the rate of 25 tons/ha. No effect of N or FYM was observed on grain yield. Nitrogen at 100 kg N/ha reduced root nodule mass.

A significant response to phosphatic fertilizer application in the soil was not observed on soils low in available P (2-5 ppm). Placement of phosphorus at a depth of 30 cm was also not effective. Further, there was no interaction between phosphatic fertilizer application and irrigation.

Lack of response to phosphatic fertilizers could possibly be due to one of the following:

i) Increasing distance between the zone where fertilizer is placed and the zone where the active roots are located. As the season advances, active roots develop deeper into the soil away from where fertilizer is placed.

ii) The P requirement of chickpea is low, and it can be satisfied from a soil with low P content. The crop is deep-rooted, and may be very efficient in extracting P from the soil.

Entomology

INSECT-PEST SURVEYS

Chickpea generally suffers relatively little damage from insect pests, but in some areas and some seasons the crop is badly damaged. In an attempt to quantify insect-caused losses, we visit farmers' fields in a series of extensive surveys throughout the major chickpea-growing areas of India, at a time which coincides with the maturity stage of the crop. In addition to collecting samples and recording the damage, we also collect details of cultural practices, including pesticide use. Data on the insect-pest problems on this crop in other countries arc obtained through visits and communication with entomologists in national programs.

The major international pest of chickpea is undoubtedly *Heliothis,* with *H. virescens* causing most damage in the Americas and *H. armigera* in the Old World. A few other lepidopteran larvae are locally damaging, and termites cause some loss of stand in some soil types and areas..

In our surveys of this year, we again noticed great variation in pod damage among fields and areas. In most fields pod damage was less than 10 percent, but in some more than half the pods had been destroyed, mostly by *H. armigera.*

In India 58 percent of the fields surveyed were of sole-crop chickpea; in intercropped fields mustard, rape, lentils, pearl millet, and barley were found as companion crops. There was no obvious association of the degree of pest damage and cropping system.

During a visit to Lebanon and Syria, the leaf miner *Liriomyza cicerina* was noted to be very common on chickpea. Investigations to quantify the yield losses caused by this pest are planned.

INSECTICIDE USE

Of the 82 Indian chickpea fields surveyed from which we obtained definite information on pest control this year, only 15 had been treated with insecticide. All had been treated with the persistent insecticides--DDT, BHC, or endrin. Endosulfan, which is less persistent, is used at ICRISAT and is commonly recommended for *H. armigera* control in most areas of India. Effective doses of endosulfan are much more costly than DDT (Fig 36), and the differential has not been decreasing with time. It is not difficult, in view of the large price advantage, to understand the farmers' preference for DDT.

HOST-PLANT RESISTANCE TO INSECT PESTS

Work on the methodology of screening for resistance to insect pests, particularly *H. armigera,* continued on this crop. Attempts to use cages and inoculation of plants with laboratory-bred eggs and larvae, to ensure even pest pressure, did not give encouraging results, With uneven infestations and such small plants, there is a large chance of escape from attack on any plant or small plot. We have adopted a method of preliminary unreplicated small-plot screening, from which obviously susceptible cultivars are rejected. In this manner, germplasm accessions being tested have been reduced from more than 11 000 to a few hundred, which can be handled in replicated trials. In such trials, the chances of escape from infestation are greatly reduced. Our search is not only for resistance, but also for the ability to tolerate pest attacks and yield well after such attacks.

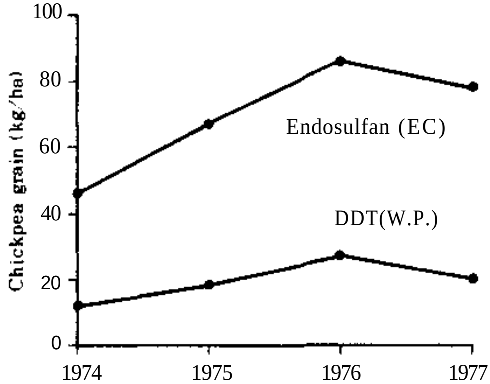


Figure 36. Cost per hectare of endosulfan and DDT required for effective control of H. armigera *in chickpea fields, expressed in kg of chickpea grain.*

In 1977 1978 the very heavy *H. armigera* infestation was ideal for open-field screening, with many plants supporting five larvae or more during the vegetative and early flowering stages. Under such an intensive attack, there was little chance of escape. Of the 955 germplasm accessions that had been recorded to be free from attack in the previous season's unreplicated tests, 231 were in replicated trials and not one was free from attack. The rest were again tested in unreplicated plots and only six were free from *H. armigera* pod damage, but all of these were of poor growth with relatively few pods. There were however, encouraging differences in percentage pod damage and yield among cultivars, many of the results confirming the previous year's observations on the same cultivars. Again in this year, the desi types proved to be generally less susceptible to *H. armigera* than were the kabuli types.

In an initial attempt to select for less susceptible plants from within a cultivar, indications of heritable differences were found. This result will be followed by selection from within a number of promising cultivars in the coming season.

Plant-exudate studies. The very acid exudate (pH 1.4) secreted by the glandular hairs of the stems, leaves, and pods of chickpea has for long been considered to play a role in the relative resistance of this crop to many potential insect pests. However, the fact that chickpea is virtually the only host that is very attractive to *Heliothis* well before flowering has also given rise to speculation that the exudate is attractive to the egg-laying moths. We are now investigating the role of the exudate, its composition, variation among the cultivars, and effect upon insects in cooperation with the Max Plank Institute for Biochemistry at Munich.

PEST-MANAGEMENT STUDIES

In our trials with chemical pesticides, *H. armigera* damage was very severe during early plant growth, with most unprotected plants eaten down to bare stalks. Recovery was rapid and, although flowering and maturity were delayed, yields of the unsprayed plots were more than 75 percent of those from the pesticide-treated plots. Such yield differences were not sufficient to pay for the endosulfan used in protecting the crop.

In a trial of differing spacings under unprotected conditions, much greater populations of *H. armigera* larvae were recorded per unit area where the plant density was increased, and the yields were lower (Table 67). Benefits from closer spacing may, as in many other crops, be obtained only when the insect-pest populations are naturally low or controlled by pesticide use.

Parasitoids, particularly hymenopterans, build up rapidly on *H. armigera* populations on chickpea. The effect of pesticide use on these beneficial insects is of obvious importance and a survey of such effects was initiated. Preliminary studies indicated great variability of parasitism rates within and between fields and with time, which swamped any differences that might exist between pesticide-treated and nontreated fields. The size and number of samples will be increased in the coming season in an attempt to quantify pesticide effects on parasitism rates.

Table 67. Populations of *Heliothis armigera* larvae and yields in a pesticide-free spacing trial of chickpea, ICRISAT Center, 1977 1978.

	Plant population (no/m²)			
	33.3	8.3	2.2	SE
H. armigera larvae (no/m²)	15.3	5.5	2.7	±1.29
Seed yield (kg/ha)	396	626	645	±60.0

INSECT DAMAGE TO NODULES

In a cooperative study by entomologists and microbiologists, the incidence and effects of insect damage in *Rhizobium* nodules was investigated. In a soil-insecticide trial the nodule damage was slightly reduced by the pesticides, but damage barely exceeded 10 percent in the untreated plots. The insects causing the damage appeared to differ from those found damaging pigeonpea nodules, but more detailed and extensive sampling will be needed before coming to a conclusion in this study.

Pathology

WILT (*FUSARIUM OXYSPORUM* F. SP. *CICERI*)

Early/late wilt. In northern India, wilt is often referred to as "early" or "late" wilt, depending upon time of occurrence. Early wilt refers to seedling wilt (Oct-Nov) and late wilt refers to wilting at post-flowering stage (Feb-Mar). Generally, the wilt incidence is negligible in the intervening period. We think it is possibly due to the cold winter in northern India that wilt incidence is negligible during the vegetative stage. With a moderate winter at ICRISAT Center, we have not noticed any clearcut "early" or "late" wilt; in fact wilt occurs from the seedling through the podding stages.

Loss estimation. We estimated the loss on a per-plant basis in relation to the stage at which the plant wilted in the 1977-1978 season. Wilting prior to the flowering stage results, of course, in total loss. We therefore selected stages after podding had begun, including flower/podding, full podding, and preharvest.

The data (Table 68) show (i) earlier wilting caused more loss than late wilting, (ii) 100-seed weight was reduced by wilt, and (iii) percent loss

Table 68. Effect of wilting at different growth stages on grain yield and seed size of four chickpea cultivars (averages of 30-plant samples).

Cultivar	Stage of plant development[a]	Average seeds	Average seed weight	Loss in seed weight/ plant	100-seed weight	Reduction in 100-seed weight
		(no/plant)	(g/plant)	(%)	(g)	(%)
CHAFA:						
Wilted		22	2.80	89.23	13.09	22.12
		60	7.85	69.80	14.00	16.71
		132	19.86	23.61	15.00	10.76
Healthy		158	26.00		16.81	
P-436:						
Wilted	S_1	25	2.08	91.40	9.44	35.16
	S_2	56	5.66	76.61	10.37	28.77
	S_3	121	12.16	49.75	11.17	23.28
Healthy		161	24.20		14.56	
JG-62:						
Wilted	S_1	15	1.44	94.26	8.44	44.51
	S_2	42	4.36	82.65	9.62	36.75
	S_3	133	14.76	41.26	12.18	19.92
Healthy		166	25.13		15.21	
850-3/27:						
Wilted	S_1	9	1.41	91.45	15.75	43.44
	S_2	20	5.83	64.66	20.85	25.13
	S_3	50	12.10	26.66	23.31	16.30
Healthy		61	16.50		27.85	

[a] S_1— Flowering and podding
S_2—Full podding
S_3—Preharvest

in both yield and seed weight varied with cultivar.

Time of infection. Invasion of the host by wilt is an important aspect of the host/parasite relationship. Limited studies on two cultivars planted in heavily inoculated soil in pots indicated that a susceptible cv was infected on the fourth day after sowing, and a moderately susceptible cv was infected on the seventh day. The susceptible reached 100 percent infection in 6 days, while it required 20 days for the moderately susceptible cultivar. Time-of-inoculation studies showed that the susceptible and moderately susceptible cultivars were not infected when inoculated after they reached 70 and 63 days of age, respectively.

Screening work. By planting in wilt-sick plots, we screened more than 3 000 breeding entries and identified 175 promising progenies.

As a result of massive screening of the germplasm (more than 6 000 lines) against wilt/root rots, we were able to identify about 80 lines which show resistance/tolerance to a number of soil-borne diseases at ICRISAT Center.

Based on screening at ICRISAT Center, the following cultivars are considered to be resistant to *Fusarium* wilt:

ICC-202	ICC-391	1CC-658
ICC-858	ICC-1443	ICC-1450
ICC-1611	ICC-3439	ICC-4552
NEC-790	WR-315	CPS-1
JG-74	BG-212	

Existence of physiologic races. The pot-culture procedure was used to study the pathogenicity of five isolates of *F. oxysporum* f.sp. *ciceri* collected from ICRISAT Center, Hissar, Jabalpur, Kanpur, and Gurdaspur, Ten genotypes, four resistant and six susceptible to the ICRISAT isolate, were used. The test was conducted three times, and reactions in most cases were consistent.

The results (Table 69) indicate that cv C-104 is

Table 69. Reactions[a] of chickpea cultivars to five isolates of *Fusarium oxysporum* f. sp. *ciceri.*

Cultivar	Isolate from				
	ICRISAT Center	Hissar	Jabalpur	Kanpur	Gurdaspur
JG-62	S[b]	S	S	S	M[b]
C-104	S	S	S	S	R[b]
BG-212	R	M	M	S	M
JG-74	R	R	R	S[a]	R
CPS-1	R	M	M[d]	S	S
WR-315	R	R	R	R	S[d]
Annigeri	S	S	S	S	s
Chafa	S	S	S	S	M[d]
L-550	S	S	S	S	M
850-3/27	S	M	M	M	M

[a]20 seedlings were used in each test and each test was carried out three times.
[b] R = Resistant (less than 20% wilt)
M = Moderately susceptible (20-50% wilt)
S = Susceptible (more than 51% wilt)
[c] Showed "S" reaction in two tests and "M" in one.
[d] Showed "M" reaction in two tests and "S" in one.

resistant to the Gurdaspur isolate but susceptible to all others. Cultivar JG-74 is resistant to all except the Kanpur isolate. Cultivar CPS-1 is resistant only to the ICRISAT isolate. Cultivar WR-315 is resistant to all isolates except the Gurdaspur isolate. Cultivars JG-62, Chafa, and L-550 are susceptible to all isolates and moderately susceptible to the Gurdaspur isolate. Cultivar 850-3/27 is susceptible to the ICRISAT isolate and moderately susceptible to all others.

The Gurdaspur isolate was differentiated from others through resistance of cv C-104 and susceptibility of cv WR-315. The Kanpur isolate was differentiated through susceptibility of cv JG-74. If "R" and "M" categories are considered as not too distinct, the ICRISAT, Hissar, and Jabalpur isolates could be considered identical; on the other hand, if these categories are considered distinct, then the Hissar and Jabalpur isolates only could be considered identical and the ICRISAT isolate distinct. The data indicate that there may be three or four distinct races.

Before we draw definite conclusions on races, we hope to determine how serious these isolates are in field conditions.

DRY ROOT ROT

The pathogen *Rhizoctonia bataticola* does cause substantial mortality and loss in a crop subjected to higher ambient temperatures (30 C and above) in the postflowering stage. This occurs in central and southern India. It is insignificant in northern India where cooler temperatures extend through March, and the crop is ready for harvest by the time temperatures rise. We have observed low incidence of this disease in Lebanon, Syria, Turkey, and Iran.

Dry root rot in ICRISAT Center sick plots is common in the postflowering stage. Our screening helps in identifying highly susceptible cultivars.

We find that Alfisol-extract medium supports less sclerotia production than Vertisol-extract medium. Dry root rot in both pigeonpea and chickpea is observed more frequently in the Vertisols at ICRISAT Center.

STUNT (PEA LEAF ROLL VIRUS?)

During the year, major emphasis was given to the identification of the causal agent and resistance sources. In addition to *Aphis craccivora, A. gossypii* was found to be a vector. The causal agent could be transmitted artificially through *A. craccivora* to *Phaseolus vulgaris* cv Turialba and Porillo-l, *Vicia faba, Lens culinaris* and *Lupinus albus.* The information obtained so far on aphid transmission, host-range symptomatology, and nontransmission through sap, indicates pea leaf roll virus as a possible causal agent.

Hissar has been found to be a "hot spot" for stunt. A very high level of disease incidence has been observed in each of the past three years. Experiments were conducted to find out if natural incidence could be increased further by planting chickpea at different dates and spacings. Relatively more disease incidence was observed in early (15 Sep) and late (15 Nov) plantings (Table 70) than at intermediate dates.

Table 70. Effect of planting time on chickpea stunt incidence.

Date of planting	Disease incidence
	(%)
15 Sep 1977	20.76
30 Sep 1977	8.74
15 Oct 1977	4.49
30 Oct 1977	8.79
15 Nov 1977	18.17

Disease incidence in different spacings was not significantly different. Of different legumes planted in advance around the fields to trap the aphid vectors and possibly the virus, pea and alfalfa served as good hosts for aphid (*A. craccivora*) buildup. Many chickpea plants showed the symptoms of pea leaf roll.

So far about 4 000 germplasm accessions have been screened under natural conditions, and 134 lines were found to be free from infection. Of these, 20 remained free from infection in a repeated replicated test. These were: ICC-2233, 2385, 2894, 2921, 2925, 3034, 3233, 3718, 3735, 4869, 6934, 8181, 10490, 10495, 10508, 10586, 10587, 10592, 10594, and 10800.

MOSAIC (ALFALFA MOSAIC VIRUS)

Based upon physical properties, host range, aphid transmission, and serology, the causal agent of mosaic has been identified as alfalfa mosaic virus. The problem at present is minor, but the disease has the potential of causing substantial damage to a susceptible cultivar.

ASCOCHYTA BLIGHT

More than 2 000 germplasm accessions were screened in the Isolation Plant Propagator and none was found resistant. However, 5 moderately resistant and 96 tolerant lines were identified. The resistant lines and some of the tolerant lines have been included in the International Chickpea *Ascochyta* Blight Nursery.

Different accessions of *C. reticulatum* varied in their reaction to the disease. Even within an accession, individual plants showed variation in the level of infection, indicating variability both among and within the accessions collected from natural populations.

POWDERY MILDEW

Because of doubts expressed by some scientists on the possibility of seed transmission of chickpea powdery mildew, this disease was studied with that specific objective. We failed to obtain evidence of seed transmission. The fungus was identified as *Oidiopsis taurica,* which has a wide host range that includes pigeonpea. Cross-pathogenicity tests involving inoculation of chickpea with pigeonpea powdery mildew and vice versa were successful. Survival of the conidia was found to be less than 24 hours.

Limited surveys revealed mild incidence of powdery mildew in the State of Karnataka, India.

INTERNATIONAL CHICKPEA DISEASE NURSERIES

The International Chickpea Root Rots/Wilt Nursery (ICRRWN) was sent to 22 cooperalors in 12 countries. The International Chickpea *Ascochyta* Blight Nursery (ICABN) was sent to nine cooperators in seven countries. There were 60 entries in ICRRWN and 24 in ICABN. A separate report will be prepared and circulated after the data have been received.

Nursery locations in India, Ethiopia, and Sudan were visited. A trip to Syria, where *Ascochyta* blight and stunt seem to be relatively more serious, was made to assess the disease situation.

Microbiology

COUNTING CHICKPEA *RHIZOBIUM*

We have now developed a suitable technique using a most-probable-number method based on growing chickpea plants axenically in 22- by 200-mm test tubes, and inoculating them with an aliquot of solution from a dilution series. The plant will nodulate if chickpea rhizobia are present in the aliquot.

We have achieved consistent nodulation of chickpea in test tubes by transplanting seedlings in which the cotyledons were excised 3 days following germination. The rooting medium can be either sand or a sand/vermiculite mixture.

Nodules appear around 20 days after inoculation. The plants will nodulate in natural light if tube temperature is kept below 30'C, but more reliably when they are grown with lateral illumination from flourescent tubes in a temperature-controlled room. The method is being used to examine *Rhizobium* numbers in soil and in inoculants.

RHIZOBIUM INOCULATION

We now have more than 800 isolates from chickpea nodules collected in India, Bangladesh, Turkey, Jordan, and Syria, and from wild

Cicer spp. from Israel. There is a wide range of symbiotic characteristics among these strains (Table 71)

In collaboration with the John Innes Institute in England, we are characterizing the intrinsic resistances of these strains to a range of 10 antibiotics. This genetic fingerprint provides an identification method that is.more sensitive and less time consuming than serological methods, and enables identification of naturally occurring strains. It thus obviates the necessity of using mutants selected for high levels of drug resistance (and may have altered symbiotic properties). We are using the method to follow competition in field trials between the inoculum strain with its unique fingerprint and the native *Rhizobium* population in forming nodules, as well as examining the influence of cultivar and site on the pattern of host-plant selection of strains when forming nodules.

Interactions between *Rhizobium* strains and host cultivars were found at ICRISAT Center in the dry winter season of 1977 in a Vertisol field with a low population of native rhizobia. Inoculation increased nodulation, with most nodules formed by strain DNRa-1. Among the five cultivars, 850-3/27 was best nodulated, followed by JG-62, with significantly fewer nodules formed on Rabat and C-235, and the fewest were on G-130. Inoculation significantly increased yields for some treatments.

A similar rainy season trial was planted in an Alfisol field (also with low numbers of *Cicer Rhizobium*) to examine the possibility for field screening *Rhizobium* strains in the off-season. There was again a significant *cultivar* x *strain* interaction in nodulation, with mean nodule number and weight per plant generally higher than for similar treatments planted in a Vertisol in the dry winter (postrainy) season.

Nodule formation continued for a longer time in the rainy season. Later in the season, *Colletotrichum* leaf blight affected the crop and also, in some early cultivars, seeds germinated in the pods prior to harvest. Harvest indices were about 50 percent of those obtained in the postrainy season; many seeds were malformed and germination percentage was poor—even with selected apparently healthy seed. This suggests that assessments of early nodulation and N_2-fixation can be made in Alfisols in the rainy season, but that yield comparisons may not be meaningful.

Another postrainy season trial on Vertisols examined response to a single and to a multistrain inoculum. Nodulation, nitrogenase activity, dry-matter production, and yield were significantly increased by inoculation (Table 72). with no advantage of the multistrain over the single-strain inoculum.

NODULATION AND NITROGENASE ACTIVITY

There was a large seasonal effect on chickpea nodulation. Nodule number in the 1977 postrainy season was about 50 percent that of the

Table 7!. Range of symbiotic characteristics" for *Cicer Rhizobium* strains screened on cv JG-62, ICRISAT Center, 1977.

Character	Range	Overall mean
Nodule (no/plant)	7-48	21
Nodule dry wt (mg/plant)	13-74	30
N_2-ase activity:		
(µM C_2H_4/plant per hour)	0.2-3.25	1.2
µM C_2H_4/g nodule per hour)	3 100	36
Root dry wt (g/plant)	0.08-0.29	0.15
Top dry wt (g/plant)	0.15-0.92	0.37
Colony growth rate[b]	3-15	

[a] Testing done during the rainy season when the ambient temperature range was above optimum for chickpea growth. Plants grown in Leonard jars watered with N-free nutrient solution, harvested around 45 days after planting. Values are means of four replications with three plants.

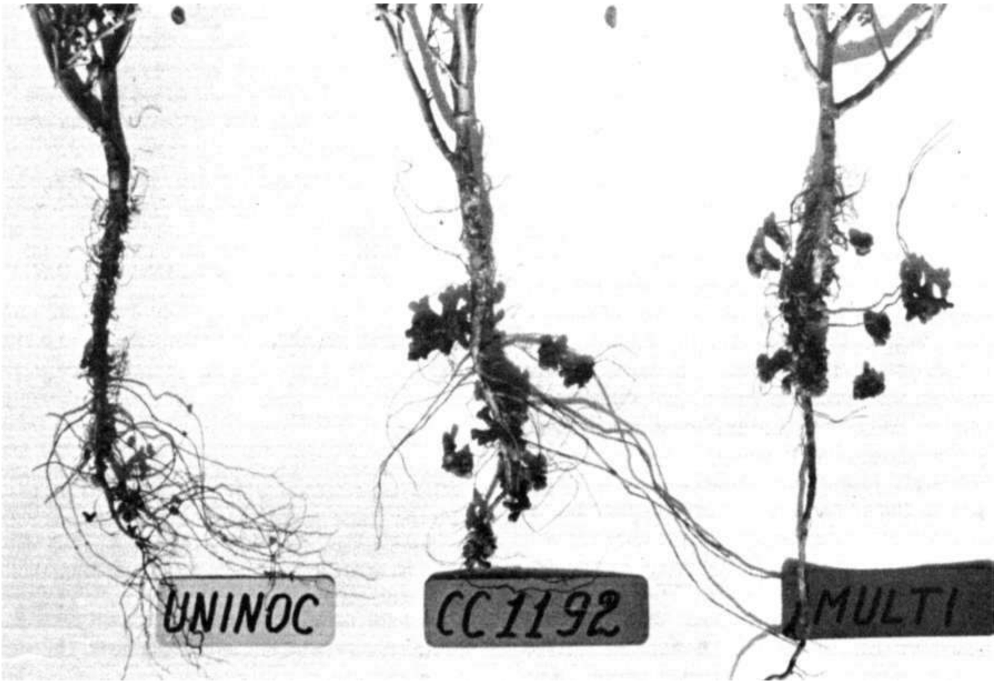
[b] Days taken for an isolated colony to reach 2 mm diameter on yeast extract, mannitol agar plate.

Table 72. Effect of seed inoculation on nodulation and yield of chickpea.

Inoculum treatment	Nodulation/plant		N_2-ase activity	Dry matter	Yield
	Number	Dry weight			
		(mg)	($\mu M\ C_2H_4$) plant per hour)	(kg/ha)	(kg/ha)
Noninoculated	4	11	0.3	2 893	1 564
Strain 3889[a]	17	42	2.2	3 735	2 143
Multistrain[b]	15	53	2.6	3 443	2 006
C.V. (%)	21	29	67	12	13
SE±	2.7	13	1.1	390	252

[a] Single-strain inoculum in peat carrier.
[b] Multistrain inoculum prepared from 20 strains grown separately on large agar slants, and suspensions of this growth used to inoculate the peat carrier.

Figure 37. Response of chickpea to inoculation with Rhizobium *strain CC 1192 or a multistrain inoculant. Few nodules are formed on noninoculated plants.*



previous season. We have no real idea of the cause of this, although the higher temperatures in 1977 were probably involved.

Nitrogenase activity of chickpea exhibits a marked diurnal periodicity (Fig 38), indicating a close relationship with photosynthesis. There is some evidence that the decline in nitrogenase activity after 1000 hours coincides with a similar crop in photosynthetic activity.

SYMBIOTIC VARIABILITY IN GERMPLASM LINES

We screened 251 lines of chickpea, including those used by breeders for crossing, for symbiotic characteristics in the postrainy season of 1977 in a Vertisol at ICRISAT Center, and 100 lines in a sandy loam at Hissar in northern India. There is a wide range for all characters examined at three growth periods (Table 73).

Nutritional Quality

As reported last year, screening of germplasm samples for protein content(N x 6.25) has been one of our activities. We analyzed 3 041 whole-grain germplasm samples for protein content by the DBC method. We have earlier shown that

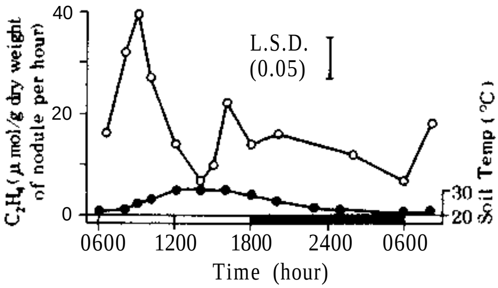


Figure 38. Diurnal variation in nitrogenase activity of chickpea cv 850-3/27 and soil temperatures at 7 cm depth 42 days after planting at ICRISAT Center, postrainy season, 1977.

this method gives satisfactory results and can be used for routine screening of a large number of samples. The majority of the germplasm samples analyzed came from Iran and India. Protein content ranged from 16.5 to 30.9 percent (Table 74), while in 126 released cultivars the range was 15.1 to 19.7 percent.

Nine wild species of chickpea were analyzed for protein content and proportion of salt-soluble protein. The wild species had a higher protein percentage (22.8 to 30.0), but the percent of salt-soluble proteins and their electrophoretic

Table 73. Symbiotic characters in crossing-block accessions of chickpea.

Character	Days after planting	ICRISAT Center		Hissar	
		Range[a]	Average	Range[b]	Average
		251	lines	100	lines
Nodule (no/plant)	25-30	2-18	7	0-27	8
	45-50	2-31	10	2-24	8
	70-75	2-31	11	2-34	10
Nodule dry weight (mg/plant)	25-30	0.3-14	4	0-21	7
	45-50	0.6-41	8	2-108	28
	70 75	0.5-82	16	1-471	54

[a]Mean of three replications per accession each with ten plants.
[b]Mean of four replications per accession each with five plants.

patterns did not indicate a marked difference from cultivated species.

TOTAL SULPHUR AND SULPHUR AMINO ACIDS IN CHICKPEA

To determine the relationship of total sulphur and sulphur-containing amino acids, 31 samples were analyzed for total sulphur by the turbidimetric procedure and by Leco sulphur analyzer, and for methionine by bioassay using *Leuconostoc mesenteroides.* Total sulphur, as estimated by the turbidimetric method, varied from 0.171 to 0.268 percent and by the Leco analyzer from 0.170 to 0.270 percent. Methionine ranged from 0.210 to 0.313 percent of the whole-seed sample and 1.05 to 1.48 percent of the total protein. A significant correlation (r = + 0.55**) was observed between total sulphur and methionine in the whole-seed sample. No correlation seems to exist between total sulphur and methionine as percent of protein.

The correlation obtained is too low to permit effective selection for methionine, using total sulphur values. Further work can include other sulphur amino acids.

Looking Ahead in Chickpea Improvement

Germplasm will be collected in Burma, Bangladesh, Pakistan, .and perhaps Ethiopia, a very important area. Local collections are expected from Mexico and Chile. We will attempt to add to the wild species collection with material from Turkey.

Breeders will increase emphasis on quantitative breeding for yield, which will involve increased cooperation with local programs. New applications of the crop will be explored, including winter planting at Aleppo, late planting in northern India, and early planting in southern India. More emphasis will be given to high-input production.

Intensive work to shorten the growth cycle will be done to provide the means of speeding up the breeding program. Work on nutrition, tolerance to salinity, and photoperiod and temperature responses will continue. Germination and growth under conditions of limited

Table 74. Range of protein content in chickpea germplasm accessions as determined from single samples.

Source/origin	Samples	Protein (N x 6.25)
	(no)	(%)
Afghanistan	143	19.0 28.9
Algeria	4	20.2-23.9
Bulgaria	2	21.8-23.1
Burma	2	20.9-24.5
Cyprus	4	23.1-24.8
Egypt	6	21.6-23.9
Ethiopia	93	17.1-24.8
Germany	1	20.2
Greece	3	22.2-24.8
India	1 061	16.5 29.6
Iran	1 332	17.8 30.9
Iraq	8	18.8 24.3
Israel	8	21.8-26.4
Italy	2	20.2-21.8
Jordan	6	20.1 23.6
Lebanon	14	18.8 24.3
Mexico	10	18.3-25.5
Morocco	19	17.6-24.3
Netherlands	17	18.8-23.9
Nigeria	2	22.9 27.1
Pakistan	55	20.2 25.3
Peru	1	23.1
Portugal	3	21.1-23.1
Spain	4	17.4-23.2
Sri Lanka	3	20.6-24.5
Syria	7	18.1-22.4
Tunisia	1	20.4
Turkey	70	17.9-24.7
USA	30	17.6-26.0
USSR	11	18.8-24.5
Unknown	119	19.0-26.0
Total	3 041	16.5-30.9

moisture will be investigated further. Our physiology work will continue to focus on field problems.

Multilocation testing of lines selected for low borer damage will be initiated. Biochemical studies, especially of the acid exudate on leaves, will be expanded. Ecology of insect pests, including their natural enemies, will be studied in at least two locations.

We will continue to refine screening techniques for disease resistance and will expand multilocation testing of resistant lines. Resistant populations for selection by local breeders will be developed. The importance of races will be evaluated in international nurseries.

Genetic studies will be initiated in crosses of high- and low-nodulating lines. Increased emphasis will be put on the use of multilocation testing of *genotype x environment* x *strain* interactions as well as response to seed inoculation.

Oilseed

Groundnut (*Arachis hypogaea*)

Groundnuts- as sources of human and animal feeds and as an economic crop— are one of the most important legumes of the semi-arid tropics. Of the world's total production, two-thirds is produced in the SAT. Yields are low, however, averaging only 500 to 800 kg/ha. Yields in the United States and some other areas can average around 2 500 kg/ha; in some areas they are as high as 5 000 kg/ha.

ICRISAT GOALS

ICRISAT's groundnut program can be summarized into three broad-based objectives:

To assemble, maintain, and screen a world collection of cultivated and wild *Arachis* material.

To seek, through breeding programs, to increase yields and incorporate resistance to important pests and diseases, and thus to bring about improvement of quality.

To provide introductions and segregating populations to all groundnut breeders in the SAT.

ICRISAT CENTER

The soil and climatic conditions at ICRISAT Center are ideal for groundnut research applicable to SAT agriculture. In addition to the major effort conducted under the rainfed situation of the normal season, irrigated crops are produced during the postrainy and hot dry summer seasons to facilitate the breeding program.

GROUNDNUT

Groundnut

ICRISAT's groundnut program aims to increase the low yields (around 800 kg/ha on average) of groundnut obtained by small farmers in the SAT, mainly by incorporating stable resistance to the prevalent diseases, such as leaf spots and rust.

During the year, we recruited a cytogeneticist whose main task is to exploit the useful genes of the wild species of *Arachis.* Three of the species with resistance to the leaf spot fungi are already being used in our breeding programs.

Staffing for our physiology work is behind schedule, so this subprogram is yet to get under way.

Germplasm

COLLECTION

Our collection of groundnut cultivars now totals 6 511 entries. Figure 39 shows the yearly acquisition of groundnut cultivars at ICRISAT and Table 75 shows our total collection by donor. This total docs not include material awaiting clearance by quarantine authorities. We feel that the task of collecting all available accessions from Indian institutions has been largely accomplished; we are indeed grateful for their excellent cooperation. As we have very strict quarantine measures to prevent the import of seed-borne pathogens into India, our acquisition of exotic germplasm has been necessarily slow. Nevertheless we have received to date more than 1 400 cultivars from abroad; these have been grown from seed to seed before being finally released to us for experimental use. In line with our mandate as a major germplasm center for *Arachis,* we have now begun to acquire wild species from Professor W.C. Gregory, North Carolina State University in the United States. Some of these species are perennials which set little or no seed and we have housed them in temporary screenhouses to prevent infection by viruses. The current species in our collection are listed in Table 76 and include four species received from Dr. V.S. Raman, Coimbatore, which have no PI or collector number.

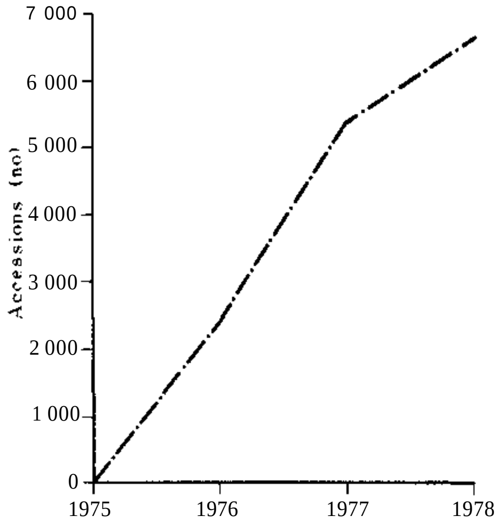


Figure 39. Groundnut germplasm accessions at ICRISAT Center, 1975-1978.

During the year, several trips were made within India to obtain remnant collections from institutions and to collect samples from farmers who were not growing improved cultivars. A total of 174 samples have so far been collected from farmers.

MAINTENANCE AND EVALUATION

Approximately 5 000 cultivars were evaluated during the 1977 rainy season. The material was so wn as far as possible on varietal groupings wit h standard checks after each 20 cultivars. Detailed observations were made on morphological characters and scientists from other subprograms visited the plots regularly and scored them for pest and disease reactions. The postrainy season was used mainly for seed multiplication, as foliar diseases and pests are less of a problem in this season.

Breeding

CYTOGENETICS

Fertile leaf spot-resistant plants were selected from each of three types of hexaploids, 2n = 60, produced at Reading University, UK, and previously tested at ICRISAT Center. Promising plants are being backcrossed to *A. hypogaea* to reduce the chromosome number to near the tetraploid level, 2n = 40.

Triploids of *A. hypogaea* x *A. cardenasii*, *A. hypogaea* x *A. chacoense*, and *A. hypogaea* x *A*. sp. HLK 410 varied in habit, size, and flower production (Fig 40). Hexaploids produced from these by colchicine treatment showed segregation for plant habit, size, *Cercospora* and rust resistance, as well as productivity. Some wild species characters, such as small and heavily beaked catenate pods, were also apparent.

Some vigorous hexaploid plants were also selected for their potential as forage plants. These plants showed many of the characters of the perennial-species parent and continued to produce new foliage throughout the year. They flowered late in the rainy season and set

Table 75. ICRISAT groundnut germplasm accessions, 1978.

Source	Accessions
	(no)
Indian institutions	4 910
Indian collections from farmers	174
Japan	37
Malawi	66
North Carolina State University, USA	1 239
Reading University, UK	12
Senegal	16
South Africa	35
United States Department of Agriculture	19
USSR	3
Total	6511

Table 76. *Arachis* species at ICRISAT.

Species	PI number	Collector number	Source
Arachis glabrata	-	-	Dr. V.S. Raman, TNAU, Coimbatore
Arachis marginata	-	-	"
Arachis villosulicarpa	-	-	"
Arachis villosa	-		"
Arachis sp.	276233	10596	Dr. W.C. Gregory, NCSU, Raleigh, USA via Reading University, UK
Arachis chacoense	276235	-	"
Arachis correntina	331194	-	"
Arachis chacoense x Arachis cardenasii		-	"
Arachis sp.	338280	HLK 410	"
Arachis duranensis	219823	-	"
Arachis pusilla	338448	-	"
Arachis batizocoi	298639	-	"
Arachis monticola	219824	-	"

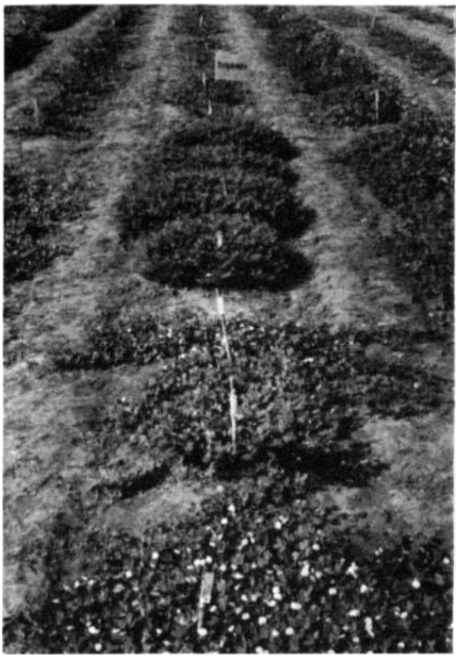
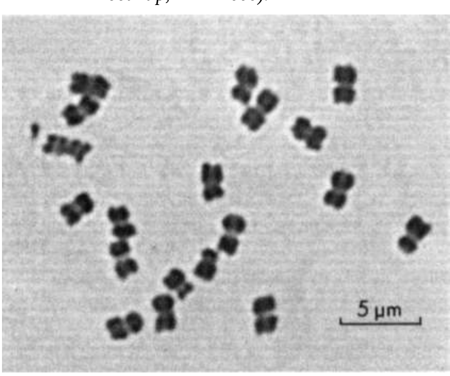


Figure 40. Triploid groundnut hybrids, A. hypogaea x diploid wild species, *showing variations in growth habits.*

Figure 41. Chromosomes of diploid wild groundnut species, A. correntina *(mitosis in root tip,* x *4 000).*



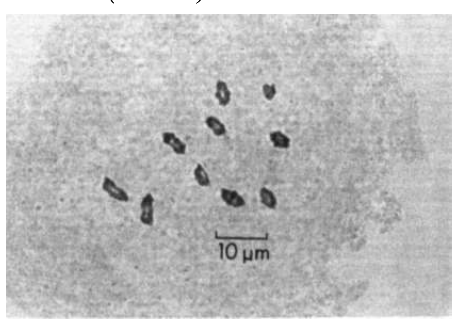
less seed than the early flowering hexaploids selected for backcrossing.

Cylological screening of the wild species is under way. Chromosome numbers were confirmed as 2n = 20 for the diploid wild species in Section *Arachis* (Fig 41), which form 10 bivalents at meiosis (Fig 42), and 2n = 40 for *A. glabrata* and another rhizomatous species in Section *Rhizomatosae.*

BREEDING FOR RESISTANCE TO RUST

This program commenced with two resistant sources, PI 259747 (Tarapoto) and PI 298115 (Israel Line 136), received from Georgia, USA. Seventy high-yielding but susceptible parents were selected for use in the hybridization program. Plants were grown in the screenhouse and during a 2-month period approximately 3 500 pollinations were made. From these, 2 074 pegs were produced, although eventually only 1 188 pods were harvested. F_1 plants were initially raised in the screenhouse and vegetative cuttings were taken to generate large F_2 populations. When further sources of rust resistance were identified (see groundnut pathology, page 155), two more cultivars, EC 76446 (292) and NC Ace 17090, were included in the hybridization program. During the period March to May, 1978, a further 9 000 pollinations were made with the old and new resist-

Figure 42. Ten-ring bivalents at meiosis in pollen mother cell of A. duranensis *(2n = 20) (* x *1 200).*



ant sources. During February 1978, additional F_1 plants were raised under irrigation in the field so the F_2 populations could be screened in the 1978 rainy season when rust is abundant.

The 14 F_3 lines (FESR 1-14) received from the USDA Puerto Rico rust nursery result from a natural cross and are claimed to be more resistant to rust than the resistant parent (PI 298115). Observations made in the postentry quarantine area showed that in the F_4 generation plants were still segregating for rust resistance as well as for growth habit and kernel color. Each plant within a line was scored for rust reaction and harvested separately. Individual plants were progeny rowed in the postrainy season and reassessed under an infector-row technique for their reaction to rust. Selections, both individual plants and bulks, were made for further studies in the 1978 rainy season. Rust reactions of some of the selections are listed in Table 77.

BREEDING FOR RESISTANCE TO *ASPERGILLUS FLAVUS*

The two breeding lines with dry-seed resistance to *A. flavus* were released from quarantine. These lines, PI 337409 and PI 337394F, remain resistant only as long as the testa remains intact. More than 3 000 pollinations were made during the 1977 rainy season and approximately 2 000 pods were produced. Some 70 crosses were completed with a range of commercially acceptable cultivars. When the laboratory for rapid screening of dry-seed resistance is completed, these hybrids will be tested and promising lines will be carried forward.

BREEDING FOR EARLINESS

Under rainfed conditions in the SAT, growing seasons can be very short or unreliable. Earliness coupled with good seed size and yield would be very useful. Two sources *of* earliness are presently being used in our breeding program. One cultivar, Chico (NC Ace 17200), is a very early Spanish type not commercially acceptable because of small kernels. The other cultivar, Robut 33-1, is a Virginia bunch line from India and is either a mutant or a natural hybrid from a Spanish cultivar. It is high yielding and has good kernel size. More than 2 000 pollinations involving 38 female parents

Table 77. Reaction of FESR groundnut lines to rust in the 1977 rainy and postrainy season trials at ICRISAT Center.

FESR Line	Plant No.	Rust reaction[a] Rainy season (individual plant)	Rust reaction[a] Postrainy season (progeny rows)	Selections made, postrainy season, 1977: Plant No.	Rust reaction	Yield (g/plant)
1	P11	3	3,8,9	P 3	8	88
				P 2	3	75
2	P 12	2	2, 3, 4, 8	P 1	2	56
3	P 1	8	4,8	P 5	4	160
3	P6	8	3,8	P 2	3	123
5	P2	3	3,4,8	P 1	3	119
5	P8	3	3,4,8	P 1	8	115
				P 4	3	115
11	P6	4	2,3	P 1	2	118

[a] 1 to 9 scale, where 1 = plant free from rust and 9 = plant severely affected with 50 percent or more defoliation.

were made with the two sources of earliness. F_1 plants have been grown and F_2 populations are now ready for planting in the 1978 rainy season.

BREEDING FOR INCREASED YIELD AND QUALITY

We intend in this project to produce high-yielding breeding lines for those areas of the SAT where pests and diseases are not a constraint and to generate high-yielding base material. The material generated can be directly fed into other breeding projects at ICRISAT and to national and international programs.

Crosses are being made in the screenhouse as well as in the field. The field technique has the advantage that large numbers of pollinations more than 1 000 per day for a 30-day period can be made. However, problems still to be overcome before the field-crossing technique is completely successful include infection by viruses and damage to emasculated flowers and hybrid pegs by insects. Nevertheless, by the middle of May 1978, our Held success rate was 31 percent.

COOPERATION WITH NATIONAL PROGRAMS

During the 1977 rainy season, seven yield trials sponsored by All-India Coordinated Research Project on Oilseeds (AICORPO) were conducted on Alfisols at ICRISAT Center. These trials were grown under rainfed conditions with fertilizer doses of 20:40:20 kg/ha of N_2, P_2O_5, and K_2O. Spacing between rows was 30 cm and within row was 10 cm (on Spanish cv) and 15 cm (Virginia cv).

In general, yields were low due to the very dry September at ICRISAT Center. Promising cultivars identified on this year's evaluation were Gangapuri, TG-16, Latur Number 33, Robut 33-1, and M-13.

Under erratic rainfall conditions, cultivation of Spanish groundnuts poses some problems. If there is rain at the time of maturity or if persisting drought (which forces maturity) is followed by rain, sprouting results. This reduces the yield and affects the quality of produce. An effort was made to estimate yield loss due to sprouting in Spanish groundnuts. In some cases, it was observed that losses due to sprouting were more than the harvested produce of the cultivars (equivalent dry-pod loss due to sprouting in cv J-11 was 572 kg/ha, whereas its harvested produce which did not sprout was only 493 kg/ha).

Four of the seven AICORPO trials were replanted in the postrainy season under full irrigation for comparison. Observations recorded last year were confirmed. There was significant increase in yield, shelling percentage, and kernel weight under postrainy season conditions (Table 78).

Entomology

PEST SURVEYS

The relative abundance of the major pests of groundnut at ICRISAT Center was recorded by weekly sampling in the three cropping seasons (Fig 43). The most important pests were the thrips, *Scirtothrips dorsalis* Hood (Fig 44) and *Frankliniella schultzei* Tryboni (Fig 45); both are vectors of TSWV, which causes a serious viral disease, bud necrosis. The incidence of thrips coincides with the incidence of bud necrosis disease. *Heliothis armigera* was important because of damage caused by feeding on a large number of flowers. Jassids were important pests during the rainy season.

Information on the major pests in India was collected from surveys and from the literature. Distribution, by state, is presented in Table 79. White grubs are probably the most important pests, causing damage to large areas of groundnuts in Gujarat, Rajasthan, Maharashtra, and Andhra Pradesh. Leaf miner and red hairy caterpillar are serious pests in southern India, where aerial spraying over large areas is practiced.

A review of the literature on groundnut pests revealed that some of these pests are of economic importance on a worldwide basis. Aphids,

Table 78. Performance of cultivars in Cooperative National Groundnut Trials [AICORPO trial (Bunch)] at ICRISAT Center during rainy and postrainy seasons, 1977.

Cultivars	Mean time to 75% flowering		Days to maturity		Mean yield		Shelling percentage		100-kernel weight	
	Rainy	Post-rainy	Rainy	Post-rainy	Rainy	Post-rainy	Rainy	Post-rainy	Rainy	Post-rainy
	(days)	(days)	(days)	(days)	(kg/ha)	(kg/ha)	(%)	(%)	(g)	(g)
Robut 33–1	24.8	44.8	99.5	150.0	1 240(1)[a]	2 829(3)[a]	55.0	78.8	24.7	76.8
X. 14–4–3–19–B	21.5	36.5	91.0	136.0	756(2)	2 409(10)	45.0	76.5	27.5	59.2
X. 14–4–3–8–B	24.3	36.8	91.8	136.0	720(3)	2 429(9)	56.0	76.4	20.6	61.8
GAUG-1	21.0	40.5	91.5	136.0	733(4)	2 884(2)	59.0	80.2	21.2	48.1
Dh-3–30	23.5	38.5	92.0	136.0	677(5)	2 703(5)	57.0	78.9	20.4	58.1
OG 71–3	22.0	39.3	92.0	136.0	639(6)	2 235(12)	58.0	77.1	23.5	52.4
JH-171	22.3	39.8	89.5	136.0	633(7)	2 727(4)	61.0	77.8	19.4	44.4
Argentine[b]	22.3	39.0	91.0	136.0	628(8)	2 387(11)	60.0	79.2	19.6	46.0
MGS-9	22.5	39.0	85.8	136.0	617(9)	2 910(1)	56.0	78.8	19.0	49.5
MGS-7	24.0	40.0	91.5	136.0	607(10)	2 497(8)	47.0	78.3	18.3	49.7
SM-1	21.0	40.5	90.3	136.0	586(11)	2 631(7)	60.0	80.2	22.3	49.0
Dh-3–20	25.0	37.5	94.0	136.0	584(12)	2 680(6)	50.0	78.2	21.2	59.6
J-11[c]	21.0	38.8	90.3	136.0	479(13)	2 203(13)	55.0	82.5	22.8	49.4
L.S.D. (0.05)					1.99	3.40				
C.V. (%)					20.30	9.21				

[a] Ranking
[b] Local check
[c] Regional check

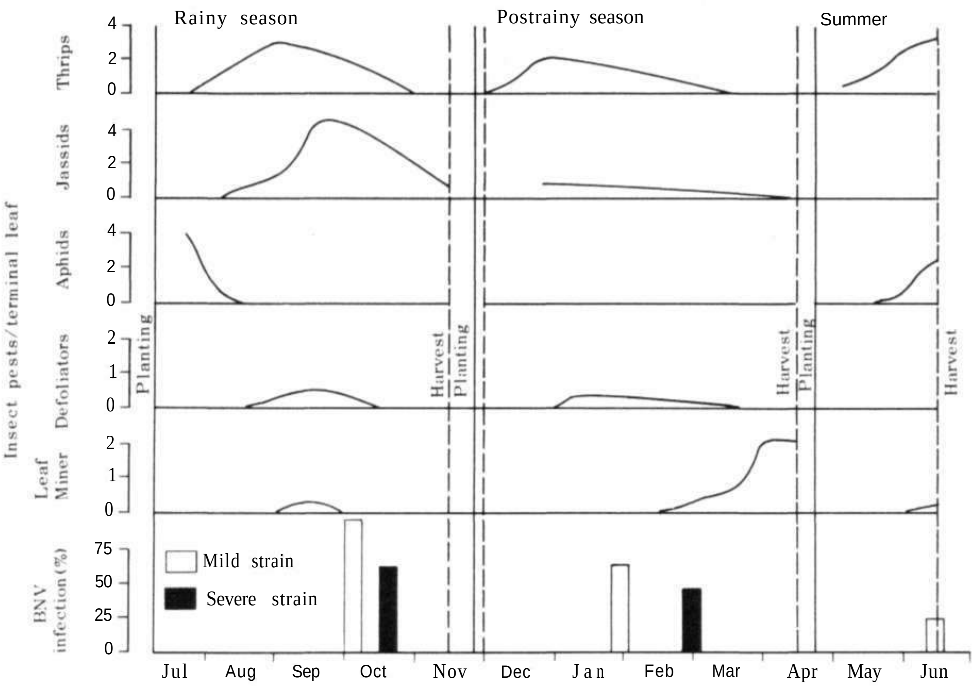


Figure 43. Relative abundance of major groundnut pests and severity of infection with bud necrosis virus disease at ICRISAT Center, 1977-1978.

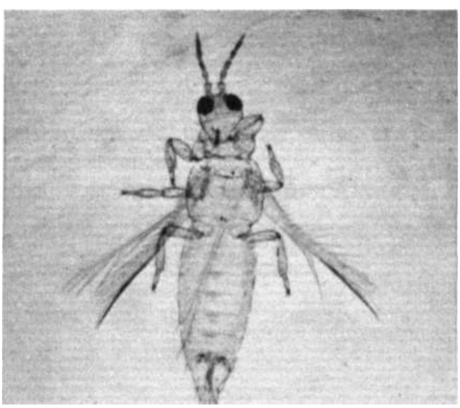


Figure 44. Thrip, Scirtothrips dorsalis *Hood (Thysanoptera: Thripidae), a new vector of the bud necrosis virus disease in India.*

Figure 45. Typical plant damage caused by the thrip Frankliniella schultzei *Trybom (Thripidae: Thysanoptera). This plant was photographed in Prakasam District, Andhra Pradesh, India.*

Table 79. Major pests of groundnut in India.

Pest	Areas where serious
Groundnut aphid, *Aphis craccivora* Koch	Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Rajasthan, and Tamil Nadu
Groundnut leaf hopper, *Empoasca kerri* Pruthi	Gujarat, Tamil Nadu, and Karnataka
Thrips, *Frankliniella schultzei* (Trybom), *Scirtothrips dorsalis* Hood, *Caliothrips indicus* (Bagnall)	Andhra Pradesh, Orissa, Karnataka, Tamil Nadu, Maharashtra, and Punjab
Defoliators, *Spodoptera* sp., *Amsacta* sp., *Heliothis* sp.	Tamil Nadu, Andhra Pradesh, and Karnataka
Leaf miner, *Stomopteryx subsecivella* (Zell.)	Tamil Nadu, Karnataka. Andhra Pradesh, and Maharashtra
Termites, *Odontotermes obesus, Microtermes* sp.	Madhya Pradesh, Andhra Pradesh, Gujarat, Rajasthan, and Haryana
White grubs, *Lachnosterna* sp.	Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Punjab, and Rajasthan

jassids, thrips, and defoliators (such as *Heliothis* sp.) are important pests of foliage; several species of termites, white grubs, wire worms, cut worms, earwigs, and millipedes attack the root and the pod in the soil; and there are many storage pests.

ROLE OF INSECTS IN CROSS POLLINATION

Several species of social and solitary bees were collected from groundnut fields. These include *Apissp., A. dorsata, Steganomus nodicornis (Sm), Nomia* sp. aff. *curvipes* (F.), *Pithitis smaragdula* (F.), *Lasiogiossum* sp., and eight unknown species. The Commonwealth Institute of Entomology in the United Kingdom and the Zoological Survey of India provide valuable assistance in identification of unknown species. Most bee visitations to groundnut flowers occurred late in the morning after self-pollination had occurred so the percentage of outcrossing remained low. In one trial, the percentage of outcrossing was estimated by using the genetic marker "krinkle" and was found to be 0.6 percent.

SOURCES OF RESISTANCE TO INSECT PESTS

Procedures were developed for screening plants for resistance to aphids, thrips, and jassids.

Five-hundred germplasm lines were screened for Aphis resistance, and no resistant plants with less than 25 aphids (apterae and nymphs) were found. Some wild species, *A. chacoense, A. batizocoi, A. pusilla, A. glabrata,* and hexaploids derived from *A. hypogaea* x *A. cardenasii* and *A. hypogaea* x *A. chacoense* were resistant.

Germplasm was screened for thrips resistance in the rainy and postrainy seasons. Not one of the erect bunch lines was resistant, but the semispreading accessions (NC Acc 1491, 2758, 2761, 2467, 2747, 2461, 814, 2575, and 17142) and the runner accessions (NC Ace 2242, 2232, 2230, and 2214) were promising.

Figure 46. Severe groundnut damage caused by white grubs, Lachnosterna *sp. (Scarabidae: Coleoptera).*

Promising lines against jassids were NC Acc 548 (erect bunch), NC 2477, NC Acc 2462, NC 17075 (spreading bunch), and NC Acc 2214. 2243, 2232, 2240, and 2242 (runner). Of these cv 2214 is particularly promising.

Germplasm lines, with susceptible cultivars as checks, were exposed to high levels of bud necrosis virus. Nine lines, all runners, showed some resistance to the severe strain, and 4 spreading bunch lines and 14 runners showed some resistance to the mild strain.

Lines were also selected for resistance to pod injury by termites.

As a result of these studies, lines NC Acc 2232, 2242, 2230, and 2243 appear to be less susceptible to thrips, jassids. both strains of bud necrosis virus, and to pod injury. These lines are being studied further.

STUDIES ON THE ROLE OF INSECTS IN TRANSMISSION AND SPREAD OF VIRAL DISEASES

In India, the bud necrosis or bud blight disease, caused by tomato spotted will virus, is the most important viral disease of groundnut. It was discovered that TSWV was transmitted by *Scirtothrips dorsalis* Hood and *Frankliniella schultzei* Trybom. TSWV virus exists as two strains the severe strain which is transmitted most efficiently by *F. schultzei,* and the mild strain which is transmitted by *S. dorsalis* Hood.

Both *F. sehultzei* and *S. dorsalis* Hood have a very wide host range. They successfully transmitted the disease to important agricultural crops such as *Vigna mungo, Vigna aurius, Vigna unguiculata, Glycine max. Solatium tuberosum. Datura stramonium,* and *Capsicum frutescens.* In *V. mungo* and *V. aurius,* the virus caused severe leaf curl. It was observed that *Sesbania* was not infested by thrips and did not contract the disease. It was therefore suggested that *Sesbania* should replace cowpea as a cover crop on ICRISAT's research plots.

It was observed that the peak period of thrip activity was from July to September and from December to February (Fig 47). The crop planted earlier in the rainy season, as well as postrainy season crops, escaped initial thrip attack and therefore had much lower incidence of bud necrosis virus. Early sowing augmented by few insecticidal sprays may help in reducing the incidence of bud necrosis disease.

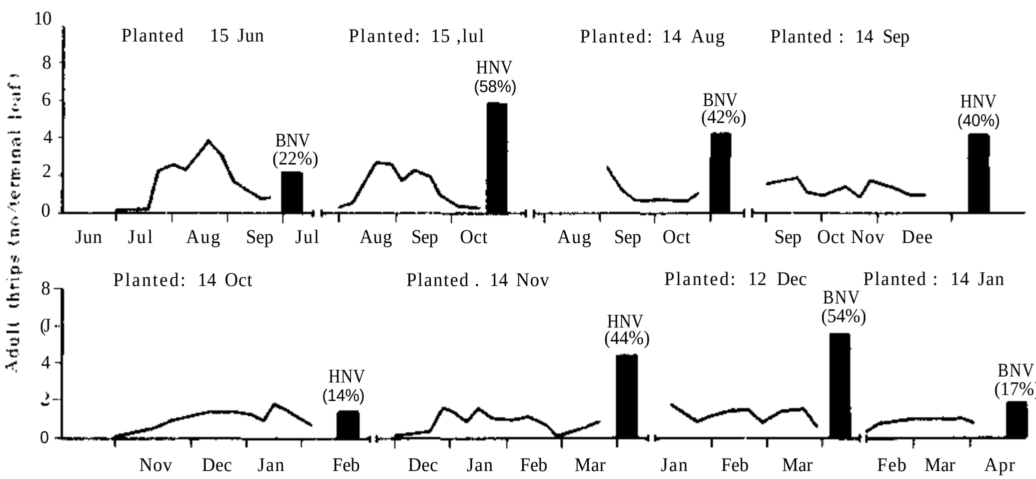


Figure 47. Population of thrips and percentage of bud necrosis virus in relation to different planting dates, ICRISAT Center, 1977-1978.

Pathology

GROUNDNUT RUST (*PUCCINIA ARACHIDIS*)

Biology. Infected leaf debris, collected at harvest in the rainy and the postrainy seasons, has been studied for the length of uredospore survival under ambient conditions. The percentage of viable uredospores was estimated on the day of collection and then at regular intervals. Viability was assessed by suspending uredospores in sterile distilled water and then placing a drop of the suspension on a slide in a moist petri dish. Plates were incubated in the dark at 25°C for 6 hours and the germinating uredospores were counted. The counts show (Table 80) that spores are short-lived under natural conditions after harvest.

The effect of temperature on uredospores was also studied. Spores were collected and stored at -16, 6, 25, and 40°C in glass vails. The initial percentage viability estimated on the day of incubation was 86.37 (Table 81). There was no loss of viability at — 16°C 120 days after collection, but at 6 and 25°C viability slowly decreased and reached zero 60 days and 40 days after collection, respectively. At 40°C all viability was lost after 5 days. Thus it appears that temperature plays an important role in the viability of rust uredospores. The effect of temperature on uredospore germination, germ-tube growth, and appressoria formation is presented in Table 82.

Light also appears to play an important role in uredospore germination. Uredospore suspensions were placed on glass slides in moist petri dishes and covered with colored cellophane sheets and incubated at 25°C in a cooled incubator containing seven (40 W) cool fluore-

Table 80. Viability of groundnut rust uredospores on infected crop debris exposed to natural weather conditions.

		Viable uredospores[a]			
Period of exposure	Collected:	Dec 1976	Jun 1977	Nov 1977	May 1978
(days)			(%)		
Initial		65.0	82.0	90.0	88.5
2		-[b]	-	88.0	-
4			-	89.2	0.1
6		35.5	9.2	74.0	0
8		-	-	78.0	0.1
10		-	-	52.0	-
12		-	·	52.0	-
14		0.8	1.1	42.0	0.3
16		-	-	45.0	-
18		-	-	30.3	-
20		0	0	25.5	0
22		0	0	10.0	0
24		0	0	0	0
26		0	0	0	0

[a] Mean of one thousand spores per sample.
[b] Not examined.

Table 81. Viability of groundnut rust uredospores during storage at temperatures of —16, 6, 25, and 40°C.

	Viability[a]			
Period of storage	-16°C	6°C	25°C	40°C
(days)		(%)		
5	88.25	84.37	80.50	0
13	82.25	84.63	88.41	0
28	88.66	82.37	80.40	0
40	90.44	35.00	24.00	0
48	89.05	15.10	0	0
60	88.24	4.00	0	0
70	92.30	0	0	0
78	92.50	0	0	0
99	92.12	0	0	0
110	93.63	-	-	-
120	93.00	-	-	-

[a] Mean of one thousand spores per treatment.

Table 82. Effect of temperature[a] on uredospore germination, germ-tube growth, and appressoria formation in groundnut rust.

Incubation temperature (°C)	Uredospore[b] germination (%)	Appressoria (%)	Mean germ-tube length[a] (μm)
- 16	0	0	0
5	0	0	0
10	2.5	0	194.7
15	24.42	22.20	379.5
20	43.53	7.24	399.5
25	68.81	6.43	212.2
30	23.48	16.75	84.9
35	0	0	0
40	0	0	0

[a] Average of two trials
[b] Mean of one thousand spores per treatment per trial.
[c] Mean length of 40 to 50 germ tubes per treatment.

scent lamps. The percentage uredospore germination was determined after 4 hours. The approximate peak wavelength transmitted by each interference filter was determined by a spectrophotometer. There was no germination in natural light and less than 10 percent in green, red, or yellow light. However, without light, germination of uredospores reached 86.9 percent. A further experiment showed that when infected leaves were sampled throughout the day, uredospore germination did not commence until 1800 hr. A check treatment in which leaves were kept in the dark and sampled at the same time showed consistent high germination rates.

Screening for rust resistance. During the 1977 rainy season, the germplasm collection of more than 6 000 cultivars was screened at ICRISAT Center. The cultivars were unreplicated, but a rust-susceptible check (cv TMV 2) was sown systematically throughout the field and rust became very severe. Each germplasm entry, consisting of two 6-m rows, was scored prior to harvest on a 9-point field scale (where 1 = free from rust and 9 = plants severely affected with 50 to 100% defoliation). All cultivars rated between 2 and 5 on the 9-point scale were rescreened in the following postrainy season.

Due to the dry atmosphere, rust is not usually prevalent during the postrainy season at ICRISAT Center. Therefore a field-inoculation technique was developed. Two susceptible cultivars with differing maturity dates (TMV 2 and Robut 33-1) were sown systematically as infector rows throughout a 2-ha field, some 14 days in advance of the test material. The planting pattern was an infector row, two test rows, and then another infector row. Rows were 75 cm apart and the within-row spacing was 20 cm. Some test rows were planted to known susceptible cultivars (TMV 2 and Tifspan) to assess the spread of rust from the infector rows. At peak flowering, the infector rows were inoculated with uredospore suspensions (about 50 000) spores/ml) made in tap water containing a wetting agent. The uredospores had been collected the previous season and stored at — 15 C. The inoculations were made at 1500 hr after the field had been furrow irrigated. Subsequently, the field was irrigated with overhead sprinklers on alternate days initially and then at irregular intervals until harvest. Pot-grown "spreader" plants, heavily infected with rust, were also placed systematically throughout the field to act as additional sources of inoculum.

Approximately 90 days after emergence, 20 to 25 plants of each test cultivar were sampled by taking leaves from the lower, middle, and upper parts of the plant. The samples were then mixed and scored for the percentage leaf area damaged by rust. Subsequent sampling took place at 10-day intervals until harvest. Each cultivar was also scored for rust reaction on a scale proposed by Mazzani and Hinojosa and also on a modified Cobb's scale. Rust development on the infector rows was good and the spread to the test rows was successful and typical susceptible reactions developed on the check cultivars. Several new rust-resistant sources were identified from the germplasm collection and two....NC Ace 17090 and EC 76446 (292)- appear to be more resistant than either Tarapoto (PI 259747) or Israel Line 136 (PI 298115), which we had been using in our breeding program. Results of the screening trials are shown in Table 83.

Screening trials, using whole plants and detached leaves, were also carried out in the screenhouse. Plants of three resistant cultivars were raised in pots and inoculated with uredospores at different growth stages (four-leaf stage, at peak flowering, and when nearing maturity). After inoculation, plants were kept in dew chambers on the screenhouse bench for 24 hours at approximately 24- 34°C. Each set of test plants included a susceptible check (cv TMV 2). The percentage leaf area damaged by rust was assessed on a total plant basis 30 days following inoculation. Plants inoculated at the seedling stage and at peak flowering developed more rust after 30 days than did plants inoculated at maturity (Table 84). Cultivar NC Acc 17090, however, showed little damage at any stage. PI 259747, rated as resistant in the field, showed 50.83 percent leaf area damaged when inoculated at the seedling stage. It appears that the decline in susceptibility to infection was associated with a corresponding decrease in leaf wettability. Reaction of detached leaves, taken from different parts of the plants, were

Table 84. Rust reactions of four groundnut cultivars in the screenhouse, 30 days following inoculation at three physiological stages of development.

	Leaf area damaged by rust (mean of live plants)		
	Stage of inoculation		
Cultivar	Seedling	Flowering	Nearing maturity
	(%)		
NC Acc 17090	4.0	6.5	2X
NC Acc 17129	26.7	38.1	5.9
PI 259747	50.8	30.8	2.9
TMV 2	100.0	85.5	41.1

Table 83. Rust reactions of 11 groundnut cultivars in field-screening trials at ICRISAT Center, 1977.

			Preliminary field screening (rainy season)	Advanced field screening[a] (postrainy season)		
Cultivar	Source	Seed color	9-point field scale	9-point field scale	Modified Cobb's scale	Mazzani and Hinojosa
NC Acc 17090	Peru	Tan	2	2	1	R_0
EC 76446(292)	Uganda	Purple	3	3	1	R_0
PI 259747	Peru	Purple	-	3	2	R_1
PI 298115	Israel	Pale tan		4	3	R_2
NC Acc 17129	Peru	Tan	4	4	3	R_2
NC Acc 17130	Peru	Tan	4	4	3	R_2
NC Acc 17132	Peru	Purple	4	4	3	R_2
NC Acc 17135	Peru	Purple	4	4	3	R_2
NC Acc 17124	Peru	Tan/purple variegated	4	4	3	R_2
TMV-2	India		9	9	5	R_4
Tifspan	USA		–	9	5	R_4

[a] In this trial, cultivars were evaluated while growing in irrigated plots alongside infector rows of susceptible TMV-2 and Robut 33-1 sown 2 weeks prior to the material being evaluated.

similar to those observed on whole plants. It appears that screenhouse testing for rust resistance alone is not advisable; this has been the case with other fungi in our work with groundnut.

Field and screenhouse testing of *Arachis* species has shown that many of them give an immune reaction to rust (Table 85).

LEAF SPOTS (*CERCOSPORA ARACHIDICOLA* AND *CERCOSPORIDIUM PERSONATUM*)

Screening for resistance. Apart from assisting in the screening of wild species and the interspecific hybrids in the breeding program for leaf spot resistance, we have also assessed the cultivated germplasm collection. As expected, no highly resistant lines were identified, but cultivars with small poorly sporulating lesions and others with apparent resistance to defoliation even when infected were observed. These may be useful characters to introduce into breeding programs.

Artificial culture. Both species produced limited conidia when grown on artificial media. We are now investigating other methods of producing large numbers of conidia for screening germplasm and breeding lines for resistance to the diseases. One promising method is to use detached infected leaves under high humidity; the leaves produce heavily sporulating lesions from which conidia can be collected under suction.

Table 85. Identity, classification, and origin of eight *Arachis* species and hybrids which developed no rust in field or in inoculation trials at ICRISAT Center, 1977.

Species	PI Number	Section	Source
A. duranensis	219823	*Archis*	Argentina
A. correntina	331194	"	"
A. cardenasii	262141	"	Bolivia
A. chacoense	276235	"	Paraguay
A. chacoense x *A. cardenasii*		F_1 hybrid"	
A. pusilla	338448	*Triseminalae*	Brazil
A. sp. 9667	262848	*Rhizomatosae* "	
A. sp. 10596	276233	"	Paraguay

DISEASE SURVEYS

Several disease surveys have been made in India to collect information on the importance of various fungi in ecological zones. Of particular importance is the distribution and spread of rust over the country and the particular leaf spot fungus involved.

Virology

TOMATO SPOTTED WILT VIRUS (TSWV)

At the time of the last report we had a great deal of evidence that bud necrosis virus (BNV), economically important in India, was caused by TSWV. The evidence included physical properties of the virus, and symptomatology on groundnuts and other host plants (Fig 48), transmission by a thrips species, and positive serological tests with TSWV antisera obtained from various sources. We have now obtained conclusive evidence from electronmicroscopy of infected groundnut tissues. These tissues were fixed at ICRISAT Center with glutaraldehyde and osmium tetroxide and embedded in Epon 812 after dehydration in acetone. The sections were cut and studied in Japan through the assistance of our visiting virologist, Dr. N. lizuka. The sections revealed typical spherical membrane-bound virus particles between 70 and 80 nm in diameter, in the cytoplasm. Some were present in the cisternae of the endoplasmic reticulum and in some cases they were present in membranous bags (Fig 49).

We have found several crop plants, apart from tomato, which serve as hosts of TSWV.

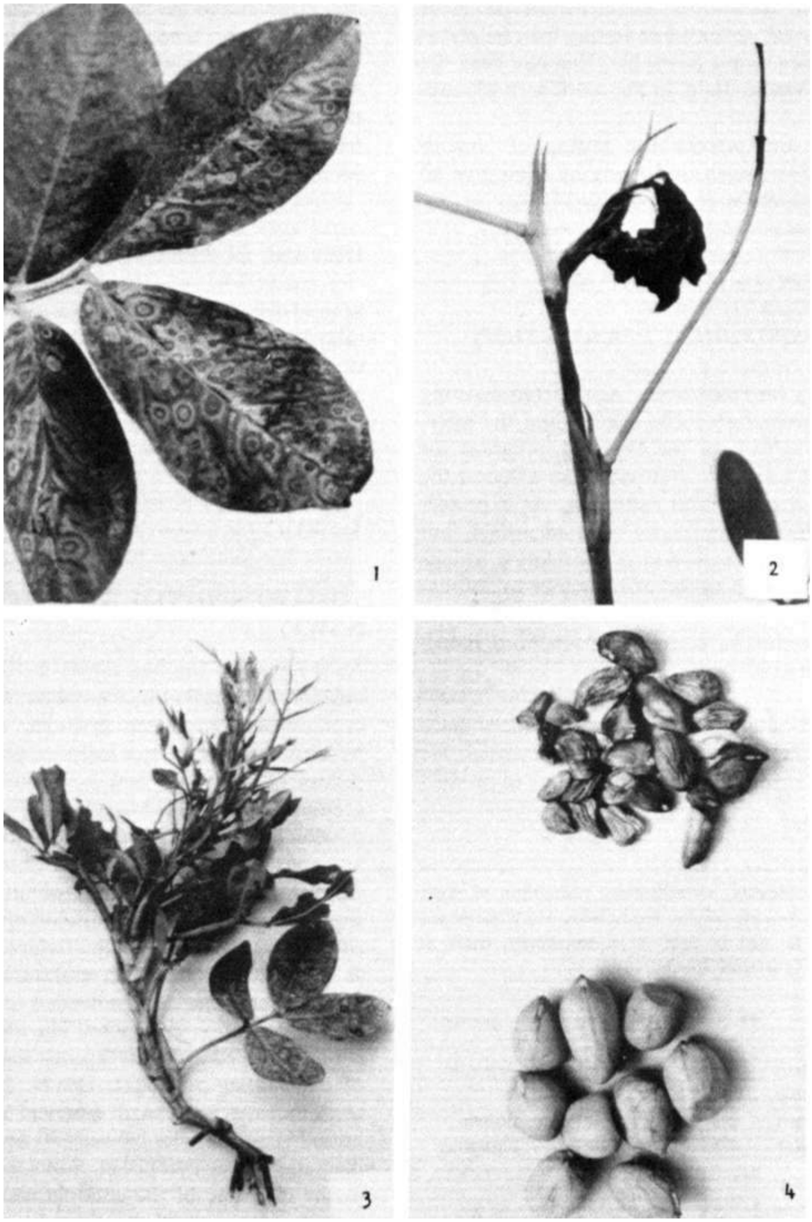


Figure 48. Typical hud necrosis virus symptoms on groundnut— 1) symptoms on leaves; 2) hud necrosis symptoms; 3) axillary shoot proliferation; and 4) seeds of healthy and diseased plants.

Mung bean (*Vigna radiata*) and urd bean (*Vigna mungo*) became heavily infected with the virus (>80%) when grown adjacent to groundnut plants. Infection appeared as veinal necrosis followed by downward curling of the leaves and the plants became severely stunted. Virus was recovered in assays to cowpea with crude sap extracts. In addition, typical symptoms of bud necrosis were reproduced when extracts from infected urd and mung beans were inoculated onto groundnut. Approximately 10 percent of the tomato plants and less than 1 percent of sannhemp (*Crotalariajuncea*) became infected in the field. The latter showed only localized symptoms. *Sesbania grandiflora* did not become infected.

CLUMP VIRUS

This disease was detected during survey trips to Punjab and Gujarat states. Symptoms included severely stunted plants with small green leaves. Diseased plants always appeared in patches, indicating that clump virus may be soil-borne. The extent of the infected areas varied from less than a square meter to nearly 0.3 ha.

More detailed examinations of newly unfolded leaves of infected plants showed mosaic mottling and chlorotic rings. Subsequently, the leaves turned dark green and remained small. No axillary-shoot proliferation takes place as it does in TSWV-infected plants. When sap from infected leaves was inoculated onto groundnut, typical leaf symptoms developed after 14 days and clumping occurred after about 10 weeks. Only 100 of the 200 kernels collected from diseased plants germinated, but they produced normal healthy plants. Three diagnostic hosts (*Phaseolus vulgaris, Canavalia ensiformis,* and *P. mungo*) have been found. Seed planted in soil taken from around clumped plants in the field have produced typical stunted plants.

The following physical properties of the virus have been determined.

Dilution end point. Infectivity was observed with sap diluted to 10^{-3} but not with a dilution of 10^{-4}

Figure 49. Tomato spotted wilt virus particles in groundnut tissue.

Thermal inactivation point. Infectivity was recovered after 10 minutes' exposure at 60°C, but not at 65°C.

Longevity *in vitro.* Virus present in crude sap retained infectivity for 72 hours at 25°C, but not for 96 hours.

Further collaboration studies are in progress with scientists from Ludhiana, Punjab.

PEANUT MOTTLE VIRUS (PMV)

PMV was recorded in the Punjab; this is the first record of this virus in India. Typical symptoms include mottling of the new leaves, interveinal depressions, and upward curling of the leaf margins. Diagnostic hosts include *Phaseolus vulgaris* cv Topcrop and *Cassia obtusifolia.* The virus is easily transmitted by sap or by the vector, *Aphis craccivora.* From 310 seeds collected and germinated from infected plants, four plants developed symptoms. For purification purposes, the virus was maintained on *Pisum sativum.* An antiserum has been prepared ; it had a titer of 1 /l 28 when reacted with a purified virus preparation.

For large-scale screening of the germplasm for sources of PMV resistance, we are investigating the use of an air compressor in conjunction with a sprayer to inoculate the plants with the virus.

OTHER VIRUSES

Several other viruses isolated from groundnuts are under investigation. They include chlorotic spot virus (CSV), cowpea mild mottle virus (CMMV), and chlorotic leaf streak virus (CLSV).

Microbiology

NITROGEN FIXATION

Seasonal and Cultivaral Effects

We estimate nitrogen-fixing activity in groundnut nodules by measuring the rate of reduction of acetylene, an alternative substrate for the nitrogenase enzyme, to ethylene. We have shown that the activity is affected by the plant-moisture status, by host plant and *Rhizobium* bacteria genome, by soil temperature, and by the photosynthetic activity of the plant. The latter is demonstrated by the marked diurnal periodicity in nitrogenase activity, when measured in either rainy or irrigated season, with maximum activity reached around 1000 hr, and a decline after 1600 hr (Fig 50). Activity declines if there is a cloud cover (see ICRISAT Annual Report, 1976-1977 p 126).

Besides photosynthesis, soil temperature is likely to have a large effect on nitrogen-fixing activity. For the cultivar Comet, nitrogenase activity at 25℃ was 46 umol C_2H_4/plant per hr, while at 30° and 35° there was a significant decrease to 34 and 32.5 µmol.

There are large differences between cultivars in nitrogen-fixing activity when assayed

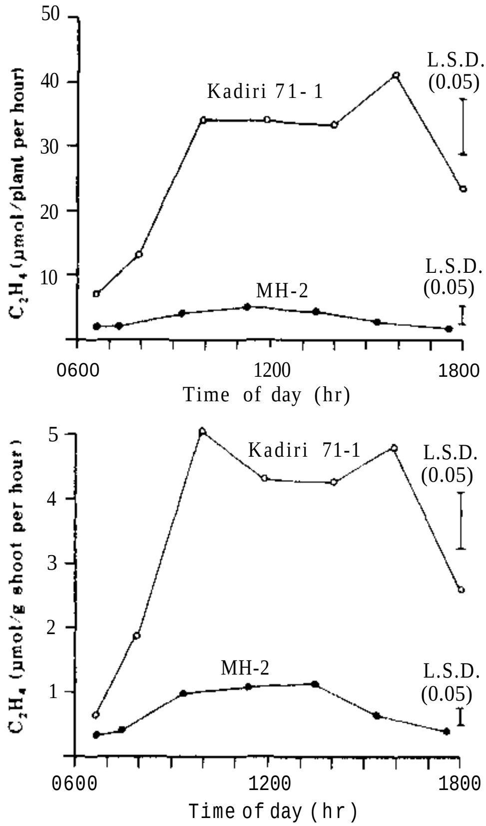


Figure 50. Diurnal periodicity in groundnut cv MH-2 and Kadiri 71-1 growing at ICRISAT Center, postrainv season 1977.

throughout the season. For example, at 57 days after planting, cv MH-2 had only one-tenth the activity of cv Kadiri 71-1, adapted for peninsular India (Fig 51). The same difference occurs even if one compares nitrogen-fixing activity on a shoot-weight basis (to allow for the different growth habits of the two cultivars), suggesting that Kadiri 71-1 is much more efficient in using its photosynthate to support N_2-fixation, as well as dry-matter production.

There are also large seasonal effects on patterns of nodulation and N_2-fixation. The

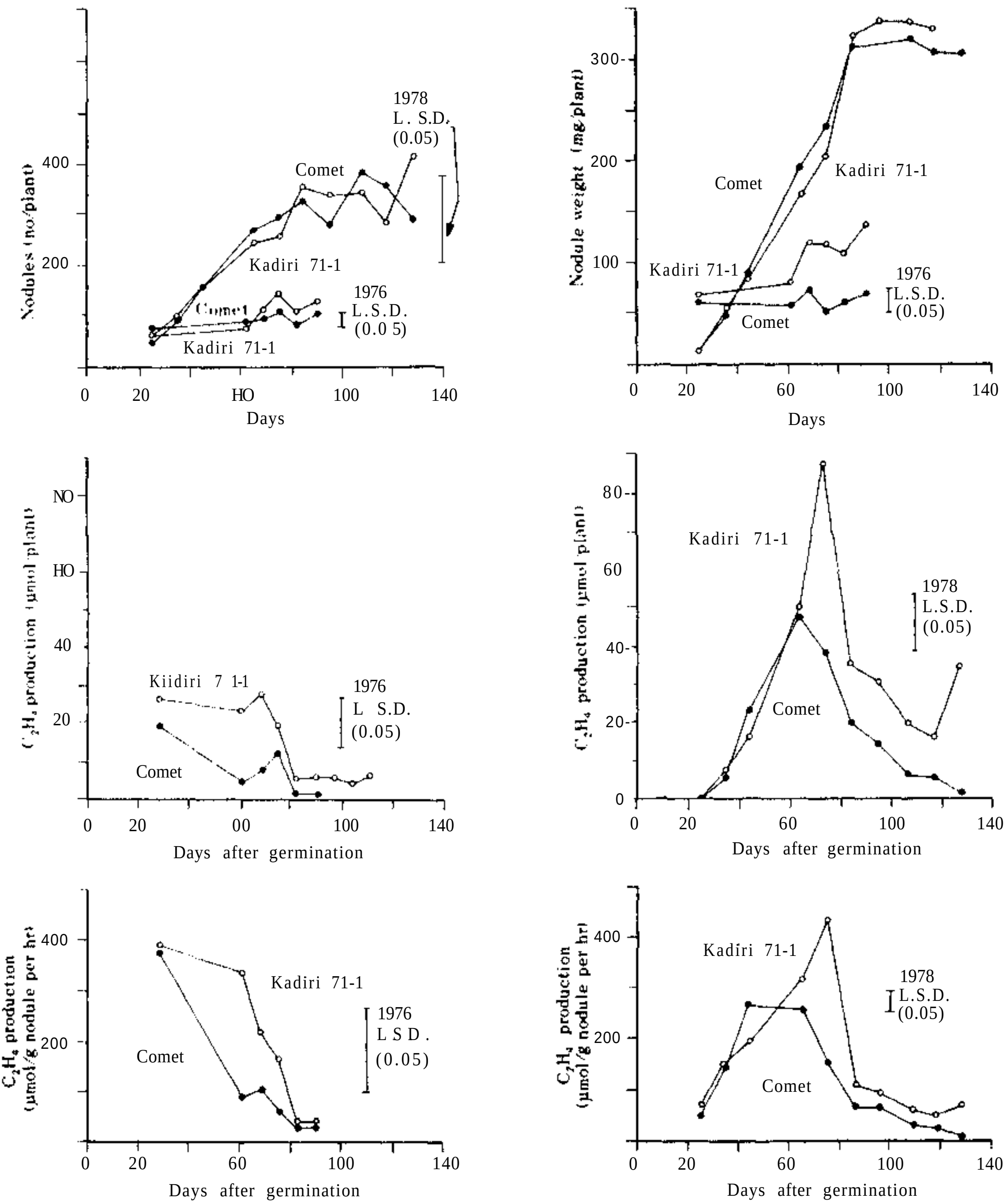


Figure 51. Seasonal variation in nodule number and nodule weight per plant and nitrogenase activity per gram nodule weight andper plant in cv Kadiri 71-1 and Comet grown during rainy season 1976 and postrainy season 1977 at ICRISAT Center. The postrainy season planting was irrigated.

nodulation and nitrogen-fixing activity of cv Kadiri 71-1 *(A. hypogaea* subsp *hypogaea, a* long-season runner cultivar) and of Comet (*A. hypogaea* subsp *fastigiata,* a short-duration erect-bunch cultivar) when grown in rainy season 1976 and under irrigation in postrainy season 1977, is plotted in Figure 51. In 1976, a 57-day dry period beginning 39 days after planting had an overriding effect on nodule formation and activity. For the rainy season planting, nodules formed rapidly during the first 25 days, but the drought restricted further nodule formation with little difference between cultivars. For Comet, nodules changed little in size after 25 days but Kadiri 71-1 nodules continued to grow so that by 75 days nodule mass per plant was twice that of Comet.

In the postrainy season, nodule formation was slower to start but then increased until 80 days after planting when three times as many nodules had formed as in the rainy season. New nodules were still forming on Kadiri 71-1 at 128 days. Nodule dry weight per plant reflected the pattern for nodule number.

Nitrogenase activity per plant and the efficiency of the nodules (N_2-ase per g nodule tissue) differed significantly between cultivars and seasons. In rainy season 1976, nitrogenase activity was at a maximum by 25 days, but from about 40 to 70 days Kadiri 71-1 nodules were more active than those of Comet. It was only after 40 days without appreciable rainfall that the nitrogenase activity of Kadiri 71-1 nodules decreased. The pattern of N_2-fixation in the irrigated season was quite different, increasing until about 75 days, then decreasing rapidly, with differences developing between cultivars. Kadiri 71-1 nodules at 128 days were still more active than at any stage during the rainy season. Peak activity per plant during the irrigated postrainy season was more than twice that of the rainy season.

The difference in symbiotic performance of Kadiri 71-1 and Comet under the drought stress of 1976, as well as between seasons, suggests that we can select cultivars which are better adapted to fix nitrogen under stress conditions.

Residual Effects

Rainy season groundnut, when compared with maize, was shown to have a large positive effect on growth and yield of millet in the subsequent irrigated postrainy season—an increase in yield of 650 kg/ha, or 45 percent. All groundnut and maize above-ground material and the groundnut main roots were removed from the field prior to the millet planting. This seems to be an effect of groundnut on N uptake by the millet, and would be consistent with the extremely high N_2-fixation rates associated with groundnut. The effect could be due to the N left in fine roots in the soil or due to exudation of N into the soil or due to less removal of available soil N by groundnut when compared with maize (Table 86).

VARIABILITY IN NODULATION

Screening of more than 500 groundnut germplasm lines for nodulation and N_2-fixation has shown a wide range for characters of interest. Table 87 shows the range of variability available in a replicated trial with 48 entries.

We have also found groundnut cultivars which consistently nodulate on the hypocotyl.

Table 86. Residual effect of groundnut and maize on millet grain yield in an Alfisol[a], ICRISAT Center, 1977.

First crop	Yield (kg/ha)
Groundnut	1 980
Maize, w/no fertilizer	1 325
Maize, 20 kg N/ha	1 456
L.S.D. (0.01)	360

[a] Groundnut and maize grown in rainy season 1977 at ICRISAT Center, followed by irrigated millet in the following postrainy season.

Table 87. Symbiotic characters in 48 groundnut germplasm entries 85 days after planting, ICRISAT Center, 1977 78.

	Range
Nodule number	247 to 628
Nodule weight (g/plant)	0.30 to 0.75
Nitrogenase activity	
µmol C_2H_4/plant per hr	36 to 176
µmol C_2H_4/g dry wt of nodule per hr	95 to 386

often without a subtending lateral root, whereas others form few or no nodules in this region. For example, in rainy season 1977, cv NC Ace 10 formed 175 nodules per plant on the hypocotyl (23% of all nodules formed), whereas cv NC Ace 770 formed only 12 nodules (2% of the total) in this region. Some cultivars, such as MK-374 (Fig 52), nodulate further up the stem, beyond the crown of the plant. Perhaps lenticels

Figure 52. Nodules formed on the stem of groundnut line MK-374.

or cracks in the stem are the site of infection as in *Aeschynomene indica,* which also nodulates freely on the stem.

We are selecting parents from this array for making preliminary crosses to study heritability and assess the potential for breeding for N_2-fixation.

Looking Ahead in Groundnut Improvement

Germplasm. Our next priority is to complete the transfer of wild *Arachis* species from the collections in North and South America to ICRISAT Center. The introduction and evaluation of *A. hypogaea* collections will be carried forward. Collecting expeditions in India will continue, and plans are under way to accompany the 1979 IBPGR expedition to South America under the leadership of Dr. W.C. Gregory.

Breeding. The emphasis on breeding for stable disease resistance, high yield, earliness, and dormancy will continue. The large numbers of crosses made will enable us to generate breeding populations for evaluation by scientists and cooperators throughout the SAT. As new and promising material is released from quarantine and produced from the hybridization programs, it will be incorporated with the general program.

Cytogenetics. Although the main objective of this program will continue to be to produce interspecific hybrids with stable resistance to the leaf spot pathogens, other activities will be expanded as the program develops. These activities will include the evaluation of other species and interspecific hybrids for yield potential and pest and disease resistance. Investigation of barriers to hybridization will be initiated; we hope to learn how to use species with known attributes which at present cannot be successfully crossed with the cultivated groundnut.

Pathology. The fungal program will be enlarged to cover not only the foliar pathogens, such as leaf spots and rusts, but other widespread pathogens attacking pods and roots at various stages of growth. Of the fungi, more emphasis will be placed on *Aspergillusflavus* and other mycotoxin producers. Plans have been formulated to set up a dry-seed screening program for resistance to *A. flavus* and we also plan to study preharvest invasion by this fungus and to search for sources of resistance before the crop is lifted.

Virology. The virology program will continue to precisely characterize important groundnut viruses and search for sources of stable resistance. Rapid-screening techniques for evaluating germplasm collections for resistance are presently being evaluated and will be used on a field scale shortly. Antisera to the most important viruses are being produced and will be sent to other researchers so that they may identify groundnut viruses *in situ.*

Entomology. This young program will continue to develop and expand. We will continue the present emphasis of evaluating and identifying major pests of groundnuts on a worldwide scale. Research will continue to emphasize the biology of virus vectors and the search for sources of resistance in the groundnut germplasm. In conjunction with the virologists, studies will continue on alternative hosts of the main insect pests and the viruses they may carry. We hope to gain information useful in formulating recommendations for cultural and biological methods of control.

Microbiology. Groundnut microbiologists hope to develop inoculation techniques, compatible with fungicidal seed dressings, that can be used by SAT farmers. The competitiveness of inoculants in forming nodules in competition with native *Rhizobium* populations in different soils will be assessed. Plans are under way to characterize the residual effect of groundnut in more detail, and to examine the relationship between photosynthesis and N_2-fixation, particularly in intercropping situations. Research on nitrogen fixation by groundnut in African locations will get under way.

Farming Systems

The goals of ICRISAT have from the beginning embraced development of improved systems of farming. In general, the goals of the Farming Systems section parallel those long-range goals of ICRISAT—to increase food production in the SAT, and to make it more reliable from season to season and year to year.

Specifically, the goals of the Farming Systems research programs can be presented in three statements:

To aid in generating economically viable labor-intensive production technology which makes a better use of the productive potential of resources, while at the same time conserving and improving resources.

To assist in development of technology for improving land and water management and resource conservation systems which can be implemented and maintained during the extended dry seasons, thus providing additional employment to people and better utilization of available manpower.

To assist in raising the economic status and quality of life for the people of the SAT by aiding in the development of systems of farming which will increase and stabilize agricultural output.

At any location, these objectives must be accomplished by providing optimum conditions for rainy and postrainy season cropping through proper management of the soil and of the total precipitation that falls on the land and by better utilization of the improved environment through more-productive cropping systems. In some areas this will also require collection and storage of runoff and the efficient utilization of stored water and groundwater.

ICRISAT CENTER

ICRISAT Center provides a range of environments for the development and testing of farming systems for the SAT. It has Alfisols and Vertisols—two major soil types of the SAT—and three growing-season environments. Certain areas are saline and others have impeded drainage, making it possible to evaluate plant performance under a variety of conditions. Realizing that the conditions of a scientific precision field are not identical to those in a farmer's field, the Center has set apart other areas—similar to farmers' fields—where the surface soil remains undisturbed and where land and water management practices which may enable better conservation and use of soil and moisture are researched. This helps better study of the potential the, application of new practices may have in farmers' fields.

FARMING SYSTEMS

Research done in 1977-1978 is reported under the following major categories: i) Research in subprograms; ii) Watershed-based resource development and utilization; iii) Cooperative research with national programs.

Research in Subprograms

Research in the subprograms ranges from investigations of physical and biological processes underlying crop production to applied studies which may have more immediate application for increased production; the approach is often interdisciplinary. However, each subprogram has a problem-oriented focus toward the stated objective: "to develop farming systems which will help to increase and stabilize agricultural production through better use of natural and human resources in the seasonally dry semi-arid tropics."

AGROCLIMATOLOGY

The Agroclimatology subprogram is concerned with resource assessment and with studies of environment and crop performance interactions. We work in interdisciplinary teams with environmental physicists, crop physiologists, agronomists, economists, and computer specialists. The main areas of work are: i) collection of meteorological data at ICRISAT Center and at cooperating research stations; ii) collection and interpretation of agroclimatological data for the SAT regions of the world; iii) microclimatological and crop phenological measurements; and iv) crop-weather modeling, work on which will begin in the 1978 rainy season.

Weather at ICRISAT Center

Rainfall. This year, the southwest monsoon was late in arrival and early in withdrawal—thus, the rainy season was short. A total of 545 mm of rain—22 percent below normal—was received from June to October. Monthly totals of precipitation from 1972 to 1978, along with the average amount of rainfall and its coefficient of variation based on long-term data, are presented in Table 88.

July and August of 1977 received above-normal rainfall while June and September received below-normal amounts, as was the case in 1976. More rainfall was recorded in 1976, compared to 1977, in all four of the rainy months of 1976. The coefficient of variation for this period was around 30 percent. October and November received nearly normal rainfall, which was slightly more than that of 1976. The dependability of rainfall during this period (Oct-Dec) is quite low; the coefficient of variation is high (90%).

Rainfall during June, July, and August was more stable compared to September and October (Table 88) in the last 6 years. In August, the rainfall amounts were above normal for 4 years and below normal for 2 years; the opposite was the case with September.

Daily rainfall amounts recorded during June through October 1977 at ICRISAT Center are plotted in Figure 53. The highest rainfall (74.4 mm) was received on 10 August. There were 21 days in which rainfall exceeded 10 mm as opposed to 19 days in 1976. There were 46 days of rainfall exceeding 1 mm. Weekly values of precipitation received during the rainy season (Jun-Oct) are shown in Figure 54.

About 10 mm of rainfall was received during the fortnight of 20 June to 3 July, when the crops were emerging. There was moisture stress in the initial stage of crop growth. September was nearly dry, except for a total of 40 mm of rainfall received on 1 and 29 September.

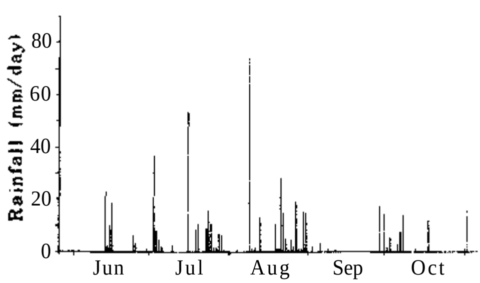


Figure 53. Daily rainfall at ICRISAT Center, 1977.

Table 88. Monthly rainfall received at ICRISAT Center from June 1972 through April 1978, and monthly mean rainfall based on 30 years' data at Hyderabad, 1940-1970.

Month	Normal							
	Mean (mm)	C.V.[a] (%)	72-73	73-74	74-75	75-76	76-77	77-78
			(mm)					
May	26.5	95	-	3.0	15.0	1.7	22.4	36.0
Jun	115.5	57	107.0	59.8	119.8	98.4	86.0	66.5
Jul	171.5	45	83.0	161.0	89.3	195.2	219.3	183.5
Aug	156.0	52	60.0	230.8	160.2	139.4	298.7	196.4
Sep	181.0	57	63.0	68.9	185.5	422.3	74.0	40.0
Oct	67.0	94	26.0	216.4	278.6	173.5	0.6	48.9
Nov	23.5	167	7.0	10.6	4.5	15.0	29.7	27.8
Dec	6.0	254	0.0	1.3	0.0	0.0	0.0	2.0
Jan	5.5	319	0.0	0.0	35.0	0.0	0,0	17.2
Feb	11.0	204	0.0	0.0	0.0	0.0	0.0	20.5
Mar	12.5	199	0.0	0.0	23.9	0.5	0.0	3.8
Apr	24.0	122	0.0	14.8	0.0	91.0	7.5	56.4
Total	800		346	767	912	1 137	738	697

[a] Source: George, C.J., P.E. Moray, and V.P. Abhyankar. 1974. "Rainfall pattern of rice growing areas prone to drought in India." *Met Mon* No. 6 (Indian Meteorological Dept).

Data on rainfall amounts associated with storms of different durations are presented in Table 89. In 1977, there were only three significant storms. Among these three, the 10 August storm contributed 74.4 mm of rainfall with an intensity of 40 mm/hr.

There are 41 rain gauges (8 self-recording) distributed over ICRISAT Center. These help in the study of the spatial distribution of rainfall over the 1 394 ha of ICRISAT Center. Frequently, rainfall is nonuniform over the Center (Table 90). These data point out the necessity of continuing measurements on a large network of rain gauge stations over the research area so as to obtain accurate data on rainfall distribution.

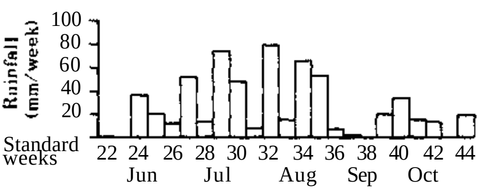


Figure 54. Weekly rainfall at ICRISAT Center, 1977.

Figures 55 to 61 represent air and soil temperatures, relative humidity, wind velocities, sunshine, evaporation, and global solar radiation respectively for 1977-1978 and the mean (except for soil temperatures and global solar radiation) of the 1973-1977 period.

Air temperatures. The highest daily maximum of 41.4°C (107°F) was recorded on 9 and 11 May 1978 and the lowest daily minimum temperature of 9.4°C (49°F) was recorded on 30 December 1977. The daily maximum temperatures generally ranged between 23 and 35°C during the rainy and postrainy seasons. The daily minimum temperatures ranged between 10 and 25°C from the second week of December through February. Minimum

Table 89. Duration and amount of intensive rains exceeding 5 mm/15 minutes during rainy season 1977 at ICRISAT Center.

Date	Duration	Amount
	(min)	(mm)
14 Jun	15	9.0
18 Jun	15	6.5
25 Jun	15	5.0
3 Jul	15	14.5[a]
3 Jul	15	5.0[a]
20 Jul	15	8.0
24 Jul	10	5.0
28 Jul	10	4.0
29 Jul	7	6.0
10 Aug	15	10.5[b]
10 Aug	30	19.0[b]
21 Aug	15	6.0
27 Aug	15	6.0
29 Aug	15	11.0

[a] Separate storms.
[b] Same storm.

Table 90. Range of rainfall recorded at rain gauges and amount recorded at agrometeorological observatory at ICRISAT Center on five rainy days in 1977.

Date	Agrometeorological observatory	Range
	(mm)	(mm)
18 Jun	19.8	5.2-36.7
17 Jul	54.4	14.4 61.0
10 Aug	74.4	65,0-85.0
20 Aug	10.8	7.2-30.6
1 Sep	14.8	5.6-44.0

temperatures of 10 to 15°C were observed in the last 3 weeks of December. A sharp fall in the minimum temperature was observed from Standard Week 49 without change in the maximum temperature (Fig 55).

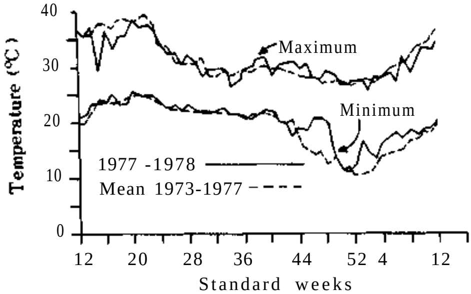


Figure 55. Weekly averages of maximum and minimum air temperature, ICRISAT Center, 1977-1978.

Soil temperatures. Soil temperatures at the 30-cm depth were generally higher than those at the surface or at 5-cm depth in the morning (except at the beginning of the season) (Fig 56). The reverse was noted in afternoon observations, although the difference was not as wide as in the morning. At the 150-cm depth, a slight decline in temperature was recorded during the rainy season. After Standard Week 48, morning temperatures showed a sudden fall at the soil surface and at the 5-cm depth, and to a lesser degree at the 30- and 150-cm depths. This seems to be associated with the fall in night temperatures during this period; changes in day temperature were minimal.

Relative humidity. Morning relative humidity exceeded 70 percent from June to January; during July and August, afternoon relative humidity also exceeded 70 percent. Humidity values dropped considerably in the postrainy season (Fig 57).

Wind velocities. Between May and July, average wind speed was around 14 km/hr (Fig 58). Increasing wind speeds were observed towards the end of June and early July. A maximum speed of 27.8 km/hr was recorded on 24 June 1977. The prevailing winds were due west during the rainy season and from the southwest October through March.

Sunshine. During July and August, due to

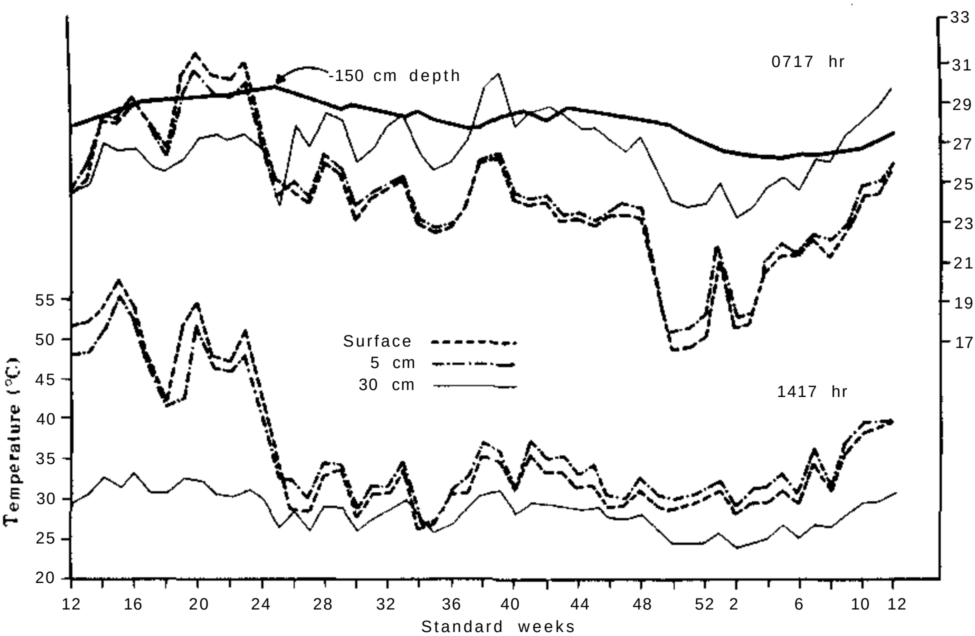


Figure 56. Weekly average morning and afternoon soil temperatures, ICRISAT Center, 1977-1978.

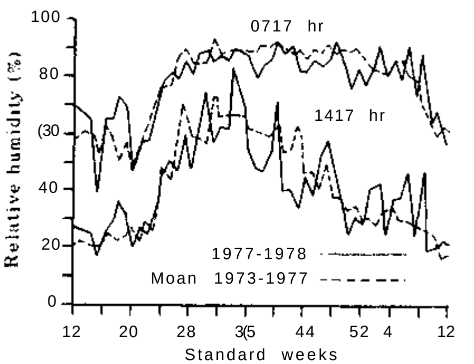


Figure 57. Weekly average relative humidity, ICRISAT Center, 1977-1978.

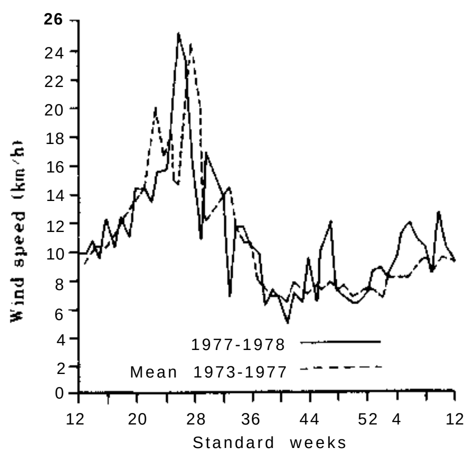


Figure 58. Weekly average wind velocities, ICRISAT Center, 1977-1978.

cloud cover, only about 4 hours of bright sunshine were recorded each day. Except for a few days in November and January, more than 8 hours of bright sunshine were recorded from the middle of September onwards (Fig 59).

Open-pan evaporation. On an average, evaporation was less than 6 mm/day during July and August, and generally higher than normal

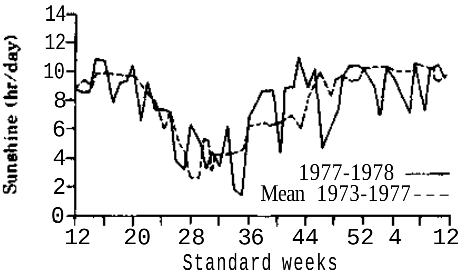


Figure 59. Weekly average hours of bright sunshine, ICRISAT Center, 1977-1978.

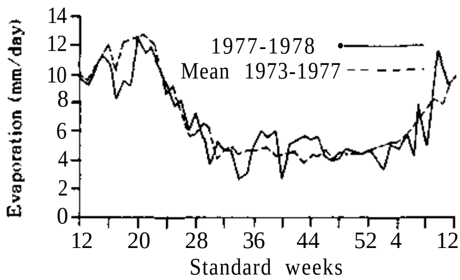


Figure 60. Weekly average evaporation, ICRISAT Center, 1977-1978.

from September onwards. Evaporation rates exceeding 10 mm/day were frequently observed during April and May 1978. The highest daily evaporation (15.4 mm) was recorded on 17 April 1978 (Fig 60).

Global solar radiation. Collection of global solar radiation data began at ICRISAT Center 28 July 1977. Average global solar radiation from Standard Week 31 is plotted in Figure 61. The low values are due to high cloudiness, also reflected in the data plotted in Figure 60.

Dew. A total of 3.7 mm of dew was deposited from October through January, of which 1.1 mm was recorded in October.

The Climatic Environment at Four Locations in Northeastern Brazil

Of the total land area and population of the SAT, nearly 6 percent of the area and 4 percent of the population are in Brazil, which has 1 036 000 km^2 of the area and 20 million of the population. Twelve percent of Brazil is SAT. Northeast Brazil is mostly arid and semi-arid except for the humid tropical areas on the east coast and in the western region (Fig 62).

A study of the climatic environment for crop production in the Brazilian northeast was undertaken by the National Research Center of EMBRAPA at Petrolina, Pernambuco State, Brazil in cooperation with ICRISAT and with Ford Foundation support. Daily rainfall, daily evaporation, soil properties, and production statistics for the major crops were collected for the Caruaru, Serra Talhada, Surubim, and Senhor do Bonfim regions. Climatic data for each of the four locations were analyzed by the procedure described by Virmani (1975) and the water requirements of short-, medium-, and long-duration crops at those locations were estimated.

Risk of crop failure is considerably higher in the Caruaru and Serra Talhada regions than in the Surubim and Senhor do Bonfim regions. The latter have higher and more dependable rainfall and the moisture availability index is above 0.33 for 3 to 4 months. In the Caruaru and Serra Talhada regions, however, both annual and dependable rainfall are less and

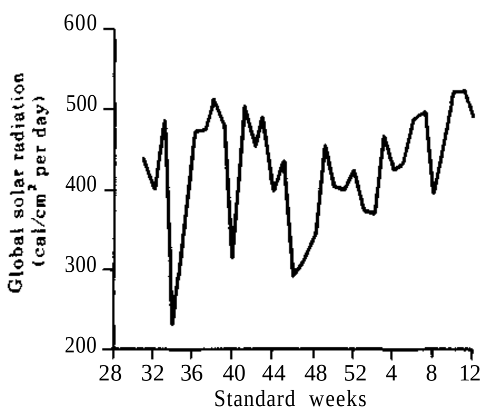


Figure 61. Weekly averages of solar radiation, ICRISAT Center, 1977-1978.

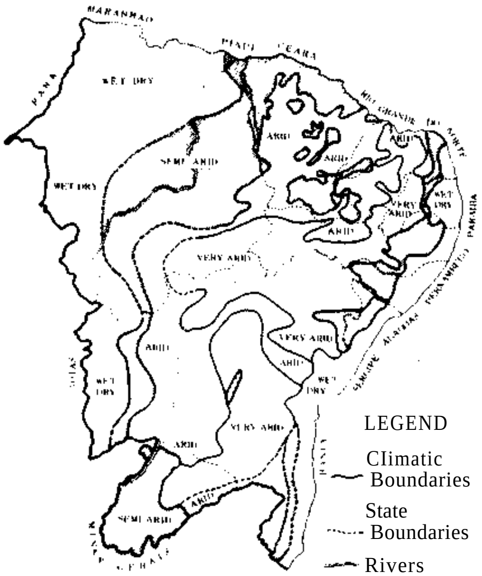


Figure 62. Climatic classifications for the Brazilian Northeast.

the MAI exceeds 0.33 for only 1 to 2 months. Although rainfall at Senhor do Bonfim is rather evenly distributed over 40 weeks per year, amounts > 10 mm/week are quite undependable; .consequently the higher annual and dependable rainfall does not represent an advantage for the Senhor do Bonfim area as far as avoiding crop failure due to drought is concerned.

Risks to crop production in the Serra Talhada region are high for all types of soils and all crop durations. Even when applying runoff water for supplemental irrigation, the region has a risk of crop failure in 3 out of 5 years.

In the Caruaru and Senhor do Bonfim regions, the risk of crop failure also is about 3 out of each 5 years, even on soils having profile storage capacities of 200 mm. If some supplemental irrigation is available during the reproductive and maturation stages of crop growth, the probabilities of successful production are 60 percent at Caruaru and 50 percent at Senhor do Bonfim.

On soils in the Surubim region having only 50 mm of moisture storage capacity, reasonable crop production can be expected in 2 years during a 5-year period. On soils with 100-mm storage capacity and with some supplemental irrigation, the risk of failure of 65- to 100-day crops can be reduced to less than one in four.

It is concluded that there is a high risk of crop failure for rainfed agriculture in each of the four regions. Although the probability of success is somewhat higher in the Surubim region, it still has an average risk of two crop failures in 5 years.

Microclimatological Studies

Crops grow in dynamic environment in which their canopies are exposed to constantly changing fluxes of radiant energy, moisture, and carbon dioxide. Measurement programs have been initiated to characterize this physical milieu and to study the crop's responses to alternative management systems.

Solar radiation and PAR. Ninety-nine percent of the solar radiation lies between the limits of 0.2 and 4 microns. The wavelength band between 0.4 and 0.7 microns is of primary importance in photosynthesis; hence, radiation in this band is called Photosynthetically Active Radiation or PAR.

Daily measurements were used to establish the relationship between PAR and solar radiation. The regression equation relating PAR (microeinsteins/sec per m^2) to solar radiation R_s (langleys/minute) is:

$$PAR = 1\,490\ R_s$$
$$R^2 = 0.997 \quad s.e. = 34$$

It was concluded that PAR can be computed from solar radiation with a certainty of about 98 percent.

PAR distribution within field canopies. Nonutilization of PAR is high when the crop canopy is not well developed. To study this effect, PAR and LAI (leaf-area index) in maize, sorghum, and maize/pigeonpea intercrop canopies were measured at different times during the 1977 rainy season. Practically all PAR entering the canopy was intercepted by the time cumulative LAI reached 2.5 (Fig 63).

The PAR attenuation data collected in the maize and sorghum canopies were analyzed using In $(1/1_0)$ as the dependent variable and cumulative LAI as the independent variable. The extinction coefficient was 0.84 for maize. This was larger than the value of 0.70 for sorghum, because maize cv SB-23 was taller and its canopy was more closed than that of sorghum. Thus, it appears that maize is more efficient than sorghum in intercepting PAR.

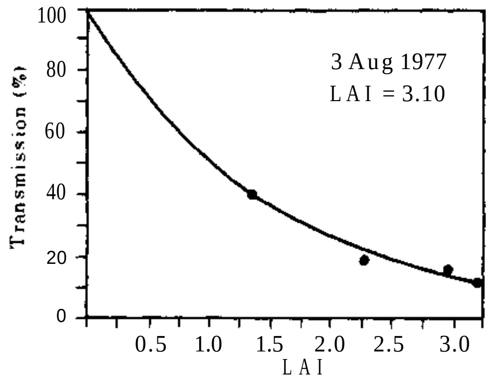


Figure 63. Percent transmission of light as a function of leaf-area index in a sorghum canopy.

Radiation interception under stress. Continuous measurements of radiation were made with tube solarimeters in adjacent irrigated and rainfed fields of sorghum from 27 December to 3 January. Because of water-stress effects, leaves of rainfed sorghum drooped so that by 3 January, 40 percent of the radiation reached the soil. On the other hand most of the leaves in the irrigated sorghum were green and active and only about 30 percent of the radiation reached the soil surface.

Energy-balance studies. The energy required to drive the processes of evaporation and transpiration is supplied by direct and diffused solar radiation, R_s, some of which is reflected from the plant and soil surfaces. The algebraic sum of the incoming and reflected radiation fluxes is termed net radiation.

Diurnal variation in the net radiation over irrigated and rainfed sorghum on 20 December is plotted in Figure 64. Integrated over the day, the difference in net radiation between the two treatments was 31 ly/day. This was sufficient to account for more than 0.5 mm of

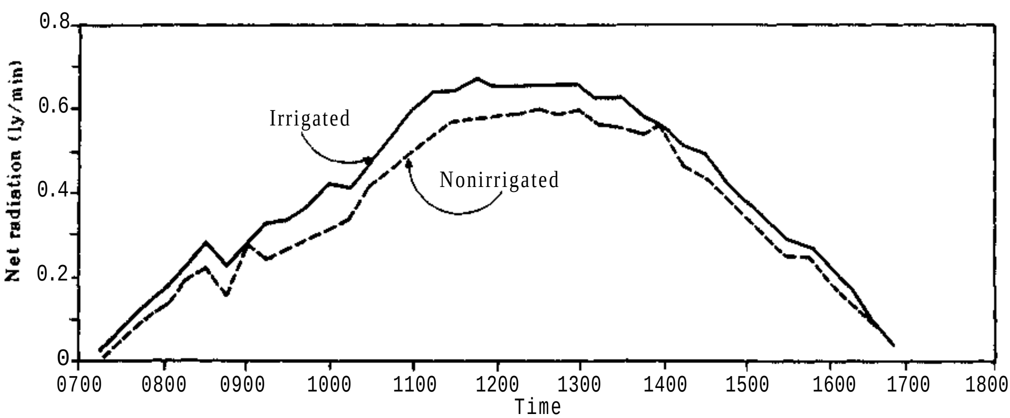


Figure 64. Diurnal variation in the net radiation over an irrigated and nonirrigated sorghum canopy on 20 December 1977, ICRISAT Center.

the higher transpiration rate in the irrigated sorghum as compared to that of the rainfed crop.

Components of the radiation balance over the irrigated sorghum are plotted in Figure 65. For a given pattern of incoming solar radiation, albedo values have a significant influence on the net radiation available for the sorghum canopy. The curve for net longwave radiation shows that loss rises gradually to a maximum at about 1400 hours.

Hourly data of net radiation, R_n, and solar radiation, R_s, over a full crop canopy were found to be related by the equation

$$R_n = -0.0177+0.65 (R_s)$$

Because the plant serves as a biological integrator, its physical and physiological behavior is being used to monitor the moisture environment of crops in agronomically relevant terms.

Stomatal physiology and leaf-water potential of sorghum were studied during the 1977 postrainy season. Under conditions of moderate water availability, the stomates of most plants open at sunrise and remain open until sundown. But under moisture stress (when an imbalance develops between supply and demand for water) the guard cells become less turgid and stomates begin to close. The slower dry-matter accumulation under such a situation could be attributed to decreasing supply of CO_2 to the photosynthetic sites, resulting in decreased photosynthetic activity. Grain yield of the irrigated sorghum was 5 990 kg/ha. Rainfall during the growing season was very low and the grain yields of stressed sorghum were 2 430 kg/ha because of low rates of stomatal conductance and reduced transpiration.

On a seasonal basis, the rainfed sorghum crop used 213 mm of water to produce 5 100 kg/ha of dry matter, whereas the irrigated sorghum extracted 321 mm of water to produce 9 300 kg/ha of dry matter.

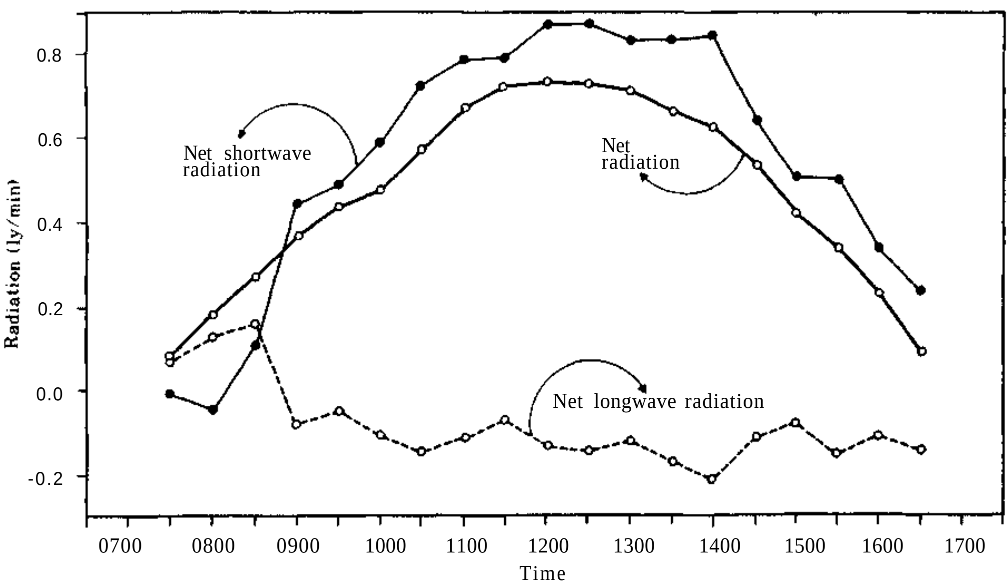


Figure 65. Components of radiation balance over an irrigated sorghum canopy on 9 December 1977, ICRISAT Center.

ENVIRONMENTAL PHYSICS

The main focus in the Environmental Physics subprogram is on the dynamics of water as it moves through the soil-plant-atmosphere continuum. We seek to understand the physical processes operating in that system and to measure *in situ* the quantities of water involved, the rates at which transfers occur, and the quantitative effects of the properties of the system which control them.

In cooperation with soil and water engineers and hydrologists, we quantify the terms in the water-balance equation and measure in the field the effects of the natural and man-induced physical properties of the soil-crop system. With plant physiologists, we measure the effects of the time and depth patterns of moisture in the root zone on transpiration and crop growth.

With agroclimatologists, we seek to develop a basis for describing and classifying climate in agronomically relevant terms. Basically this consists of translating the intermittent water supply, i.e. daily rainfall, and the atmospheric water demand into daily values of available water in the root zone. This data is then used to model transpiration and crop yield. It is our hope that such a process-based weather-driven soil- and crop-modulated model will be useful in i) explaining and generalizing the results of site- and season-specific field experiments, ii) identifying agroclimatic analogs, and iii) analyzing the likely consequences of alternative systems of soil, water, and crop management under different sets of soil and climatic conditions.

Water use by rainy and postrainy season crops grown on deep Vertisol. Time and depth patterns of profile recharge and depletion under several crops were measured by neutron moderation during the rainy and postrainy seasons. Data on the deep Vertisols were obtained for maize, sorghum, pigeonpea, and maize/pigeonpea intercrop during the rainy season and for irrigated and rainfed sorghum and chickpea and for a rainfed pigeonpea during the postrainy season.

During the rainy season, time and depth patterns of profile water content under the various crops clearly show the seasonal downward progression of the recharging process and the cyclical recharging and depletion of the upper part of the Vertisol profile. At the beginning of the rainy season, the profile was depleted below the 15-bar value to a depth of 30 to 45 cm. Below this, the 187-cm profile contained about 80 mm of available water.

Using data on daily rainfall, irrigation, open-pan evaporation, runoff, fractional radiation at the soil surface (B), and water flux at 187 cm together with the measured changes of water content in the 187-cm profile, it was possible to quantify the water-balance equation. Transpiration, T_m, was computed as the residual in the equation. Another independent estimate of transpiration, T_c, which assumes no plant water stress and no advective energy, was also computed as $T_c = E_0\ (1 - \beta)$.

Little or no runoff was recorded during 1977. About 40 mm of water, representing 10 percent of the rainy season precipitation, drained beyond 187 cm. The drainage estimates reflect the size and seasonal timing of the rains and the corresponding time and spatial variations of residual storage capacity in the 187-cm profile.

Good agreement between T_m and T_e from mid-July to mid-September supports the view that the crops did not experience moisture stress and that advection was negligible during that period. In all cases, T_m was substantially lower than T_e during September. Although some stress may have developed at shallow depths during the latter part of that period, the maturation of maize was the major factor responsible for the decline in transpiration, T_m, below its energy-dependent potential value, T_e.

During the postrainy season, profile depletions ranging from 97 to 150 mm were measured. The differences in depletion by the rainfed crops were largely caused by differences in the length of the growing season. In all cases, the early October moisture data showed that the profile contained about 200 mm of available water and was about 90 percent recharged. By the end of the season this had dropped to 75 mm. Available water in the profile at the end of the season was unaffected by the irrigation treatments.

Runoff or drainage did not occur during the postrainy season. Losses by evaporation were small and largely confined to the October periods. Irrigation caused a slight increase in evaporation, but even in irrigated plots the total for the season was less than 25 percent of the amount lost by transpiration and less than 10 percent of the open-pan value. In the postrainy season, T_m was generally less than T_e. For pigeonpeas that difference tended to increase as the season progressed. The crop was well established at the beginning of the season and, since the profile was well recharged at that time, the pigeonpea transpired close to their rate, $T_m \sim T_e$.

By measuring the areas between moisture-profile curves taken at different times, it was possible to compute the rates of water extraction by roots at any depth. During periods of progressive profile depletion, such extraction rates are interpreted as the *de facto* root distribution of the crop. Seasonal changes in root extraction rates of pigeonpea from the deep Vertisol are plotted in Figure 66. Also shown are the changes in fraction available water, i.e. the available water at a given depth divided by the available water capacity of that layer.

The seasonal progression in depth and time of the root extraction rates of pigeonpea shows that in the 0- to 22-cm layer, the rate of daily water use was 0.022 mm/cm until the end of

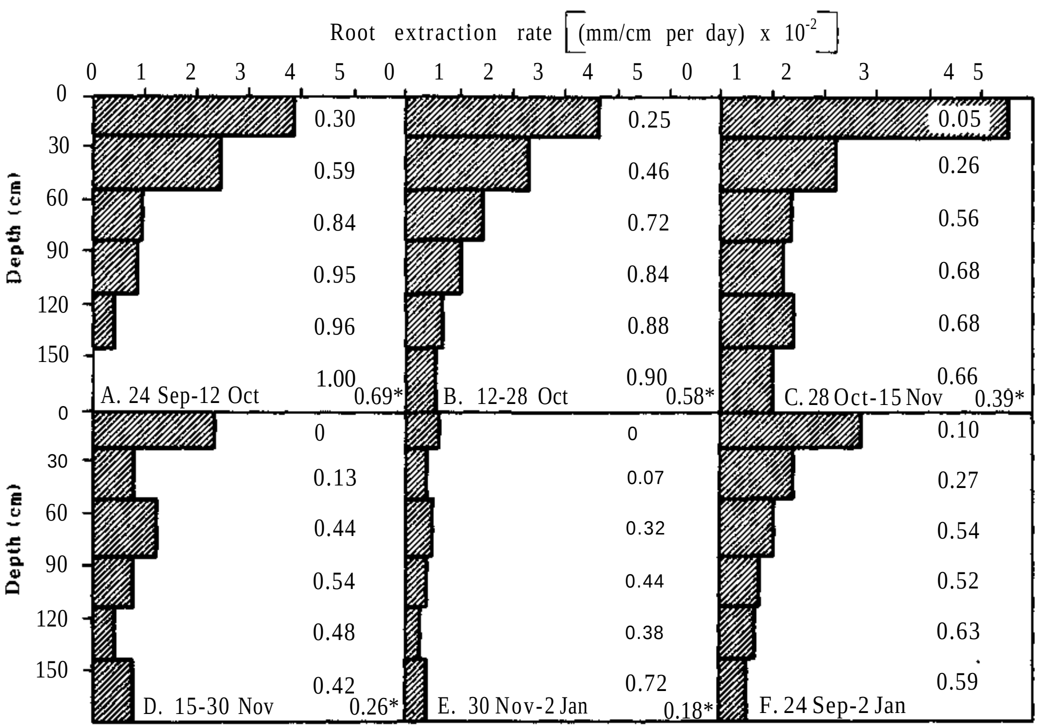


Figure 66. Root extraction rates by pigeonpea and fractional available moisture for six layers of a deep Vertisol.

November, even though the average fractional available water content was low for each of the four periods. This suggests that the layer was well ramified by roots which were able i) to exploit quickly and effectively the short-term increase in water in the 0- to 22-cm layer resulting from the small showers during those periods, and ii) to effectively extract water down to the — 15-bar value.

The vertical distribution of extraction rates for the 12-28 October period (Fig 66 B) is believed to give a realistic picture of the root distribution of the pigeonpea crop, since at that time the profile was well supplied with water at all depths; hence the extraction rates should have reflected rooting density. At depths from 22 to 112 cm, there was a gradual decline in extraction rates with time, corresponding to the decline in fractional available water. The relative importance of extraction at depths below 142 cm increased as the rates in the upper layers declined. Because of the way in which the lower limit of available water is defined, the low fractional water content in the lower layers does not imply high suction values.

Weighted available water fractions for the profile (designated by asterisks in Fig 66, A-E) were computed by multiplying the fractional available water content of each layer by the estimated relative root concentration in that layer, as inferred from Figure 66 B, and summing over the six layers. The resulting values are believed to give a realistic picture of the declining profile water supply to which the crop was exposed during the postrainy season.

Changes in water supply, rainfall, and available profile water during the 210-day period following the 15 June start of the rains are plotted in Figure 67. The amount and seasonal distribution of evaporation and transpiration by maize and by irrigated and nonirrigated sorghum in the postrainy season also are plotted. The profile water content increased from 100 mm on 15 June to about 200 mm in early September. Water lost during the subsequent 25-day rain-free period was replaced and the profile was filled to capacity by the rains in early October. Subsequently, the profile supply declined steadily; first by evaporation and, after early November, by transpiration, in the nonirrigated sorghum crop. It reached a minimum of 75 mm, 33 percent of capacity, by 9 February when the crop was harvested.

The relation between available water in the profile and cumulative transpiration by sorghum is plotted in Figure 68. Effects of recharging the profile by irrigations on 18 November and 19 December are clearly shown, both in the available water in the profile and by the T/E_0 ratios. The rates of dry-matter accumulation of the irrigated and nonirrigated sorghum (see Sorghum Physiology, page 45) showed that the growth per unit of water transpired was not significantly different for the rainfed and irrigated crops. The ratios of the grain yields of the two crops to their seasonal transpiration also were similar.

Effects of three different cropping systems on annual evaporation and transpiration losses are plotted in Figure 69. It is evident that the traditional system of rainy season fallow followed by postrainy cropping results in very low efficiency of water use. During the rainy season, the loss of water by evaporation will be high since the soil surface is rewetted frequently. In 1977, evaporative loss from a fallow Vertisol during the rainy season was 50 percent of the open-pan value. This was two-thirds as great as the combined loss by evaporation and transpiration from a cropped area. The intercropping system largely eliminates evaporation losses associated with the lack of crop cover during the harvesting and postrainy season planting period observed with the sequential-cropping system.

Profile water use by sorghum from an Alfisol. The time and depth patterns of profile recharge and depletion during the rainy and postrainy seasons were determined by neutron moderation in replicated field experiments on the Alfisol in area ST-2 during 1977-1978 cropping season. Tensiometers were used to measure hydraulic heads throughout the profile. Runoff was prevented and drainage beyond

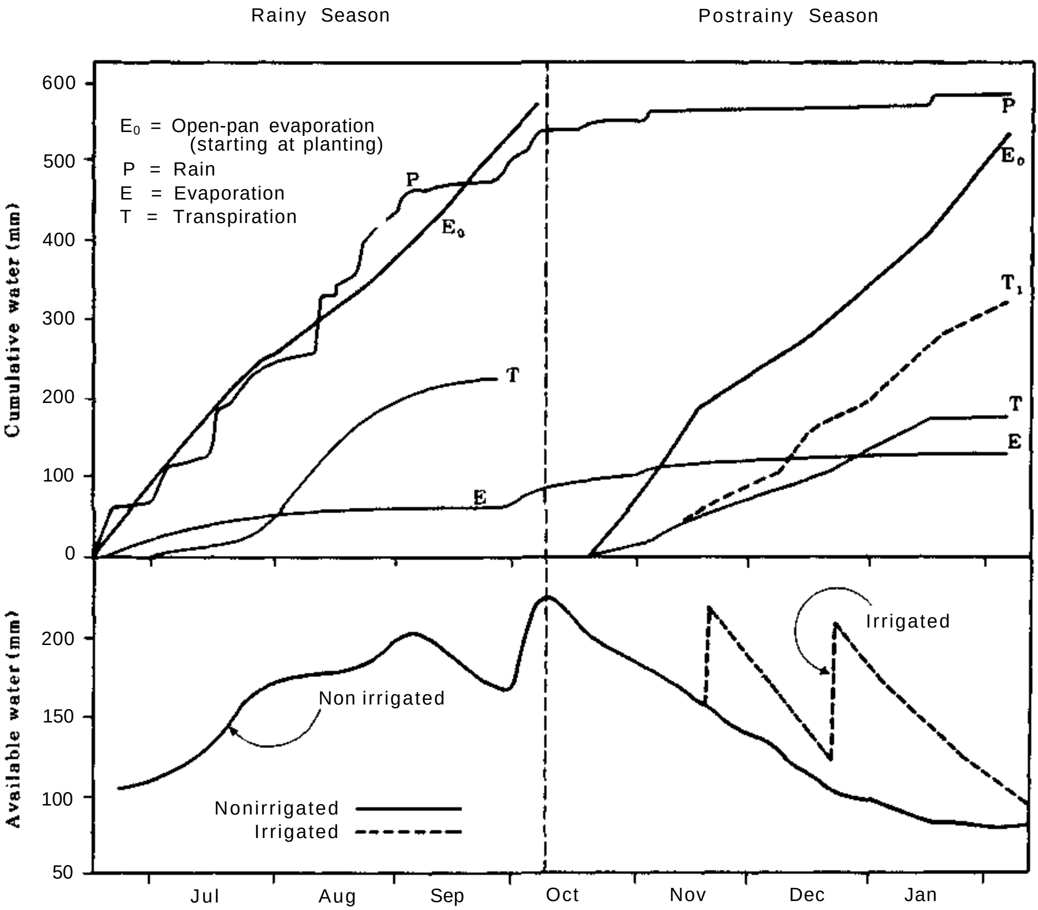


Figure 67. Cumulative rainfall, open-pan evaporation, transpiration, evaporation, and available profile moisture in a deep Vertisol.

127 cm was estimated by daily water-balance calculations.

Progressive accretion of water in the profile occurred during the period from 13 July to 5 September. Available water in the upper 127 cm of profile at time of planting was 90 mm. This constituted 68 percent of available capacity of the soil to that depth. During the relatively rain-free period in September, there was progressive loss of moisture in the profile. This permitted the determination of root extraction rates from the various soil layers. During 12-26 September, transpiration from the 0- to 22-, 22- to 52-, 52- to 82-, and 82- to 127-cm layers was 29, 21, 25, and 25 percent, respectively, of the total. During 5 September-5 October the percentages for those layers were 24, 31, 21, and 23, respectively.

During the postrainy season, transpiration by rainfed sorghum, as estimated by the energy-balance method, was greater than T_m except during the initial stages of growth in November. But in the case of irrigated sorghum, transpiration values as estimated by the two methods were very close. Study of the water balance of individual periods suggests that evaporation was underestimated for wet periods and over-estimated for dry periods. A little drainage was computed for the period between 20 to 30 days after the start of the postrainy season. This is supported by the occurrence of positive water potentials and positive hydraulic gradients for a very short period at the 135-cm depth.

The loss of substantial fractions of seasonal rainfall as drainage and evaporation from the cropped Alfisol emphasizes the opportunities for better water management. On the cropped plots in the present study, loss of water as evaporation and drainage during the growing season was 50 percent of the total seasonal available water, i.e. initial available water to 127 cm plus total rainfall plus irrigation. Only 42 percent of the rainfall was used for crop production during the rainy season. The drainage results are supported by the fact that (except for brief rainless periods) during most of the rainy season, the hydraulic gradients throughout the profile were downward.

In the postrainy season, frequent irrigation resulted in more soil evaporation (62 mm) than occurred in the nonirrigated sorghum (35 mm). Transpiration by irrigated and rainfed sorghum was 120 and 93 mm, respectively. Water depletion rates from a particular layer were very much controlled by the fractional available water in the layer and by root activity. Based upon the limited amount of available root data, root

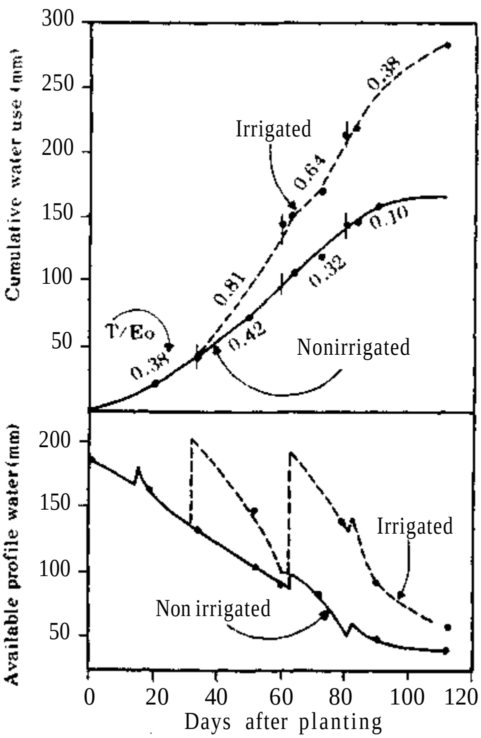


Figure 68. Seasonal trends in transpiration and available profile water for rainfed and irrigated sorghum on a deep Vertisol.

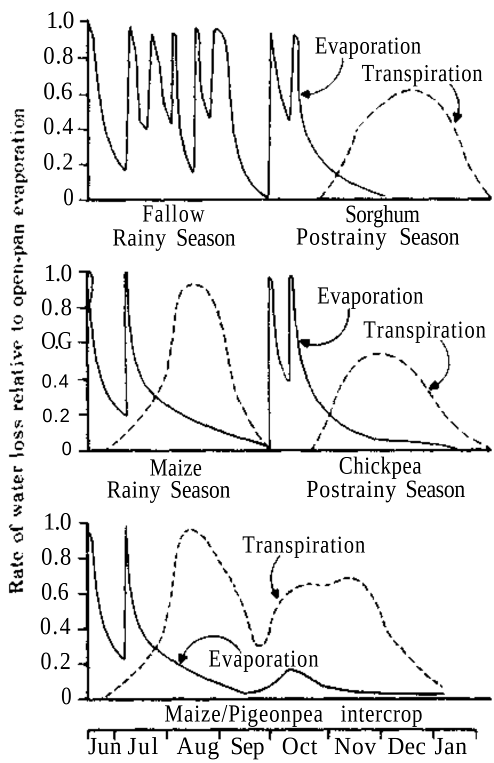


Figure 69. Seasonal trends of evaporation and transpiration for three systems of cropping on a deep Vertisol.

water uptake rates ranging from 0.001 to 0.032 cm^3/cm per day were computed for irrigated sorghum. In the nonirrigated plots, uptake rates varied from 0.003 to 0.011 cm^3/cm per day in different layers. They were comparatively smaller than those for the irrigated sorghum, presumably because of the lower fractional water availability in the nonirrigated profiles.

Pearl millet growth and water use on an Alfisol. A replicated field experiment was conducted in the 1977 postrainy season in cooperation with scientists from the Environmental Physics group of the University of Nottingham, UK. Millet, cv BK-560, was sown on 13 October on 0.5 ha in RW-1 watershed. Eight 15-m by 9-m plots were established, each having 4 or 6 neutron-probe access tubes. In one irrigated and one nonirrigated plot, two sets of tensiometers at depths of 15, 30, 60, 90, 120, and 150 cm and four root periscope tubes were installed. Soil psychrometers also were installed at 15, 30, 45, 60, and 75 cm in a nonirrigated plot. Irrigations of about 30 mm were applied to four plots on 12 and 24 November and 10 December. Rain fell on 18 October (12 mm), 2 November (16 mm), and 8 January (16 mm). Small showers also occurred on 14, 23, and 24 November. Samples for complete analysis of leaf area and dry weight were taken weekly. Root-density profiles were measured from core samples taken at six dates from the irrigated plots. Stomatal conductance was measured with an automatic diffusion porometer and used with green-area data to compute crop conductance.

Forty days after sowing, root dry weight increased exponentially and then linearly to reach 48 g/m^2. Total root weight did not change between 40 and 80 days after sowing, although the fraction of fine roots unattached to the hypocotyl, obtained from cores of soil, decreased over this period. Irrigation increased the dry weight of roots to 62 g/m^2, but all of this increase is accounted for by the additional short thick axes attached to the hypocotyl.

While total root length was unaffected by irrigation, distribution of roots within the soil profile was changed. The irrigated crop had more root length in the 0- to 20-cm layers than did the rainfed crop. Both treatments showed that the density of roots decreased down the profile initially, then increased again, often to the maximum value, at 30 to 40 cm followed by a continual decrease to 100 cm.

The progressive depletion of profile water is clearly shown in Figure 70 by the changes in capillary potential with time at various depths in the rainfed plot. These data also show that root extraction essentially ceased by 10 December, 8 weeks after sowing. At that time the potential at 30 and 45 cm had reached - 15 bars. The continued fall in potential at 15 cm beyond — 15 bars was attributed to evaporative moisture loss. It is concluded that the number of roots at depths below 50 cm were insufficient to withdraw water at the rate needed to maintain the millet crop, which ceased to transpire and grow even though the capillary potential at 60 and 75 cm and presumably at deeper depths was above the wilting point.

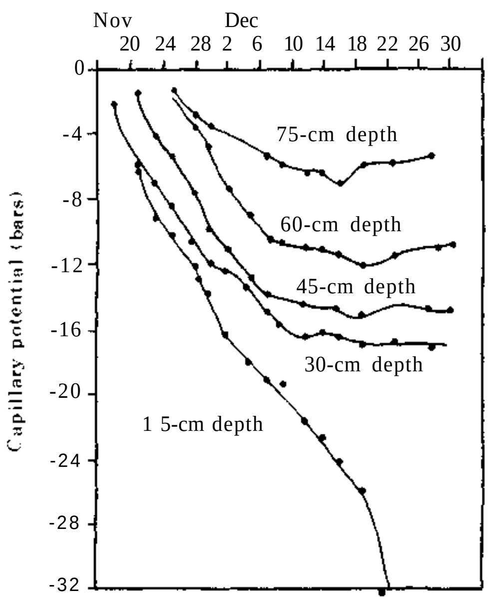


Figure 70. Capillary potentials under nonirrigated pearl millet on an Alfisol.

Evaporation constituted 20 percent of the water lost by both the irrigated and rainfed plots. For the rainfed crop the value of T_m and T_c were similar during the first 6 weeks, indicating that the crop was not experiencing moisture stress. However for the next 3 weeks T_m was $< T_e$. indicating severe moisture stress. In the irrigated crop $T_m \sim T_e$ throughout the 80-day growing season. Yields of the irrigated and nonirrigated crops were 1860 and 1110 kg/ha, respectively. These yields, divided by the amount of water transpired, gave water-use efficiencies of 150 and 144 kg grain/cm of water transpired for the two crops. The constancy of the yield-to-transpiration ratio supports the validity of using seasonal transpiration as a means of estimating yield.

Profile-water dynamics in uncropped Vertisols and Alfisols. Seasonal changes in water content in an uncropped Vertisol were studied in a 20-m by 60-m plot in watershed BW-3. The volumetric water content at 15-cm intervals from 30 to 180 cm were determined at fortnightly intervals throughout the year by neutron moderation in 24 access tubes. Composited gravimetric samples taken with a sampling tube were used to determine the moisture content at the 0- to 10- and 10- to 20-cm depths. The hydraulic head at depths of 15,30,45,60,75, 90, 120, 150, and 180 cm were measured daily with three sets of tensiometers.

The progressive recharging of the deep Vertisol profile during the 1977 rainy season is plotted in Figure 71. During the 85-day period from 14 June to 7 September, there was a net accretion of 133 mm in the 187-cm profile. During this period, 466 mm of rain fell in well distributed showers which caused only 7 mm of runoff. Evaporation from the soil surface during the 85 days was 240 mm. This value was calculated by a method described later in this report. Drainage beyond 187 cm, computed as the residual in the water-balance equation, was 86 mm. Thus, for the fallow deep Vertisol during the 1977 rainy season about half of the rain was lost by evaporation and one-fifth by runoff and drainage beyond 187 cm; hence slightly less than three-tenths was retained in the 187-cm profile, which was fully recharged by early September. The distribution of losses and profile accretion is highly dependent on the number, size, intensity, and, distribution in time of the seasonal rains. Had the same 466 mm of rain occurred in a different pattern of size, timing and intensities, the amounts lost by runoff, evaporation, and drainage, and the amount retained by the profile, would have been quite different.

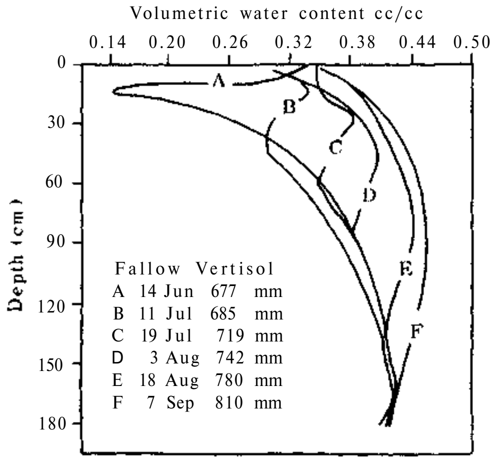


Figure 71. Moisture profiles of an uncropped deep Vertisol during the rainy season, ICRISAT Center, 1977.

The rate of evaporative loss is a time-dependent function of the evaporative demand and of the frequency of wetting of the soil surface. We estimated the daily evaporative loss, E* as a function of E_0, the daily open-pan evaporation; t, the number of days following a rain of sufficient size to recharge the upper 10 cm of soil, and β, the fraction *of* incoming solar energy reaching the soil surface. For fallow soil $\beta = 1.0$ but under a crop it is a time-dependent function of crop development and is closely related to LAI. Daily evaporation from the soil is computed as $E^* = \beta(E_0/t)$. This expression was used with data on daily rainfall, daily open-pan evaporation, and an initial moisture content to compute the daily water content of the surface 20 cm of the fallow Vertisol and the upper 50 cm of an uncropped Alfisol throughout the rainy and postrainy season. Calculated and measured values are presented in Figure 72.

The physical capacity of the soil profile for water retention is determined by its depth and porosity. The fraction of the total capacity that will retain water against the force of gravity depends on the size distribution of the soil pores. The proportion of the retained water that can be utilized by the crop is determined by the amount and depth distribution of roots and by the extent and intensity of the surface forces of the soil—which are largely functions of the percentage of clay. We define the lower limit of plant extractable water as the minimum water content throughout the profile as measured in the field under a well-managed deep-rooted long-season crop grown in the postrainy season.

Distribution of the various categories of water through the 187-cm profile of a deep Vertisol is plotted in Figure 73. It is assumed that root extraction does not occur beyond the 15-bar percentage, which is 0.27 cc/cc throughout the deep Vertisol. Evaporation will, however, reduce the, moisture content in the surface layers below that limit. Below

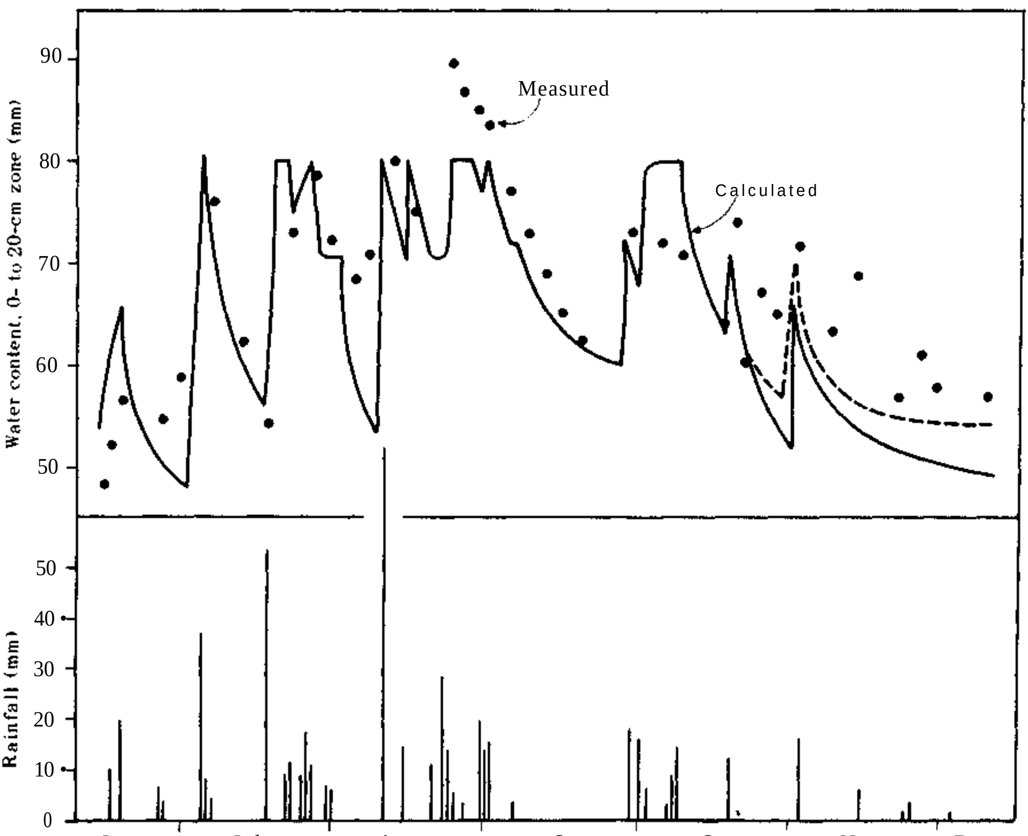


Figure 72. Calculated and measured water in surface 20 cm of a fallow Vertisol.

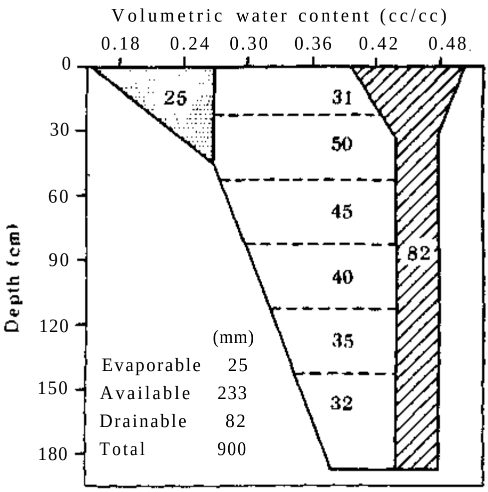


Figure 73. Drainable, evaporable, and available water profiles of a deep Vertisol at ICRISAT Center.

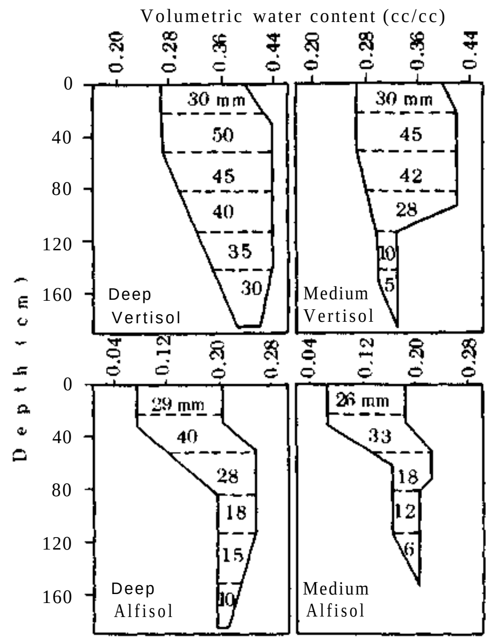


Figure 74. A vailable water profiles for four soils at ICRISAT Center.

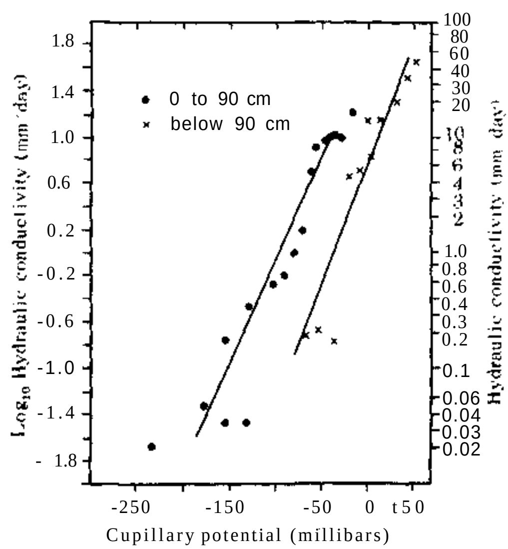


Figure 75. Unsaturated hydraulic conductivity of a deep Vertisol as a function of capillary potential.

45 cm, the limit of extractability increases linearly from the 15-bar percentage to 0.38 cc/cc at 187 cm, not because of an increase in the retentive forces of the soil, but because of the reduction in root density and in the length of time that the layers are occupied by roots. Thus, the lower limit of plant extractable water is an operationally defined limit affected by physical properties of the soil and the rooting characteristics of the crop. The values used in this report must, therefore, be considered as provisional since they are based on a limited number of data. The plant-available water profiles for the four soils that we have studied at the ICRISAT Center are plotted in Figure 74.

Data on the time and depth changes in water content of the fallowed deep Vertisol during the postrainy season were used with those for the associated changes in hydraulic head to compute unsaturated conductivity as a function of capillary potential shown in Figure 75. These data represent unsaturated flow both in a drainage phase and an evaporation phase, and are based on moisture content and capillary potential profiles at different times measured independently *in situ.* The value of hydraulic conductivity of saturation is in good agreement with other estimates based on water-balance considerations and tensiometer readings in other plots in the deep Vertisol. The fact that K for the 0- to 90-cm depths was essentially constant for capillary potentials from 0 to — 50 millibars (mb) is interpreted to mean that the air-entry value of the profile is about — 50 mb; hence no pore drainage or reduction in conductivity occurs until this suction is exceeded.

The soil moisture characteristic curve depicts the functional relationship between the volumetric water content, θ_v, and the capillary potential, . It is one of the basic relations used to describe and analyze the interaction of water with soil. To determine this function, we used tensiometer data obtained from several depths in the fallow Alfisol in ST-2 and in the fallow deep Vertisol in BW-3, together with the volumetric water contents measured at the same depths during the rainy and postrainy seasons. The data are shown in Figure 76. Although the range of potentials was not great, particularly in the fallow profiles at depths below 30 cm, it appears that the Alfisol data could be represented by two curves and the deep Vertisol by three. In the Alfisol, this reflects the large difference in texture between the 0- to 30-cm zones and the deeper layers. In the deep Vertisol, the differences with depth arise primarily from changes in bulk density and pore-size distribution.

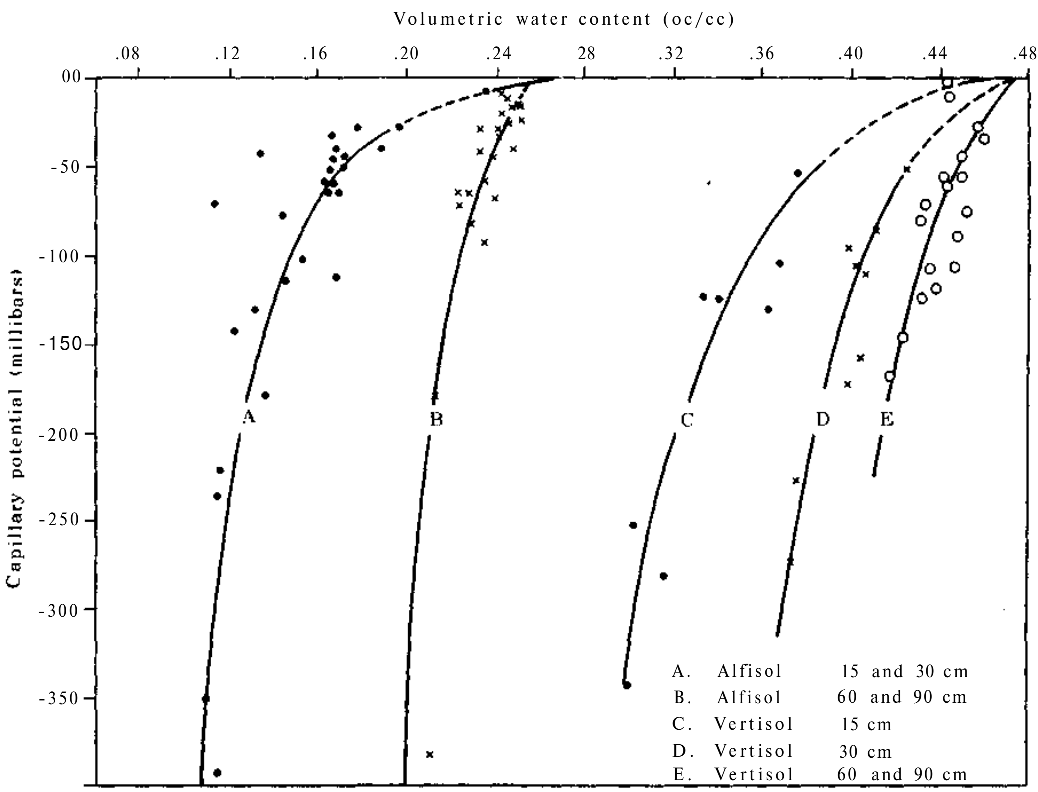


Figure 76. Moisture characteristic curves determined from in situ *field measurements.*

Infiltration characteristics of the deep Alfisol were measured on four plots in ST-2 which had been fallow during the previous rainy and postrainy seasons. Double-cell infiltrometers, 1.5- by 1.5-m inner cell surrounded by a 2.5- by 2.5-m outer or guard ring, were used. Equal heads of 2.5 cm of water were maintained in each cell throughout the 12-day infiltration period. Water required to maintain the constant head in the inner cell was recorded. The inner cell was covered to eliminate evaporation losses.

A set of previously installed tensiometers at depths of 15, 30, 45, 60, 75, 90, 120, 150, and 180 cm in each test cell was used to monitor the hydraulic heads throughout the water-intake and subsequent profile-drainage phases of the experiment. Four neutron-probe access tubes installed in the guard-ring area of each infiltrometer were used to follow the changes in volumetric water content of the profile during the drainage phase. After 340 hours of water intake, the metal frames were removed and the test area was covered with polyethylene sheeting to prevent evaporation and with a thick layer of straw for thermal insulation. The profile was allowed to drain for 15 days and the time changes in hydraulic head and volumetric water content measured.

Terminal infiltration rates in the four plots ranged from 14 to 25 mm/hr, with an average of 17 mm/hr. Except for Plot 9, the rates measured between 10 and 30 hours were virtually the same as those measured during the longer intake period. The infiltration rates at I hour, as determined from the slopes of the cumulative infiltration vs time curves, were two to three times the terminal rates attained after 10 hours.

With cessation of water intake, the hydraulic heads (Fig 77) decreased quickly and uniformly at all depths. After 3 days of drainage the profile between 22 and 157 cm had lost 17 mm of water and the water table was at 120 cm. After II more days of drainage, the profile had lost only 1 mm of water from the 120-cm depth and the water table had fallen to 150 cm. The hydraulic gradient in the unsaturated soil during drainage was 0.7 cm/cm. In the saturated soil below the water table, it was only 0.25 cm/cm. Since the flow rate of water increases with depth during drainage, the gradients indicate a steady increase in hydraulic conductivity as the soil changes from an unsaturated to a progressively more saturated condition. After 14 days of drainage, the soil moisture suction ranged from 0.06 bars at 15 cm to 0.02 bars at 120 cm. These values suggest that the use of 0.10-bar values as an estimate of field capacity is conservative.

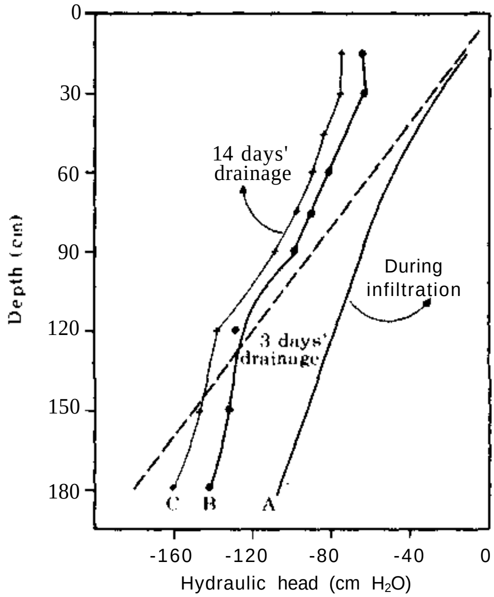


Figure 77. Hydraulic head profiles in a deep Alfisol during infiltration and drainage, ICRISAT Center.

SOIL FERTILITY AND CHEMISTRY

Crop yields in the SAT are limited by low soil fertility. Nitrogen is universally deficient. Phosphorus and zinc are often marginally so, and other nutrients such as sulphur and potassium are occasionally in short supply. The application of fertilizers usually increases crop yields under existing cropping practices, but much greater responses are obtained if nutrients are added when improved varieties are grown and improved land- and water-management techniques practiced. Such improvements raise the potential yield of crops, with a concurrent increase in the amounts of nutrients required to realize that potential.

Traditionally, the input of nutrients to soils in the SAT has been meager. Small quantities of FYM are usually applied every 3 to 4 years. Inorganic fertilizers are rarely used, because they are costly for a subsistence farmer, and breakeven or a profitable return on the appreciable cash outlay may not be realized due to the unpredictability of the growing season.

The emphasis in current research in the Soil Fertility and Chemistry subprogram has therefore been given to studies of i) changes in fertilizer requirements resulting from the introduction of improved varieties and management, and ii) conservation of nutrients contained in the soil-nutrient "pool" and recycling in subsequent crops.

Nitrogen Fertilization

Because nitrogen is universally deficient in the SAT, learning the most efficient way of using fertilizer is now a major goal. Studies were made of the relationships between yield and rate of nitrogen fertilizer applied, and population pressure in an intercropping situation.

There was no interaction between effect of population density and rate of N application on grain yield of sorghum (Table 91) or pigeonpea in a sorghum/pigeonpea intercrop. Maximum yield of sorghum was obtained with an application of 80 kg N/ha, or higher. There was no significant reduction in pigeonpea yield with increasing rate of fertilizer application, indicating that the stimulation of sorghum growth by nitrogen did not result in excessive competition for light, water, or nutrients.

Seasonal Changes in Mineral Nitrogen

Information on the inorganic nitrogen content in the soil profile is necessary to assist in planning of soil- and water-management practices, especially as other work in the SAT has shown that there is a flush of mineralization on the wetting of the soil during early rains. Unless crops are established at the beginning of the rainy season, nitrate may be lost from the soil by leaching or denitrification.

Initial measurements in a Vertisol have shown that nitrate concentration in cropped sorghum/pigeonpea and in fallow areas diminished with time after the onset of the rainy season, and again after further nitrification in November (Fig 78). Although concentrations of nitrate

Table 91. Effect of varying sorghum and pigeonpea populations and nitrogen application rates on yield of sorghum grain on a Vertisol, 1977-78.

Nitrogen application rate	Sole crop 100:0[a]	Sorghum/pigeonpea population[a] 40:40[a]	80:80	120:120	160:160	Mean
(kg/ha)	(kg/ha)	(kg/ha)				(kg/ha)
0	2 030	1 760	1 570	1 650	1 890	1 780
40	3 590	3 540	3 360	3 150	2 970	3 320
80	5 400	4 040	4 100	4 010	3 740	4 260
120	5 210	4 500	4 310	3 850	4 570	4 490

[a] Sorghum/pigeonpea populations: values are % of optimum plant populations—optimum for sorghum and pigeonpea is 180 000 and 40 000 plants/ha, respectively.

in the soil were small, plant uptake was insufficient to cause complete depletion.

Phosphorus Fertilization

Results for the second year of a long-term experiment investigating the usefulness of rock phosphate as an alternative (to superphosphate) source of phosphorus, were broadly similar to those obtained during the first year. Sorghum grain yields obtained from 0, 5, and 10 kg P/ha applied as superphosphate were 580, 1 550 and 2 050 kg/ha. The application of 20 P gave no additional response. Annual applications of 20 and 40 P as rock phosphate yielded 1 040 and 1 000 kg/ha of sorghum grain.

FARM POWER AND EQUIPMENT

This subprogram has as its primary objective: "To define and develop power and equipment systems for improved soil, water and crop management." Research was conducted in majorproject areas of i) machinery management, ii) soil management, and iii) design and fabrication.

Facilities were improved this year through the construction of a workshop, drawing office, small tillage laboratory, and two offices. Until November 1977, the FSRP was sharing minimal workshop facilities with the Farm Development and Operation unit.

Machinery Management

Machinery-use data from the Vertisol watersheds have been analyzed to determine the extent of area that can be farmed with a wheeled tool carrier and its implements when using the broadbed-and-furrow system. Field capacities of the wheeled tool carrier for different operations are listed in Table 92. Field capacities

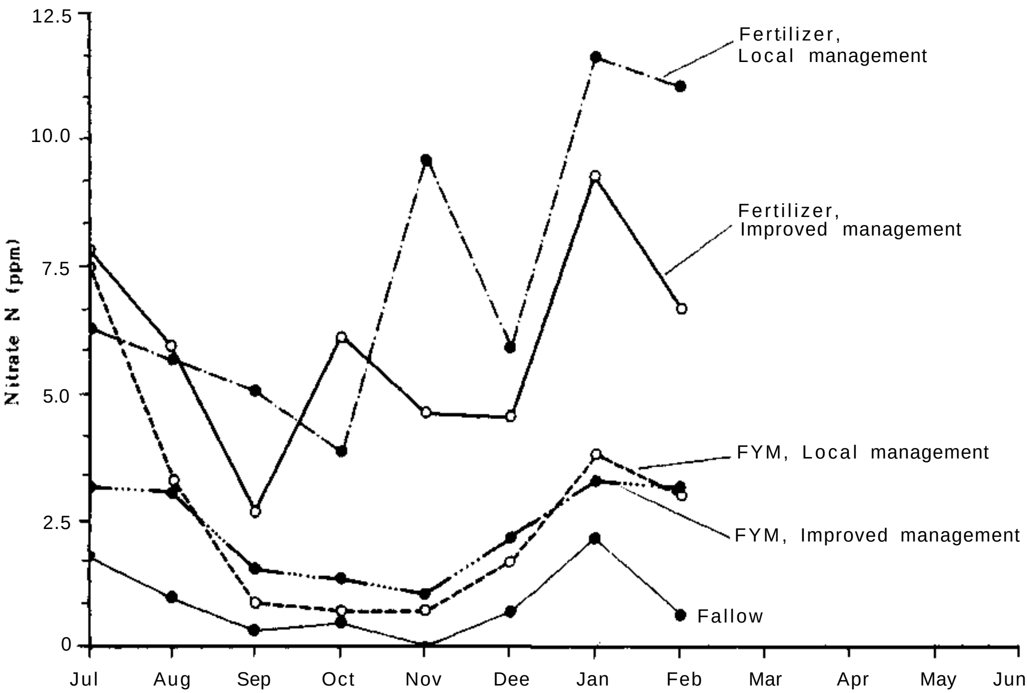


Figure 78. Mean Nitrate-N concentrations in profile (() to 90 cm) of pearl millet/pigeonpea intercrop and fallow on an Alfisol during 1977-1978.

were then related to the total time available for various operations, as presented in the cropping calendar (Fig 79); from this the area that can be covered during various operations is calculated. The smallest of those values determines the largest area that can be farmed with a single tool carrier and a pair of bullocks.

The amount and timing of rainfall have a major effect on the total number of days available for all operations. To calculate the total number of days available for different operations, it was assumed that i) plowing and initial ridging must be completed immediately after harvesting the postrainy season crop; ii) cultivation and bed shaping be completed after receiving showers during the dry season; iii) planting and fertilizer application be completed near the end of the dry period; iv) interrow cultivation be completed twice after the crops are at least 10 to 15 days old; v) 75 percent of available days are effectively utilized during fertilizer application, planting, and interrow cultivation; and vi) only half of the available time will be utilized for cultivation and bed shaping, because these operations are controlled by prerainy season showers received during this time. To calculate the area that can be covered by different operations, it was assumed that a

Table 92. Average field capacities and their ranges for various operations, using the wheeled tool carrier and its attachments.

Operations	Field capacities	
	Range	Average
	(ha/hr)	(ha/hr)
Moldboard plowing	0.11-0.22	0.17
Ridging	0.12-0.43	0.24
Cultivation	0.11 0.46	0.21
Bed forming	0.11-0.37	0.23
Fertilizer application	0.17-0.42	0.31
Planting	0.17 0.37	0.28
lnterrow cultivation 1	0.16-0.45	0.30
Interrow cultivation II	0.19-0.45	0.33

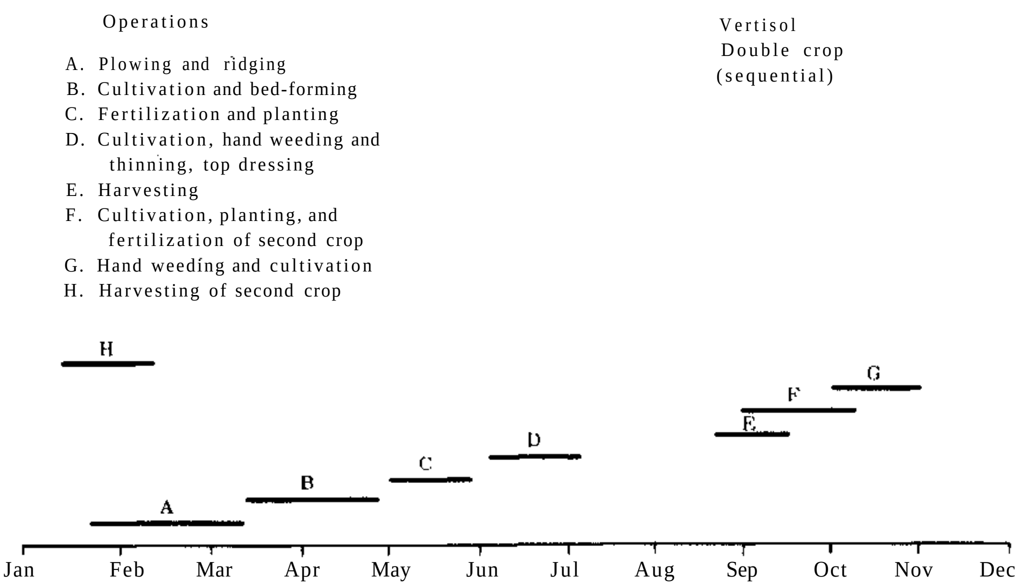


Figure 79. Cropping calendar for a sequential crop on a Vertisol at ICRISAT Center.

6-hr working day was used with one pair of bullocks, but that in a 12-hr day two pairs of bullocks would be used.

Because of heavy draft requirements, the average field capacity for plowing was lowest at 0.17 ha/hr (Table 93). Field capacities were 0.3 ha/hr for fertilizer application and interrow cultivation. Because of the importance of timeliness, planting is the most limiting operation with a value of about 14 ha/season. However, by using two pairs of bullocks, the area covered per day with one implement can be doubled (see footnote. Table 93).

One of the factors affecting field capacity is "field-use efficiency" which is defined as the ratio of effective field capacity to the theoretical field capacity, expressed as a percentage. One of the major factors affecting this is field length, which determines the frequency and hence the time required for turning. This effect was measured, using the wheeled tool carrier for ridging. Length of runs of 10, 20, 50, 75, 100 and 150 meters were used. The pull varied from 50 to 90 kg. A half hectare was used for each length of run. Field speed was measured and operating and turning times recorded. The average field speed was 3.4 km/hr. The results (Fig 80) demonstrate the importance of length of run.

Soil Management

As shown in Figure 81, the graded bed-and-furrow system creates three separate management zones, each with its own distinctive characteristics. Compaction is restricted to the

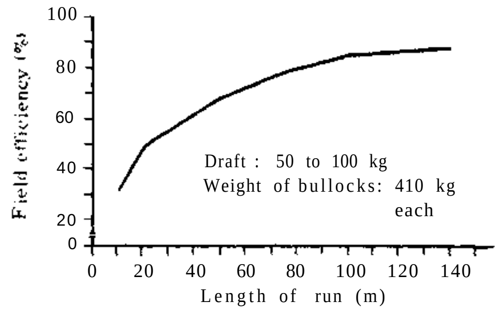


Figure 80. Field efficiency as affected by different lengths of run for ridging in loose soil with a wheeled tool carrier, ICRISAT Center.

Table 93. Hours available for different operations, field capacities with wheeled tool carrier for improved management system, and area coverage during various periods.

Operations	Working days available	Working time	Total working time	Operations required	Field capacity	Area
	(days)	(hr/day)[a]	(hr)	(no)	(ha/hr)	(ha)
Plowing	30	6.0	180	1	0.17	30.60
Ridging	30	6.0	180	1	0.24	43.20
Cultivation	11	6.0	66	1	0.21	13.86
Bed forming	11	6.0	66	I	0.23	15.38
Fertilizer application	8.25	6.0	49.5	1	0.31	15.35
Planting	8.25	6.0	49.5	1	0.28	13.86
Interrow cultivation I	10.5	6.0	63	1	0.30	18.90
Interrow cultivation II	10.5	6.0	63	1	0.33	20.79

[a] For critical operations such as planting, fertilization, and cultivation—which are dependent on soil-moisture conditions a farmer may prefer to have a second pair of bullocks and thus use the implement for 12 hours a day.

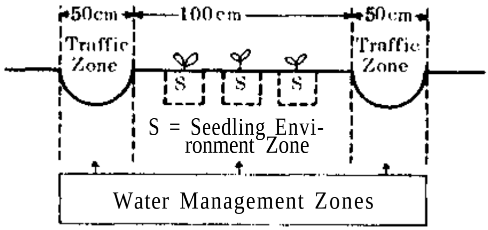


Figure 81. Three management zones associated with the broadbed-and-furrow system.

traffic zone, while the crop-production zone in the Vertisol remains friable far into the dry season. Confining tillage to the bed zone concentrates plant residues and fertilizers in this area, which further improves its productive potential.

A reduction in energy expended on primary tillage is achieved because less force is needed in the uncompacted crop-production zone. To quantify the physical changes occurring during primary tillage of the broadbed on a Vertisol, measurements were made of the amount of soil displaced and of the forces required.

A relief meter has been used to quantify the amount of soil displaced. Soil surface elevations were measured from a horizontal reference level to the nearest 0.5 cm on a 5-cm by 5-cm grid for a 90-cm by 150-cm area. This covers the width of two half furrows and the bed zone over a length of 90 cm. During the cropping season, cultural operations and wetting and drying increase the bulk density and tend to flatten the beds. The typical shapes before and after

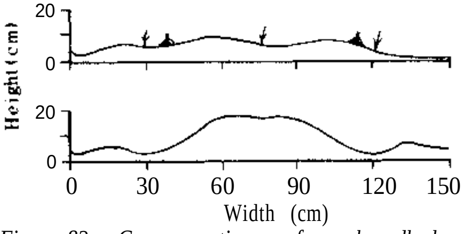


Figure 82. Cross sections of a broadbed-and-furrow system before and after plowing as measured by a micro relief meter.

primary tillage are sketched in Figure 82. Cross-section areas above the furrow bottom baseline before and after tillage were 333 cm^2 and 396 cm^2; the increase is due to soil displacement of the two plow slices.

Soil shear strengths across the Vertisol bed taken before tillage are plotted in Figure 83. The lines represent soil shear strength of constant depths below the soil surface. Each line was constructed from 16 shear values, each the mean of nine readings, taken at 10-cm intervals across the 150-cm bed. Shear strengths were lower at all depths on the beds; this was a residual effect of previous tillage operations. This residual effect was corroborated by the distinct decreases in the soil strength profile near the edges of the bed, which apparently correspond to the location of the previous tillage and interrow cultivation operations. The increased friability of the bed facilitates plowing in the dry season, a necessity if dry planting is to be practiced.

A primary requirement for a seedbed is that it must permit seeds to be placed at the required depth. With the dry-seeding technique that has been successfully practiced on the Vertisols at ICRISAT, the minimum seed depth is considered to be 5 cm. Because the unfilled soil is very dry and hard at the time of seeding, it is essential that the tilled seedbed layer should be at least

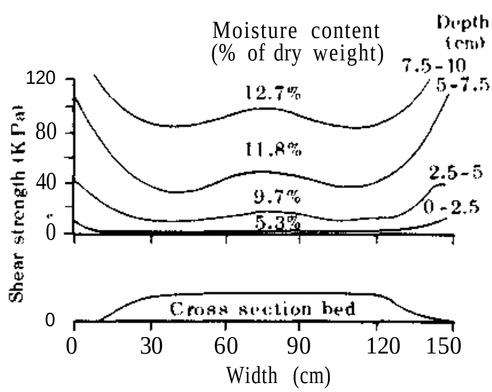


Figure 83. Soil (deep Vertisol) shear strength at successive depths before plowing, as measured by shear vane, ICRISAT Center, December 1977.

5 cm thick. Therefore, the thickness, uniformity, clod-size distribution, and bulk density of the seedbeds of soil-management systems in a deep Vertisol were measured. Flat cultivation, the 75-cm ridge-and-furrow, and the 150-cm broad-bed-and-furrow systems of management of the Vertisol were compared.

A relief meter was used to determine the profile and thickness of the seedbed. As shown (Fig 84). variability in thickness of the seedbed layer across the bed was quite high for the three tillage systems. In the bed-and-ridge systems, seeds are not planted in the furrow bottom. Seedbed evaluation should be based on thickness and variability in the direction of the path of the furrow openers of the planter.

The only significant differences in seedbed properties of the three systems of management were the greater variability in seedbed thickness and the greater hardness of the underlying untilled soil in the flat cultivation areas. These two effects resulted in excessive planter vibration and poor seed placement on those plots.

Metering is a critical phase of planting to ensure an adequate well distributed plant population. When ungraded seeds are planted, matching seed and plate cell-size will always be a compromise. Plate cell-size must be sufficiently large to accommodate the largest seed, and multiple seed drops will inevitably occur. One of the characteristics of the inclined seed-plate mechanism is that increasing the seed-plate peripheral speed beyond the optimum usually results in a progressively increasing occurrence of skips due to less effective cell filling.

Response to seed-plate peripheral speed was similar for most seeds. Beyond a certain speed, cell filling was less effective. This was particularly true for sorghum seeds when a seed plate 3 mm thick and 60 mm in diameter, with seed cells 5 mm in diameter, was used. The variability in output was minimal for optimum seed-plate speed (Fig 85). The level of seed in the hopper had no measurable effect on metering performance.

Design and Fabrication

Several modifications have been incorporated in the Tropicultor, the multipurpose wheeled tool carrier. Pivot points in the lifting linkages which were wearing rapidly have been strengthened by providing hardened steel bushings. It was found difficult to adjust the pitch when the adjustment bolt became rusty. This has been improved by changing the threads on the bolt from metric screw threads to Acme threads, which are less liable to damage.

The Ebra inclined-plate planters required several modifications to improve their performance. The furrow openers were not satisfactory as they opened too wide a furrow, creating difficulty in covering the seeds, particularly in wet soil. This difticulty was overcome by designing a narrow shoe-type furrow opener. For planting in dry Vertisols, steel press wheels having a solid flat surface performed well. However, when planting in wet Alfisol, the resulting compaction probably was a contributing cause to crusting. Split press wheels were developed to avoid packing the soil directly above the seeds.

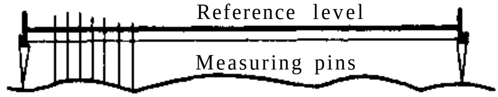


Figure 84. Relief meter for measuring seedbed profile.

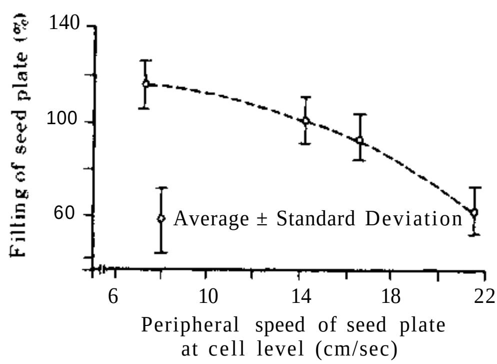


Figure 85, Seed-plate peripheral speed versus filling percentage of a sorghum seed-plate with round-hole cells.

Figure 86. Angle blade scraper fitted with side and tilt angle adjustment.

Two new land-development implements were designed. A meter-wide scraper attachment for earth moving is available with the multipurpose wheeled tool carrier. Because the blade had no tilt adjustment, it could not be used for forming or reshaping field drains, bunds, etc. It has been replaced by an angle blade scraper (Fig 86), which has side- and tilt-angle adjustments. The lift angle adjustment can be made by using the pitch-angle adjusting bolt on the frame of the carrier. This modification is now undergoing field trials.

Farmers' fields often need some grading and leveling for better control and management of water. A land plane (Fig 87) is being designed for this purpose. One prototype has been fabricated to test the concept. It has a 1.8-m blade on a chassis 4 m in length; the multipurpose wheeled tool carrier serves as its front support. In initial trials, two pairs of bullocks were required on the first pass across the field, but on subsequent passes where the cut was reduced the implement could be pulled by a single pair.

Cooperation is being extended to manufacturers for the production of improved implements and components. Several firms have expressed interest in manufacturing plows, ridgers, and cultivator shovels. The Indian Standards Institution has been very helpful in providing guidelines to ensure interchangeability of parts fabricated by different manufacturers.

LAND AND WATER MANAGEMENT

The goals of the Land and Water Management subprogram are to contribute to the realization of more productive and dependable farming systems for farmers of the seasonally dry tropics and to assist national organizations in the development and implementation of improved natural-resource-management technology. Major areas of land- and water-management research are i) land-management technology for runoff and erosion control and for an improved moisture environment for crops, ii) design criteria for waterway systems for safe movement of excess water from the land, with minimum interference to agricultural operations, and iii) systems for the collection of runoff and the utilization of surface and groundwater on rainfed crops.

Effect of Contour Bunds on Crop Yields

Crop yields were measured as a function of distance from the bund in six fields on a medium-deep Vertisol at ICRISAT Center. The contour bunds were constructed in 1975 at a vertical interval of 1.5 m. Thirty-five lines perpendicular to the bunds were established and 6-m^2 yield samples were taken along these at increasing distances from the bund.

Rainy season yields at points 3 to 5 m upslope from the bund were generally lower than those at greater distances (Fig 88). The yield reductions were ascribed to the frequent waterlogging at these positions. Because rainfall in 1977 was low and well distributed, this effect was less than was reported in years of higher rainfall, such as 1976 (Annual Report 1976-1977). There was no indication of yield increases due to water conservation by bunding in any field.

Yield samples in bunded fields were also taken on farms in the villages of Kalman in Sholapur District and Kanzara in Akola District. Both are areas of medium to deep Vertisols. In farmers" fields, the bunds are normally straight and usually constitute field boundaries. Postrainy season sorghum yields from 16 sampling lines in eight fields at Kalman village (Fig 88) showed a significant yield reduction of about 25 percent below the upper bund, whereas yields 3 meters above the lower bund were equal to the field average. Along 14 lines on seven fields at Kanzara village, cotton yields near the bund were significantly lower than those 25 to 50 m from the lower bund. Yields near the upper bund also were lower, but the difference did not reach the 0.05 level of significance. The loss in yield was probably due to prolonged saturation of the profile just above and below the bunds. Another large yield loss resulted from the approximately 6-m width of uncropped area associated with each contour bund in these fields (Fig 89). Together, the two types of losses often amounted to nearly 10 percent of the potential yield. None of the data seem to indicate positive yield effects of the extra water impounded in contour-bunded fields.

The usefulness of contour bunds to reduce peak discharge is doubtful. Large peak discharges, and the associated damage caused by the concentration of flow, are in most situations due to a few extreme runoff events. While contour bunds may considerably reduce peak runoff rates in small storms, which would not cause much damage anyway, their benefit during large storms is often minimal. When the storage

Figure 87. Animal-drawn land plane gives finishing touches for land leveling.

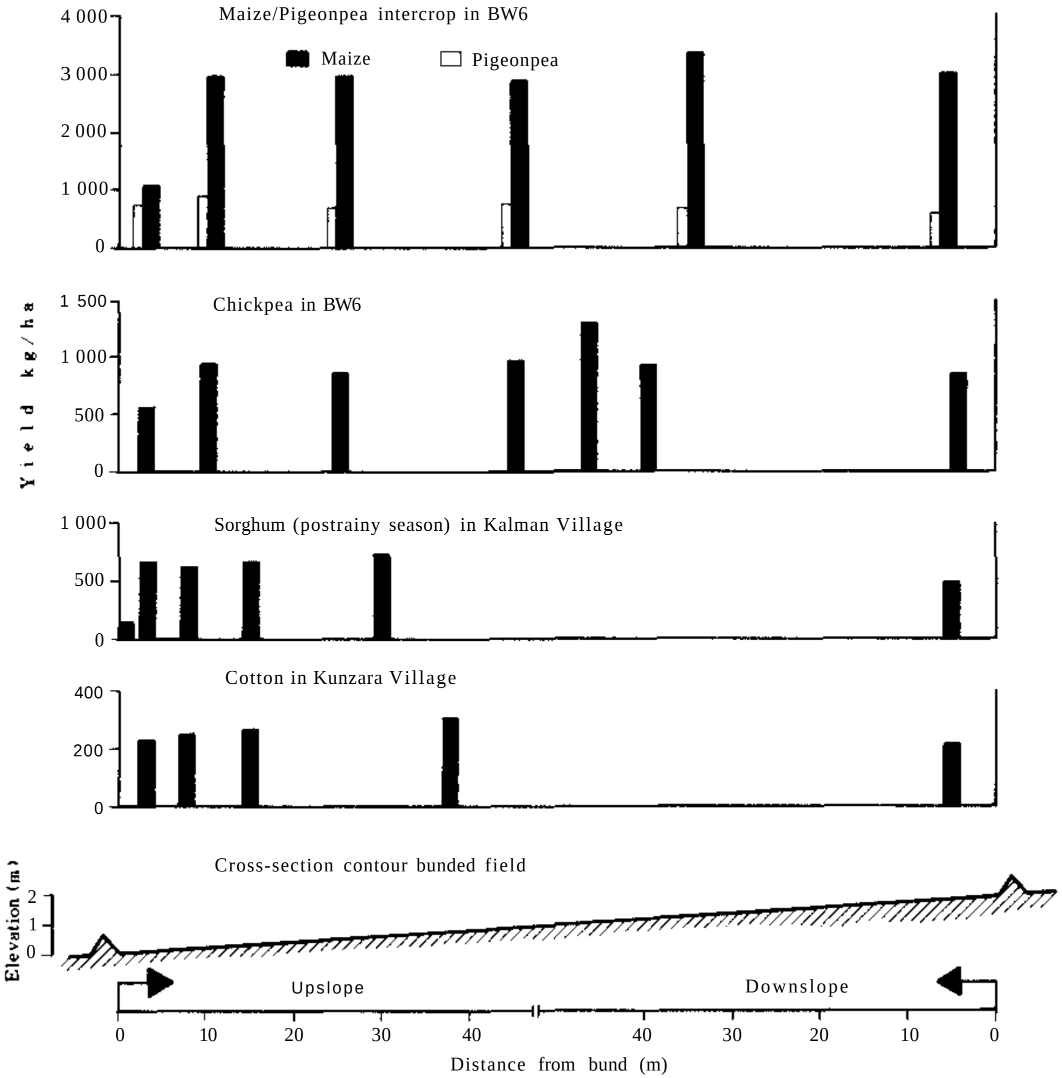


Figure 88. Yield in relation to distance from contour bunds at different locations.

capacity of a contour-bunded area is filled, the discharge rate at the spillways will be the same as the runoff from the fields. The possibility of a bund giving way during an intense rain, thus suddenly releasing a large volume of high-velocity runoff, is an additional risk in this system.

Contour bunds do decrease the sediment load in water that leaves a given area, but this does not necessarily mean that the system reduces soil loss from the area between the bunds. The bund acts as a "second line of defense." A portion of the soil that has been eroded from the upper part of the fields is de-

Figure 89. Example of loss of land in contour bunded field.

posited at the bund, rather than in an off-site stream bed or on alluvial bottom land.

Land Management Effects on Crop Yields, Runoff, and Erosion

Different land-management techniques were compared- on a field scale—on deep Vertisols, on medium-deep to shallow Vertisols, and on Alfisols. The main objective of these studies was to measure theeffects of different practices on the yield of rainy and postrainy season crops. Runoff was also measured in two of the four replications with V-notch weirs and water-stage recorders. Soil losses were estimated by manual sampling of runoff. In 1977, rainfall was relatively low and well distributed; runoff and soil losses during the year were negligible.

There were no significant differences between the three management treatments on production of crops growing on either the deep or medium-deep Vertisols. This is in contrast to 1976, when in both soils yields on the 150-cm broadbed-and-furrow plots were substantially higher than those of the flat-planted and the 75-cm ridge-and-furrow treatments. Chickpeas planted on deep Vertisols in mid-September when the top soil was dry emerged normally on the broadbeds, whereas on areas with flat cultivation or narrow ridges less than 50 percent of the seeds germinated prior to receipt of a 60-mm rain during the first week of October. This reflected the better tilth of the broadbeds, which permitted more uniform seed placement into soil having moisture sufficient for germination.

In both deep and medium-deep Vertisols, the flat-cultivation treatments required about 20 percent more labor for hand weeding than did those with beds or ridges. The more friable surface layer on the beds and ridges apparently reduced germination of weed seeds.

The effects of flat cultivation, and of the broadbed-and-furrow system, were also studied on an Alfisol. In both treatments, the slope in the direction of cultivation was 0.4 percent. On flat-planted plots, both crops of the sorghum/pigconpea intercrop showed very poor performance, mainly due to poor drainage and subsequent shoot fly and pod borer attack. Gross values of the crops in the flat and broad-ridged systems were 1 150 and 2 280 Rs/ha, respectively.

The Optimum Use of Supplemental Water

Semi-arid tropical areas have short-duration rainy seasons, often with periods of drought erratic in occurrence and duration. Water resources of such regions are usually insufficient to permit large-scale conventional irrigation. Therefore, our research on the use of the limited amount of water stored on-site is aimed at establishing principles and evaluating alternative strategies for its use as a supplement to rainfall in increasing and stabilizing crop production.

The need for supplemental water to break a drought during the rainy season varies from year to year, depending on the amount and timing of rainfall, and the cropping calendar. In 1977, rainfall was fairly well distributed throughout the rainy season; consequently responses to supplemental irrigation were small. However, the use of stored runoff' or shallow groundwater in the postrainy season consistently increased yields.

Responses of planted sorghum and ratoon sorghum to supplemental water application were similar on the three soils studied (Table 94). These and other data (see Environmental Physics subprogram, page 178) indicate substantial benefits from use of collected runoff

Table 94. Effect of supplemental postrainy season irrigation on grain yields of ratooned and planted sorghum on an Alfisol and on a deep and a medium deep Vertisol, ICRISAT Center, 1977.

Water applied	Planted			Ratooned		
	Deep Vertisol	Medium-deep Vertisol	Deep Alfisol	Deep Vertisol	Medium-deep Vertisol	Deep Alfisol
(cm)	(kg/ha)					
0	820	770	180	750	240	1 170
75	1 650	1 770	830	1 070	940	2 020
100	2 100	2 460	1 370	1 330	1 110	2 310
200	2 400	2 790	1 570	2 440	1 900	2 570
L.S.D. (0.05)	330	620	160	330	140	390

water for supplemental irrigation during the postrainy season.

CROPPING SYSTEMS

Intercropping has again received the most emphasis this year, because of increasing evidence that it offers many SAT farmers an opportunity to achieve large yield advantages inexpensively and easily. Our research has been streamlined by focusing on only a few cropping combinations. The two main combinations are sorghum/pigeonpea and pearl millet/groundnut; subsidiary combinations are sorghum/chickpea and sorghum/millet. The combinations are studied as "crops," with the same emphases given to their improvement as sole crops. Basic to the program are certain physiological studies in which we seek to understand factors which made yield advantages possible. Relationships which determine how these advantages are expressed in practice are investigated in the agronomy phase of our program.

Yield advantages in intercropping are indicated by use of LER (land-equivalent ratio), defined as the relative area of a sole crop or sole crops required to produce the yield or yields achieved in intercropping. This enables direct comparison of crops with different types, or levels, of yield. Although based on land areas, LER also reflects relative yields. A total LER, i.e. total of both crops, of 1.2 indicates an intercropping yield advantage of 20 percent. Similarly, an LER of 0.7 for one of the crops indicates that this crop has produced in intercropping 70 percent of its yield as a sole crop.

This program aims to contribute to an understanding of the fundamental principles, or relationships, which will provide a scientific basis for intercropping improvement. An important aspect of the work is the improvement of methodology, as intercropping is a young area of research. One approach receiving particular attention at ICRISAT is the use of improved experimental designs, some of which are reported here.

Physiological Studies in Intercropping

The objective of physiological studies is to gain an understanding of the factors which make intercropping yield advantages possible. Growth patterns are being examined to determine how component crops complement and compete with each other, and considerable effort is being put into the direct measurement of the use of light, nutrients, and water.

Sorghum/pigeonpea was selected for the first detailed growth study because of previous evidence that this combination can give assured yield advantages. In a constant row arrangement of two sorghum/one pigeonpea in 45-cm rows, with a range of plant populations for each, sorghum cv CSH-6 was harvested 85 days after emergence and pigeonpea cv ICP-1 after 180 days.

Sorghum gave just as much dry matter and grain in intercropping as in sole cropping, confirming earlier evidence that the two/one row arrangement can achieve "full" sorghum yield as usually desired by farmers growing this combination. Pigeonpea, however, was very much suppressed in intercropping and at the time of sorghum harvest had produced only 14.5 percent of the dry matter produced by the sole crop. Thereafter, it compensated to some degree and by final harvest it had produced 46 percent of the dry-matter yield of the sole crop. As in last year's experiments, it was observed that sorghum competition mainly reduced early vegetative growth; this resulted in a HI (harvest index) of 32 percent for intercropped pigeonpea, compared with only 19 percent for the sole crop. Thus the actual seed yield was 709 kg/ha, compared with 1 017 kg/ha for the sole crop, and the total LER for the whole system was 1.67—a yield advantage of 67 percent over sole cropping.

Results of resource-use studies are illustrated by light-interception data (Fig 90). Because of the rapid growth of the sorghum, the intercrop in its early stages was very efficient in intercepting light, but interception fell to only 19 percent after sorghum harvest. Even at the later peak interception, it was only about 50 percent. Thus the weeks immediately following sorghum harvest appeared the most efficient period of growth for the intercrop. The total amount of water lost from the soil profile, i.e. transpiration plus evaporation, was virtually unaffected by the

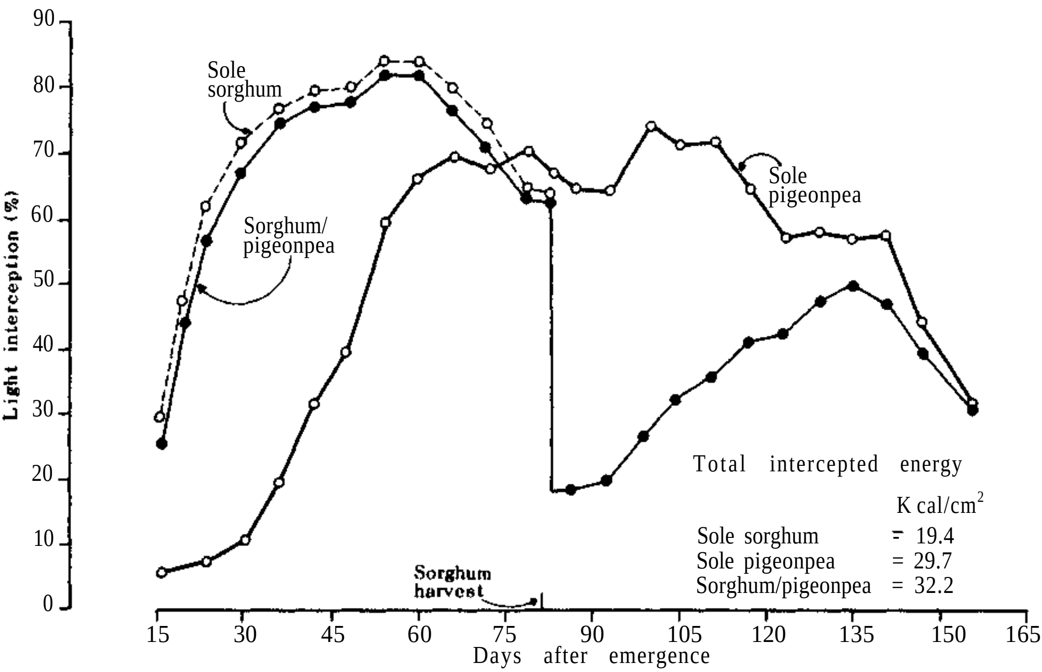


Figure 90. Light interception by sole-cropped sorghum and pigeonpea and a sorghum/pigeonpea intercrop, ICRISAT Center, 1977.

growth patterns of the different crop treatments. Thus it was concluded that achieving better canopy cover after sorghum harvest should increase the overall efficiency of the system, without increasing demands on soil moisture. Means of achieving this are being examined in a subsequent experiment.

A preliminary growth study was also carried out with pearl millet/groundnut, mainly to gain experience with this combination. This will be developed into a detailed study next season.

Plant Population and Spatial Arrangement in Intercropping

The main objective of these studies was to distinguish the separate effects of total population of both crops combined, component populations of each crop, and spatial arrangements. This has been done mainly by examining factorial combinations of different populations of each crop at constant row arrangements.

Studies on sorghum/pigeonpea and maize/pigeonpea have continued with a row arrangement of two cereal/one pigeonpea on 45-cm rows. A wide range of cereal populations had surprisingly little effect on cereal yield, but the higher levels reduced pigeonpea yields. Increasing the pigeonpea population had no effect on cereal yields, and gave a small but consistent increase in pigeonpea yield. On this basis, the requirement would seem to be: first, a cereal population somewhat below the sole-crop optimum so that competition on pigeonpea is reduced to a minimum while still maintaining near-maximum cereal yield; second, a pigeonpea population at least as high as the sole-crop optimum, and probably higher.

The systematic design tried with safflower/chickpea last season was repeated with millet/groundnut. Groundnut populations were in subblocks within which the millet population was systematically changed from row to row; a 12 percent change between rows gave a sixfold population change in 17 rows. This was a constant row arrangement of one millet/three groundnut with 30 cm between rows.

Because of poor emergence, the experiment had to be resown, and final yields were low and rather variable (optimum sole millet 778 kg/ha; optimum sole groundnut 589 kg/ha). In intercropping, increasing the millet population tended to increase millet yields and decrease groundnut yields, but these effects were surprisingly small (Fig 91). At low populations of groundnuts, the yield contributions of that crop were low, but as population increased, the groundnut yields were markedly higher with only moderate losses in millet yields. The optimum combination appeared to be a moderate millet population combined with a high groundnut population; in this situation, yield advantages of 20 to 25 percent were achieved.

An experiment in the postrainy season examined the effect of sorghum population in sorghum/chickpea intercropping at one/one and/two row arrangements. The optimum situation appeared to be a low population of sorghum (60 to 120 thousand pl/ha) in alternative rows with the chickpea; this gave a yield advantage of more than 20 percent.

The Effect of Different Moisture Regimes on the Yield Advantages of Intercropping

It has often been suggested that intercropping may be advantageous under stress situations, but not so much so when resources are plentiful. This suggestion was examined with four combinations in the postrainy season by creating "stress" and "no-stress" water regimes in cereal/legume and cereal/cereal combinations on an Alfisol (Table 95). The cereal/legume combinations were in a one/two row arrangement and the millet/sorghum in a one/one row arrangement; all treatments were on 30-cm rows.

These preliminary results appear to bear out traditional beliefs; all four combinations gave yield advantages in the stress treatment, but these were not nearly so apparent in the no-stress treatment. It appears that intercropping combinations have a potential for better use of moisture when compared with sole cropping, presumably because of complementary rooting patterns. This potential would produce a yield advantage when moisture was limiting, but not so when it was in adequate supply. However,

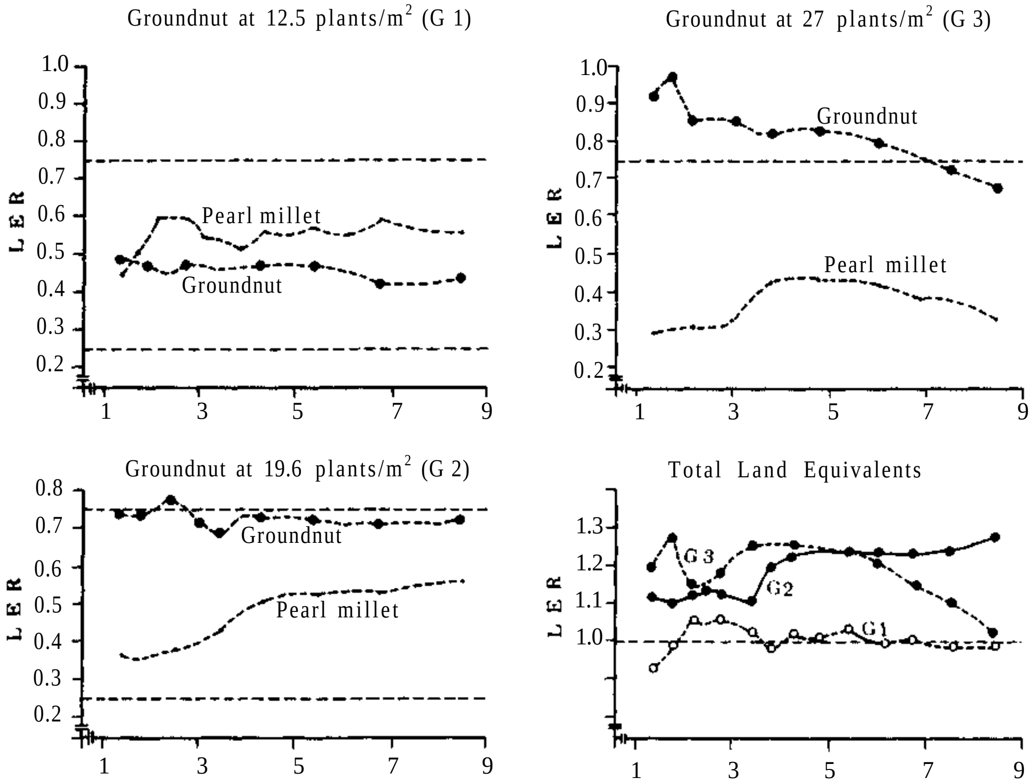


Figure 91. Plant population in millet I groundnut intercropping.

the results also indicated that relieving the moisture stress usually resulted in a yield increase only for the dominant crop. Thus it may be that the loss of a yield advantage under no-stress was partly due to a swing towards a less favorable balance of competition. This important area will be examined further next season.

The other major genotype experiment examined all combinations of three millet genotypes, ranging in height from 120 to 170 cm, with four groundnut genotypes ranging in maturity from 98 to 125 days. Seven of the 12 combinations gave yield advantages greater than 10 percent. The most consistent genotype effect was with cv M13 groundnut (125 days) which gave yield advantages of 30, 30, and 27 percent with millet genotypes G A M 73 (height 120 cm), PHB 14 (150 cm), and IVSA 75 (170 cm), respectively. As with the population experiment described earlier, these results suggest that, with a little experience, yield advantages of at least 20 to 25 percent should be consistently achievable with this crop combination.

Relay and Sequential Cropping on Vertisols

This experiment was a further development of previous studies examining the feasibility of double cropping on deep Vertisols. The basic rainy season treatments of i) maize for grain, ii) alternate rows of maize for green cobs and the remaining rows for grain, and iii) a bare fallow, were continued, and a treatment of rainy season sorghum was added. Crops studied in the

Table 95. **Effects of different moisture regimes on yields and land equivalent ratios (LER) of different intercropping combinations on an Alfisol at ICRISAT Center, postrainy season 1977.**

	Stress		LER	No stress		LER
	As sole crop	As intercrop		As sole crop	As intercrop	
	(kg/ha)	(kg/ha)		(kg/ha)	(kg/ha)	
Millet	2 018	1409	0.69	2 522	1 802	0.71
Groundnut	1 712	850	0.50	2 573	860	0.33
Total LER			1.19			1.04
Sorghum	2 6%	1 380	0.51	3 735	1 620	0.43
Groundnut	1 712	1 277	0.75	2 573	1 342	0.52
Total LER			1.26			0.95
Sorghum	2 696	1625	0.60	3 735	1 950	0.52
Chickpea	244	131	0.54	821	273	0.34
Total LER			1.14			0.86
Millet	2 018	1 595	0.79	2 522	2 006	0.79
Sorghum	2 696	1 190	0.44	3 735	1 089	0.29
Total LER			1.23			1.08

postrainy season were sorghum, chickpea, and pigeonpea. These were sown as relay crops 20 days or 10 days before the rainy season crop was harvested, or as sequential crops immediately after harvest of the rainy season crop.

First crops were sown on 20 June, but due to delayed rains emergence was not until 7 July; maize and sorghum were harvested on the same day, 14 October. Some late rains during the sowing period of the postrainy crops were particularly favorable, and establishment of all three second crops was excellent.

Growing a first crop of maize had little effect on the yield of the postrainy season crops, when compared with uncropped fallowing (Table 96). Removing half the maize for greencobs had a significant beneficial effect on the 20-day relay crop of pigeonpea, but other crops and treatments were not affected. In genera!, therefore, these results are similar to those of the previous year, indicating that a first crop of maize can be taken without much risk of reducing the yield of crops in the postrainy season.

Because of an attack of earhead bugs, sorghum yields in the rainy season were low. Even so the crop had a very deleterious effect on the crops following it, especially on chickpea and sorghum. A number of factors may have been involved but it is thought that a phytotoxic effect from the decaying sorghum roots and stubble almost certainly occurred.

As was the case in 1976, effect of time of sowing during the postrainy season varied with the crop. Excluding the bad effects of following rainy season sorghum, pigeonpea again benefited from earlier sowing, whereas chickpea was adversely affected; sorghum was also adversely affected by earlier sowing after fallow, but there was no consistent effect in sowing following maize.

In monetary terms (Table 96), the maize green-cob system appeared best, though the potential for this in any given situation obviously depends on the local market for green-cobs. Of the other systems, maize with chickpea was best, followed by maize with sorghum, then maize with pigeonpea. With the exception of pigeonpea, relay sowing did not appear to give an advantage this year. On average, earlier relay sowing increases the chances of having sufficient moisture for good crop establishment in the postrainy season, a factor which may be of paramount importance in unfavorable seasons.

Screening of Sorghum Genotypes for Ratoonability

Ratooning can be a very convenient way of "double" cropping; it reduces the costs and difficulties of establishing a second crop. In SAT areas especially, it can be a useful way of growing a "partial" second crop where moisture is limited. In conjunction with the sorghum-breeding program, a preliminary experiment was conducted to assess ratoonability of 54 sorghum genotypes growing on a Vertisol. Management factors for the first crop and subsequent ratoon

Table 96. Yields and monetary returns of maize and sorghum during the rainy season and of sorghum, chickpea, and pigeonpea as subsequent relay and sequential crops at ICRISAT Center, 1977.

Treatments	Rainy season	Postrainy season crops			Total value of system[a] Rainy season crop plus:		
		Sorghum	Chickpea	Pigeonpea	Sorghum	Chickpea	Pigeonpea
	(kg/ha)	(kg/ha)			(Rs/ha)		
Maize grain + 20 days relay	4017	3 068	972	911	6 109	5 842	5 705
Maize grain + 10 days relay	4 247	2 532	1 226	896	5 890	6 623	5 880
Maize grain + sequential	4 055	3 044	1 279	732	6 125	6 568	5 337
Maize greencob/grain + 20 days relay	2 183 (+ 21 305 cobs)	3 310	922	1 107	6 765	6 192	6 608
Maize greencob/grain + 10 days relay	2004 (+ 23 183 cobs)	2 966	1 356	870	6 515	7 193	6 100
Sorghum + 20 days relay	1046	1002	193	529	1 534	1 166	1922
Sorghum + 10 days relay	900	1 442	287	462	1 784	1 276	1 670
Sorghum + sequential	802	648	167	377	1078	936	1408
Fallow + 20 days relay	-	2 891	1013	890	2313	2 279	2 002
Fallow + 10 days relay	-	3 395	1 246	789	2716	2 803	1 775
Fallow + sequential	-	3 864	1456	684	3 091	3 276	1 539

[a]Value of rainy season crop (where present) plus postrainy season crop. Maize valued at 91 Rs/100 kg; rainy season sorghum, 70 Rs/100 kg; chickpea and pigeonpea, 225 Rs/100 kg; postrainy season sorghum, 80 Rs/100 kg; green-cobs valued at 10 per rupee.

crop, respectively, were exactly as for the first and second sorghum crops in the relay experiment above.

With only one or two exceptions, the very early genotypes (75 to 85 days) gave a good first crop (mean 3 313 kg/ha) and a good ratoon crop (mean 2 251 kg/ha). Several genotypes, especially some of the grain-grass types, gave a ratoon yield more than 80 percent that of the first crop. The early genotypes (85 to 95 days) were rather more variable and the mean yields were slightly poorer for both crops. Cultivar CSH-6 gave the best overall performance with 4 143 kg/ha first crop and 2 548 kg/ha ratoon.

CROPPING ENTOMOLOGY

This year, intercropping trials were conducted at ICRISAT Center and results compared with the off-station situation. Experimental work in the pest-parasitoid complex in mixed cropping and intercropping was intensified. Surveys were made to elucidate factors involved in maximizing the effect of natural control agents of *Heliothis armigera* (Hubner) on mixed and intercrops.

Heliothis armigera (Hubner)

Studies of the pest-parasitoid relationship enabled an understanding of natural population regulation of *Heliothis* in the region. Egg-parasitism levels by *Trichogramma confusion* Viggiani in cereals were highest on sorghum (80%, in late Dec) and in legumes on cowpea (80%, in mid Apr). Pigeonpea and chickpea were least attractive to this egg parasite, and this is an important contributory factor in the high larval buildup and heavy yield loss on these two pulses in the region.

On larvae, the nematodes (mermithids) were predominant in mid-late July, Hymenopterans in mid- to late September and early October, and Dipterans in early December. Mermithids dominated on groundnut, while Hymenopterans were predominant on sorghum, pearl millet, and chickpea; Dipterans were prominent on pigeonpea. At ICRISAT Center, the total area cropped increased steadily from 1974 to 1978 and this appeared to influence moth population. There was only a marginal increase in natural control by larval parasitoids during the period (Table 97).

Summarized data on light-trap records of this Noctuid for 1977 show that of 31 560 moths trapped at the Crop Improvement Building, 56 percent were females, and of these 80 percent were caught between 3 and 23 December, when it is suspected that weather conditions favored influx of moths from elsewhere. A vast majority of the suspected immigrant females were virgin, supporting this hypothesis. The entry of these migrant moths resulted in a disequilibrium with the local parasite fauna, leading to a rapid increase in larval populations and heavy yield losses in intercropped pigeonpea and chickpea at ICRISAT Center and in Andhra Pradesh generally.

Trials were initiated to determine if sex-lure traps were more effective than light traps for early detection of this Noctuid in the summer months. In Vertisol watersheds, traps with virgin females attracted more moths at 2.8 m above ground than at 0.9 m—36 as opposed to 2

Table 97. Total crop area (ha); light-trap records of adults of gram pod borer, *Heliothis armigera* (Hubner), at the Crop Improvement Building; and annual natural larval control by parasitoids, ICRISAT Center, 1974-1978.

Year	Area in cultivation	Adult moths trapped	Larval parasitism	
	(ha)	(no)	(%)	
1974-75	230	2 521	11.7	(1 747)[a]
1975-76	345	2 491	12.4	(4 488)
1976-77	413	3 591	13.4	(20 801)
1977-78	556	34 735[b]	22.3	(26 758)

[a]Figures in parentheses are total field-collected larvae incubated for parasite emergence.
[b]Of these, 25 959 moths are thought to be of the suspected migratory influx occurring 3-23 Dec.

in late May and early June (only one male was trapped in the three light traps during this period).

Preliminary field tests in collaboration with Boyce Thompson Institute, USA, using a local strain of nuclear polyhedrosis virus obtained from the Tamil Nadu Agricultural University, Coimbatore, for control of *H. armigera* larvae in chickpea showed that a significant reduction in larval numbers could be obtained with high dosages within 14daysof application. There was an increase in larval numbers in plots treated with adjuvants.

Surveys. Surveys of natural control agents of *H. armigera* were intensified in Andhra Pradesh. Cropping patterns played an important role on distribution and abundance of parasitoids. In general, the parasitism levels by Dipterans were higher on larvae from intercropped sorghum and pigeonpea in cotton-growing areas. This was the result of a parasitic shift from the main cotton crop. Levels were higher in mixed and intercropped sorghum—20 percent, compared to 13 percent in sorghum grown as a sole crop. However, larvae from sole-crop pigeonpea had higher overall parasitism levels than in mixed or intercrop (27% compared to 18%). Mermithids were present only in the Alfisols during the rainy season. On chickpea, parasitism levels declined as the season progressed. Data so far obtained has indicated that the conservation and encouragement of natural enemies is a potential means of providing more effective management of *H. armigera* populations, especially in subsistence and mixed farming where insecticidal control is too expensive and beyond the reach of most farmers.

Field Trials on Mixed and Intercropped Sorghum and Pigeonpea

A large-scale replicated trial using sorghum (CSH-6) and pigeonpea (ICP-1) was sown in low-fertility conditions in mid- to late June 1977 at seven locations-two each in Alfisols and Vertisols at ICRISAT Center and at three locations in Vertisols of adjoining villages. Mixed crops were grown only at ICRISAT Center locations, as farmers refused to grow a mixed crop with the hybrid sorghum. The treatments were sole-crop pigeonpea [PP], sorghum intercropped with pigeonpea at full stand [S/PP] and at half stand [S/PP($^1/_2$)] and sorghum and pigeonpea seeds mixed and broadcast [S + PP($^1/_2$)].

Sorghum

Significant differences in levels of shoot-fly, *Atherigonasoccata* Rond., attack did not appear on sorghum sown mixed or intercropped with pigeonpea in equal plant populations. By 23 days following emergence, highly significant differences ($p < 0.01$) in levels of shoot-fly attack were observed between locations within a radius of 15 km. Incidence was high at ICRISAT Center and low in adjoining villages.

Highly significant differences in egg numbers of *H. armigera* and in egg parasitism by *Trichogramma* sp. were observed on intercropped sorghum al and around ICRISAT Center (Table 98). At the Center, levels were higher on Vertisols. Subsequently a collection of 2 150 larvae revealed that the differences in larval parasitism levels were highly significant by location ($P<0.01$) there were higher levels at ICRISAT Center (35 to 60%) than at the village sites (19 to 27%).

Sorghum in mixed or intercropping was an important source of buildup of *Trichogramma* sp., an egg parasite, and *Diadegma* sp., a larval parasite of *H. armigera,* but this was of no advantage to the immediate intercrop pigeonpea in this region as the parasite complex that builds up in *Heliothis* on sorghum does not transfer to pigeonpea (Fig 92). We hope to improve our understanding in this complex area in coming seasons and attain the ability to predict the effects of parasitism on pest attack in cereal/ legume cropping systems.

Pigeonpea

There were no significant differences in pest numbers, pest-parasitoid ratios, and insect-induced final yield losses between intercrop [S/PP($^1/_2$)] and mixed crop of pigeonpea and sorghum [S + PP($^1/_2$)] with equal plant stands. However, significant differences in these factors

Table 98. Mean egg numbers of *Heliothis armigera*/10 earheads of intercropped sorghum (CSH-6) with pigeonpea (ICP-1) and egg parasitism (%) by *Trichogramma confusum* Viggiani at seven fields in Medak District, Andhra Pradesh, 1977-78.

Experimental sites	Soil	Location	Eggs/10 earheads[a]	Eggs parasitized	
			(no)	(%)	
A. ICRISAT Center	Deep Vertisols	1	31.2	49.0	(44.4)*
		2	66.2	61.1	(51.4)
	Alfisols	3	14.5	42.0	(40.1)
		4	20.0	56.7	(48.9)
B. Adjoining Villages	Vertisols	5	13.2	24.1	(29.0)
		6	16.7	26.6	(27.2)
		7	11.5	14.5	(19.4)
L.S.D. (0.05)			15.8		(13.5)
SE±			6.4		(5.5)
Location			**		**

[a]On 5-day-old earheads after 15 days of first earhead emergence.

[b] Figures in parentheses are the arc-sine transformed values used for analysis.

**Highly significant (P < 0.01)

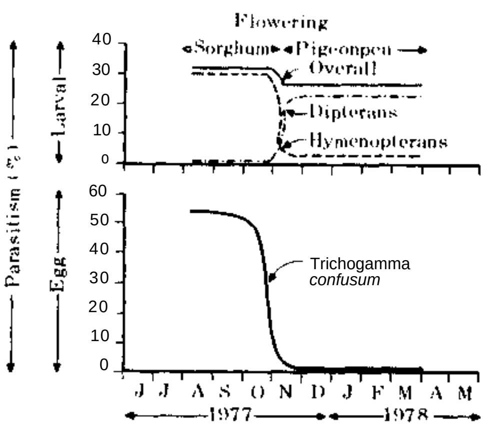


Figure 92. Transfer of parasitoids of Heliothis armigera *in a cereal/pulse intercrop, ICRISAT Center, 1977-1978 (simplified diagram).*

were observed in blocks with equal plant populations of sole-crop and intercropped pigeonpea [PP and S/PP].

At ICRISAT Center, the number of eggs laid and number of larvae of *H. armigera* were far higher on the unsprayed crop growing on Vertisols than on Alfisols. The number of moths trapped at light was also higher on the Vertisols area. At all the locations, the first peak of oviposition occurred on a moonless night in November. A similar situation was observed in the intercrop grown at the village sites. There was no yield from the early flower flush produced in unsprayed pigeonpea on Vertisols, because of the large numbers of feeding larvae—a result of the migratory influx of moths at this time (Fig 93). Loss of the first crop resulted in a second flower flush in intercrop and even a third flush in sole-crop pigeonpea. Second and third oviposition peaks were observed 5 to 7 days prior to a moonless night in January and on a moonless night in February. More flowers were produced on Alfisols (Fig 94). Significantly more eggs and larvae/100 pigeonpea terminals were recorded in intercrop blocks at peak oviposition than in sole-crop blocks, a repetition of 1975-1977 findings.

A collection of 5 191 larvae during the flowering period on pigeonpea (Nov-Mar) revealed that the overall parasitism by Diptera was higher (23.8%) than by Hymenoptera (3.2%). The levels were higher at 1CR1SAT Center than in the village sites (29% compared to 14%), on unsprayed than on sprayed crop (32% to 17%) and in intercropped pigeonpea as opposed to pigeonpea growing as a sole crop (27% to 23%). The highest parasitism levels (63%) were obtained in early February, and again Dipterans predominated (58%). These Dipterans are of little importance in affecting the immediate pigeonpea yield, since larvae were killed in the prepupal or pupal phase- i.e., after the host larvae caused pod damage.

The total loss in seed weight due to insect pests was obtained by using the actual weights of damaged and undamaged pods and seeds and calculating the potential yields if all pods had been undamaged. Data shows that the percent damage was greater on intercropped compared to sole-cropped pigeonpea with the same plant densities in typical low-fertility situations (Table 99). Since yield from sole-crop pigeonpea is higher than from intercrop, the actual weight

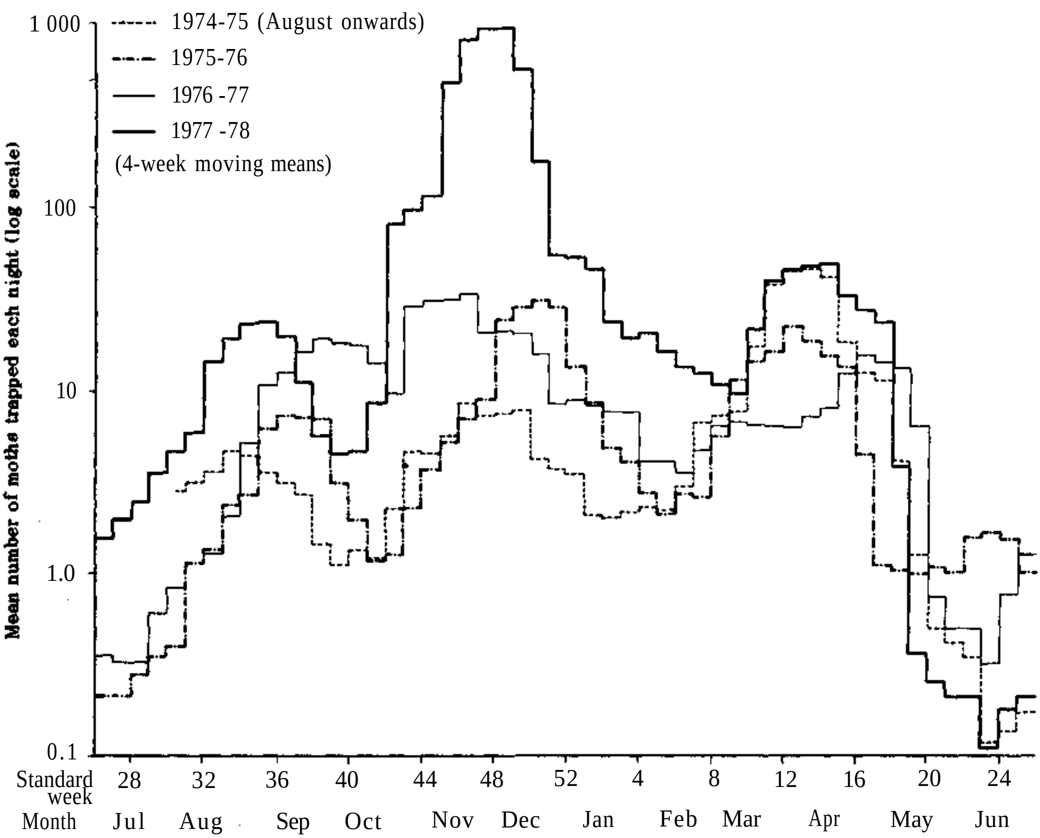


Figure 93. Light-trap catches of Heliothis armigera *(Hubner) at Crop Improvement Building, ICRISAT Center, 1974-1978.*

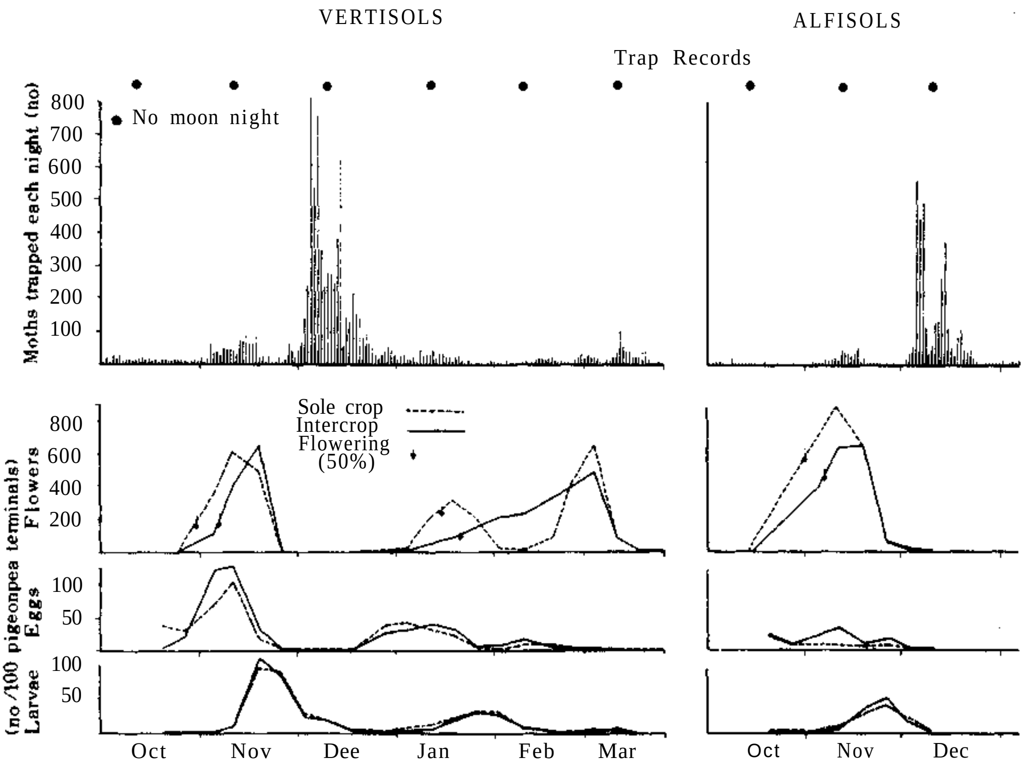


Figure 94. Light-trap catches of Heliothis armigera *(Hubner) in relation to flower, egg, and larval numbers per 100 terminals on intercropped and sole-cropped pigeonpea on Alfisols and Vertisols at ICRISAT Center, 1977-1978.*

Table 99. Final harvest assessments on pigeonpea (ICP-1) grown as a sole crop and intercropped with sorghum (CSH-6), ICRISAT Center, 1977 78.

Pigeonpea grown as	Pigeonpea population	Pods	Loss	Pigeonpea yield	Shelling
	(plant/ha)	(no/25 plants)	(%)	(kg/ha)	(%)
Sole crop (PP)	26 545.4	4 325.3	29.9	509.3	58.6
Intercrop (S/PP)	27 818.1	2 234.1	50.1	202.1	44.1
L.S.D. (0.05)	2 306.4	1 015.5	9.2	205.2	8.6
F-test	NS	*	*	*	*

[a] With 96 850 sorghum plants/ha.

* Significant (P < 0.05).

loss was greatest in the sole crop. Increased insect damage to intercropped pigeonpea was reflected in reduced shelling percentages.

In sorghum/pigeonpea intercropping on Vertisols, the sprayed pigeonpea was ready for harvest in 160 to 170 days, compared to 260 to 270 days in the pigeonpea which received no insecticide.

At village sites, pest numbers, parasitism levels, and yield losses on pigeonpea were lower than at ICRISAT Center. At one site, irrigation of the flowering intercropped hybrid sorghum in mid- to late September resulted in more flower production on pigeonpea than was observed on nonirrigated fields.

The irrigated crop also had higher numbers of H, *armigera* eggs and larvae and higher levels of larval parasitism. This greatly increased the insect-induced yield loss on the irrigated crop (45% against 18% on the nonirrigated crop).

Village-level Observations on Intercropped Pigeonpea

In collaboration with the group from the Economics program doing village-level studies, data on intercropped pigeonpea were obtained from selected villages in Andhra Pradesh and Maharashtra. In general, at low plant populations typical of subsistence farming practices, intercropped pigeonpea was attractive to ovipositing moths and had high larval populations. Factors such as low plant population with high pest numbers, absence of egg parasites, low larval parasitism by Hymenoptera, no spraying measures, and (in this season) an influx of migratory moths of *H. armigera* were responsible for high yield losses on intercropped pigeonpea in these areas.

Light-trap Studies and Insect Fauna at ICRISAT Center

Dissections of trapped female *C. partellus* revealed that all *Chilo* moths were mated and carried only one spermatophore/female. This is in contrast to the situation with *H. armigera.* The trap catch for November/December of some pest species (the legume borers: *H. armigera, Maruca testulalis* Geyr., *Etiella zinckenella (TR.), Adisura marginalis* Walker., *Adisura stigmatica* Warr., and two important cotton pests: *Earias vitella* F. and *Dysdercus* sp.) was unexpectedly high this year. These differences were presumably due to unusual cyclones in the western coastal region of southern India in November and December 1977.

Cereals were very badly affected by *Mythimna separata* Walker. The attack began during the wet spell in mid-August and by mid-September many cereal trials at ICRISAT Center were badly damaged; leaves of millet, maize, and sorghum were stripped. Cereals in the vegetative phase carried more larvae than those in the reproductive stage. In early September, intercropped sorghum on Alfisols carried significantly ($P < 0.05$) more larvae than that on Vertisols.

Diapause was observed in *Acherontia styx* W., *A. stigmatica, Cydia ptychora* Meyr, *Diacrisia obliqua* Walk., *E. zinckenella, H. armigera,* and *Heliothis assulta* Guenee.

Basic information on seasonal variations of more than 55 cereal and legume pests and beneficial insects of the SAT, obtained over the past four seasons by field counts and light trapping, will be utilized in forecasting and developing pest-management strategies at the farmer level, particularly in mixed and intercrop subsistence farming.

AGRONOMY AND WEED SCIENCE

Weed Science

Weed-management research was intensified, both in intercropping systems and on individual crops. Field trials were conducted i) to obtain increased weed suppression by manipulating the spatial arrangement and crop density and by introducing additional "smother" crops into the system; ii) to evaluate herbicides in combination with hand weedings in intercropping systems; iii) to determine the efficacy of different weed-control measures on deep Vertisols; and iv) to study methods of enhancing the efficacy and selectivity of herbicides. Herbicides screening trials on individual crops were continued mainly to improve techniques and to obtain more information on the most effective application rates of herbicides. The weed competitiveness and herbicide tolerance of different cultivars of ICRISAT's mandate crops were also studied. Studies were initiated in farmers' fields to evaluate traditional weeding systems.

Investigations involving "smother" crops were initiated in sole sorghum, sole pigeonpea, and in sorghum/pigeonpea intercropping along with two, one, or no hand weedings. The inclusion of cowpeas and mungbean as "smother" crops showed promise in minimizing weed infestation and reducing the number of hand weedings without significantly affecting the yields of the main crops (Fig 95, 96). Cowpea gave better yields on Alfisols and mungbeans gave higher yields on Vertisols. The smother crops not only replaced one hand weeding, but also provided additional produce. With the inclusion of smother crops, net returns were considerably higher than with sole-crop systems. However, inclusion of cowpeas or mungbeans as a third crop in a sorghum/pigeonpea intercrop system was not profitable on either of the soils. Further studies are being planned to improve the efficiency of the system. In general, these results indicate that the manipulation of light by the provision of additional canopy has considerable potential in minimizing the intensity of weed growth and thereby reducing hand-weeding costs.

Crop density and spatial arrangement of component crops of intercropping systems are important aspects to be considered in seeking

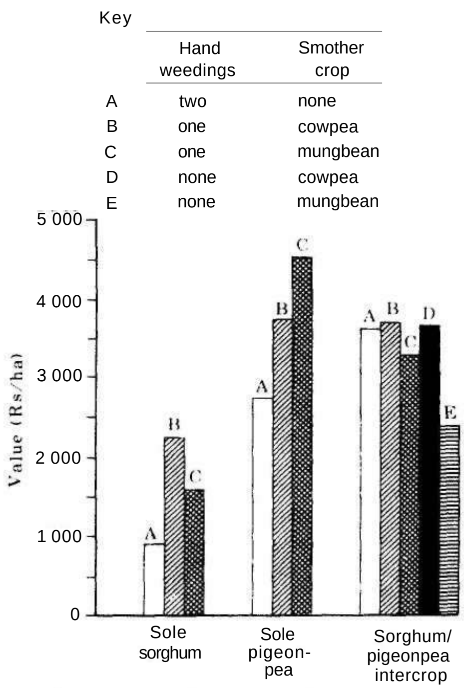


Figure 95. Net monetary value of various cropping systems under different weed-management systems on Alfisols at ICRISAT Center, 1977.

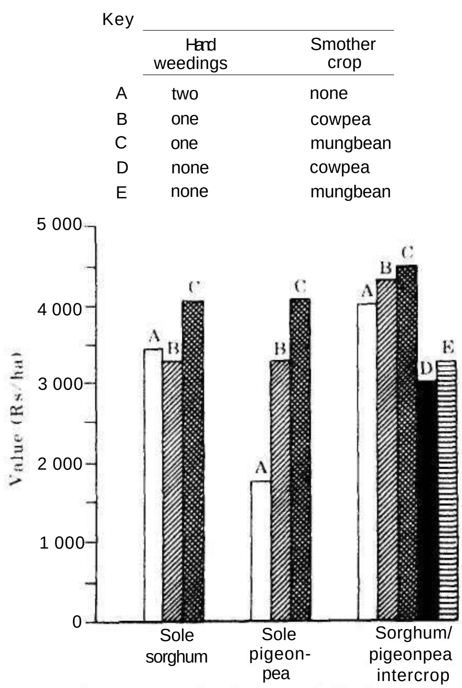


Figure 96. Net monetary value of various cropping systems under different weed-management systems on Vertisols at ICRISAT Center 1977.

maximum yield advantage. In a trial conducted in deep Vertisols primarily to examine the effect of plant population of a sorghum/pigeonpea intercrop system, the contribution to the weed suppression was more evident with the increased population of sorghum than that of pigeonpea. Though there was no substantial yield increase, there was a decrease in weed dry-matter weights when the sorghum population was doubled from its normal 80 000 per hectare. The increase in sorghum population reduced the number of weeds in the crop row.

Prometryne and terbutryne continued to show promise as herbicides for the sorghum/pigeonpea system; methabenzthiazuron, dinitramine, and fluchloralin were also effective. All were applied preemergence at the rate of 1 to 2 kg/ha; one hand weeding was made about 4 weeks following crop growth.

It was further confirmed that herbicides, applied as preemergence on deep Vertisols, coupled with later cultivation and/or hand weedings form a very effective weed-management system during rainy season cropping. Band application of low rates of atrazine and alachlor on the maize rows was economical and as effective as two hand weedings.

Conventional methods of herbicide screening require large areas of land and fail to give precise information on the exact limits of crop tolerance or of the range and degree of weed control. A logarithmic sprayer, which gives an exponential decrease of an original selected herbicide concentration as it proceeds at a constant speed along the plot, was tested; it was found to be a useful means for screening potential herbicides in sorghum, chickpea, and groundnuts.

Trials were conducted, in collaboration with the economists, in farmers' fields to determine the feasibility of including herbicides in farmers' present-day weed-control methods. Even under the existing systems, higher yields could be obtained with improved weed management, especially where the resource base has been improved. Three treatments—farmers' method alone, farmers' method with herbicide, and weed-free—were evaluated under field conditions. In Kanzara Village, atrazine application increased sorghum grain yield over that realized under the farmers' method alone. However, the value of the increase was just sufficient to cover the cost of the herbicide.

Relay and Sequential Cropping on an Operational Scale

Some crops such as postrainy season sorghum and pigeonpea are benefited by early planting as relay crops before the normal harvest time of the preceding rainy season crop, such as maize. However, it is operationally very difficult to relay plant between standing crops. The planting arrangement used in the broadbed-and-furrow system offers an opportunity for developing operationally feasible relay-planting systems. An experiment was initiated in which the two maize rows in every second bed were harvested for greencobs and green fodder, thus providing an opportunity for relay planting with the wheeled tool carrier in a 235-cm space between the standing maize plants. In all systems, chickpea was planted in the remaining 65-cm space after maize grain harvest, which occurred at physiological maturity. Thus chickpea occupied 22 percent of the space of the postharvest season, while the pigeonpea, safflower, or sorghum occupied 78 percent of the space. Since all yields are recorded on a hectare basis, it is possible to add the monetary values to determine total monetary value. The aim of this experiment was to explore problems encountered on an operational scale, so as to determine production opportunities and operational constraints. After the greencob harvest and the maize grain harvest, areas between the maize stubble were cultivated and planted with the bullock-drawn equipment. Difficulties were not encountered.

Where 50 percent of the maize was harvested for greencob and the rest for grain, the total monetary value was Rs 7 510/ha, 40 percent greater (due largely to the high value of maize greencob) than its value when harvested for grain alone. Likewise, relay-planted pigeonpea produced 180 kg/ha more than the sequentially planted pigeonpea. However, the companion chickpea crop produced 140 kg/ha less with relay pigeonpea than with sequential pigeonpea. Thus, the net advantage for relay planting was slight. It is recognized that the market for maize greencobs may be limited. However, where a market is available, the system with relay planting appears to be promising; the experiment will be repeated.

Forage- and Fodder-evaluation Program

Forage evaluation. One objective of our forage-evaluation program is to develop a minimal research effort on forage, fodder, and fuel crops to complement operational research on resource management and agricultural production at ICR1SAT. Its purposes are to: i) evaluate forage legumes and grasses for longevity, rapidity of regrowth, soil-erosion control, and ability to tolerate grazing pressure during the dry summer season; ii) determine biological and economic values of crop residues as livestock feed; and iii) evaluate annual and long-term shifts of grasses, legumes, and other species in the Alfisol and Vertisol "wilderness" areas (protected from grazing, cultivation and other disturbing activity).

A nursery for grasses and legumes was established on a Vertisol for evaluating their potential in grassed waterways and tank bunds.

Two legumes and three grasses have been planted for a trial comparing the effects of dry season grazing on forage production and longevity of six grass-legume mixtures.

In the "wilderness" areas, perennial species are increasing and annual species are decreasing. The dominant species in the Alfisols are *Heteropogon contorus, Sehima Nervosum,* and *Hyparrhenia rufa.* The Vertisols are dominated by a thick cover of perennial *Dichanthium* and *Acacia* and an annual, *Indigofera glandulosa.*

Steps Towards Improved Technology

The transfer of improved technology involves many factors or "steps." To investigate each of the component practices in all possible combinations is clearly an unmanageable task. For this study, therefore, the factors involved were grouped into four "steps," i.e., variety, fertilization, soil and crop management, and, in some instances, supplemental irrigation.

Sorghum and chickpea on medium deep Vertisols. Sorghum was "dry planted" just prior to the onset of the rainy season. Germination and seedling growth were excellent in all treatments. Vegetative growth and grain formation of sorghum cv CSH-6 were excellent, even though rainfall was 25 percent below normal. Yields on the rainy and postrainy season crops are summarized in Table 100. Sorghum gave a large response to fertilization and to soil and crop management, and showed a marked synergistic effect when fertilization and management were combined. The sum total of sorghum yield increases with improved management, fertilization, and variety applied separately was 3 640 kg/ha. When these three factors were applied together the yield increase was 5 370 kg/ha. Thus, the synergistic effect of the three factors in combination was 1 730 kg/ha.

During the main cropping season, water was not applied to Treatments 9 and 10. Thus the yields of these treatments were combined with 4 and 8, respectively. In the postrainy season, a 5-cm irrigation applied to the ratoon crop at the flag-leaf stage (Treatment 10 vs 8) increased the grain yields of the ratooned sorghum by 1 130 kg/ha. This represented a value of Rs 18 080 per ha/m (Rs 2 230 per acre/foot) for the applied water. When a similar irrigation was given to the local variety of sorghum, the yield increase was only 240 kg/ha.

When all four improved technologies were applied in combination, the total grain yield of the main and the ratoon sorghum crops was more than six times the yield when only traditional practices were used. The combined use of the four improved practices also had the highest rate of return per rupee of variable cost.

In the 1977-1978 season, the main plots were split and subplot A (without herbicide) was planted to a sequential crop of chickpea. A local variety was used in all ten treatments.

Table 100. Effect of traditional vs improved levels of four "Steps in Improved Technology" upon grain yields of sorghum with a ratoon crop and a sequential crop of sorghum and chickpea on a medium-deep Vertisol at ICRISAT Center, 1977–1978.

Treatment No.	Var.	Fert.	Soil and crop manag.	Supp. water	Sorghum (b)[a] Main crop	Sorghum (b)[a] Ratoon crop	Sorghum (b)[a] Total	Sequential crop (a)[a] Sorghum	Sequential crop (a)[a] Chickpea	Sequential crop (a)[a] Total value
				(cm)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
1	Trad[b]	Trad	Trad	0	1 000	160	1 160	1 110	170	1 060
2	Trad	Trad	Impr[c]	0	1 380	300	1 680	1 370	190	1 250
3	Trad	Impr	Trad	0	1 660	250	1 910	1 670	130	1 310
4	Trad	Impr	Impr	0	2 170	260	2 430	2 090	290	1 930
5	Impr	Trad	Trad	0	3 230	300	3 530	2 950	480	3 110
6	Impr	Trad	Impr	0	3 350	330	3 680	3 570	600	3 800
7	Impr	Impr	Trad	0	4 650	460	5 110	4 800	560	4 570
8	Impr	Impr	Impr	0	5 570	960	6 530	5 840	710	5 620
9	Trad	Impr	Impr	5[d]	2 170	540	2 710	2 090	660	2 760
10	Impr	Impr	Impr	5[d]	5 570	2 090	7 660	5 840	990	6 250
L.S.D. (0.05)					442	180	–	444	179	–

[a] Subplot (a), planted to chickpea, received no herbicide; subplot (b), planted to sorghum, received 0.75 kg/ha of atrazine as preemergence application and was allowed to ratoon.

[b] Trad = Traditional: Varieties—sorghum, PJ8K; chickpea, local. Fertilization—10 ton/ha farmyard manure (FYM) in 1976, none in 1977. Soil and crop management simulates the present traditional farmer practice with bullocks and desi implements; fertilizer broadcast; seed sown with three-row desi drill, 30 cm between rows. One insecticide application to chickpea only.

[c] Impr = Improved: Varieties—sorghum, CSH-6; chickpea, local. Fertilization—75kg/ha 18-46-0 plus 107 kg N/ha topdressed. Crop and soil management —all tillage, planting, and cultivation with improved animal-drawn implements. Fertilizer banded and seeds planted in three rows, 45 cm apart on broad beds 150 cm apart. Subplot (b) of treatments 4, 8, 9, and 10 received 40 N/ha topdressed and was cultivated immediately after harvest of main crop. Chickpea received no nitrogen. One insecticide application to chickpea only.

[d] Water was not applied to the main (rainy season) crop. Treatments 4 and 9 as well as 8 and 10 were averaged. Five cm of water was applied at flowering stage of the ratoon crop in subplot (b) and to chickpea in subplot (a).

Chickpea yields following the long-duration traditional sorghum were much lower, because of the 11-day delay in planting. Improved soil- and crop-management practices consistently increased chickpea yields, as did the application of 5-cm supplemental water. The combined use of improved varieties, fertilization, and soil- and crop-management practices and 5 cm of irrigation in the postrainy season on a sequential cropping system of sorghum and chickpea gave a gross return of Rs 6 250/ha. This contrasts sharply with the Rs 1 060/ha return from the the same cropping system and traditional production practices.

Crop production in Alfisols. The erratic rainfall pattern in late June and early July of 1977 created severe emergence problems on Alfisols due to crusting. This problem was particularly severe in pearl millet which was planted at a shallow depth. In the "Steps in Technology" experiment, the pearl millet stand was so poor that replanting was required in all treatments, whereas the stand of pigeonpea was good. The replanting of pearl millet was done 18 days after the planting of pigeonpea, which appeared to give the pigeonpea an early growth advantage. Because of the late planting, the general yield level of the pearl millet was low. As shown in Table 101, improved soil and crop management had by far the most consistent effect upon pigeonpea grain yield.

Table 101. Effect of traditional vs improved levels of three "Steps in Improved Technology" upon grain yields of sorghum in 1975 and 1976 and of pearl millet/pigeonpea intercrop in 1977/1978, and on mean annual monetary value for the 3 years. Crops grown on medium-deep Alfisol at ICRISAT Center.

Treatment No.	Var.	Fert.	Soil and crop manag.	Sorghum 1975	Sorghum 1976	Pearl millet/pigeonpea intercrop: Millet	Pearl millet/pigeonpea intercrop: Pigeonpea	Monetary value"
				(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(Rs/ha)
1	Trad[b]	Trad	Trad	1 190	520	650	344	960
2	Trad	Trad	Impr'		940	450	709	1 560[d]
3	Trad	Impr	Trad	1 770	1 450	970	484	1 590
4	Trad	Impr	Impr	2 240	2 270	1 160	940	2 410
5	Impr	Trad	Trad	1 010	830	960	662	1 250
6	Impr	Trad	Impr		1 300	660	776	1 630[d]
7	Impr	Impr	Trad	2 390	1 930	1 080	483	1 750
8	Impr	Impr	Impr	3 480	3 780	1 750	1 025	3 010
L.S.D. (0.05)				540	590	70	249	

[a] Three years' mean value. Market prices per 100 kg: 1975, sorghum CSH-5 and PJ8K, Rs 75. 1976, sorghum PJ8K, Rs 85; sorghum CSH-6, Rs 68. 1977, pearl millet (local), Rs 95; pearl millet WC-C75, Rs 100; pigeonpea (local), Rs 267; pigeonpea ICP-1, Rs 220.

[b] Trad = Traditional: Variety—sorghum PJ8K. Fertilization, 10 ton FYM in 1975 and 1977, none in 1976. Soil and crop management simulates the present traditional farmer practice with bullocks and desi implements. Fertilizer broadcast. Seed sown with three-row desi drill, 30 cm between rows. One insecticide application on pulses only.

[c] Impr = Improved: Variety-Sorghum 1975, CSH-5; 1976, CSH-6. Fertilization - 75 kg/ha 18-46-0 plus 67 kg N/ha topdressed on cereal only. Crop and soil management—all tillage, planting, and cultivation with improved animal-drawn implements. Fertilizer banded and seeds planted in three rows, 45 cm apart on broad ridges 150 cm apart. Atrazine at 0.75 kg/ha applied in 1976 only. One insecticide application on pulses only.

[d] Average of two years, 1976 and 1977. Treatments 2 and 6 were not applied in 1975.

Grain yields and the mean annual monetary values for the 3 years show a consistent synergistic effect of improved management and fertilization. The greatest and most consistent response to improved management was obtained where both improved variety and fertilization were used.

The summary of 3 years' results on Alfisols and 2 years' results on Vertisols indicates the extreme importance of changing to improved soil and crop management—which is a non-monetary input—when using improved varieties and fertilization.

Watershed-based Resource Utilization Research

Watershed-based resource development and utilization research is conducted on watershed units on Alfisols and Vertisols. The activity serves as an operational testing ground for principles and methodologies developed in other subprograms, where rainfall productivities and economics of alternative farming systems are investigated. Thus, scientists in all subprograms of the Farming Systems Research Program, as well as economists, plant breeders, entomologists, pathologists, physiologists, and microbiologists, are involved in operational-scale systems research in the watershed units.

The watersheds consist of 15 subunits on deep Vertisols, 8 subunits on medium deep to shallow Vertisols, and 6 subunits on Alfisols. Several systems of soil and crop management are studied on an operational or field scale, using animal draft power. The studies include inventories of the natural resources, water balance, and hydrologic investigations, the determination of rainfall productivity, total annual production, human labor and bullock power utilization, and various other inputs used in the systems.

Watershed Development on Alfisols

A cooperative research project with the AICRPDA required the development of four watershed units on Alfisols. The objective of this project is to derive region-specific design criteriafor improved soil and water management which more effectively conserves and utilizes the rainfall and the soil and which, integrated with new crop-production systems, increases productivity and assures more dependable harvests. Four watershed treatments are compared: i) traditional land- and crop-management practices of the region; ii) improved cropping systems and crop management and standard contour bunding; iii) such systems supported by improved soil- and water-conservation measures; and iv) improved soil and water management and cropping systems backed up by runoff collection and supplemental water use (Table 102).

ICRISAT allotted to the project an undeve-

Table 102. Land-development treatments and costs for the four submits of the AICRPDA-ICRISAT Cooperative Project on an Alfisol at ICRISAT Center.

Watershed units	Land development treatments	Development costs[a] (Rs/ha)
A	Traditional; without land smoothing	0
B	Standard contour bunds without land smoothing	350
C[b]	Land smoothing; grassed waterway construction; bed-and-furrow system	200
D[b]	-do-	300

[a]Costs are based on those at ICRISAT; Rs 5.50/day for laborers and Rs 13.20/day for a pair of bullocks. If computations were made on the basis of opportunity costs, the costs would be less.

[b]C and D were similar, but development costs in D were higher than those in C due to a larger amount of gulleys and rocky ridges requiring more land loosening, stone removal, and smoothing. In addition, the D unit was provided with a water-storage reservoir for runoff collection and supplemental irrigation.

loped 14-ha Alfisol watershed area (RW3) consisting of four subunits. The area, not cultivated for many years, contained many old field bunds, thorn bushes, bunch grass *(Heteropogon contortus),* exposed stones, and gulleys. It was developed in the postrainy season using bullock power and human labor (Fig. 97,98).

In watersheds RW3 C and D, the average cost of drainage-way construction was Rs 49/ha. The average cost of preparing the graded 150-cm bed-and-furrow system was Rs 7/ha. The balance of the land-development cost in these two subunits was for harrowing, chiselling, and land smoothing.

Figure 97. Wheeled tool carrier fitted with angle blade is used to construct a grassed waterway on an Alfisol watershed.

In addition to providing excellent soil- and water-conservation facilities, the broad bed-and-furrow system also provides graded furrows which can be used for supplemental irrigation under rainfed conditions. However, the same land development, including land smoothing and the establishment of the graded bed-and-furrow system, can also be used for conventional irrigated agriculture at a cost of less than 10 percent of the conventional land levelling or grading commonly used for irrigated agriculture. Also, conventional land levelling, which usually requires relatively deep cuts, can reduce productivity on shallow Alfisols and Vertisols. Land smoothing and establishment of the graded bed-and-furrow system require only minimal earth movement to reduce microrelief. The semi-permanent bed-and-furrow system also provides protection from soil erosion year-round.

Construction of a runoff storage tank in RW3 D. A 5 100 m^3 runoff storage tank was constructed at the outlet of the waterway of watershed unit D (Table 102). Heavy equipment

Figure 98. An indigenous wooden scraper is used for final shaping of the grassed waterway and deposition of excess soil in microrelief depressions.

Figure 99. Final shaping of side slopes of the tank and tank bund.

was used for major excavation, bund building, and bund compaction. Final shaping of side slopes of the tank and the tank bunds was done by hand labor (Fig 99).

About 5.4 machine hours of scraping and 25.6 machine hours of bulldozing were required for tank and bund construction, at a cost of Rs 3 900. About 96 man days, costing Rs 525. were required for bund and tank shaping. Materials and labor costs for the inlet and diversion structures were Rs 292 and Rs 121, respectively. Thus, the total cost of tank construction was about Rs 4 850 or Rs 0.95/m^3 of storage. Watershed RW3 D contains 3.8 ha and thus the cost was about Rs 1 280/ha.

The cost for land development with a graded bed-and-furrow system and tank construction for supplemental irrigation amounted to about Rs 1 600/ha. This is less than 10 percent of the average cost of conventional irrigation systems, including cost of dam and canal construction and land leveling—estimated to be $2 800 or about Rs 23 000/ha.[1]

Water Balance and Hydrologic Investigations

In most farming systems of the SAT, only about 20 to 50 percent of the annual rainfall is actually used for crop production. To determine the potentials for improvement, hydrologic studies are concerned with the fate of all water, not only that which is immediately available in the root zone for evapotranspiration, but also that which runs off or drains to deeper layers beyond the roots.

Runoff from research watersheds. Fifteen Vertisol watershed units and seven Alfisol units were monitored for runoff during the 1977 rainy

[1]Peterson, Dean, 1977. "Water: A World Problem." *War on Hunger,* July 1977 (USAID publication).

Figure 100. ICRISAT scientist explains that water is the most limiting factor in agricultural production in the SAT, and how runoff water can he stored for future use.

season. Compared to the previous 4 years, the 1977 season resulted in the smallest amounts of runoff. In cropped deep Vertisol areas, only 0 to 2 mm of runoff were observed. Two reasons can be identified to explain this: i) the rainfall was well-distributed throughout the season; ii) there were few high-intensity long-duration storms. As in past years, the runoff from cropped Alfisols was greater than from cropped Vertisols. The average runoff from four cropped Alfisol watersheds was 8 percent. In the rainy season fallow flat-cultivated field-bunded Vertisol watershed, BW4C, seasonal runoff amounted to 53 mm, or nearly 9 percent of the rainfall. On rainy season fallow watersheds, cultivated to broad graded beds and furrows, BW5 B, the average runoff was only 2 percent.

Soil erosion from research watersheds. A total of 328 runoff samples were collected from the Alfisol and Vertisol watershed units. In the cropped Vertisol watershed units, either very small or zero amounts of soil loss were observed at the outlets. Vertisol watershed BW4 C, uncropped in the rainy season, had the largest amount of soil loss (1.7 metric ton/ha). The 74-mm storm on 10 August with a weighted mean intensity of 22 mm/hr caused 68 percent of the total annual soil loss.

Groundwater on Vertisol watersheds. Average groundwater fluctuations for the deep Vertisol areas and the cumulative rainfall minus runoff during 1975,1976, and 1977 are shown in Figure 101. In all three years, the trends of net cumula-

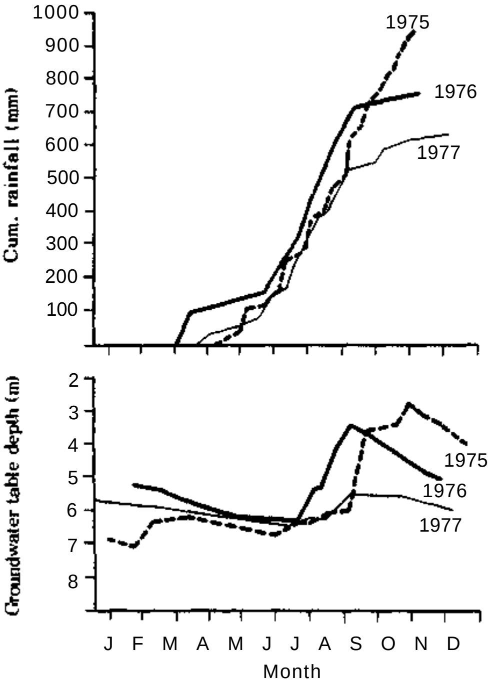


Figure 101. Rainfall and groundwater table depths on deep Vertisols in 1975, 1976, and 1977.

tive rainfall and groundwater levels are similar. The 1.0-m rise in the water table in 1977 resulted from the drainage beyond the root zone of an estimated 60 mm of water on the double-cropped deep Vertisols. Thus, even in a relatively low rainfall year such as 1977, significant quantities of water appear to drain beyond the effective root zone.

Seasonal changes in profile water storage. Soil moisture samples taken from the Vertisol and Alfisol watersheds at the beginning and end of the rainy season and at the end of the post-rainy season were used to evaluate effects of soil- and crop-management practices on profile water storage and use.

On deep Vertisols, profile water storage on cropped areas increased 110 mm from June to September. On uncropped areas, the profile storage increase was 240 mm. From September to December, postrainy-season crops reduced the profile water content by 96 mm on the double-cropped areas. On areas that were fallowed during the rainy season, the postrainy season profile water use averaged 140 mm. Thus, in 1977 the rainy season crop significantly reduced the supply of profile water that was available for the postrainy season crop. This difference in profile water content in September was primarily in the upper 60 cm of the Vertisol profile. Fortunately, it was almost entirely eliminated by the 60 mm of rain in the first week of October which largely recharged the upper 45 cm of the profile and resulted in good stand establishment and early season growth of the postrainy season crops on both the rainy season fallow and rainy season cropped fields.

Analysis of losses front runoff storage in tanks. Substantial amounts of runoff were measured in all Alfisol watershed units. The water in the RW1 tank was analyzed with respect to evaporation and seepage losses and availability of water in the tank during storage period, and total inflow of water into the tank.

During the period from 1 July to 15 November, the RW1 tank lost one-half of its total inflow of 81 mm by seepage and one-fourth by evaporation. The minimum amount of water available for irrigation of the 3.8 ha watershed was 2.5 cm. During the rainless period in September, the tank could have supplied 4 cm of irrigation water to the whole watershed.

A similar analysis was done for 1976; the results show (Fig 102) that total inflow into the tank by the end of November was 182 mm of which 66 mm were lost as outflow. Seepage and evaporation losses to the end of November were 38 and 30 mm respectively. Seepage losses were considerably reduced after 30 September, probably because of the high water tables in the surrounding area during October and November. Figure 103 shows the relationship between the amount of water available and its availability period expressed as a percentage of the total period. About 45 mm of water was available in the tank during 80 percent of the period.

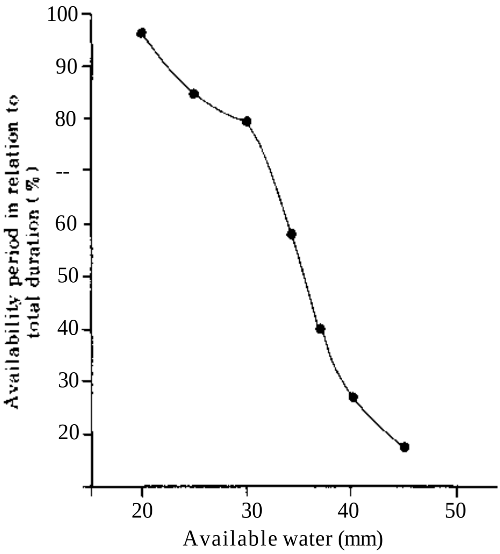


Figure 102. Relative availability of given quantities of water, 1977.

During 30 percent of the period, 70 mm of water was available in the tank.

Crop Production and Economic Data from Operations Research

In addition to providing opportunities for hydrologic and water balance investigations, the watershed units serve as an excellent facility for crop production and economic research on an operational scale. The main objective of this research is to develop systems which can effectively utilize the soil and water resource base to increase agricultural production on a sustained basis while conserving resources for future generations. This involves the development of farming systems which can effectively utilize the current season's rainfall directly, as well as provide for supplemental irrigation from stored runoff and/or well water.

By investigating alternative soil-, water-, and crop-management systems on a field scale in operational units, it is possible to study methods of improving production as well as needs and potentials for reducing peak labor and draft-power demands. In resource development and agricultural production operations, emphasis has been given to timeliness of operations and to carrying out operations in the "off seasons" when feasible (Fig 104). In this manner, animal power can be used more effectively and labor-use distribution can be more uniform throughout the year.

In order to determine the net crop production of each watershed, the yields obtained were adjusted to actual crop areas in each unit. In other words, the areas occupied by field bunds, contour bunds, and grassed waterways were subtracted to obtain the percentage of net cropped area in each watershed area.

Before 1976, guide bunds or channels were needed to re-establish the narrow (75 cm) bed-and-furrow systems each year at the proper grade. With the establishment of the 150 cm broadbed-and-furrow system on a semi-permanent basis, there is no need for guide bunds; all these bunds were erased in the land preparation process before the start of the 1978 season. Some grassed waterways which had been built wide enough for tractor operation were reduced in width to the minimum required for erosion control. These two operations greatly reduced the amount of land involved in bunds and grassed waterways for the 1978 season.

Planting in dry soil just prior to the onset of the rainy season has been practiced in deep Vertisols by the Farming Systems Research Program since the establishment of ICRISAT in 1972. In the 1977 season, the dry-planting system was given its most severe test with two early prolonged rainless periods after only minimal rainfall. Dry planting was performed during 13-15 June; on the evening of 15 June, 24 mm of rain occurred. This was sufficient to wet the soil at the seed level (6 cm) and to germinate the seed. The subsequent small showers until 18 June wetted the soil to about 15 cm, then there was no more rain for 15 days. The hot dry winds during this period caused considerable wilting. By the end of the rainless period, the rapidly developing Vittal variety maize seedlings showed severe wilting symptoms, sorghum CSH-6 showed slight wilting and SB-23 maize was intermediate. The slowly developed pigeonpeas showed no wilting.

On the evening of 3 July, 37 mm of rain fell at fairly high intensity. With this and several small showers which occurred on 4 July, the plants revived completely. However, this rain mainly rewetted the surface soil (0-22 cm) but the 30 and 45 cm depths had not been wetted by the monsoon rains. Following this, there was another rainless period of 12 days. Again very severe wilting occurred, particularly in the Vittal variety of maize. However, no plants died. Analysis of 75 years of rainfall data indicates that the probability of such rainless periods in the seedling stage is less than one in ten years.

Some observed advantages of dry planting are: i) the ease, speed and precision of planting in dry soil (Fig 105)—planting between showers in wet Vertisols takes 2 to 3 times as long as in dry soil; ii) all rainfall is used for crop germination and seedling growth and no water is wasted during tillage operations; iii) dry planting usually results in better plant stands than does planting in wet soil immediately after the onset of the rainy season; and iv) in some seasons, prolonged early monsoon rains delay planting until a serious sorghum shoot fly buildup has occurred.

Crop production in flat vs bed-and-furrow systems. In 1976 the broadbed-and-furrow system (150-cm bed) was first established in the

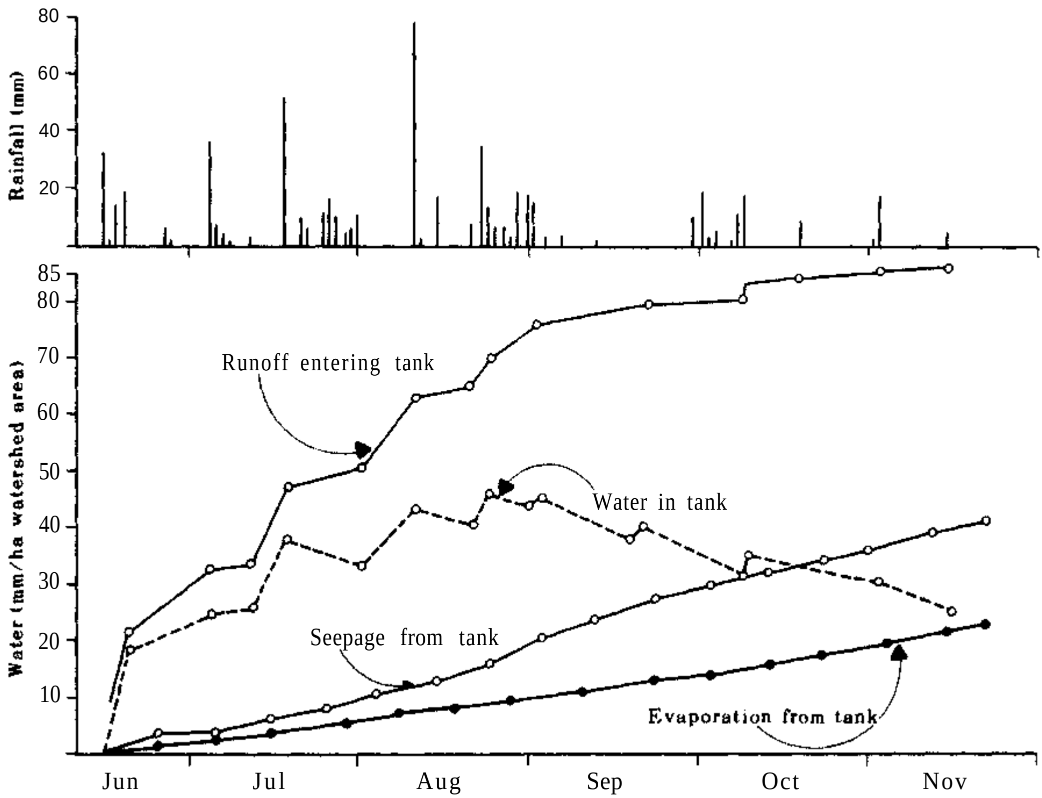


Figure 103. Amount of water entering tank, amounts lost to seepage and evaporation, and amount remaining in storage, Watershed RWI,1977 (cumulative values).

Figure 104. The virtue of timeliness: after harvest of the intercropped pigeonpea, the broadbeds are plowed, throwing the soil to the center. This covers the pigeonpea stubble, stops its regrowth, and allows it to rot during the rainy season. The difficult task of uprooting pigeonpea stubble with traditional equipment is thus eliminated, and organic matter content of the soil is increased.

Vertisol watersheds in place of the narrow 75-cm ridge. At the same time, each watershed unit was divided into two replicates which made it possible to get more reliable yield data. The average monetary values for both the intercrop and sequential cropped systems under flat vs bed-and-furrow system for 1976 and 1977 are given in Table 103. In the deep Vertisols, the average yields and gross monetary value of each of the four crops were consistently better with beds and furrows (BW1, 2 and 3 A) as compared to the flat system (BW3 B & 4 B). In the deep Vertisol, the mean monetary value of all systems and years for the bed-and-furrow system was Rs 650/ha greater than that of the flat system and this difference is highly significant.

The monetary values of the medium to shallow Vertisols were about 20 percent below those of the deep Vertisols in 1977. The lower yield is believed to be due to the low nutrient status and water-holding capacity of these relatively shallow soils. The monetary values were lessconsistent in the medium to shallow Vertisols than in the deep Vertisols and the increase of beds over the flat system was only Rs 180/ha which was not significant.

In another watershed unit, sorghum/pigeonpea intercrop was grown under flat planting. The yields were similar but slightly below that of the maize/pigeonpea intercrop on the flat system. As in the past years, the yield of the traditional postrainy season single cropping system watershed (BW4 C) was less than 20 percent of the improved intercrop system shown in Table 103. The rainy season fallow system, in addition to producing low yields, also leaves the soil unprotected and subject to severe raindrop erosion during high-intensity storms in the rainy season.

In the Alfisols, the general yield level was about 30 percent below that of the deep Vertisol watersheds (Tables 103 and 104). One of the major reasons for this is the lower water-holding capacity and the much smaller postrainy season crop potential in the Alfisols compared to deep Vertisols. Where supplemental irrigation is available under rainfed conditions, these differences would probably be reduced.

With the erratic rainfall pattern that occurred in late June and early July of 1977, stand establishment was difficult in Alfisol experiments. Many experiments, particularly those with pearl millet, had to be replanted or transplanted which made it difficult to get valid yield comparisons. In 1976, the bed-and-furrow system was appreciably better than the flat system; however, the average of the 2 years showed a difference of only 7 percent (Table 104).

In addition to increased crop yields and monetary values, there are many other features of the bed-and-furrow system which show potentialities for improved soil and water conservation and management. Some observed features of the semipermanent bed-and-furrow vs flat system are the increased yield, reduced erosion on a year-around basis, greater opportunity for "off season" land preparation, less weed problem, reduced power input and the provision of graded furrows for crop drainage and supplemental irrigation.

Figure 105. Dry seeding in deep Vertisols has been practiced successfully for the last six years in fie Id-scale operational research.

Table 103. **Mean monetary values of flat vs semipermanent bed-and-furrow system on Vertisol watersheds using improved technology at ICRISAT Center in 1976 and 1977.**

Watershed No.	Land management	Year	Intercrop Maize	Intercrop Pigeonpea	Intercrop Total	Sequential crop Maize	Sequential crop Chickpea	Sequential crop Total	Means Both systems	Means Both years
			(Rs/ha)			(Rs/ha)			(Rs/ha)	(Rs/ha)
A. Deep Vertisols										
BW1,2,3A	Beds	1976	2 840	2 080	4 920	2 730	950	3 680	4 300	
BW1.2, 3A	Beds	1977	2 270	2 770	5 040	2 880	2 400	5 280	5 160	
Mean										4 730
BW3 B, 4B	Flat	1976	2 530	1 680	4 210	2 300	570	2 870	3 540	
BW3 B, 4B	Flat	1977	2 450	1 810	4 260	2 790	2 200	4 980	4 620	
Mean										4 080
L.S.D. (0.05)										280
C.V. (%)										9.2
B. Shallow to medium deep Vertisols										
BW7 B/C/D	Beds	1976	2 020	1 570	3 590	1 970	560	2 530	3 060	
BW7 B/C/D	Beds	1977	2 460	1 630	4 090	2410	1 550	3 960	4 030	
Mean										3 550
BW3 B, 4B	Flat	1976	1 960	1 490	3 450	1 570	560	2 130	2 790	
BW3 B, 4B	Flat	1977	2 310	1 880	4 190	2 290	1 390	3 680	3 940	
Mean										3 370
L.S.D. (0.05)										N.S.
C.V.(%)										15.6

Cooperative Research

The semi-arid tropics represent great diversity of soils, climate and people. The new concepts, approaches, and methodologies developed at the ICRISAT Center need to be adapted to various regions of the SAT. This activity can best be handled through cooperative research with various national and regional programs in carefully selected climatic and socioeconomic regions.[2] Preliminary investigations have been made at select bench-mark locations in Africa.

During the past year, two projects have been developed in cooperation with the Indian Council of Agricultural Research. The following projects have been started in a preliminary manner at several locations across the Indian SAT.

Research on Resource Development, Conservation and Utilization in Rainfed Areas

The objectives of this project are to develop a research system for testing the semipermanent

[2] All India Coordinated Research Project on Dryland Agriculture (AICRPDA) and Soil and Water Conservation Institute (see ICRISAT Annual Report, 1976-77).

Table 104. Grain yield and mean monetary values of flat planting vs semipermanent broadbed-and-furrow system (150-cm bed) on Alfisol watersheds using improved technology at ICRISAT Center in 1976 and 1977.

Watershed No.	Land management	Slope of beds	Year	Intercropping[a] Pearl millet	Intercropping[a] Pigeonpea	Sequential cropping[b] Sorghum	Sequential cropping[b] Safflower	Sequential cropping[b] Groundnut	Sequential cropping[b] Safflower	Mean gross value All systems	Mean gross value Increase for beds
		(%)		(kg/ha)						(Rs/ha)	(Rs/ha)
RW1 D, 2B	Beds	0.6	1976	1 040	900	2 830	350	1 240	210	3 200	
RW1 D, 2B	Beds	0.6	1977	1 730	350	3 160	360	–	–	3 130	
Mean of 2 years										3 170	210 or 7%
RW1 C/E	Flat	–	1976	980	650	3 010	80	1 080	190	2 780	
RW1 C/E	Flat	–	1977	1 810	290	3 020	440	-	–	3 140	
Mean of 2 years										2 960	–

[a] In 1976 Setaria was used instead of pearl millet; in 1977 pigeonpea seedlings were destroyed by cutworms and safflower was sown as a sequential crop.
[b] In 1976 sorghum was ratooned and no safflower was planted. In 1977 groundnuts were not sown due to disease problems with present varieties.

In 1977 sorghum was planted partly in the blocks following groundnuts and partly in the blocks following sorghum and/or pigeonpea Setaria intercrop in 1976. The average sorghum grain yield following groundnuts was 3 840 kg/ha, compared to only 2 340 kg/ha following sorghum or the intercrop system.

broadbed-and-furrow system of cultivation under several agroclimatic conditions and to quantify production effects of presently accepted soil- and water-conservation practices. The locations where these projects are being initiated are Akola, Bangalore, Bellary, Hyderabad, ICRISAT Center, Indore,Ranchi,and Sholapur.

Hydrologic Studies to Improve Land and Water Utilization in Small Agricultural Watersheds

The objective of this project is to derive region-specific design criteria for improved resource management which will more effectively conserve and utilize the rainfall and the soil and which, when integrated with new cropping systems, will increase productivity and assure dependable harvest. This project has been started at Bangalore. Hyderabad, and ICRISAT Center.

A preliminary on-farm research program was planned in the premonsoon period in cooperation with three agricultural universities and AICRPDA personnel. Plans were developed for initiating field-scale research in three villages where the Economics Program lias been collecting baseline data for the last three years. These villages include Aurepalle. Mahboobnagar district, in shallow Alfisols; Kanzara, Akola district, in medium deep Vertisols; and Shirapur, Sholapur district, in deep Vertisols. In the first year, it is planned to introduce the broadbed-and-furrow system and the use of improved animal-drawn implements on several cropping systems.

Looking Ahead in Farming Systems Research

The Farming Systems Research Program will continue to be involved in problem-oriented research that will provide more basic understanding of the processes involved in all components of farming systems research and develop models for various components to be integrated in a holistic manner. This will be aimed at further improving the potentialities for optimum utilization of the SAT resources.

More emphasis will be placed upon establishment of cooperative research at bench-mark locations, including the low rainfall belt of the Ustipsamments (sandy soils) and moderate rainfall regions of Alfisols and Oxisols in West Africa. On-farm research will be expanded, involving physical, biological and socioeconomic studies of integrated crop-livestock farming systems, with the national programs furnishing the expertise for the livestock components. Establishment of a network of cooperative on-farm research and development projects will provide considerable feedback to operational-scale research methodology at the ICRISAT Center and at bench-mark locations.

Agroclimatology

The studies on rainfall probabilities will continue over the next 2 years so that we can characterize the climatic environment of the different areas with which we are concerned. Studies on water balance in collaboration with the Environmental Physics and the Land and Water Management subprograms will continue up to 1980. The objectives for the next 5 years include the following: i) to develop an understanding of rainfall variability across diverse locations for quantifying associated risks in crop production; ii) to characterize crop response to prevailing moisture environment, and to assist in crop planning for increased and stabilized agricultural production; iii) to develop a climate-driven crop-production model based upon crop-weather interaction studies, and to predict crop performance under different locations; and iv) to develop agronomically relevant classification of the climate for identifying isoclimes for assisting in the transfer of technology.

Environmental Physics

We will continueto participate in interdisciplinary field research with emphasis on quantitative studies of the relevant physical properties and processes of the soil-plant-atmosphere continuum. Experience gained during the past two years indicates that questions of when, where, and how much water occurs in the root zone can be quantitatively studied in the field with sufficient precision to be used in evaluating alternative systems of soil and crop management. Therefore, we plan to extend such studies to other research centers in India during the coming year.

In cooperation with the physiologists, engineers, and agroclimatologists, we plan to initiate a new project on the physical and physiological processes which dominate the physical environment in the seed zone during the critically important stand-establishment period.

We plan to integrate more fully our work on evaporation, profile-water dynamics and drainage with that in soil and water engineering and hydrology. The integration will include the water-balance model being used for agroclimatic classification and for analyzing the consequences of alternative systems of management on crop production under various soil and climatic conditions.

Soil Fertility and Chemistry

Studies on soil nitrogen will be expanded. Emphasis will be given to measuring the rates of accumulation and depletion of soil nitrogen under different management systems, and the effects of each companion species in an intercrop on the nitrogen economy of the system. Particular attention will be given to experimental design, as studies of seasonal changes of nitrogen were hampered by high spatial variability. The long-term experiments on phosphorus and potassium nutrition of plants will be continued.

Farm Power and Equipment

Improved animal-drawn implements will continue to play an important role in the total farming systems concepts that are to be investigated on on-farm situations. An important facet will be the farmers' acceptability of this machinery.

Machinery management will continue to emphasize the measurement of factors affecting the efficiency of farm machinery on both the bed-and-furrow and flat-cultivation systems. Linear programming will be initiated as a means of simulating the capability of machinery under various cropping systems and climatic regimes. Tillage will receive more emphasis and will involve measurement of power requirements of different tillage methods and their effects on plant establishment, weed control, and crop yield. The problem of crusting in the Alfisols will continue to be investigated.

Small threshers will be evaluated on a variety of crops and crop-moisture conditions. Considerable effort will be extended to developing a close relationship with manufacturers and assisting those who are interested in taking up the manufacture of machinery which has been under evaluation at ICRISAT during these past years.

Land and Water Management

During the past five years, it has been repeatedly observed in Alfisols that substantial runoff lakes place early in the growing season when the profile is not yet recharged. If drought occurs after planting, a hard surface crust develops, seriously impeding seedling emergence and resulting in poor stands. Means will be explored to infiltrate larger rainfall quantities into the soil, to reduce direct evaporation, and to deal with crust formation.

During stand establishment, large evaporation losses occur in dry weather. On deep Vertisols in particular, if dry planting is practiced, such losses affect the total moisture available to the seedling and ultimately the crop survival chances. Methods to reduce this risk will be investigated. Large water losses through percolation beyond the root profile take place in shallow Vertisols and Alfisols. Thus, techniques should be investigated which permit a a better use of available profile-storage through more efficient extraction and which facilitate collection of a larger portion of excess rainfall for subsequent supplemental use.

Cropping Systems

The first physiological study on sorghum/ pigeonpea intercropping clearly showed the need to develop a more efficient pigeonpea canopy during the period after sorghum harvest. The preliminary physiological study on pearl millet/groundnut gave no such obvious pointers, but the agronomic evidence of quite large advantages with this combination suggests the need for development of more detailed studies.

The agronomic intercropping studies suggest that considerable effort will be required in the future on plant population and spatial arrangement, perhaps with greater emphasis on systematic designs. The genotype work also needs to be expanded, hopefully with more preliminary screening in the breeding programs as is being done with pigeonpea. The initial evidence that yield advantages may be modified by the degree of moisture stress indicates that this area should receive some priority in future.

The striking phytotoxic effect of a rainy season sorghum crop on subsequent postrainy season crops needs to be reexamined, and the ratoon yields of sorghum should be further assessed in future seasons.

Cropping Entomology

Entomological work on intercropping will intensify with fewer treatments, increased plot size, and more replications. Sole-crop sorghum plots will be added to monitor differences in pest numbers and to make comparisons with off-station situations. With the establishment of cooperative programs, including those in India, the pest-parasite situations on cereal and legume mixed cropping in the different SAT regions will be compared. We plan to establish a light-trap grid at cooperative centers within India.

Surveys of parasitoids of *Heliothis armigera* (Hubner) will be extended to other areas of the SAT. Factors governing crop preference in egg and larval parasitoids of *H. armigera* will be studied. Collaboration with COPR, CIBC, and BTI on expanding work on biocontrol in mixed farming is being discussed. Training opportunities for young entomologists from developing SAT regions will be increased.

Agronomy and Weed Science

At the ICRISAT Center, the main emphasis will be to evaluate the individual components of the "integrated weed-control system" in an effort to develop effective measures of weed management. There will be more emphasis on developing principles of agronomic manipulation of the crop-weed balance in favor of crops. In collaboration with engineers, studies will also be initiated to determine the relative merits of contrasting implements in relation to weed spectrum, weed size, soil type, soil moisture, etc. To obtain backup information for direct weed control studies, it is planned to expand the ecophysiological studies. In the watersheds, the improved weed management methods will be evaluated, along with improved soil- and water-management and cropping systems, on an operational scale.

In the context of holistic multidisciplinary farming systems research, future weed research will place more stress on determining the interaction of different management factors such as land preparation, fertilizer application, cropping systems, etc., with different weed control methods in respect of increased crop production.

A minimal forage crop program will be initiated to evaluate forage grasses and legumes as to their yield of palatable forages, their capability to control soil erosion, and the rapidity of regrowth at the onset of the rains. The objective of this program is to identify forage grass and legume combinations which will be suitable for use in waterways and tank bunds in order to make them productive as well as to provide soil-erosion control.

Operational-scale agronomic and weed science research will be conducted to adapt new developments from small plots to field-scale systems research. After these developments have been tested on an operational scale at the ICRISAT Center, they will be further tested at bench-mark locations and in villages in cooperation with national research programs.

Watershed-based Resource Utilization

Process-based simulation techniques can

quantify and predict the hydrology of different environments. A recently initiated modelling effect effort by scientists in the USA on hydrology, erosion, and sedimentation is expected to result in useful models. Informal discussions with some scientists have indicated scope for information exchange and cooperation. Attempts will be made to calibrate and test such models on the basis of semi-arid tropical data.

A greater effort needs to be made to develop viable operational systems for use of supplemental water in rainfed agriculture. Although this is expected to greatly increase levels and stability of production, many questions remain to be answered. Research to identify and test lower-cost water lifting, conveyance and application systems, improved seepage control methods, more productive and responsive cropping systems and more reliable decision criteria for water application will be intensified.

Crop production and economic data in the operational research program will continue to be collected in the research watersheds in both Vertisols and Alfisols. These operational research units are the testing ground for bullock-drawn implements and other such innovations. With the introduction of improved implements, the cost of cultural operations in the improved management units will continue to decrease.

Cooperative Programs

In the future, greater emphasis will be given to work outside of ICRISAT in cooperative programs, village studies and associated training programs. The two cooperative projects with AICRPDA will be strengthened with improved implements and instrumentation, particularly in the hydrologic studies in small agricultural watersheds.

Phase II of Village-level Studies initiated during the past year will be continued in the three villages in cooperation with universities, AICRPDA, and the village farmers. This project involves physical, biological, and socio-economic facets of research and provides an opportunity for the national and regional research programs to test ideas developed on research stations and under on-farm conditions in cooperation with ICRISAT. These on-farm research efforts, which involve the active participation of farmers in planning and implementation of improved farming systems, are essential to determine constraints and to adapt improved practices to on-farm conditions in the three agroclimatic regions represented in the villages. Recent requests for such information from national action programs further emphasizes the importance of this research.

Economics

The human side of agricultural development also needs to be studied if technologies recommended are to have an impact. ICRISAT has paid due attention to this aspect, especially as it concerns the five crops under its mandate and the farming systems that prevail in the SAT, through studies on production and marketing economics.

The major objective of ICRISAT's Economics program is listed as follows:

To identify socioeconomic and other constraints to agricultural development in the semi-arid tropics and to evaluate alternative means of alleviating them through technological and institutional changes.

Within this broad framework, several studies have been undertaken on traditional cultivation practices, sources of irrigation and traction, effects of risk and uncertainty on farmers' behavior, human nutritional status, group action for improved management, consumer preferences, population, and such other trends as may have a bearing on agricultural development, with special reference to ICRISAT's mandated crops. Areas of study are defined in consultation with scientists from ICRISAT's other programs and frequently involve joint participation.

These studies aim at answering questions and helping evolve guidelines for policy makers, administrators, and scientists, through providing information of relevance in research-resource-allocation decisions. They are also used as focii for evaluation of prospective technologies.

Village-level studies have provided some indication of the types of technologies appropriate for the small farmer of the Indian SAT. These studies have also provided useful data which is being carefully analyzed for economic and sociocultural factors that may influence adoption of new practices.

ECONOMICS PROGRAM

Economics Program

The studies completed by the Economics program during the 1977-1978 year, which were all aimed at furthering the third of ICRISAT's four major listed objectives, are discussed below under nine subject categories.

MEASURING THE EXTENT AND DISTRIBUTION OF RISK AVERSION

Among a group of studies concerned with the nature and significance of risk in SAT agriculture, progress was made in measuring pure attitudes towards risk and their distribution in a representative sample of the Indian SAT population of farmers and landless laborers. An experimental technique with practically no theoretical restrictions was used; individuals choose among alternatives where increasing expected (or average) returns can be purchased only by increasing the risk or dispersion of possible outcomes. In contrast to most work in experimental psychology and in economics, the experiment used *large real payoffs to induce participants to reveal their risk preferences.* The highest expected payoffs for a *single decision* in the experiment exceeded monthly incomes of unskilled workers in India. Furthermore, the participants consisted of the random sample of the rural population of the village-level studies of ICRISAT, which contains a large variation in wealth, education, and other personal characteristics.[1]

The experiment—carried out with 330 individuals in Maharashtra and Andhra Pradesh — consisted of a sequence of games of the following nature: People were offered a set of eight alternative choices in which a higher expected return could only be "purchased" for a larger standard deviation. The alternatives A to F are described in the upper panel of Table 105. Each consists of a "good luck" and a "bad luck" outcome with a probability of 0.5, which is decided on the toss of a coin. Alternative zero is a certain outcome in which the individual is simply paid Rs 50 regardless of the toss, whereas alternative F pays nothing or Rs 200 with equal probability. Each alternative is given a name, classifying the extent of risk aversion of the person who chooses it. These names are arbitrary, and more precise measurements of risk aversion are given in Panels 3 and 4 of Table 105.

The game was played and payments actually made seven or eight times over a period of 6 weeks or more, with intervals of from 1 day to 2 weeks between games for reflection. In the first five games, all amounts shown in Panel 1 of Table 105 were divided by 100—i.e. the alternative F paid Rs 2 on good luck while alternative zero paid Rs 0.5 with certainty. This game level is therefore called the 0.5-rupee game level. At least 2 weeks later, two games at the 5-rupee level followed (all amounts in the table divided by 10). After 2 more weeks, a subsample of 118 household heads played the 50-rupee game of Table 105 and only the results for this subsample are shown for this stake in Panel 2.

The results show that when payoffs are small (Rs 0.5) we find nearly 50 percent of individuals in the intermediate and moderate risk-aversion categories (B and C). More than a third of the individuals show a nearly neutral or risk-preferring behavior pattern (E and F), and fewer than 10 percent are extremely or severely risk averse (0 and A). When the stakes rise, the proportion of individuals in the intermediate and moderate categories rises till it reaches 80 percent of the individuals in these two classes. Near-neutral and risk-preferring behavior virtually disappears; only one of the 118 in-

[1] For a more detailed description of the experimental methods and results, see Binswanger (1978b). The sample conies from the states of Andhra Pradesh and Maharashtra; it is a random sample of the rural population with agriculture or agricultural labor as its primary or secondary occupation. The mean physical wealth of the sample was Rs 22 370, with a coefficient of variation (C. V.) of 137 percent. Mean years of schooling was 2.6 years with a C. V. of 130 percent. Mean age of sample was 42 years with C. V. of 30 percent.

Table 105. Effects of payoff size on distribution of risk aversion and on the partial, absolute, and relative risk-aversion coefficients.[a]

	Extreme O	Severe A	Inter-mediate B	Moderate C	Slight to neutral E	Neutral to preferred F	Inefficient D_1	Inefficient D_2	No. of[b] observa-tions
			1. Alternatives at the 5-rupee level						
Bad luck (50%)	50	45	40	30	10	0	35	20	
Good luck (50%)	50	95	120	150	190	200	125	160	
			2. Frequencies of choices at different levels (%)						
Stake level:									
0.5-rupee(No.2)	1.7	5.9	28.5	20.2	15.1	18.5	10.1		119[b]
5-rupee (No.7)	0.9	8.5	25.6	36.8	12.0	8.5	7.7		117
50-rupee(No. 12)	2.5	5.1	34.8	39.8	6.8	1.7	9.3		118
500-rupee (No. 16)'	2.5	13.6	51.7	28.8	0	0.9	2.5		118
			3. Tradeoff between profit *(n)* and deviation (SE) $Z = \Delta\pi/\Delta SE^a$						
	.90	.735	.585	.415	.165	$\leqq 0$			
			4. Partial risk aversion S"						
All levels	$\leqq 7.5$	3.615	1.189	.506	.168	$\leqq 0$			

[a]Risk aversion measures can be computed only for indifference points between any two efficient alternatives. Therefore, one can only assign an interval to each of the alternatives 0 to F. To compute a unique value for each alternative. one can take the mean of measures at the endpoints of each interval. In the case of Z, the interval length did not vary greatly and the arithmetic mean was used. For S, the interval length increases sharply from alternative 0 to F and therefore the geometric mean was used (with the exception of alternative E, which has a zero endpoint and where the arithmetic mean was used).

[b]Due to temporary absences of some individuals from the villages selected for the 50-rupee game, the number of observations varies slightly and was always less than the full number of 120 selected in the panel.

[c]Hypothetical game.

dividuals chose F. On the other hand, the fraction of extreme and severely risk-averse choices stays below 10 percent up to the 50-rupee level and rises to 16 percent at the 500-rupee level (a hypothetical question). The extremely risk-averse fraction never exceeded 2.5 percent. At higher stake levels, the risk-aversion distribution is thus single peaked, with most of its weight in the intermediate and moderate risk-aversion classes.

The main conclusion from this experiment is that in the three Indian SAT areas studied, virtually all farmers have intermediate or moderate degrees of risk aversion once the payoffs of a game approximate the cost of small-sized to medium-sized agricultural investments. We observed almost no farmers in the risk-neutral or severely risk-averse classes of behavior; i.e., attitudes are strikingly similar, despite the fact that the individuals involved have widely different income and wealth levels. In particular, at the higher-payoff levels, we were unable to establish significant statistical relationships between risk aversion and the personal characteristics of wealth, farm size, sex, age, and tenancy status. On the other hand, the following variables are generally associated with very modest decreases in risk aversion: scliooling, salaried employment, receipt of transfer income, and the number of winning draws in the sequence of experiments.

These results are in many ways surprising. Earlier work in Brazil by Dillon and Scandizzo (1978), based on interviews rather than monetary experiments, had indicated a much wider spread of risk aversion; in particular, they found fairly high proportions of extreme risk-averters and risk-preferrers. Second, economists are very surprised at the weak relationship between risk aversion, as measured in the experiments, and measures of wealth such as asset holding and farm size. The implications of these results for agricultural research and economic policy in the semi-arid tropics have been explored by Binswanger (1978b).

THE ECONOMICS OF TRACTORS IN SOUTHERN ASIA

During the past year, Binswanger (1978a) completed a review of about 30 survey-based and other empirical studies of the effects of tractors in Southern Asia, and tabulated the findings of these studies in a way which enables comparison of various effects of tractors within each of the studies and across studies. The conclusions emerging from this review are surprisingly clear and uniform for almost all the agroeconomic zones of Southern Asia.[2]

The studies fail to provide evidence that tractors are responsible for substantial increases in (i) cropping intensity, (ii) crop yields, (iii) timeliness, and (iv) gross returns per ha. At best, such benefits may exist, but are so small that they cannot be detected and statistically supported, even with very massive survey research efforts. This is in marked contrast to new varieties or irrigation, where statistically significant yield effects are regularly documented, even from fairly modest survey efforts. Indeed, the consistent picture emerging from the review of tractor surveys largely supports the view that tractors are substitutes for labor and bullock power, which implies that, at existing and projected human and animal hiring rates, tractors fail to be a strong engine of economic growth. They would gain such a role only under rapidly rising prices of those factors of production which they have the potential to replace.

In view of this finding, many of the benefit-cost studies reported may have overestimated the benefits, both social and private, which arise from the agricultural uses of tractors. Except in situations where area expansion is possible—or by renting or buying land from others— *private* returns to tractors from *agricultural operations* must be close to zero, or even negative at current fuel prices.

The other main conclusion from the surveys relates to the labor-saving nature of the tractor investments. That tractor farms generally do not show much less labor-use per hectare than than do bullock farms does not imply that tractors are not labor-displacing. What counts is, first, that the frequently higher levels of output on tractor farms (not due to tractors *per se* but due to better capitalization and use of other inputs) are generally produced by equal amounts or even less labor. Hence labor employment per unit output is less than it would be without tractors. Second, even if tractor investments left actual employment unaffected, we must count the foregone employment from not investing the additional capital required for tractors in other employment-creating projects such as irrigation, or even in nonagricultural investments, as an employment cost of tractors.

Finally, it must be stressed that tractorization of agriculture in the subcontinent has not proceeded far. It has been confined to the higher wage areas, such as Punjab, or to the more prosperous coastal areas of Tamil Nadu and Andhra Pradesh. Tractorization has further been largely confined to operations such as

[2] A few exceptions may exist, such as the arid zones of Rajasthan.

tillage and transport of all kinds, in which either power or running speed give it a substantial comparative advantage. In particular, it has not yet been used for a host of highly labor-intensive operations, such as transplanting or (in conjunction with herbicides) weed control. Nevertheless the potential for such uses is there, as are other potential labor-saving innovations such as combine harvesters, threshers, or herbicides. Many of these innovations may be unprofitable or only marginally profitable at present, but may obtain a cost advantage after fairly modest increases in labor cost. They do not seem to be constrained by lack of engineering designs or by other supply bottlenecks. Therefore, public and research policies aimed at relieving supply bottlenecks appear not only inappropriate because these technologies displace labor, but also because the private sector seems to be entirely capable of removing the bottlenecks within short periods of time once the technologies become profitable.

A PREFERENCE INDEX OF FOOD GRAINS TO FACILITATE SCREENING FOR CONSUMER PREFERENCE

In an attempt to examine what constitutes good quality of food grains, the relationships

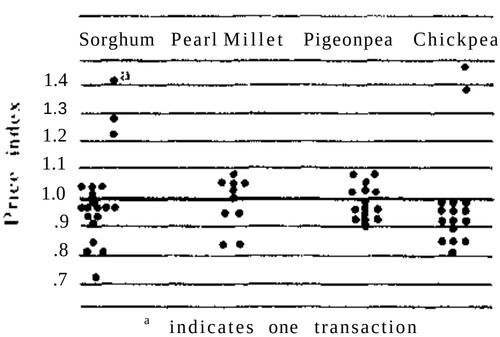


Figure 106. Variation of prices of individual lots of food grains transacted on a selected market day (index of 1.0 indicates average price).

between market prices and quality characteristics were studied in India. On any market day in a major wholesale market, prices of the ICRISAT food grains vary around the average. This variation is generally wider for sorghum than it is for millets (Fig 106). Since we know that average market prices in India are being formed on a competitive basis in a relatively efficient way, it is reasonable to assume that price variation within a market day would also reflect variations in consumer preferences (von Oppen, 1976). Investigations to identify the relevant characteristics of four of ICRISAT's food grains are under way. For sorghum and pearl millet, so far, these have revealed the following:

> Cryptic as well as evident quality characteristics are of significance in explaining market-price variation (Table 106);
>
> In sorghum as well as in pearl millet, preliminary results suggest that swelling capacity,[3] dry volume,[4] and protein content[5] are reflected in market prices.

The two sets of coefficients for all comparable characteristics between sorghum and millet—i.e., molds and the cryptic qualities-have the same signs. A statistical test on an estimation model, which includes only these comparable variables, shows no significant difference in consumers' assessment of these qualities in either sorghum or millet. The sorghum samples for this analysis were collected in Hyderabad in 1977 and the millet samples in Jodhpur in 1978; thus—as far as they are representative — these samples suggest that consumer preferences for cryptic quality characters are probably of more than merely regional significance. Unlike evident qualities, preferences for which

[3]Weight increase over volume increase after soaking. This variable measures the capacity for water uptake without swelling and should probably more appropriately be called swelling "incapacity," or resistance to swelling.
[4]Volume of 10 g dry seed, measured by the water-displacement method.
[5]Determined by Technicon auto analyzer.

seemed to vary considerably from one region to another, cryptic qualities may face universal preference patterns across similar crops and regions.[6]

These estimated coefficients suggest that, *ceteris paribus,* an increase in the protein content of sorghum to 10 percent from the average 8.25 percent would result in an increase in the market price of 4 percent above the average. An increase in 100-seed weight to 3.75 g from an average of 2.75 g would increase the market price by 10 percent above the average price. For swelling capacity, an increase from an average of 1.10 to 1.25 would reduce market price by 2 percent below the average.

The interdependence which seems to exist between these characteristics requires the simultaneous consideration of all relevant characteristics when screening and breeding for varieties with high consumer acceptance. The estimation equations (Table 106) are designed to form the basis for such a simultaneous quality assessment. They allow derivation of an *index of consumer preferences,* computed on the basis of the degree to which a number of measurable and relevant qualities are available in a particular variety or line, each of these qualities being weighted by the coefficients derived above.

Table 106. Market price[a] as a function of quality characteristics.

Quality characteristics		Sorghum[c]	Pearl millet[d]
Evident :	Color mix		
	-white[b]	nil	dna[1]
	yellow[b]	0.05**[c]	dna
	red[b]	-0.1	dna
	white[b]	dna	- 0.05*
	-grey[b]	dna	ni
	Glumes[b]	-0.22***	- 0.02
	100-seed weight[a]	0.3***	0.05*
	Moldiness		
	light[b]	-0.09***	- 0.06***
	-severe[b]	- 0.24***	-0.12***
Cryptic :	Dry volume[a]	0.52*	0.43*
	Swelling[a]	-0.18**	-0.12
	Protein content[a]	0.22***	0.16***
	R^{-2}	0.77	0.83
	Observations	65	25

[a]Variable was defined as the natural logarithm of the ratio of the observed value of a particular grain sample over the average value for all samples on the market day.

[b]Variable was defined as the difference between the observed percentage of seeds with this quality in a particular grain sample and the average of all percentages of seeds of this quality for all samples on the market day.

[c]Samples collected in Hyderabad market over 4 days in 1977.

[d]Samples collected in Jodhpur market over 2 days in 1978.

[e]*** Significant at 0.01

** Significant at 0.05

* Significant at 0.2

[f]dna = variable does not apply; ni = variable was not included.

EFFECTS OF CONSUMERS' QUALITY PREFERENCES ON PRICES OF FOOD GRAINS AT DIFFERENT PRODUCTIVITY LEVELS

As an extension to the research reported in the previous section, a simple theoretical framework has been developed by von Oppen (1978b) to show how food-grain demand is determined, and how shifts in relative supplies of different qualities of food grains affect their prices. The traditional theory of consumers' demand for good and inferior qualities of food grains as a function of prices has been applied (Fig 107). With the help of this theory, it is possible to trace the effects of increased supplies of a high-quality food grain on prices and consumers' and producers' welfare.

During acute scarcities as well as during relatively abundant supply periods, the absolute price differences between good and inferior quality grains would tend to be lower than in "normal" situations. Relative prices of good

[a]In a study on wheat quality, Bhatia (1973) reported that protein content has a significantly positive relationship with market prices paid by private traders in two markets in Delhi.

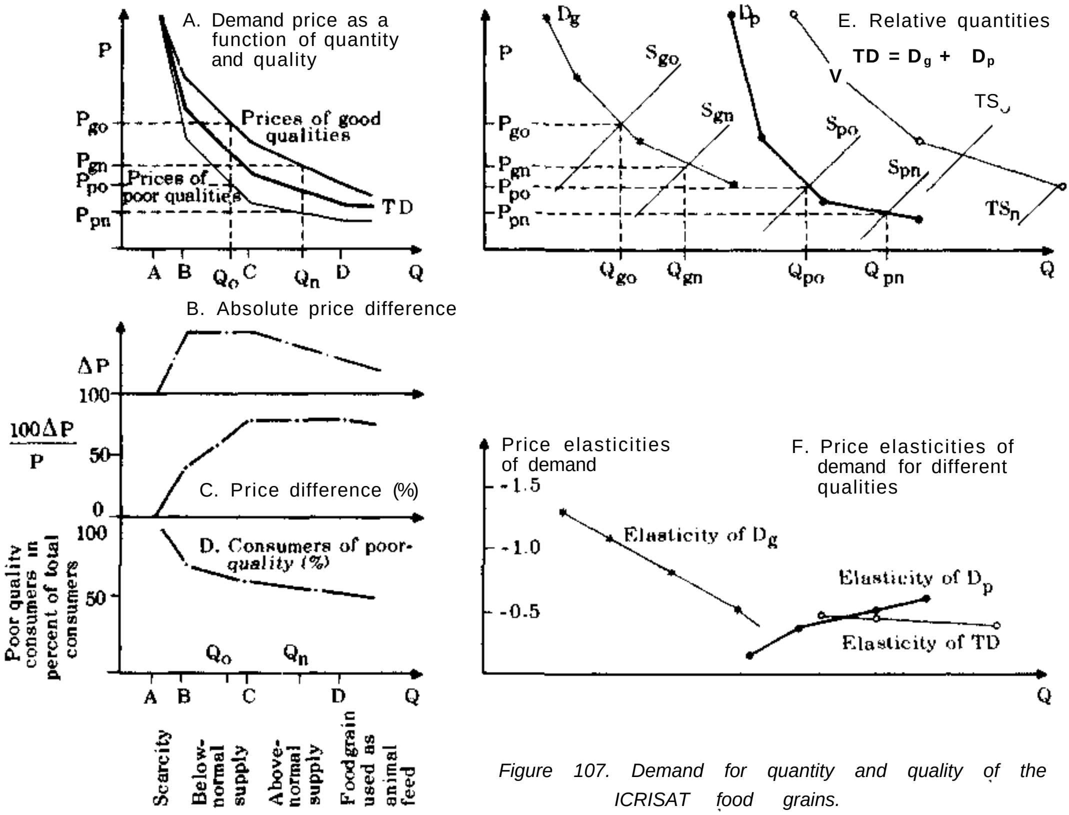


Figure 107. Demand for quantity and quality of the ICRISAT food grains.

and inferior qualities remain constant at times of above-normal supplies (Fig 107).

The effect of plant breeding for larger quantities of better-quality grain can be shown within Figure 107. If a successful plant-breeding effort leads to a substantial increase in the supply of good quality from S_{g0} to S_{gn} and a comparatively small increase in the supply of poor qualities from S_{po} to S_{pn}, then the price difference would fall from (P_{go} -P_{po}) to (P_{gn}-P_{po}). The degree to which this price differential between qualities is reduced would be an indicator of the success of the breeding program. Up to the point where price differentials between qualities disappear, this development would imply gains to all consumers who will increasingly shift to the consumption of "good quality"-i.e., more people can afford to buy good quality at lower prices.

AGRICULTURE AND RESEARCH IN THE SAT

Ryan (1978) analyzed the relative importance of ICRISAT's five mandate crops across the seven major regions of the SAT and the degree of congruence between research expenditures of ICRISAT plus national programs and the relative regional crop-production shares.

Currently around one-fifth of all the protein, energy, and lysine produced from crops in the SAT is derived from the five ICRISAT crops. Oil from groundnut supplies almost half of the edible vegetable oil energy produced in the SAT. These percentages have been declining over time, reflecting the low productivity growth rates of the five crops.

Presently, sorghum and millets account for about 16 percent of the world's cereal area, but only about 7 percent of its production. Chickpea, pigeonpea, and groundnuts represent some 24 percent of the world food-legume area and 20 percent of its production. Hence the yield disadvantage of ICRISATs mandate crops vis-a-vis their counterparts seems great in the case of the cereals when compared with the legumes.

In 1977, ICRISAT spent $560 on crop-improvement research for every million dollars of SAT production value of its five crops, or a total of $5.7 million (Table 107). The expenditure was highest for pulses, followed by cereals and groundnuts. When estimated national-program research expenditures in the SAT are added, overall research expenditure reaches almost $1 200 per million dollars. Total SAT crop-research expenditures on the cereals and pulses are about the same at $1 400 per million dollars of their respective crop-production values. Groundnut lags far behind, with only half of the research investment per unit output of that of the cereals and pulses.

In terms of total SAT crop-research expenditure per unit area, groundnut fares much better with $150 being spent per thousand hectares, compared to $190 for pulses and $110 for cereals (Table 108).

Congruence analysis of ICRISAT's crop-improvement research budgets showed that groundnuts received less of the research budget than the relative value of groundnuts in total SAT crop production would justify (Fig 108). The pulses seem to receive more of the research budget than their relative importance would suggest, whereas the cereals seem almost congruent.

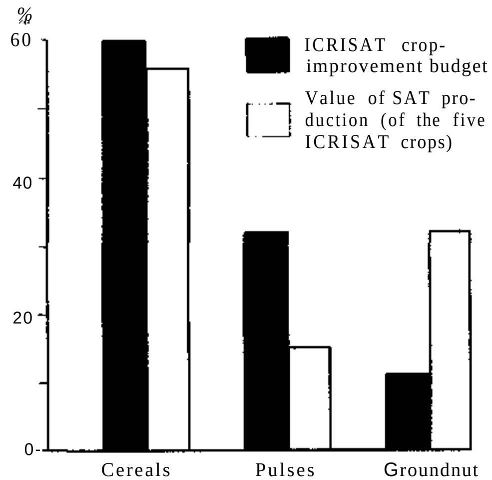


Figure 108. Congruence of ICRISATs 1977 crop-improvement research expenditures and value of the crop produced in the SAT.

Table 107. 1977 crop-research expenditures per million dollars of production in the SAT (United States dollars).

	Sorghum and millets	C'pea and P'pea	G'nut	Total
ICRISAT only	600	1 140	190	560
ICRISAT plus national programs[a]	1 360	1 420	730	1 180

[a]Estimated.

Table 108. 1977 crop-research expenditures per thousand hectares sown in the SAT (United States dollars).

	Sorghum and millets	C'pea and P'pea	G'nut	Total
ICRISAT only	40	150	40	60
ICRISAT plus national programs[a]	110	190	150	130

[a] Estimated.

Taking each crop separately, it seems that the regional allocation of ICRISAT's cereal-improvement budget fits fairly well the relative regional importance of these across the SAT. For the pulses, additional research investment is suggested for the SAT regions of North, Central, and South America, and East Africa, relative to India. For groundnuts, additional research was indicated for the East and West African SAT regions, with reduced growth in India.

A review of authoritative projections of future demand and supply of the ICRISAT crops suggests that in the African and Indian SAT regions, there is an imperative need for substantial research efforts in pulses and oilseeds in order to alleviate the large projected deficits of the future. In Africa, there is also an urgent need for cereals research for the same reason. The urgency for cereals research in India and South America is not as great as it is in Africa.

The relative geographical area and population of the various SAT regions were used as the criteria for evaluation of the regional allocation of ICRISAT's farming systems and economics research budgets. Much greater emphasis on research in West, East, and southern Africa is suggested for both these programs, along with North, Central, and South America.

Analysis of projected changes in regional allocations of ICRISAT's research resources suggests that some of the incongruences revealed by the above analysis of the 1977 situation will be rectified in the future. However, more needs to be done to xedress the remaining imbalances.

EFFECTS OF TECHNOLOGY AND POLICY IN ARID AND SEMI-ARID TROPICAL AREAS OF INDIA

Weather-induced instability of agriculture is a major problem of arid and semi-arid tropical areas. This has conditioned the evolution of fanning systems in these areas, as well as the nature and type of external intervention. For instance, the reliance on mixed farming and mixed cropping as a means of agricultural diversification (to alleviate risk) can be directly attributed to the relative instability of agriculture in these areas. Similarly, the degree of instability has also determined the extent and type of external response to the problems of these areas, including measures like public relief during periodic distress, provision of protective irrigation, etc.

The extent of agricultural diversification in response to amount and variability of rainfall is reflected by farm-level data from extremely arid and semi-arid tropical areas in India, taken from Jodha (1978a). Data in Table 109 reflect the declining role of livestock (both in terms of asset position and household income) in mixed farming systems as rainfall (and therefore intensity of crop farming indicated by proportion of geographical areas devoted to cropping) increases. Furthermore, the extent of mixed cropping in farming as a strategy against risk declines with increased farm size and with increased irrigation. The main implication of these findings is that any research and development in arid and semi-arid tropical areas should be directed towards the improvement of livestock and mixed cropping systems, which have evolved over time in keeping with the limitations and potentials of the natural resource endowments in these areas. Past experience reveals that well-intended intervention measures designed to help these areas have given rise to several adverse effects which have offset to some extent the positive contribution of these interventions.

The first major intervention was the provision of so-called "protective irrigation" in these drought-prone areas (Jodha, 1978a). Protective irrigation—moving water from areas where it was available to drier areas to protect crops during droughts—was conceived as a solution to the instability problem. Such schemes were given a high priority in drought-prone areas of SAT India up to 1930. However, these schemes devolved into intensive irrigation projects because of factors such as:

—inadequacy of outside water resources to meet needs of total drought-prone areas;
—technical designs of canals unsuited for the

timely reticulation of water required for extensive irrigation;

—large differences in payoffs from irrigated upland crops like pearl millet and sorghum when compared with high-value crops like sugarcane and paddy.

The final result was creation of small pockets of prosperity with very intensive irrigation of high-value crops within the drought-prone areas. Furthermore, these "pockets" attracted the bulk of resources like fertilizer and extension services, even those intended for the non-irrigated parts of the regions. Labor also tended to migrate to the irrigated areas, leaving non-irrigated crops uncared for.

The second intervention in semi-arid tropical and arid areas was the introduction of what was described as the "Bombay Dry Farming Technology." This technology resulted from experiments conducted at five locations during the early 1930s. The technological package induced some agronomic practices and soil-conservation measures like contour bunding to protect land resources and increase farm productivity. This technological intervention—despite massive state support in the form of subsidies and grants for the contour-bunding program—did not have the desired impact because it lacked a strong biological component such as high-yielding varieties (HYV). Also, the construction of bunds on the contour were largely rejected by farmers as such bunds disturbed their field boundaries.

Introduction of HYVs of pearl millet and sorghum during the middle of the 1960s offered another opportunity for technological intervention to help the SAT areas. Despite considerable extension effort and subsidies, the HYVs did not spread beyond assured rainfall or irrigated areas in SAT regions of India. Furthermore, the fairly standardized packages of HYV technology which were extended did not fit the highly variable climatic environment of the SAT—which requires a technology with maximum flexibility. The HYVs did not also readily fit into the traditional risk-minimizing crop-diversification strategies of small farmers, which seem to rely on intercropping.

This past experience has offered useful lessons for technology generation in these areas. The arid and semi-arid tropical areas require a technology which—apart from being inexpensive—should be highly flexible to permit adjustment according to interseasonal and intraseasonal vagaries of the weather. Since seed-centered technology does not express its potential without adequate soil moisture, and since moisture-management technology does not pay off unless it too is accompanied by a strong biological component, technology for these areas calls for a blend of seed-centered and (land and water) resource-centered elements in the technological options developed. Furthermore, as resource-centered elements of technology (e.g. moisture conservation, rainfall-runoff collection, etc.) may require implementation on a watershed basis rather than on an individual-farm basis, the potential institutional constraints they face are likely to be strong. This calls for proper recognition of the institutional component in the design of technology for the SAT.

The consequences, in arid areas of India, of public interventions which disregarded the limitations of the natural-resource endowments are more alarming than those in SAT areas. One major intervention consisted of land reforms (1952-1954) in the State of Rajasthan, which comprises about 63 percent of the arid areas of India (Jodha, 1978b). Without underrating the positive contribution of land reforms in achieving equity goals, these policies did lead to the allocation of previously submarginal lands to crop cultivation. Prior to the reforms, these were predominantly grazing lands. The area under crops was 6.6 million hectares in 1951. It increased by 50 percent by 1961 and by a further 13 percent by 1971. One consequence was a decline in average crop yields per hectare. Another was the reduction in grazing land. The latter, in association with increased livestock numbers, led to an increase in the density of livestock (expressed in standard animal units) from 36 per 100 hectares in 1951 to 67 per 100 hectares in 1965.

The reduction in land-revenue rates on crop lands, and the abolition of all taxes on animals

Table 109. Details of enterprise combinations on sample farms in arid and SAT areas of India.

	Annual average rainfall	Irrigation extent[a]	C.V. of rainfall	Sample households	Details of enterprises per household: Land	Livestock (animal units)	Asset value: Land	Asset value: Livestock	Gross farm income: Crops	Gross farm income: Livestock	Extent of mixed cropping in gross cropped area: Small farms	Extent of mixed cropping in gross cropped area: Large farms
	(mm)	(%)	(%)	(no)	(ha)	(no)	(%)	(%)	(%)	(%)	(%)	(%)
Jaisalmer (Rajasthan)	179	–	88	43	32	40	18	82	26	74	–	–
Jodhpur (Rajasthan)	240	1	53	48	23	18	63	37	71	29	–	–
Nagaur (Rajasthan)	310	–	42	50	18	17	61	39	63	37	–	–
Sholapur (Maharashtra)	601	11	29	60	5	3[b]	92	8[b]	89	11	45	27
Mahbubnagar (Andhra Pradesh)	673	22	28	60	2	5	87	13	92	8	35	31
Akola (Maharashtra)	824	4	27	60	4	4	93	7	94	6	88	74

Source: Jodha (1978a).

[a]Extent of gross cropped area irrigated during the reference year.
[b]Due to impact of three consecutive droughts. the figures for Sholapur are very low.
[c]The data on mixed crops in the first three areas are not available in comparable form. However, about 90 percent of their cropped area is sown to mixed crops. Mixtures include pearl millet and various rainy season pulses.

and grazing which accompanied the land reforms, caused a substantial reduction in the private cost of exploiting arid lands (Table 110). This was complemented by improved economic integration of arid areas with the rest of the country which enhanced the marketability and profitability of the products of the arid lands, especially animal products. The reduced private cost and increased profitability of exploitation of land were key elements of the operating mechanism of desertification in arid areas of India.

EFFECTS OF MARKETS AND FOOD POLICIES ON AGGREGATE AGRICULTURAL PRODUCTIVITY IN INDIA

Methodologies are required to assess the impact of agricultural markets on aggregate productivity net of other inputs. The approaches suggested include normative activity analysis as well as positive regression analysis.

For didactic purposes, a normative model was set up which demonstrates the effect of changes in the freedom of interregional exchange on crop allocation and productivity at different levels of technological advance (von Oppen, 1978a). The model showed that if the rate of technological advance differs across regions, the wider become differences in regional comparative advantages, and consequently the more does enhancement of aggregate agricultural productivity depend upon uninhibited interregional exchange.

To verify the above normative approach, generalized least-squares regression analysis, combining cross-sectional and time-series data, was carried out to measure the lagged effect of food zoning on aggregate yields of food grains in 13 states of India (von Oppen, 1978a). The result of this analysis shows that, net of the effects of other agricultural inputs, the establishment of food zones (and trade restrictions) for food grains in India has had a significant causal effect upon productivity: the less were food-zoning restrictions in years t-2 and t-4, the higher were aggregate crop yields in year t. A total relaxation of food zoning from average levels of restriction in t-2 would raise productivity by about 5 percent in year t; an increase which is comparable to the estimates arrived at above with the help of the normative activity-analysis model. Further research on this subject is required, especially to better understand the lags, e.g., the phenomenon of a recurrence of the lagged effect in year t-4 in this data set and the existence of negative productivity effects in years t-1 and t-3.

Generalized least-squares regression was also used to analyze cross-section and time-series data on aggregate productivity, regulated markets, surfaced roads, and other inputs in districts of Andhra Pradesh (von Oppen, 1978a). In this study, a causal effect of density of markets on aggregate productivity of agriculture was established.

The methodologies presented above offer scope for measuring the returns from investments in physical and institutional marketing infrastructures. These returns appear to be of magnitudes which should attract the attention of decision makers in India, and also in many other countries where food supplies are limited.[7] Improvement of agricultural marketing to increase efficiency of interfarm and interregional exchange is an investment alternative with high payoffs in terms of increased agricultural productivity at the national level.

DETERMINANTS OF DENSITY OF SMALL IRRIGATION DAMS AND THEIR PERFORMANCE IN SAT INDIA

In India, small-dam irrigation systems (termed tanks) have been in existence since Vedic times.

[7] According to Narain, given the persistently low level of commercialization of Indian agriculture and the minimal locational shifts in cropping patterns which have occurred during the past decade, it can be expected that the abolition of food zones in 1977-1978—if maintained and especially if enforced by judicious development of other important market facilities-will trigger quite substantial reallocation effects followed by corresponding increases in commercialization from 1979/1980 onwards.

Table 110. **Details indicating private cost (taxes, etc.) of land use during the period before and following land reforms in some villages in the arid region of Rajasthan (all values in 1976-1977 prices)[a].**

Particulars	Situation during	
	Pre-land reforms period (1950-1951)	Post-land reforms period (1964-1965)
Better crop land (Chahi):		
Pearl millet yield (kg/ha)[b]	$\geq$520	520
Times cropped in 5 years (no)[c]	4	5
Land revenue (rent) (Rs/ha)[d]	83	6
Submarginal land (Barani):		
Pearl millet yield (kg/ha)[b]	$\geq$200	200
Times cropped in 5 years (no)[c]	2	3
Land revenue (rent) (Rs/ha)[d]	16	1.5
Pearl millet-av. cost of production (Rs/ha):	na[f]	285
Grazing land (Gohar):		
Grazing tax (Rs/animal)	1.25	0
Other livestock-related levies/penalties (Rs/household)	23	0
Value of contribution to protection/maintenance of pasture/tank, etc. (Rs/household)	18	0
Animal product prices:		
Wool price (Rs/q)	90	480
Ghee (Rs/kg)	5	18
Milk (Rs/liter)	na	0.60

[a]Details relate to a cluster of three villages in Nagaur District collected from village records and interviews during the field work in 1963-1966 for a study of capital formation in arid agriculture, as reported in Jodha (1978b).

[b]Pearl millet yields as recorded on both types of lands during 1964-1965.

[c]Frequency of cropping due to the practice of periodical fallowing of land. This also indicates the number of times when rent (25% of crop produce) was paid during pre-land reforms period.

[d]Land revenue during the pre-land reforms period was charged in the form of 25 percent of the grain yield of the plot whenever it was cropped. The annual rent has been calculated by multiplying the money value (at 1976-1977 prices) of crop share by number of years when land is cropped, and dividing by five. During land reforms, the land revenue at a much lower rate was fixed on permanent basis, as indicated in the table.

[e]Prices as obtained in the villages.

[f]na = not available.

However, many of these irrigation tanks were built only during the past 100 years, and they are mainly concentrated in parts of southern India, and in certain pockets of central and northern India (Fig 109).

In view of the regional variation in density of tank irrigation and the need for making full use of the meager rainfall in SAT India, the following questions arise. Why do we find much more tank irrigation in some districts than in others? Is it possible that some of those areas with less tank irrigation have a potential which has not yet been exploited, perhaps because institutional structures in the past did not encourage or permit collective action?

Distribution of Indian territory between

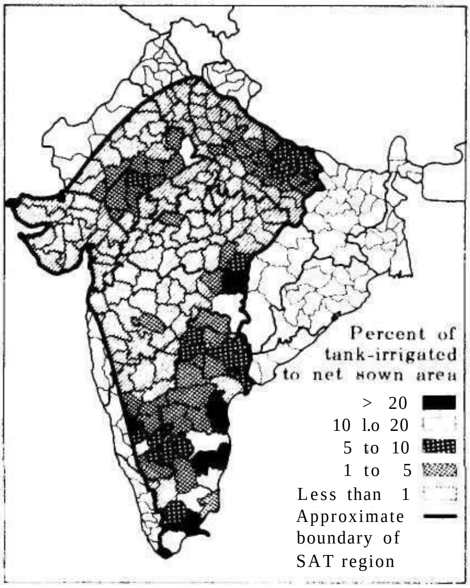


Figure 109. Density of lank irrigation in SAT India.

British and princely rule in 1890 gives rise to the hypothesis that perhaps princely rule was more conducive to the promotion of tank irrigation. On the other hand, if the hypothesis about the impact of princely rule on the creation of tank-irrigation systems is not accepted, then physical factors should be major determinants of tank irrigation. A test of this hypothesis was made to measure the degree to which physical conditions are related to density of tank irrigation, and to test whether the influence of these factors differed significantly between areas under British and under princely rule.

Statistical analysis of district data on tank-irrigation densities in selected former British and princely territories in SAT India by von Oppen and Binswanger (1977) shows that tank irrigation is determined primarily by physical conditions—such as granite substrata and high vapor pressure—rather than by differences in government organization. The data revealed no significant differences between British districts and princely states in the effect of physical factors on tank density.

A further analysis of data on tank-irrigated areas in India indicates that in some parts the area commanded by tank irrigation has become more and more unstable over the past two decades (von Oppen, 1978c). This finding contradicts the general notion that irrigation lends a source of stability to a region. The increasing instability in area of, and production from, tank irrigation in some regions is alarming. It seems to be caused partly by the following factors: (i) increase in the inefficiencies in water-management systems of these regions; (ii) lack of maintenance of bunds, tank beds, canals; (iii) increase in siltation of tank beds due to denudation of the vegetation in catchment areas and a consequent reduction in the water-storage capacity of the tanks; and (iv) secular shift in the (seasonal) distribution of rainfall.

Depending upon which of the reasons we believe to be most important in explaining the phenomenon of increasing instability of tank irrigation, our expectations about future developments may vary. If it was mainly the periodical decrease in rainfall, in and around Hyderabad, which caused variability to increase here and not in Tamil Nadu, then one could perhaps expect a reversal sooner or later. However, it must be envisaged that other factors—especially water control and maintenance—are likely to be at least as important as rainfall. Unless policies are implemented to reverse the trends, it seems that the present trends may continue-possibly even including regions such as the three districts in Tamil Nadu, where until now comparative stability has been observed in tank irrigation. However, firm conclusions in this regard will require more investigation.

HUMAN POPULATION IN RELATION TO AGRICULTURAL DEVELOPMENT

Agricultural development presents problems in human ecology as well as in biological and physical sciences. One of the most urgent of these problems is to understand the forces behind rising human population levels on the one hand and stable populations on the other. There is potential for improving the world food supply in both quantity and quality, yet .there is at least equally great potential for any gains to be eroded by population growth. In an attempt to understand the position of agricultural populations within the total populations of developed and of developing countries, a comparative review of literature on the subject was undertaken, particularly in demography and anthropology as well as in the economics of the family.

The main hypothesis emerging from this study is that neither growth nor stability of human populations depends upon any supposed Malthusian inevitabilities; they are determined by the type of economic system instituted in a given area. In the agricultural sphere, continued high birth rates despite a decrease in death rates in underdeveloped agricultural areas seem to be connected with institutionalized, primary reliance on unskilled and family labor. Subsistence agriculture seems to perpetuate the system. Commercialization under conditions of interregional balance seems to promote change by tying farmers together into a network of interdependence within a healthy diversifying economy. This suggests that countries concerned about population growth must look carefully at the social organization of agricultural labor and the economy in their countries, in order to affect demographic processes.

Looking Ahead in the Economics Program

We plan to extend the Village-level Studies project to northwestern SAT India in 1979. This will enable us to cover adequately the major chickpea-, groundnut-, and pearl millet-growing areas of the subcontinent. Existing VLS work has been confined to the major sorghum- and pigeonpea-growing areas.

In the present study villages, collaborative research with the Farming Systems program in farmers' fields is being intensified. These are diagnostic experiments; the most significant is the evaluation of watershed-based broadbed-and-furrow technology in the village context'. This involves agronomists, hydrologists, agricultural engineers, economists, and social anthropologists from Indian programs and from ICRISAT in an innovative study aimed at assessing the technical, economic, and social viability of this technology, especially as it relates to the necessity and scope for group organization and action required for implementing such technology.

A continuing effort will be made to assemble all relevant statistics on the SAT and on the five crops of particular concern to ICRISAT. These are essential for research, particularly for the projects on demand and supply analysis of the five crops.

In the coming year, we will have a major expansion of our research activities in West and central Africa; two principal staff will be posted there. Most of the methodological approaches developed during our work in India over the past 3 years will be immediately applicable to certain SAT regions of Africa. In particular, we plan to undertake work in village-level studies, risk attitudes, group action, mechanization and improved animal-drawn implements, water harvesting and supplementary irrigation modelling, food-grain market channels, markets and agricultural productivity, and supply and demand of the crops researched at ICRISAT.

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Cooperative Programs

ICRISAT continued to develop programs of assistance and cooperation with SAT countries around the world, focusing on the urgent problem of strengthening the indigenous capability to increase food production. The major objectives are to generate improved genotypes of the ICRISAT crops as well as adaptive technology which will increase and stabilize yields. ICRISAT played a key global role in providing a broad spectrum of useful plant material for testing under the various SAT environments. Reciprocally, germplasm resources were made available to ICRISAT by cooperating national programs, thereby adding valuable genetic diversity to our germplasm collection.

ICRISAT scientists posted to selected sites in SAT countries collaborated closely with national programs in both breeding and agronomy research. Although a high priority is given to assisting the host country program, ICRISAT assumes regional and international responsibilities as well, so that neighboring countries benefit.

West African Cooperative Program

In January 1975, ICRISAT and UNDP entered into a 3-year contract (GLO/74/005) which had as its prime objective cooperation with and strengthening of existing West African agricultural research programs and the development of higher-yielding varieties of sorghum and millet with the characteristics of consistent and reliable yield, as well as the development of improved technology to go with them. The drought-stricken Sahel area below the Sahara was the focus of concern, as this is where sorghum and millet are staple foods of the majority of the people and where the food-population balance remains seriously constrained.

Initially, the project covered 12 countries from Senegal to Chad. Early in 1977, following discussions between the Government of Sudan, UNDP, and ICRISAT, the contract was expanded to include Sudan. The ICRISAT/UNDP West African Cooperative Program now concerns 13 countries-Senegal, Gambia, Mauritania, Mali, Upper Volta, Ghana, Togo, Nigeria, Niger, Benin, Cameroon, Chad, and Sudan.

The strategy for implementing an effective program of assistance which would have an early and measurable impact was outlined. Basically, the concept was to post ICRISAT scientists to existing research institutions at Ba.mbey, Senegal; Samaru, Nigeria; Kamboinse, Upper Volta; Maradi, Niger; and Wad Medani, Sudan. These scientists would be linked to and would work in conjunction with ICRISAT Center at Hyderabad, other ICRISAT cooperating centers internationally, and national programs in the region, as well as the programs of the host countries. Implementation of the program has continued to gain momentum and became fully operational for the 1977 crop year. By May, the 12 research positions foreseen in the ICRISAT/UNDP cooperative program were filled. They include:

i) A project manager, based in Dakar, Senegal. He provides the management and supervision of the overall project, maintains close liaison with all agencies that work on programs of assistance in the region, and, through a French-English translation service, disseminates technical and scientific information in both languages.

ii) Two sorghum breeders; one posted in Kamboinse, Upper Volta, and the other in Wad Medani, Sudan.

iii) Five millet breeders, respectively posted in Bambey, Senegal; Kamboinse, Upper Volta; Samaru, Nigeria; Maradi, Niger; and Wad Medani, Sudan.

iv) Two cereal pathologists, posted in Kamboinse, Upper Volta; and Samaru, Nigeria.

v) One cereal entomologist, posted in Bambey, Senegal,
vi) One agronomist, posted in Kamboinse, Upper Volta.

In addition to the important UNDP contribution, ICRISAT's West African program receives complementing support from other agencies. The Republic of France, through IRAT, contributes to the salary of the project manager. The Government of the Netherlands provides salary for a soil-management agronomist posted in Kamboinse, Upper Volta. Finally, USAID provides full support for an agronomist-selector based in Bamako, Mali.

In 1977, 14 scientists in all were working in ICRISAT's West African Cooperative Program. They were posted in 6 of the 13 countries involved in the Project.

Agreements between ICRISAT and the host countries vary, to some degree, according to the country. As a general rule, however, the program of each ICRISAT scientist posted in a cooperating country can be regarded as including three components:

i) A direct contribution to the national program.
ii) A contribution to the regional program, consisting mainly in the organization and supervision of regional trials and consultancy visits to other countries.
iii) A contribution to the international program by carrying out trials or nurseries that provide ICRISAT Center with information on behavior and performances of different types of vegetative materials in various ecologies, and to provide unique germplasm from cooperating countries for incorporation into breeding programs at ICRISAT Center.

As can be expected, the distinction between these three components is not always clearly defined and may sometimes appear somewhat arbitrary. However, in order to make as clear as possible the relationship ICRISAT scientists can be expected to develop with their colleagues in the national programs, an attempt has been made in each case to establish this tripartite role.

To the extent possible and desirable, ICRISAT scientists are integrated into the local research centers and are expected to follow the general working regulations of these centers. Being closely associated with national research, while keeping some reasonable degree of autonomy, the ICRISAT scientists are fully aware of the research problems in the host countries, of the progress accomplished by national research programs, and of the various constraints with which research and extension must cope. They are in the best position to orientate their programs so as to continually make them more efficient. They also have an important role in providing practical training to local technicians, and in some cases scientists on the staff. Exchange of scientific and technical information between ICRISAT and the national research services is rapid and easy under these conditions. It is a truly cooperative effort, with benefit to both parties.

SORGHUM PROGRAM

Background and Past Research Accomplishments

The existing local cuitivars of sorghum in this region are mostly tall and photosensitive. They generally show some resistance to the main pests and diseases as well as good consumer acceptability. Due to late flowering, they usually escape serious grain mold attacks, but residual soil moisture and nitrogen supply are frequently insufficient to mature the grain properly, and yields are thus seriously limited. Other yield reducers include low harvest index, low population density, and poor cultural practices—including little, if any, mineral fertilization. The combination of these limiting factors results in low yields of 600 to 900 kg/ha in farmers' fields.

ICRISAT's General Objectives and Strategy

ICRISAT has taken a major responsibility for the introduction and development of non- or less photosensitive types, more suitable for

Figure 110. An African SAT farmer proudly displays the sorghum and millet crops from which his food and beer are made.

sowing in drier areas and in shallow soils with low water-holding capacity. These types would have higher yield potential, greater stability, and would be complementary in cropping systems and land use with the late types, providing more flexibility in farmers' cropping calendars.

The sorghum types provided from ICRISAT Center are expected to flower about 2 weeks earlier than the local cultivars and to mature in humid conditions. They must therefore have resistance to grain molds. Other desirable characteristics for stable yield are resistance to diseases (charcoal rot, leaf diseases), pests (head bugs, stem borers), *Striga,* and drought. Shorter plant height and less foliage are also desirable from the standpoint of improved harvest index and increases in the plant population. Stover is an important factor in Africa, so a dwarf-plant type is unacceptable. Plant height of 2 to 2.5 m is desitable.

To be readily adopted by farmers, newer cultivars must show superior performance under low as well as high management conditions. In some cases, new agronomic recommendations for these introduced cultivars will have to be developed, taking into account soil preparation, dates of sowing, and optimum plant populations.

In addition to the major objectives stated above, attention will be given to developing a large-panicle plant type which tillers readily. Such a type is useful where plant populations are low, as in farmers' fields.

In an attempt to utilize the available resources most effectively, the program has been organized on a regional basis. The sorghum breeder in Upper Volta was assigned the major responsibility of screening material introduced from ICRISAT Center, selecting the material which seemed best adapted to African conditions, and distributing it to plant breeders in other cooperating West African countries. He was also assigned the responsibility of organizing annual regional West African trials for advanced material.

The cereal pathologists share a regional responsibility. The pathologist in Upper Volta surveys the western part of the zone (mainly Senegal, Mali, and Upper Volta), while the pathologist based in Nigeria takes care of the eastern part (Nigeria, Niger, Cameroon, Chad, and Sudan). The cereal entomologist in Senegal serves the entire zone, pending appointment of an entomologist in Nigeria. The agronomists will be expected to concentrate their research in the countries in which they are posted, with occasional consultancy visits to other countries.

Progress in Sorghum Improvement

The sorghum-breeding program in Upper Volta started in May 1975, when about 2 500 entries consisting of segregating families and finished lines were introduced. During the 1977 rainy season, many of the varieties which showed promise in the preceding two seasons maintained their superiority over local cultivars using a relatively later planting. The most promising were cv SPV 35,926, A 1567, VS 701 (EC 64734-2), VS 702 (324), VS 703 (2KX-2-E21), 940, SC 103-4-8, and 9289. Hybrid cv CSH-6, although a top yielder, was susceptible to charcoal rot in many locations. The variety CSV-1 performed quite well in the Sahel region for the second consecutive year. Cooking tests to evaluate the grain for use in making "TO" confirmed the results of the preceding year.

A new group of elite lines have been identified from the preliminary yield trial containing F_5 and F_6 material. Some have very high cooking quality for "TO." A comprehensive crossing program, involving elite lines and local cultivars, is expected to provide a range of variability for selection suited to the objectives set in the program.

Among the new introductions during 1977, the Grain Mold x Adapted Segregants material received from ICRISAT Center and the others received from Sudan were impressive. Experimental hybrids from Texas A & M University also did well.

In Mali, very promising lines from ICRISAT material were identified in the 1976 and 1977 seasons. Worthy of special mention is E35-1 which originated in Ethiopia (Zera-Zera type); E35-1 showed a good resistance to grain molds in the two seasons (especially in the 1976 season, which was characterized by late rains). Resistance to shoot fly, grain acceptability, and level of yield were very satisfactory.

Progress in Sorghum Pathology

The activities of the two ICRISAT West African program pathologists (at Samaru, Nigeria and at Kamboinse, Upper Volta) are closely integrated with the core cereal pathology program at ICRISAT Center and with the needs of breeders in country programs in the region.

Their main objectives are to identify effective stable resistance to the important regional diseases and, in conjunction with the breeders, to incorporate this resistance into new high-yielding cultivars.

Pathology activities include:

i) Surveys of the country and regional disease situation.
ii) Collection and initial screening of potentially resistant local landraces and cultivars.
iii) Participation in the disease nursery screening of the International Sorghum and Pearl Millet Disease Resistance Testing programs.
iv) Screening breeding progenies for disease reactions.

The pathologist stationed at Samaru (since Jun 1977) has worked mainly in Nigeria, Niger, and Cameroon, while the pathologist stationed at Kamboinse (since Jul 1976) worked mainly in Upper Volta, Mali, and Senegal.

Grain molds, charcoal rot, certain leaf diseases, and possibly long smut, are the sorghum diseases of greatest importance in West Africa.

Grain molds. The major activity has been the testing of the International Sorghum Grain Mold Nursery (ISGMN) at several sites in both 1976 and 1977. In 1976, under prolonged wet conditions in Upper Volta, the ISGMN entries E35-1, IS 2261, IS 2327, IS 2328, and IS 3443 received the best field ratings. On evaluation of threshed grain, entries IS 2327, IS 2328, IS 9225, IS 956, and IS 5246 were selected as the best. In Mali, E35-1 attracted considerable attention for its low mold development and in Senegal E35-1, IS 2327, and IS 2328 performed well, as did earlier maturing lines such as cv CSH-6, IS 4327, and EKK-1-E20. The 1977 ISGMN results confirmed the superiority of entries IS 2327, IS 2328, E35-1, IS 9225, and IS 7261, although under conditions of severe mold attack no entry was highly resistant or immune.

New generation lines from the core program at ICRISAT Center, which are progenies of crosses among the best mold-resistant ISGMN entries and of crosses between the best ISGMN and elite agronomic entries, performed well in Upper Volta and Mali in 1977 (the SEPON trial) and further advanced generations of these materials will be widely tested for grain mold reactions in West Africa in the ISGMN and SEPON 1978 trials.

Leaf diseases. The main leaf diseases in the region arc sooty stripe (*Ramulispora sorghi*), zonate leaf spot (*Gloeocercospora sorghi*), anthracnose (*Colletotrichum graminicola*), and oval leaf spot *(Ramulispora sorghicola).* At Samaru in 1977, a severe outbreak of grey leaf spot (*Cercospora sorghi*) occurred.

In 1976 and 1977, the International Sorghum Leaf Disease Nursery (ISLDN) was tested at several locations. In the 1977 ISLDN, Samaru provided excellent screening conditions for five diseases, and Kamboinse provided sufficient pressure to screen for three diseases. Entries IS 7254, IS 10240, IS 10262, IS 4150, IS 2223. and BY x Entol were the best overall entries but, except for IS 7254, not one showed resistance to grey leaf spot at Samaru.

The Texas A & M All Disease and Insect Nursery was planted in Upper Volta and Mali. Several resistant entries were identified.

The ISLDN will be continued at several locations in the region in 1978.

Charcoal rot. Charcoal rot. caused by the sclerotial stage of the fungus *Macrophomina phaseolina,* can be severe on sorghums which are filling grain during periods of drought and high soil temperatures. Cultivar CSH-6, which otherwise has performed very well, has shown high susceptibility to charcoal rot at various locations, and is therefore regarded as undesirable for extension. Other susceptible cultivars are CSH-l and SPV-13. The local cultivar S 29 and EC 04734-2 and 2 KX-E-21 appear resistant, but systematic screening of source materials and breeding progenies is needed in the region.

Long smut. Long smut, caused by *Tolyposporium ehrenbergii,* has occurred with quite high severity on certain cultivars at certain locations. The potential importance of this disease needs further evaluation. If necessary, inoculation and screening techniques will be developed.

Progress in Sorghum Entomology

The program in Senegal covered five aspects.

Varietal resistance of sorghum against major pests. During rainy season 1977, a pest-resistance nursery trial consisting of 29 entries was planted at CNRA, Bambey. The shoot fly (*Atherigona* spp) infestation was low (maximum 15%) and none of the borer species (*Sesamia* spp, *Eldana saccharina, Acigona igncfusalis*) was found damaging the crop. However, high infestations of grain midge *(Contarinia sorghicola)* enabled screening for resistance to be carried out. EN 3337-1, SGIRL-MR-1, and 210-P4-1-1 were found relatively resistant. The 1977 International Sorghum Midge Nursery Trial No. 3 was also planted for screening against grain midge. Based on head infestation, midge population, pupal cases in glumes, and yield.

three entries (IS 25790, IS 12573C, IS 12666C) appeared promising.

Inventory on insect pests of sorghum. Surveys were conducted on cultivators' fields and in experimental plots on research stations in different regions of Senegal. About 25 species of insects were noted damaging the sorghum crop in growth; they can be classified under three categories—seedling, foliage, and earhead pests. The most numerous are of the two last categories. None of the stem borer species was found damaging to sorghum.

The incidence of each insect pest varied from location to location and higher infestations were observed on research stations than on cultivators' fields. Regional differences in insect pest distribution were obvious; for example, there was a predominance of *A. ignefusalis* in the south and *C. sorghicola* in the center of the region.

Evaluation of economic importance of major pests. Trials were conducted on local (Congossane) and improved local cultivars (CE90, 51069 AT) using two sowing dates at Bambey and Nioro du Rip. Observations were made on all insects present. The first sowing was free from shoot fly attack, but was infested by leaf caterpillars (*Laphygma exigua, Amsacta monoleyi*) and aphids (*R. maidis*). There was practically no difference in the two sowings in infestation level of grain midge. In general, local was more susceptible than improved local and suffered greater yield loss.

Identification and population dynamics of major pests of sorghum. The fish-meal technique was adopted for trapping shoot flies. More females were caught than males, and it was noted that the population was highest from mid-July to mid-September. The most important species found was *Atherigona soccata.* Studies on grain midges indicated that parasite buildup continued during the growing season and parasitism was high only at the later maturity stages of the crop. Major parasites were *Tetrastichus* and *Eupelmus popa.*

Laboratory rearing. Caterpillars of *Masalia* (*Raghuva*) sp. *A. ignefusalis* and *Heliothis armigera* were reared for biological observations. High parasitism was noted only on *H. armigera.*

As a contribution to the regional program, visits were paid to study the pest problems in research stations and farmers' fields in neighboring countries (Gambia, Mauritania, and Upper Volta). These visits were helpful in establishing direct contacts between ICRISAT scientists and national research organizations, and to discuss matters of common interest to further cooperation. The sorghum crop was infested by shoot flies, grasshoppers, aphids, defoliating caterpillars, and grain midges; the infestation varied from country to country and even from region to region within each country. Cultivators' fields were less infested than experimental fields on research stations. Little has been done in these countries regarding pest identification, biology, etc., and no control measures are being practiced by farmers at present.

Progress in Sorghum Agronomy

In Upper Volta, the ICRISAT agronomy program began in April 1977. During the first season, some exploratory experiments were conducted with sorghum at the Kamboinse station. These included studies on seeding techniques, planting arrangements, interactions between sorghum varieties, plant populations, nitrogen responses, responses to different soils in a toposequence, and delays in planting.

These experiments provided a good number of interesting observations:

Cultivar SPV 13, chosen as the improved nonphotosensitive short-duration variety, outyielded the local and improved local varieties in all experiments except on the lower parts of the toposequence. On these deep soils cv S29 (the improved local photosensitive variety maturing later) was able to utilize the residual soil moisture during the grain-filling stage, providing noticeable increase in yield.

Despite the drought which followed immediately after planting in early July, sorghum appeared to be relatively insensitive to depth and method of planting. However, subsequent early growth was considerably enhanced by planting on the side of the ridge rather than on the top (where the soil dries out much faster).

While hill planting, the traditional way of planting in the region, appears to be more effective in getting good germination and early establishment and to be particularly suitable for widely spaced tall-growing local material, line planting seems to be more advantageous for short nontillering new varieties of sorghum.

In Mali, an experiment was conducted at Sotuba in 1977 with the objectives of evaluating the ratooning abilities of several nonphotosensitive varieties of sorghum and the possibilities of combining forage and grain production. Three varieties (CSH-6, S10, and SB66-42) gave important grain yield gains after one cutting for forage. Where green forage is scarce and costly, as in the vicinity of towns, the ratooning system with combined production of forage and grain appears to be much more profitable than production for grain alone.

PEARL MILLET PROGRAM

Background and Past Research Accomplishments

Pearl millet is a staple food in semi-arid West Africa, especially in the drier northern areas or the Sahelian zone. Because of its exceptional drought resistance and qualities of adaptation to poor environments, this crop is the best cereal for sandy soils under low and erratic rainfall, up to the 250-mm isohyet in the North.

Local types of millet found in West Africa can be divided into two broad categories: the early non- or only slightly photosensitive types and the late photosensitive type which flowers only at the end of the rainy season.

Local millets are generally tall (2.5 to 4 m); sown in widely spaced clumps; and characterized by moderate and nonsynchronous tillering, abundant foliage with long leaves, thick stems. poor harvest ratio, medium to long or very long spikes, and medium to large grain size. The grain color varies from white through sandy brown to greenish brown. As for sorghum, the grain is most commonly used as "kus kus" or "TO", a thick paste prepared by mixing millet flour with boiling water. But unlike sorghum, consumers' acceptability for millet is wider and the introduction of new varieties is quickly accepted unless grain mold development is severe.

Pearl millet in West Africa suffers from several diseases; the most important are downy mildew, smut, and ergot.

Striga is also a serious cause of loss of pearl millet throughout West Africa, although the susceptibility common in most exotic varieties is not readily detected on research stations.

Though the same pattern of insect pests occurs on millet as on sorghum—namely shoot fly, midge, and stem borer (although of different species)—they generally are less troublesome. Following the dry years an ear worm, *Masalia (Raghuva)* sp. caused increasing damage in the Sahelian area, although in 1977 the incidence was light.

Pearl millet in traditional cultivation is planted by hand in widely spaced hills (usually a meter or farther apart), especially in the northern area where competition for water is severe. Many seeds are planted per hill and thinning is therefore an important operation which should be completed within 2 or 3 weeks after planting. As it is also a time-consuming operation, often in competition with other work such as weeding or planting of other crops, it is rarely completed at the proper time, causing a substantial decrease in yields. Pearl millet may be grown in pure stands or in mixtures, mostly with cowpea and groundnut in the northern and central zones or with late sorghum in the southern zone. There is little or no mineral fertilization. In these conditions, yields of millet in pure stands are low and average from 400 to 700 kg/ha.

ICRISAT's General Objectives and Strategy

Local or improved local millets have three main characters which tend to limit yield.

Insufficient earliness. In many cases local varieties flower too late, at a time when residual soil moisture is no longer sufficient for grain formation. This is more evident in the drier northern area.

Plant architecture. Local cultivars are tall with abundant foliage and low harvest index. Under the low fertility levels and low plant populations adopted by most farmers, there is good yield stability, but yield is low. Improvement in soil management usually increases the vegetative growth of the plant even more, reducing further the harvest index.

Tillering. The less photosensitive local cultivars have moderate tillering which is not synchronous, thus many of the tillers are not effective for grain production.

ICRISAT's objectives are to modify these unresponsive characters by crossing the local materials with exotic (especially Indian) materials which possess qualities of earliness, short height, moderate vegetative development, and abundant and synchronic tillering. This will result in new synthetics and composites which should also inherit the resistance shown by the local materials to diseases like downy mildew, smut, ergot, and blast; to major pests; and to *Striga.* Exotic varieties, when introduced into West Africa, are very susceptible to these diseases and pests. Therefore, while incorporating the desirable characters from- the exotics to the local cultivars, it is essential that the resistances of the local cultivars are retained.

Exposure in West Africa of material supplied by ICRISAT Center is vital for selection of durable disease resistance of the type most likely to be stable in India. This is most important for downy mildew, but may well be similarly important for smut and rust.

Due to scanty rainfall and its poor distribution during the cropping season in West Africa, resistance to drought stress (particularly at increased plant densities) is also an important consideration for the breeding program. New cultivars should be superior under traditional farm practices, but at the same time responsive to an improved management that is within small farmers' resources. The adoption of improved farming techniques is dependent upon this. Such cultivars should, therefore, possess a low *genotype* x *environment* interaction.

Studies to define management techniques most suitable for these improved new varieties are needed. Special attention should be paid to line planting, common in India but not practiced with existing local cultivars in West Africa. If line planting could be adopted, it would substantially reduce the need for thinning. Thinning is presently a major constraint on farm size, since 100 to 200 man hours/ha are required to perform this operation.

Progress in Millet Breeding

A brief summary of the work accomplished in each host country is listed, followed by some general conclusions.

Upper Volta. The main objective in 1977 was to introduce a wide range of genetic variability and critically evaluate the performance of these, before deciding in which direction to orient the program. Consequently 5 840 lines were tested in 7 060 plots in 33 experiments. Most of this material originated from ICRISAT Center, but there were also some cultivars from the IRAT programs in West Africa and a germplasm collection of local landrace varieties.

The 1977 results clearly indicate that advanced breeding material generated totally outside West Africa is unlikely to be adapted. To generate variability, therefore, it is necessary to have a West African parent in initial crosses to increase the probability that the progeny will be adapted to Upper Volta.

The selections made from various classes of exotic material (above) tested in 1977, though few, are likely to be important as parents in these crosses, as they represent phenotypes not available for West African sources.

Hence in the 1977-78 off-season, a crossing program was started to generate new breeding material.

Senegal. The program began in January 1977 and, as is the policy in all countries, its operation can be broken down into three objectives: contributions to national, regional, and international programs.

The contribution to the national program pertains to the "GAM corrected Indian" part of the new GAM (Groupe d'Amelioration des Mils at CNRA, Bambey) program. It consists of crossing the best of the introduced ICRISAT material with the leading GAM lines, and the exploitation of the variability thereby created to correct some of the faults of existing GAM material (poor grain setting and disease susceptibility) and to fully exploit the excellent phenotypes generated in the GAM program. In 1977. a number of lines in the ICRISAT material were found to have a good general combining ability with the GAM material, and as a generality crosses with the Nigerian material appeared to be especially interesting. The contribution to the regional program involved setting up and supervising international pearl millet adaptation trials (IPMAT) in Senegal and in the neighboring countries of Mauritania and Gambia. In Senegal, the best performances were achieved by experimental varieties and hybrids. The first hybrid was ICH 108 (1 900 kg/ha), thus confirming the results of the last IPMAT-2. Except for Sauna III, most entries appeared to be rather susceptible to smut.

The IPMAT trial failed at Kaedi in Mauritania because of the very severe drought (less than 250 mm of rainfall) and in Gambia because of the combined effects of the drought and of very severe attacks from diseases.

The contribution to the International Program consisted of cooperating with the fundamental objectives of the ICRISAT Center core program in intrapopulation improvement and hybrid evaluation. The intrapopulation improvement consisted of testing of two Serere (Uganda) composites and experimental varieties. The hybrid program includes the creation of a relatively inbred material and its multilocational evaluation as well as the creation of synthetic varieties of F_1 hybrids.

In summary, the millet-breeding material grown in the first main season of the program was exposed to very poor rainfall (376 mm at Bambey). The best performances were observed in the Serere and Super Serere composites and in experimental varieties and hybrids in evaluation trials. A satisfactory proportion of the first crosses made between ICRISAT and GAM material, particularly where Nigerian parents were involved, gave promising performances. Parents for new crosses were identified.

Niger. The breeding program started in Niger in June 1977. The 1977 rainy season at Maradi can be described as normal in terms of total rainfall (608 mm) and its distribution during the season. Unfortunately, because of late arrival of seed material from ICRISAT Center in India, only a small part of the experiments could be planted in due time (10 Jun); the main part was sown too late (1 Jul).

Severe *Striga* damage was observed in the crop planted in July, while the crop planted in June was more or less free from *Striga* infestation.

The main contribution to the national program will be to generate breeding material having intermediate height; moderate tillering with synchrony of tillering; and long head type with good grain filling, appearance, and size. Such genotypes are expected among the progenies of the crosses of parent material carefully selected from African and Indian origin.

Some crosses were made in the 1977 wet season, but essentially this season was used for selecting parents. The main crossing blocks were planted in the 1978 off-season (Jan) consisting of African x Indian inbreds and crosses between and within population progeny. The F_1's of the wet season crosses were also grown.

In addition, the ICRISAT breeder collaborated with the national millet breeder and the USAID expert in the conduct of their trials. Some were of special interest to the ICRISAT program; selfed-seed of selected lines were obtained for further utilization in the ICRISAT breeding program.

As a contribution to the regional program, the ICRISAT breeder visited several neighboring countries, seeking relevant material for- the Tarna breeding program. Selected Sj's of four downy mildew-resistant experimental varieties were being planted in the 1978 off-season. Bulk sibbing has been done to reconstitute these experimental varieties which will be incorporated in future West African regional trials.

The International Pearl Millet Adaptation Trial was carried out at Maradi. In this trial, the first two entries were hybrids, BD 111 and ICH 118, yielding around 2 000 kg/ha, though both of them were about a week earlier than the local check, cv CI VT 11_2, which was in third position. Cultivar CIVT 11_2 is an experimental composite made from four Niger cultivars. Mildew infection varied from 0 to 80 percent in this trial. All entries except the local check were affected by smut. The contribution to the International Program consisted of a number of trials including the Synthetics Trial, Composites Bulk Trial, a Population Trial, and evaluation of S_2 lines from the Early and Dwarf composites. Several F_2 nurseries were grown, such as African x Indian inbreds and selections from Nigeria. Yields in these trials rarely surpassed 2 000 kg/ha. In the first three trials where the local check, cv CIVT 11_2, was incorporated, it outyielded all other entries. The Composites Bulk Trial was severely affected by *Striga.* Downy mildew attacks were generally moderate, but it was possible to identify from these trials a number of lines possessing interesting characters for earliness, resistance to downy mildew and smut, and level of yield. In the Composites Bulk Trial, a positive increase in grain yield and in levels for downy mildew resistance through selection was evident in some populations.

As a general observation from the rainy season of 1977, the performance in Niger of the hybrids and populations developed in India appears to differ from their performance in India. The material having some degree of local adaptation from African conditions performed the best at Maradi. Thus, as at Kamboinse, it appears necessary to first make many exotic x local crosses to generate suitable variability for further selection.

Nigeria. The ICRISAT millet-improvement program in Nigeria, as in Senegal, is aligned to a strong national program. The theme of the national part of ICRISAT's program is to identify, by introduction and evaluation, more diverse breeding material useful in Nigeria, and to test regionally- -for use elsewhere—products from the Nigerian program.

The 1977 season was characterized by a severe drought (until 18 Jul) after planting in early June. New material from ICRISAT Center did not arrive on time for the first planting and consequently was planted only in July. IPMAT was conducted at Kano and Samaru—only cv ICH 118 and IVS A75 and the World Composite (originally from Nigeria) gave yields comparable to the local checks, Ex-Bornu, and Nigerian Composite. In the Hybrids trial, only combinations with pollinators of West African origin gave good yields. Twenty-two (of 140) F_4 selections and 38 (of 300) F_3 selections were retained from the segregating material tested. At the request of IAR, 105 early maturing ("gero") germplasm lines, collected by IBPGR in Nigeria in 1966, were grown out and evaluated. A small collection of bristled and disease-resistant lines from the IAR program was also evaluated.

Progeny trials of the Intervarietal Synthetic and the Nigerian Composite (ICRISAT Center) were grown for the core program and progeny selected in Nigeria contributed 50 percent to the total selected at all locations. Selections of dwarf populations received from the breeder in Niger were grown out in the 1977-1978 off-season for distribution to all West African breeders.

As a general observation, the reactions of the material tested in 1976 and 1977 made it obvious that both Samaru and Kano (which are in different agroclimatic zones) are West African "hot spots" for downy mildew, ergot, and smut. Comparisons across West Africa and India showed, Bambey excluded, that material resistant in Nigeria is resistant elsewhere. This confirmed findings that the best sources of resistance to downy mildew, smut, (and rust) were Nigerian.

Mali. The International Pearl Millet Adaptation Trial was carried out in the rainy season of 1976 and 1977 in the Seno region in Mali and at Sarmi in 1977. In the Seno region (characterized by low rainfall, sandy soils, and high level of infestation from downy mildew and smut), the general level of yield was moderate in 1976 and low in 1977 due to late sowing. In both years, the local improved variety NKK ranked first: 1 600 kg/ha in 1976 and 1 100 kg/ha in 1977. A few exotic entries performed relatively well; most suffered from severe attacks of downy mildew and smut. At Sarmi in 1977, the rainfall was very low (265 mm between planting and harvest), but the pressure from diseases was also low. None of the varieties showed symptoms of downy mildew and ergot, but smut affected all varieties to some extent. Yields were relatively good (around 1 000 kg/ha) in spite of the late sowing; many entries equalled the local checks.

General Conclusions on the Millet Breeding Program

Several conclusions can be drawn from the performance of material during the 1976 and 1977 rainy seasons:

i) Purely in terms of yields, except at Bambey and perhaps at Wad Medani, ICRISAT final products were not better than existing West African varieties. This was largely due to lack of disease resistance and, in some cases, unsuitably early maturity.

ii) It seems obvious that in material originating from West Africa (e.g., the World Composite), where subsequent selection was based on multilocation testing which did not include West Africa, adaptation to West Africa decreased. Bambey appears to be an exception, principally because downy mildew there appears less severe and of a different nature.

iii) ICRISAT Center material represented a much wider range in plant morphology than is available in West Africa. Despite attrition due to disease, 1977 field tests of exotic material identified a number of lines and composite progeny valuable for crossing to local varieties at each of the ICRISAT West African locations.

Progress in Millet Pathology

The major disease problems are downy mildew (DM), ergot, and smut; diseases of potential importance include leaf blast and zonate leaf spot.

Downy Mildew. Of all the locations in the international testing programs, West African locations provide the most severe pressure for DM-resistance screening. The detailed reports of the 1976 and 1977 International Pearl Millet Downy Mildew Nurseries (IPMDMN) provide information on locations and entry reactions. The West African locations provide the key for identification of stable DM resistance in pearl millet, for not only is the pathogen generally more virulent and aggressive than in other locations, but there is mounting evidence for the occurrence of different races of the DM pathogen among the West African locations. Two of the most resistant IPMDMN entries exhibited a high level of DM resistance across all West African locations in 1976 and 1977.

Results so far show that materials of West African origin have the best and most durable levels of DM resistance, and to this end collection of local varieties has been started in Nigeria and Upper Volta to fully exploit locally available sources of resistance.

The success of the control of millet DM throughout the SAT depends upon efficient use of locations and source material from West Africa.

Ergot. In Upper Volta and Mali, a preliminary ergot-resistance trial was grown at three sites, and though differences were detectable among entries, the levels of ergot infection were such that no entry had acceptable resistance to the causal pathogen. Some entries appeared to have consistently reduced susceptibility when the results from the locations were viewed together.

In Nigeria and Niger, it appears from surveys that ergot has been confined to a few areas and is especially high where continuous rain occurs, particularly in the late-sown crop. An ergot nursery was carried out at Samaru. Ears were spray-inoculated soon after emergence; some were bagged and the others left without covering. Ears bagged were 100 percent infected with moderate to high level of intensity. In the nonbagged ears, infection varied from 43 to 73 percent and the intensity grade was low to moderate. Only three entries showed a low level of infection and intensity.

Smut. In Upper Volta, preliminary trials show that West African materials are more likely to possess resistance to smut than materials from outside the region. The identification of resistance was not possible using an assessment scale in which all heads with more than 20 percent smutted grains were placed in the category of most susceptible types.

In Nigeria and Niger, smut is next to downy mildew in intensity and occurrence, and causes considerable damage to grain yield. During the surveys, hot spots were identified, especially in the northern area. In the smut nursery grown at Samaru, none of the entries was absolutely free from smut infection. A dozen lines showing a good level of resistance were identified. A good correlation was observed in this trial between crop per unit infection and infection index for the most resistant varieties.

Millet Agronomy

In Upper Volta, the ICRISAT agronomy program was initiated only in April 1977. One of its major aims is to develop suitable agronomic recommendations for new cultivars developed by ICRISAT breeding programs. Major emphasis was therefore placed on studies of optimum planting dates for different varieties, optimum plant populations under various levels of management and soil fertility, and responses of different varieties to soil conditions—especially depth of planting.

The first year's data indicate the following:

i) Millet germination is best when planted shallow and in hills, using many seeds, Planting on the side of a ridge results in better early growth but germination is reduced.
ii) Hill plantings outyielded line plantings.
iii) Early planting of early cowpea and millet as a mixed crop could be profitable.

East African Cooperative Program

SUDAN

At the request of the Government of Sudan, in 1977 the UNDP/ICRISAT West African program was expanded to provide two plant breeders for sorghum and pearl millet improvement to cooperate with and strengthen the national programs. Subsequently, two scientists were recruited and posted to the Agricultural Research Corporation headquarters at Wad Medani. They were able to establish full-fledged programs immediately, in line with the prime objectives:

i) Development of high-yielding varieties, synthetics, and hybrids well adapted to different agroclimatic conditions in the Sudan and possessing good eating and nutritional qualities.

ii) Development of resistances and practical control measures for *Striga* and for pests and diseases, especially stem borer, head worms, downy mildew, smut, and ergot.

iii) Training of local research workers and technical assistants in breeding and production technology.

A laboratory-office building, funded jointly by the Sudanese Agricultural Research Corporation, UNDP, and ICRISAT, was constructed to provide the required facility for the scientists and support staff.

During the rainy season, five international sorghum trials from ICRISAT Center were grown in order to select source material for further improvement. In addition, a screening nursery of 3 625 exotic lines was evaluated. An off-season nursery was established under irrigation in November and an ambitious crossing program was undertaken to produce new combinations which would be useful to the national program and also the ICRISAT West African program.

Work on pearl millet improvement commenced in the rainy season of 1977 with the evaluation of an indigenous collection of 197 entries, and nurseries of exotic breeding material from both Arid Land Agricultural Development Program (ALAD) and ICRISAT (F_3 UPN). Unfortunately, the major consignment of seed from ICRISAT Center for this season was lost in airline transit and not recovered until September. Crosses were made in this season between the best local and introduced lines, and other

Figure 111. ICRISAT germplasm scientist records plant characteristics of a landrace sorghum grown by a farmer in East Africa.

research deals with pearl millet, chickpea, and early pigeonpea. The land and operational facilities are provided by the Haryana Agricultural University. At Gwalior (26°N), where the program is mainly concerned with long-duration pigeonpea, facilities are provided by the JNKVV, Jabalpur. Dharwar, where the University of Agricultural Sciences, Bangalore, extends land facilities, provides an excellent site for research on the screening of sorghum for resistance to downy mildew and charcoal rot. Bhavanisagar (11°N) is being used for cooperative research on off-season sorghum and pearl millet crops through the courtesy of Tamil Nadu Agricultural University, Coimbatore. These sites are indispensable for the achievement of ICRISAT's research goals. They provide specific conditions for screening against pests and diseases, as well as a range of climatic conditions for studying the expression of genotypes under different environments.

The cooperation of the agricultural universities has been excellent and the program is progressing well.

For raising off-season nurseries of chickpea, preliminary experiments were carried out in Kashmir Valley with the cooperation of the Department of Agriculture of Jammu and Kashmir. These studies have given valuable leads for the future program. It has become evident that sowing of chickpea in the first week of June at the Taparawaripura farm produces a good crop for evaluation and for advancing the generation of the material. ICRISAT intends to use this facility regularly.

Visits to ICRISAT have been organized for Indian scientists engaged in research on sorghum, pearl millet, pigeonpea, chickpea, and groundnut so they may become acquainted with ICRISAT programs and material. Scientists engaged in dry-farming research have been invited also to visit the Farming Systems Research Program. These visits have been extremely useful. They have facilitated exchange of information and material between scientists, and led to development of scientist-to-scientist cooperation and contact. Seed material- which appears promising and of specific interest to a particular breeder is made available for use in his research program. It is not a one-way system. ICRISAT scientists have also visited Indian programs, benefited by exchange of ideas, and developed more cooperative and collaborative research.

ICRISAT scientists have participated in the All-India workshops on sorghum, pearl millet, pulses, oilseeds, and dryland agriculture. This has provided a valuable forum for exchange of ideas and materials.

On the recommendations of the Advisory Committee for ICAR-ICRISAT coordination, a number of cooperative projects involving the ICAR Dryland Project, the agricultural universities, and ICRISAT have been started under the Farming Systems Research Program (see page 225).

Joint surveys of pests and diseases were undertaken by ICRISAT and ICAR scientists to study the causes and pattern of their occurrence.

Along with the village-level studies being conducted by the Economics Program of ICRISAT, collaborative nutritional surveys have been carried out by the Home Science College of APAU, the National Institute of Nutrition, and ICRISAT. These provide valuable information on the nutritional status of people living in selected SAT villages of India.

During the year, cooperative programs between ICRISAT and Indian agricultural research organizations and universities increased in intensity and magnitude. This collaboration is leading to better understanding and a speedier attainment of the national and international goals for which the Institute was set up.

Middle East Cooperative Programs

Selected trials of sorghum, millet, pigeonpea, and chickpea were supplied for testing to a number of middle eastern countries, notably Saudi Arabia, Yemen Arab Republic, People's Democratic Republic of Yemen, and Syria.

Cooperation with ICARDA

A chickpea breeder has been posted to the ICARDA Center at Aleppo, Syria to coordinate a joint ICRISAT-ICARDA Chickpea Research Program and to integrate the program with ICRISAT Center. The major emphasis will be on improving kabuli types at ICARDA, desi types at ICRISAT Center, and on late-maturing desi types and kabuli types at Hissar, India. Each center has regional responsibilities and also serves those countries outside its region that are growing the type of chickpea for which it is responsible.

Other Organizations

ICRISAT recognizes a great backup resource in the scientific laboratories and institutions of its host country -India—and of the various nations represented in the Consultative Group. Such resources will be cultivated and developed as they are identified so that mutual interests and opportunities can be carried forward.

Among those of particular interest are several programs with universities of North America, the United Kingdom, and Australia; these include the sorghum protein-quality program at Purdue University, the conversion and disease-resistance programs with sorghum at Puerto Rico and Texas A & M University, the program on physiology of stress at the University of Nebraska, the drought-stress program at Saskatoon University, the program in pearl millet grain quality and seed establishment at Kansas State University, the cooperative project on genetic improvement of groundnut with North Carolina State University, cooperation in environmental physics research with the University of Nottingham, genetics-resources documentation projects with the University of Colorado, the project on development of short-season photoinsensitive and short-statured pigeonpea adaptable to mechanical harvesting at the University of Queensland, and many others.

A number of research institutes and laboratories also share cooperative projects with ICRISAT; these include virus control of *Heliothis armigera* with the Boyce Thompson Institute in the United States; development of ICRISAT's Sorghums and Millets Information Center with IDRC of Canada; work with pheromones of *Chilo* and *H. armigera* at the Tropical Products Institute of London, England; work with downy mildew resistance with the Quarantine Department of the Royal Botanic Gardens in Kew, England; projects in pigeonpea pollination with the Rothamsted Experimental Station in England, projects on stimulants to germination of *Striga* and orobanche at Sussex and the Weed Research Organization of the UK; nitrogen-fixation and rhizobium cultures for tropical legumes with the CSIRO, Australia; and the project with the John Innes Institute in England on the genetic fingerprinting of *Rhizobium* strains.

Generally, the major financing of these projects comes from sources outside ICRISAT, but their results are expected to be of considerable importance to ICRISAT's clientele. Through joint collaboration, the relevance of such projects to the SAT can be sharpened, and facilities and scientific talent better utilized.

Fellowships and Training

Educational opportunities for agricultural personnel who are working or who intend to work in national, regional, and international research and development programs of the rainfed semi-arid tropics were provided at the ICRISAT Center. The training program serves as a link between national agricultural research and development programs in the SAT and ICRISAT's scientific expertise, germplasm resources, collection of research findings, and facilities.

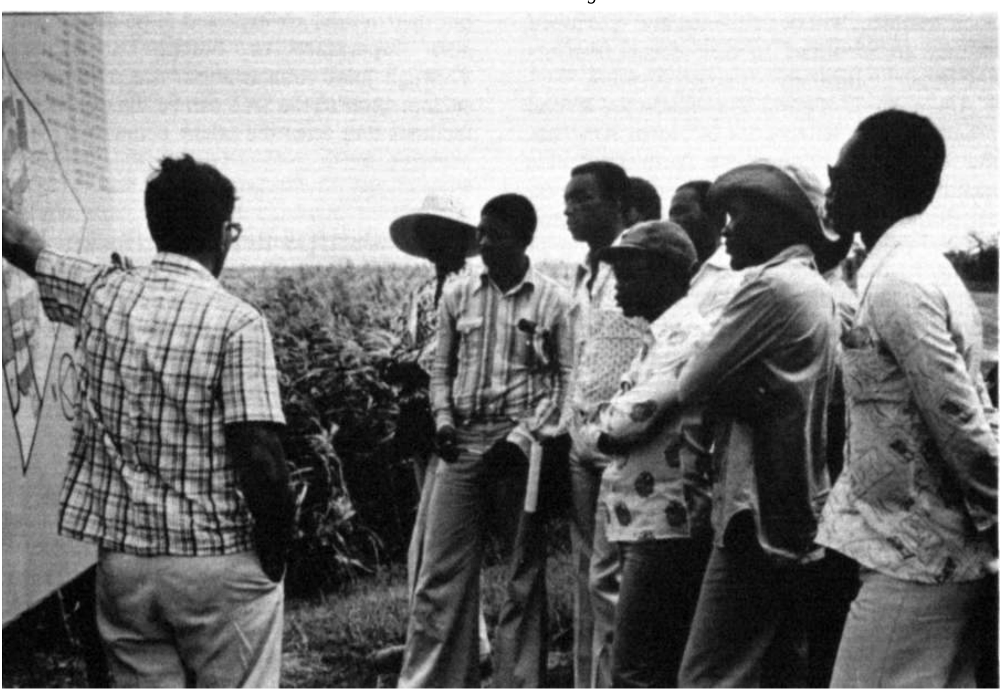
Training programs for in-service trainees, research scholars, research fellows, and junior principal scientists (now called international interns) were conducted during the year.

Training programs for each category of

candidates were organized within the specialized sciences of ICRISAT's five crops, farming systems, and other ICRISAT Center programs. Comprehensive individualized programs, based on precourse evaluations and interviews, were developed. Individual programs provided practical and theoretical experiences in agricultural research, crop improvement, crop production, extension programs, and training methods. The duration and content of each training program was adjusted to the required number of sessions necessary to obtain adequate data and the desired specialization of the trainee. As an integral part of his training, each trainee developed and conducted laboratory and field experiments or demonstrations which were within the mandate and capabilities of the research program of the Institute. Field and laboratory studies were supervised by research scientists and training staff with practical training activities forming the core of the research and managerial experiences. Field and laboratory responsibilities occupied more than 60 percent of each individual's training program. Each individual's accomplishments were periodically evaluated on the basis of skill, performance, and theoretical-concept development.

Final evaluations determined an individual's progress, assisted in establishing his personal confidence, and provided an evaluation of his reaction to the training program. Evaluations are also used in assessing performance when following up trainees who continued working in fields related to training received while at ICRISAT.

Figure 112. Explaining land and water management techniques, which are a key input of the training at ICRISAT Center. In the past four years, 225 trainees from 26 countries have participated in our training programs. Followup correspondence revealed that 86 percent of trainees continued work in areas related to their training at ICRISAT.



STAFFING AND PROGRAM INTERACTIONS

The major portion of the practical and theoretical field, laboratory, and classroom learning experiences was conducted by research scientists, assisted by the training staff. Ninety-two scientists participated directly in the training activity and/or served as thesis research guides and supervisors of research fellows. The three-man training staffcoordinated the instruction, individualization of research projects, evaluation of practical-concept comprehension, and follow-up programs. The functioning of the training staff insured a balanced and comprehensive learning opportunity for each person.

PROGRAMS COMPLETED

In the past 4 years, 225 trainees from 26 different countries have participated in the program. A wide range in educational background and experience was represented by these trainees. Individualized programs were necessary to accommodate, simultaneously, students who completed secondary school and those with university degrees. Research scholars and fellows were trained by scientists in almost all research programs at ICRISAT.

In-service Trainees

Forty-one in-service trainees from 14 countries completed their individualized programs in practical field and laboratory experience in crop improvement, crop production, or the Farming Systems research program (Table 111). There were 17 in-service trainees from Francophone West Africa—Upper Volta, Senegal, Mali, Chad, Niger, Mauritania, and Togo. During the initial 8 weeks, they attended an intensive English-language course at the Central Institute of English and Foreign Languages, Hyderabad, and improved their English-language capability to a level that permitted them to work with our scientists. The number of in-service trainees in various programs is as follows.

Sorghum improvement	11
Pearl millet improvement	8
Farming systems	7
Crop production	10
Microbiology	2
Biochemistry	1
Pigeonpea and chickpea improvement	1
Computer science	1

A special training program in land and water management was organized for 35 officers from four states of southern India in collaboration with the Indian Council of Agricultural Research, New Delhi, and the ICRISAT Farming Systems program.

Apprentices

Seven apprentices completed work in farm development and operations, land and water management, and agricultural economics.

Research Scholars

Three M.Sc. (Andhra Pradesh Agricultural University) scholars completed their training in agronomy and soil sciences. One Ph.D. scholar continued his research in sorghum improvement and another M.Sc. scholar is working in cereal pathology.

Eleven M.Sc. and Ph.D. degree candidates from the Sudan, Canada, United States, the Netherlands, Thailand, England, Ethiopia, and India started work on thesis problems as research scholars under the supervision of ICRISAT scientists. Upon completion of their research programs, they will submit their theses to their respective universities.

Three professors and 12 M.Sc. students from the University of Dacca, Bangladesh, acquainted themselves with latest techniques in sorghum and pearl millet improvement.

Research Fellows

Research fellows holding postgraduate degrees obtained specific practical and theoretical experience while working under the supervision of research scientists. Six research fellows completed their programs: two in soil and

Table 111. Persons completing long-term training programs during the 1977-1978 report year.

Name	Country	Program
IN-SERVICE TRAINEES:		
M. Laxmi Kumari	India	Microbiology
Mamadou Ba	Upper Volta	Pearl Millet Improvement
Koita Abdoulaye	Upper Volta	Sorghum Improvement
Romain Coulibaly	Upper Volta	Farming Systems
Mamadou Wade	Mauritania	Sorghum Improvement
Mahmadou Kone	Niger	Farming Systems
Nayessa Mamane	Niger	Sorghum Improvement
Dan Douna Sani	Niger	Pearl Millet Improvement
Ousmane Ali	Niger	Pearl Millet Improvement
Mamadou Doumbia	Mali	Farming Systems
Bassirou Keita	Mali	Farming Systems
Issaga Dit Moriba Konate	Mali	Pearl Millet Improvement
Salif Kanoute	Mali	Farming Systems
Saliou Niang	Senegal	Farming Systems
Madicke Niang	Senegal	Farming Systems
Djime Koskal	Tchad	Crop Production
Sayam Dingamnayal	Tchad	Sorghum Improvement
Assiongbon Kpodar	Togo	Sorghum Improvement
L.R. Malangahe	Tanzania	Crop Production
H.S. Chambo	Tanzania	Crop Production
Albert Cox	Gambia	Sorghum Improvement
O.O. Ogunsemi	Nigeria	Crop Production
S.A. Gaya	Nigeria	Crop Production
Rabe Iro Mani	Nigeria	Crop Production
D.M. Mamza	Nigeria	Crop Production
A.T. Mafara	Nigeria	Crop Production
Muhammed Waziri	Nigeria	Crop Production
G.K. Sowley	Ghana	Sorghum Improvement
G.Z. Gbiriche	Ghana	Crop Production
H.M. Saadan ,	Tanzania	Sorghum Improvement
D.R. Akbary	India	Pulse Improvement
K.A. Nayeem	India	Analytical Techniques (Biochem)
R.S. Raut	India	Microbiology
Hahn Weon-sik	Korea	Computer Science
Md. El Amin	Sudan	Pearl Millet Improvement
I.S. Khauriwal	India	Pearl Millet Improvement
I.T. Hassan	Nigeria	Pearl Millet Improvement
A.C. Obasi	Nigeria	Pearl Millet Improvement
Cirilla C. Punongbayan	Philippines	Sorghum Improvement

Continued

Table 111 *Continued*

Name	Country	Program
Gilberto Gonez B.	Colombia	Sorghum Improvement
Rogeloi Humberto Cordora	El Salvador	Sorghum Improvement
RESEARCH SCHOLARS:		
K..A. Shams	Sudan	Soil and Water Management
J.B. Okeyo Owuor	Kenya	Pigeonpea Entomology
Bharata Laxmi	India	*Striga* Laboratory
RESEARCH FELLOWS.		
Abdul Aziz Sy	Senegal	Pearl Millet Improvement
A.F. Lima	Brazil	Soil and Water Management
O.P. Aragao	Brazil	Soil and Water Management
A. Djigma	Upper Volta	Groundnut Improvement
Narong Singburaudom	Thailand	Cereal Pathology
W. Tse-Horng Liu	Brazil	Climatology
JUNIOR PRINCIPAL SCIENTISTS:		
Brian Hare	Australia	Pearl Millet Improvement
APPRENTICES:		
Subrata Sen	India	Farm Development Operations
Ashok Kumar Roy	India	Farm Development Operations
PR. Santra	India	Farm Development Operations
Parthasarathi Haldar	India	Farm Development Operations
Ashwini Kumar	India	Soil and Water Management
K.S. Gathode	India	Farm Development Operations
S. Rajendran	India	Agricultural Economics

water management, one in agroclimatology, two in cereal pathology, and one in groundnut improvement.

Interns

During the year the category of international internship was established. Through an ICRISAT international internship, a recent recipient of the Ph.D. degree in an agricultural science can gain research experience in a developing country. The international intern will be working in a muitidiscipiinary program of research and training in a specific problem area. Trainees completing their training are listed in Table 111.

FOLLOW-UP ACTIVITIES

Contact was maintained with former trainees through correspondence and through personal contact by ICRISAT scientists working and travelling in their respective countries. Trainees received germplasm, research reports, and educational material from ICRISAT.

During recent follow-up correspondence, it was found that 86 percent of our trainees were continuing in a type of work related to their training at ICRISAT. Of 81 trainees, four have started or completed a degree program; only two seem to have left agricultural service.

FUTURE TRAINING PROGRAM

The number of persons receiving training at ICRISAT Center is expected to increase by 1980 to an optimum yearly average of 60 in-service trainees, 20 research scholars, 15 research fellows, and 10 international interns, plus special-area trainees (a few days to a few weeks for intensive skill development in pathology, microbiology, entomology, or other specific areas). With the anticipated scientific (100) and training (6) staff, the projected number of trainees would result in each staff member being associated with an average of 1 or 2 trainees throughout the year.

Workshops, Conferences, and Seminars

Exchange of information for the transfer of technology and cooperative research is essential in a worldwide approach to crop improvement, and workshops and conferences provide an effective channel for this purpose. The 1977-1978 report year included an international workshop and several smaller conferences and workshops. ICRISAT scientists cooperated with research agencies in India and elsewhere in organizing conferences and meetings, and participated in practically every major scientific meeting involving one or more of the five ICRISAT crops in the SAT environment.

INTERNATIONAL PEARL MILLET WORKSHOP

Forty-four pearl millet specialists representing national millet improvement programs in Africa, Latin America, and Asia, as well as

Figure 113. Showing pearl millet workshop participants how nitrogen fixation is measured.

IRAT, CIMMYT, the USDA, and the Title 12 universities in the USA participated in the 1977 International Pearl Millet Workshop at Hyderabad, 29 August-2 September. The purpose of the Workshop was to exchange information about pearl millet research in the SAT, determine how best to develop cooperative research among pearl millet scientists of the world, review arrangements for exchanging seed material and information, and assess training needs.

A highlight of the Workshop was the presentation of country papers. These, along with information gleaned from questionnaires submitted by workers in concerned SAT nations, provided the most up-to-date appraisal of the pearl millet situation available anywhere. Such data is essential for international planning.

To inform Workshop participants about ICRISAT's program, fifteen scientists presented details of the Institute's work in germplasm collection and maintenance, breeding, physiology, entomology, pathology, microbiology, and nutrition. Participants also visited the fields; many of them were able to select plant materials useful for their own programs back home.

Face-to-face interchange of ideas and suggestions was perhaps the most valuable feature of the Workshop. Information flow (from national program to ICRISAT, from ICRISAT to national program, and between national and regional programs) is essential if the pearl millet workers of the world are to provide the most effective assistance to the small SAT farmer of limited means.

A summary of the information received in the country questionnaires and the recommenda-

Figure 114. Chickpea breeders at the Hissar meeting discuss experiments on the farm.

tions of the working groups on breeding, plant protection, and crop growth and plant nutrition were published in Volume 4 of ICRISATs newsletter, *Semi-Arid Cereals.*

FARMING SYSTEMS CONFERENCE FOR INDIAN SCIENTISTS

Sixteen scientists representing 12 agricultural universities, the All-India Coordinated Research Project for Dryland Agriculture, and the Central Soil and Water Conservation Research and Training Institute, participated in a 2-day Conference at ICRISAT Center in October. Brief visits were made to most of the Farming Systems research activities, and to the crop-improvement programs. A highlight of this Conference was the afternoon devoted entirely to questions, discussion, and general exchange of ideas. Stimulation of communication between the several programs working in this area may be the real payoff of such a Conference.

PULSE BREEDERS' MEETINGS

The Fourth Annual International Chickpea Breeders' Meeting was held at Haryana Agricultural University at Hissar 5 and 6 April 1978. Twenty-five participants representing Chile, Mexico, Nepal, Turkey, Pakistan, the United Kingdom, and India met to review the progress of breeding, pathology, germplasm, entomo-

Figure 115. Explaining a chickpea experimental field to a visiting group of farmers at ICRISAT Center. There was an increasing number of visitors this year, including scientists from national and international programs, administrators, legislators, students and media personnel.

logy, microbiology, physiology, and nutritional quality research at ICRISAT and elsewhere, and to plan future efforts in these areas.

A similar program was held at ICRISAT Center for pigeonpea breeders 13-15 December 1977. At this event were 21 scientists from India; scientists also came from Panama, Kenya, and the Dominican Republic.

SEMINARS

Institute and program-level seminars are a regular feature of the scientific effort at ICRISAT. Visiting scientists usually present one or more seminars during their stay at the Center; ICRISAT scientists use the seminar to keep other members of the Institute informed about programs and research results. These activities provide a valuable forum for exchange of ideas and information.

FIELD TRIPS AND VISITS

ICRISAT frequently arranges field trips and other short-time activities for visiting groups, aiming to project its research work to diverse groups of visitors. There were a total of 6 093 visitors this year, including scientists from national and international programs, fanners, students, journalists, administrators, and legislators.

Mr. Surjit Singh Barnala and Mr. Bhanu Pratap Singh, Minister for Agriculture and Minister of State for Agriculture, respectively, in the Government of India; Mr. P.J. Curtis, Australian High Commissioner in India; Lord Gore Booth, British High Commissioner in India; and Mr. Lennart Finnmark, Swedish Ambassador in India, were among those receiv-ed at ICRISAT during the year.

Plant Quarantine

The importance of plant-quarantine is now widely appreciated, since it is realized that while "genetic resources" is the base of crop improvement, quarantine is the key to this base. ICRISAT's Quarantine Unit has an arduous task, because of i) a greater number of international seed exchanges by the Institute, ii) higher degree of responsibility expected, lest negligence in international shipment result in export or import of a pest or disease, and iii) the greater speed required in moving seed so as to ensure its timely planting by cooperating scientists.

In spite of the strengthening of India's plant quarantine staffing and ICRISAT's assistance in providing additional resources, facilities for handling the ever-increasing volume of seed exports continued to remain inadequate at CPPTI (the Central Plant Protection Training Institute). Never, in the history of India's quarantine agencies, has the workload been so great. This was a new experience and required new strategy. After careful consideration and discussion, the Government of India agreed to the establishment of an "Export Seed Certification Quarantine Laboratory" on site at ICRISAT Center, to be operated under the overall authority of CPPTI. ICRISAT provides the buildings and other support staff, including a senior Quarantine Officer, for carrying out initial operations in preparing seed for export. The ultimate examination of the seed is done by CPPTI authorities, who issue the Phytosanitary Certificates. It is gratifying to note that this arrangement has cut down the time required for clearance from 5 weeks to 1 week, and reduced manpower and transport costs by more than 80 percent. Without this arrangement, there was no hope of moving seed to our cooperators in other countries in time for effective planting. During the final quarter of this report year, more than 33 000 samples were processed through this laboratory.

Procedures for importing cuttings of wild species of *Arachis* from the Gregory collection at North Carolina University in the United States were finalized after negotiations with the Government of India. This material is first flown to the United Kingdom, where it is grown in glasshouses at the University of Reading. Healthy samples are then airlifted to India. This has removed a great bottleneck and will help ICRISAT in acquiring this most valuable collection.

Export of Seed Material

Export of seed material increased by 54 percent over that of 1976-1977. A total of 59 584 samples were exported to 27 countries in Africa, 17 countries in Asia, 16 American nations, 9 European nations, and 3 in Australasia (Table 112).

Table 112. Seed samples exported or imported by ICRISAT during 1977-1978.

Country	Sorghum		Pearl millet		Pigeonpea		Chickpea		Groundnut		Others	
	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp
AFRICA												
Botswana	687	26	60		21							
Cameroun	492											
Cape Verde Islands					15							

Continued

Table 112 *Continued*

Country	Sorghum		Pearl millet		Pigeonpea		Chickpea		Groundnut		Others	
	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp	Exp	Imp
Egypt			120				374					
Ethiopia	2 909	130	60	7			1 263	3				
Gambia	132		88									
Ghana	415		12									1
Kenya	1 103	2	20		147	73	20					
Libya	20						20					
Malagasy			14									
Malawi	184		72		15					143		
Mali	784		176		20							
Mauritania	60				6							
Mozambique	62											
Niger	755	2	2 806	194			3					
Nigeria	1 131	1	5800	32	162	5						1
Rhodesia			7									
Rwanda			9									
Senegal	714	82	4 670	4	32					16		
Sudan	2 074	290	1920	8			253	3				
Swaziland	51		11									
Tanzania	1357		203		36		56					
Tunisia							243					
Uganda			60									
Upper Volta	1851	4	12 758	657			4					
Zaire	70				11							
Zambia			60		36							
ASIA												
Afghanistan								14				1
Bangladesh	26	1			13		222		50		2	
Burma							165					
Iran							527					
Iraq							941					
Japan							500					53
Jordan							178					
Malaysia					24				38			
Nepal							149					
Pakistan	200		2				536	3				
People's Republic of China		9										
Philippines	1 264	3			53	1	20					
Sri Lanka	468	2			3							

Continued

Table 112 *Continued*

Country	Sorghum Exp	Sorghum Imp	Pearl millet Exp	Pearl millet Imp	Pigeonpea Exp	Pigeonpea Imp	Chickpea Exp	Chickpea Imp	Groundnut Exp	Groundnut Imp	Others Exp	Others Imp
Syria		1929					506	3				1
Taiwan		1			11							
Thailand	1070	495	62				30					
Yemen Arab Republic	6		208		16		214					
AMERICA												
Argentina							56					
Belize					6	1						
Bolivia	72											
Brazil	118	2	147			1						
Canada	32				843		325					
Chile			60				187	2				
Colombia	53		70		10							
Dominican Republic							10		30			
Mexico	709	227					419					
Panama						8						
Peru							224					
Puerto Rico		190			36	2 020						
USA	292	1038		11	70		106			514		11
Uruguay	47											
Venezuela	64		86			8	10					
West Indies			1		36	2					2	
EUROPE												
England	139		42				39			1086		
Federal Republic of Germany	1						4				1	
France	10											
Greece							16					
Italy	50			109								
Netherlands				63								
Spain					16							
Turkey		13					601					
USSR	15	67		9				16		3		
AUSTRALASIA												
Australia	51	3	77	1	63		154	4			2	13
Fiji					12							
Papua New Guinea	122								30			
	19 660	4517	29 681	1095	1 713	2 119	8 375	48	148	1 762	7	81
Total	24 177		30 776		3 832		8 423		1910		88	

Sorghum. The 19 600 sorghum samples exported consisted of breeding nurseries and trials, including "Elite Progeny Observation Nursery," "Grain Grass Trial," "*Striga*-resistant Nurseries I and II, "Progeny Yield Trials I and II," "Population Progeny Trials II, III, and IV," "Shoot Fly, Stem Borer, and Midge Nursery Trials," "Disease Nursery Trials (lines for selection for resistance to grain molds, leaf diseases, sorghum downy mildew, and charcoal rot)," as well as germplasm accessions, segregating breeding material, hybrids, and lines for conducting studies in longevity, physiology, biochemistry, and disease and pest resistance. Elite lines from AICSIP were also included in this activity.

Pearl millet. The 28 170 pearl millet samples included the International Cooperative Pearl Millet trials, made up of entries from "Adaptation Trial IV," "Source Material Hybrid Trial I," "*Striga* Nurseries," "Synthetics," "Early and Late Composite Material," and the International Pearl Millet disease nurseries for downy mildew, ergot, and smut.

A total of 1 511 millet cultivars—germplasm lines, segregating material, hybrids, synthetic varieties, composite bulks, A, B, and R lines, dwarf-population lines, and lines for conducting longevity and water-stress studies—were sent to 19 countries.

Pigeonpea. Of the 1 713 pigeonpea samples exported to 26 countries, 258 were entries from "Vegetable-type Pigeonpea Trials I and II," and "international Pigeonpea Adaptation Trial" for growing in Kenya, Nigeria, Tanzania, Republic of the Philippines, Puerto Rico, and the West Indies. Germplasm lines; replicated test lines; cultivars for testing for forage grain, and vegetable production; short-, medium-, and long-duration lines; cultivars from the variety-purification program; sterility mosaic wilt-resistant lines; and samples for biochemical studies were also processed.

Chickpea. Chickpea samples totaling 8 375 were cleared for shipment to 34 countries. These included seeds for the second year of international cooperative trials, specifically "International Chickpea Cooperative Trial," "Desi Short," "Desi Late," "Screening Nursery," "Root Rots/Wilt Nursery," and "*Ascochyta* Blight Nursery." Germplasm accessions; cultivars for conducting microbiological, physiological, biochemical, and longevity studies; and segregating material were dispatched to Japan, Chile, Canada, USA, Syria, Federal Republic of Germany, and Turkey.

Groundnut. A total of 148 groundnut cultivars were exported this year; recipients included cooperating scientists in the Dominican Republic, Bangladesh, Malaysia, and Papua New Guinea.

Other crops. Samples of *Setaria italica, Eleucine coracana, Cicer cuneatum,* and *C. judaicum* were examined and cleared at the National Bureau of Plant Genetic Resources in New Delhi for Australia, Bangladesh, Federal Republic of Germany, and the West Indies.

Rhizobium culture. Four-hundred vials of *Rhizobium* cultures were sent to the Rothamsted Experimental Station in the United Kingdom for experimentation. A consignment of 70 g of ICRISAT culture No. 3827 was sent to the agricultural experiment station at Addis Ababa University in Ethiopia.

Import of Seed Material

Nearly 10 000 samples of the crops researched by ICRISAT and miscellaneous crops were imported from 32 countries (Table 112).

Sorghum. Of the 4 517 sorghum samples imported, 644 represented accessions for the ICRISAT germplasm bank; they were received from Kenya, Senegal, Sudan, Brazil, Puerto Rico, Turkey, USSR, People's Republic of China, Philippines, Sri Lanka, and Australia. Other materials received included bulks, com-

Figure 116. Inspecting sorghum growing in the postentry quarantine isolation area at ICRISAT Center. All seeds from outside India are examined for phytosanitary acceptance, and then grown for one generation in the quarantine area to ensure absence of disease.

posites, sorghum x sugarcane crosses, segregating material, A and B lines, and cold-tolerant lines.

Pearl millet. Pearl millet samples were imported from 11 countries; the great majority (1 041 lines) represented germplasm accessions from Niger, Sudan, Upper Volta, the ORSTOM collection in Italy, Netherlands, USSR, and Australia. Fifty-four samples for use in the breeding and physiology subprograms were received from Ethiopia, Senegal, Nigeria, and USA.

Pigeonpea and chickpea. More than 2 000 samples of pigeonpea were added to the ICRISAT germplasm bank; they came from Kenya, Nigeria, Belize, Brazil, Panama, Puerto Rico, West Indies, and the Republic of the Philippines. Forty-five chickpea germplasm samples were received from Ethiopia, Sudan, Chile, USSR, Afghanistan, Pakistan, and Australia. Three chickpea cultivars possessing resistance to sterility mosaic were received from Syria.

Groundnut. Groundnut lines imported during the year included 1 086 unrooted cuttings from the University of Reading. An additional 676 entries included germplasm lines, rust-resistant lines, and cultivars for cytogenetic studies from Malawi, Senegal, USA, UK, and USSR.

Other crops. Eighty-one samples of *Atylosia* sp., *Cajanus karstingi,* cowpea, lentil, and virus-indicator plants were received from Australia, Ghana, Afghanistan, Nigeria, Syria, Japan, and the United States. These were cleared by the National Bureau of Plant Genetic Resources for use in the pulse germplasm and groundnut virology programs.

***Rhizobium* culture.** The Plant Protection Adviser to the Goverment of India authorized the introduction of 200 cultures of *Rhizobium* from North Carolina State University in the USA. Sixteen cultures have been received.

Postentry Quarantine

Seed of all materials, after release by Quarantine authorities, is grown in the Postentry Quarantine Isolation Area at ICRISAT Center for the first generation and closely examined for symptoms of exotic diseases. Inspection is conducted co-operatively by quarantine specialists of the Government of India and ICRISAT scientists. During the year, nearly 6 000 samples of the crops researched by ICRISAT were grown out and harvested for release to the crop-improvement programs.

Computer Services

The Computer Services Unit provides time-sharing services to ICRISAT personnel through the RSTS/E (Resource Sharing Time Sharing/ Extended) operating system running on a DEC PDP-11/45 Computer System.

OBJECTIVES

The goal of the Computer Services Unit is to integrate the use of the ICRISAT computer system into the daily routine of the research, administrative, and service departments of the Institute. In order to achieve this goal, the Computer Services Unit is (i) developing interactive systems which are easy to use, (ii) providing data-entry services, and (iii) conducting seminars on computer usage and programming.

CURRENT STAGE OF DEVELOPMENT

The capacity of ICRISAT's Computer System was doubled during July through December by the addition of more memory, a second disk drive, a second tape drive, and ten terminals. These additions permitted more people to simultaneously gain access to the computer system, and analyses were completed more quickly. Also, in order to increase the efficiency of computer terminal time and to permit computer users to concentrate on data analysis,

Figure 117. ICRISAT's computer system is integrated into the daily routine of the Institute's programs of research, administration and service, through interactive systems which are easy to use. Frequent seminars on computer usage and programming are held. In terms of Central Processing Unit (CPU) time, computer usage doubled during the year.

a data-entry service was introduced in July. The data-entry service prepares the disk resident files required for analysis and thus relieves the scientist of this time-consuming process. Since the initiation of this service, nearly half a million lines of data, averaging 14 variables per line, have been entered into 1 662 disk files by Computer Services personnel.

CRISP (Crop Research Integrated Statistical Package) continued to be expanded to meet the needs of ICRISAT scientists. The multiple regression option was improved to estimate models with up to 39 independent variables; a special regression package for estimating models from time-series cross-sectional data was developed ; analysis of variance routines for balanced lattice square, *line* x *tester*, and multilocational diallel experimental designs were completed; a linear-programming capability was added; a "missing plot" estimation routine for an RCB design was developed; a data-subsetting capability which permits selection of data based on logical combinations of characteristics imposed on the stored data was completed; the transformation utility was improved; and five additional data-editing and utility options were added to the file-maintenance subsystem.

An on-line fiscal accounting system, which permits accounts to be maintained on a daily basis, was completed. A prototype system for storing and maintaining ICRISAT's germplasm data was developed. Chickpea and pigeonpea germplasm data were entered into data files, and the sorghum germplasm data originally prepared at the University of Colorado was transferred from magnetic tape into this system.

Dr. Jerry A. Warren, statistical consultant from the University of New Hampshire, USA, returned to ICRISAT for 4 weeks during January-February, 1978. In addition to consulting with users about their statistical-analysis problems, he performed research in statistical methods for eliminating differences in responses due to field variation.

Mr. Hahn, Weon-Sik from the Office of Rural Development, Suweon, Korea, spent 9 weeks as a trainee in early 1978, to become familiar with our computer system and with CRISP.

Looking Ahead in Computer Services

The following projects are scheduled for consideration during the coming year:

i) Completion of a general data-management and -retrieval system which can be used for both research and administrative data.

ii) Revision and enhancement of the statistical-analysis collection.

iii) Addition of a payroll capability to the fiscal accounting system.

iv) Development of improved documentation for computer users.

Library

The present temporary accommodation at ICRISAT Center, although more spacious than its earlier accommodation in Hyderabad, is not sufficient. The present-day input of recorded knowledge in the Library is enormous and demands adequate area for smooth working. However, this difficulty is expected to be solved upon completion of its permanent quarters in early 1979.

Aims and Objectives

The Library plays an important role in serving as a center for world literature on major and related subjects of concern to ICRISAT. We are striving to make our services available to our cooperators throughout the SAT. A present effort involves the collection of literature on African agriculture.

Acquisition

Advanced and highly specialized research literature, including books and other documents pertaining to the areas of interest to ICRISAT scientists, have been procured. During this year, the Library acquired a total of 6 731 items. (Table 113).

Current Periodicals

During the year, 598 new periodicals dealing with the sciences, sociology, economics, and statistics have been subscribed. The subject-wise break-up of the periodicals is given in Table 114.

The Library is trying to cover all the scientific disciplines appropriate to our mandate and is also making special efforts to collect literature from various SAT regions. Assistance of our cooperators and our staff in Africa was sought in the attempt to improve our collection of African scientific literature.

Catalog

The card catalog of back volumes of periodical holdings has been maintained, as have the usual official, public catalog, shelf-list, and accession list. The theses catalog is also maintained independently. Back volumes and the subscribed completed volumes of periodicals have beed bound. In all, 2 600 books/periodicals were bound during the period of this report.

Interlibrary Loan

The ICRISAT Library, from its inception, has developed excellent relations with local and foreign libraries and documentation centers. During the 1977-1978 period, we have borrowed 1 162 documents from various libraries and loaned out 27 documents on interlibrary loan.

Table 113. Holdings and acquisitions, ICRISAT Library, 1977-1978.

	Total holdings, 31 May 1977	Added	Total holdings, 31 May 1978
Books	7 610	3 815	11425
Back volumes of periodicals	4 020	2 521	6 541
Microforms	860	395	1255
Total	12 490	6 731	19 221

Table 114. Periodical acquisition by the ICRISAT Library, 1977-1978.

	Source		
Subject	Other	Indian	African
Agricultural sciences	196	61	8
Biological sciences	70	15	3
Physical sciences	3	2	-
Social sciences, economics, and statistics	49	25	1
Others	124	37	4
Total	442	140	16

Figure 118. The location of the library at ICRISAT Center, though in temporary quarters, was a great convenience for ICRISAT's scientific staff. Access to information was also improved through acquisition of new holdings.

Reprints totaling 111 were supplied to interested scholars in India and other countries.

Annual Reports

The Library has updated its collection of annual reports of national and international institutes with areas of research similar to that of ICRISAT. Annual reports of 150 research institutes of 30 countries were added during this year. This helps our scientists in avoiding research-in-parallel and in planning their research-in-series. A unique collection includes copies of all papers and tour reports by ICRISAT scientists.

Publications

The Library continues to publish its Monthly List of Additions. A paper entitled "International Flow of Agricultural Research News Information" was presented at the All-India Seminar on Science News Service at Calcutta on 12 March 1978. Compilation of the *Bibliography of Indian Theses on Groundnuts Submitted to Indian Universities* and *Indian Literature on Groundnut upto 1976* is under way and is expected to be completed by the end of the year.

Sorghums and Millets Information Center (SMIC)

A world information center on sorghums and millets (SMIC) was initiated in 1976 and its documentation work commenced in 1977. Work is in progress for the creation of a data base on sorghums and millets in the English and French languages. Master copies of the references cited in existing bibliographies are being collected. At present various data bases such as CAB (UK): BIOSIS, CAS, NAL, ISI, and AGRICOLA (USA); RTI (Netherlands); CNRS and IRAT (France); and FAO-AGRINDEX (Italy) are extensively searched, and current and back volumes of periodicals are regularly scanned for world coverage of the literature on sorghums and millets. SSIE (USA) is also being consulted for project information. Statistics of the references collected are presented in Table 115.

Table 115. Number of French and English references in SMIC holdings at ICRISAT.

	Sorghums		Millets	
	English 1970-78	French 1900-78	English 1970-78	French 1900-78
References	4195	998	2 879	1011
Master Files	1111	713	1 166	304

The *Annotated Bibliography on Sorghum* (1900-1976) in the French language is almost completed, and will be published soon. The *Annotated Bibliography* (in English language) *on Sorghums and Millets* is also under preparation. The Library plans to publish annual supplements to update these bibliographies.

Termatrex Model 301, a semi-automatic device for information storage and retrieval was acquired by SMIC. It will use the *Thesaurus of Sorghums and Millets Terminology,* prepared by Don Leatherdale of IDRC, Canada, as a basic indexing tool.

SMIC is responsible for collection, documentation, and retrieval of all information on sorghums and millets. The Center plans to develop the capability of performing specific subject searches on demand and of maintaining profiles of sorghum scientists' specific subject-areas of research. A world directory of these workers is also under compilation and will be published by the end of the year.

ICRISAT Publications

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