ICRISAT
ANNUAL REPORT
1978-1979

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

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for the Semi-Arid Tropics
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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 sixth Annual Report covers research by ICRISAT for the crop year beginning 1 June 1978 and ending 31 May 1979. It includes work done at ICRISAT Center near Hyderabad, India, at substations on the campuses of agricultural universities in four different climatic regions of India, and at national and international research facilities in the nine countries of Africa, Latin America, and the Middle East where ICRISAT scientists are posted.

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. For easier management of material, the year's activities are, in general, reported unit by unit under individual research programs; however, it should be borne in mind that most research at.ICRISAT is highly interdisciplinary and the scientists work in teams. Their work is reported in more detail in individual program publications, which usually are available from the particular research program.

Contents

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Krishi Bhavan
New Delhi
India

a. Deceased Feb 1979
b. Now retired from service
c. Now Member, National Planning Commission

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Deputy Director General, IRAT
110 rue de l'Universite
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d. Deceased Jan 1979

ICRISAT Personnel—

31 May 1979

Administration

L.D. Swindale, Director
J.S. Kanwar, Associate Director, Research
R.C. McGinnis, Associate Director, International Cooperation
B.F. Dittia, Principal Administrator
V. Balasubramanian, Executive Assistant to the Director
S.K. Mukherjee, Personnel Manager (until Apr 1979)
N.S.L. Kumar, Personnel Manager (acting) (as of May 1979)
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A. Banerji, Assistant Manager (Fiscal)
R. Vaidyanathan, Purchase and Stores Manager
R. Seshadri, Assistant Manager (Purchase and Stores)
R.G. Rao. Records Manager
S.K. Das Gupta, Scientific Liaison Officer
A. Lakshminarayana, Scientific Liaison Officer (Jr)
S.B.C.M. Rao, Travel Officer
Col. P.W. Curtis, Security Officer
R. Narsing Reddy, Transport Officer
N. Rajamani, Liaison Officer, New Delhi Office

Crop Improvement

Cereals

J.C. Davies, Principal Entomologist, and Leader
L.R. House, Principal Plant Breeder (Sorghum)
D.J. Andrews, Principal Plant Breeder (Millets)
Aran Patanothai, Principal Plant Breeder (Millets) (as of Oct 1978)
F.R. Bidinger, Principal Physiologist
R.J. Williams, Principal Pathologist
Claude Charreau, Project Leader, West Africa Project, Senegal
A. Lambert, Principal Plant Breeder, Senegal
R.T. Gahukar, Principal Entomologist, Senegal
C M . Pattanayak, Principal Plant Breeder (Sorghum), and Team Leader, Upper Volta
P.K. Lawrence, Principal Plant Breeder (Millets), Upper Volta
W.A. Stoop, Principal Agronomist, Upper Volta
J.A. Frowd, Principal Plant Pathologist, Upper Volta
Ph. J. van Staveren, Assistant Agronomist, Upper Volta
J.F. Scheuring, Principal Plant Breeder (Sorghum and Millets), Mali (as of Jan 1979)
S.A. Clarke, Field Trials Officer, Mali (until July 1978)
P.J. Serafini, Field Trials Officer, Mali
B.B. Singh, Principal Plant Breeder (Millets), Niger
S.O. Okiror, Principal Plant Breeder, Nigeria
N.V. Sundaram, Principal Plant Pathologist, Nigeria
Gebisa Ejeta, Principal Plant Breeder (Sorghum), Sudan (as of Apr 1979)
R.P. Jain, Principal Plant Breeder (Millets), Sudan
Vartan Guiragossian, Principal Plant Breeder (Sorghum), Mexico
S.Z. Mukuru, Principal Plant Breeder (Sorghum and Millets), Tanzania
K.V. Ramaiah, Principal Plant Breeder (*Striga*), Upper Volta
Bholanath Varma, Plant Breeder (Sorghum)
D.S. Murthy, Plant Breeder (Sorghum)
B.L. Agrawal, Plant Breeder (Sorghum)
B.V.S. Reddy, Plant Breeder (Sorghum)
S.C. Gupta, Plant Breeder (Millets)
K. Anand Kumar, Plant Breeder (Millets)
B.S. Talukdar, Plant Breeder (Millets)
K.N. Rai, Plant Breeder (Millets)
N. Seetharama, Plant Physiologist
G. Alagarswamy, Plant Physiologist

R.K. Maiti, Plant Physiologist
K.N. Rao, Plant Pathologist
S.D. Singh, Plant Pathologist
R.P. Thakur, Plant Pathologist
S.R.S. Dange, Plant Pathologist
K.V. Seshu Reddy, Entomologist
R.V. Subba Rao, Microbiologist
S.P. Wani, Microbiologist
V. Mahalakshmi, Post-doctoral Research Fellow (as of Jan 1979)
S. Krishnan, Executive Assistant

Pulses

J. M. Green, Principal Plant Breeder (Pigeonpea), and Leader
K.B. Singh, Principal Plant Breeder (Chickpea), Alleppo, Syria
W. Reed, Principal Entomologist
Y.L. Nene, Principal Pathologist
P.J. Dart, Principal Microbiologist
D. Sharma, Sr. Plant Breeder (Pigeonpea)
I.V. Subba Rao, Pulse Physiologist (until June 1978)
K.C. Jain, Plant Breeder (Chickpea)
Onkar Singh, Plant Breeder (Chickpea)
C.L.L. Gowda, Plant Breeder (Chickpea)
S.C. Sethi, Plant Breeder (Chickpea)
Jagdish Kumar, Plant Breeder (Chickpea)
K.B. Saxena, Plant Breeder (Pigeonpea)
L.J. Reddy, Plant Breeder (Pigeonpea)
S.C. Gupta, Plant Breeder (Pigeonpea)
N.P. Saxena, Plant Physiologist
S.S. Lateef, Entomologist
S. Sithanantham, Entomologist
M.V. Reddy, Plant Pathologist
M.P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist
O.P. Rupela, Microbiologist
A.N. Murthi, Botanist (until Aug 1978)
J.V.D.K. Kumar Rao, Microbiologist
Satish Rai, Post-doctoral Research Fellow (as of Apr 1979)
G.K. Bhatia, Post-doctoral Research Fellow (as of May 1979)
I. Madhusudhan Rao, Post-doctoral Research Fellow (as of Apr 1979)

Groundnuts

R.W. Gibbons, Principal Plant Breeder, and Leader
W.C. Gregory, Consultant
J.P. Moss, Principal Cytogeneticist
Duncan McDonald, Plant Pathologist (as of Aug 1978)
K. Maeda, Visiting Scientist, Plant Physiology
N. Iizuka, Visiting Scientist, Virology
D.V.R. Reddy, Sr. Plant Pathologist (Virology)
S.N. Nigam, Plant Breeder
A.M. Ghanekar, Plant Pathologist
P. Subramanyam, Plant Pathologist
V.K. Mehan, Plant Pathologist (as of Dec 1978)
P.T.C. Nambiar, Microbiologist
P.W. Amin, Entomologist
A.K. Singh, Cytogeneticist

Farming Systems

B.A. Krantz, Principal Agronomist, and Leader
J. Kampen, Principal Agricultural Engineer (Soil and Water Management)
S.M. Virmani, Principal Agroclimatologist
R.W. Willey, Principal Agronomist
L.P.A. Oyen, Assistant Agronomist (until Aug 1978)
G.E. Thierstein, Principal Agricultural Engineer (Small Implements Development)
M.C. Klaij, Assistant Agricultural Engineer (Small Implements Development)
F.P. Huibers, Assistant Agricultural Engineer (Soil and Water Management)
M.B. Russell, Consultant, Soil Physics
J.R. Burford, Principal Soil Chemist (as of Oct 1978)
S.V.R. Shetty, Agronomist
Piara Singh, Soil Scientist
Sardar Singh, Soil Scientist
T.J. Rego, Soil Scientist
K.L. Sahrawat, Soil Scientist
M.V.K. Shiv Kumar, Agroclimatologist
A.K. Samsul Huda, Agroclimatologist (as of Aug 1978)
S.J. Reddy, Agroclimatologist
M.R. Rao, Agronomist

M.S. Reddy, Agronomist
M. Natarajan, Agronomist
V.S. Bhatnagar, Entomologist
R.C. Sachan, Agricultural Engineer
P. Pathak, Agricultural Engineer
J. Hari Krishna, Agricultural Engineer
P.N. Sharma, Agricultural Engineer
K.L. Srivastava, Agricultural Engineer (as of Aug 1978)
Harbans Lal, Agricultural Engineer
R.K. Bansal, Agricultural Engineer
O.P. Singhal, Agricultural Engineer
Kabal Singh Gill, Post-doctoral Research Fellow
S.K.. Sharma, Sr.Research Technician
Siloo Nakra, Administrative Assistant

Economics

J.G. Ryan, Principal Economist, and Leader
M. von Oppen, Principal Economist
H.P. Binswanger, Principal Economist
V.S. Doherty, Principal Social Anthropologist
N.S. Jodha, Senior Economist
D. Jha, Sr. Visiting Economist (as of July 1978)
V.T. Raju, Economist
S.L. Bapna, Economist
B.C. Barah, Economist
R.D. Ghodake, Economist
R.S. Aiyer, Administrative Assistant

Biochemistry

R. Jambunathan, Principal Biochemist
Umaid Singh, Biochemist
V. Subrahmaniam, Biochemist

Genetic Resources

M.H. Mengesha, Principal Germplasm Botanist, and Leader (as of July 1978)
L. J.G. van der Maesen, Principal Germplasm Botanist
K.E. Prasada Rao, Botanist
S. Appa Rao, Botanist
R.P.S. Pundir, Botanist
P. Remanandan, Botanist (as of Aug 1978)
V.R. Rao, Botanist

Plant Quarantine

K.K. Nirula, Plant Quarantine Officer

Fellowships and Training

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A.S. Murthy, Sr. Training Officer
B. Diwakar, Training Officer
T. Nagur, Training Officer

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T.A. Krishnamurthi. Administrative Assistant
S.M. Sinha, Senior Artist and Printshop Supervisor
K.S. Mathew, Editor/Writer (as of Sept 1978)
D.R. Mohan Raj, Editor/Writer (as of Dec 1978)
H.S. Duggal, Head Photographer

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J.A. Warren, Consultant
S.M. Luthra, Computer Services Officer

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Rama Tirth, Librarian (as of Mar 1979)

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G.B. Gaind, Assistant Manager (Food Services) (as of Apr 1979)
H.S. Ratnagar, Administrative Assistant
K.C. Saxena, Administrative Assistant

Physical Plant Services

E.W. Nunn, Station Manager
N.N. Shah, Project Manager (until Oct 1978)
F.J. Bonhage, Construction Supervising Officer
Sudhir Rakhra, Chief Engineer (Civil)
D. Subramanyam, Chief Engineer (Electrical)
B.H. Alurkar, Senior Engineer
Manmohan Singh, Senior Engineer
S.K. Tuli, Senior Engineer
T.J. Choksi, Senior Engineer
J.K. Majumdar, Senior Engineer (until Dec 1978)
S.S. Jangi, Engineer (until Jan 1979)
S.K. Samy, Engineer
D.V. Subba Rao, Engineer
A.R. Das Gupta, Engineer (as of Nov 1978)
A.E. Jaikumar, Architect
B.K. Sharma, Senior Engineer
S.K.V.K. Chari, Electronics Engineer
V. Lakshmanan, Executive Assistant
P.M. Menon, Executive Assistant

Farm Development and Operations

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S.N. Kapoor, Chief Engineer (Farm Operations)
D.N. Sharma, Senior Engineer
S.K. Pal, Plant Protection Officer
K. Santhanam, Executive Assistant

International Interns

Tetsuo Matsumoto, Microbiology
L.K. Fussel, Cereal Physiology
N.J. Neville, Groundnut Pathology

ICRISAT Center's Research Environment

Most of the research reported in this volume was carried out at ICRISAT Center, the Institute's main research facility in south-central India, with important contributions made by ICRISAT scientists posted at substations in India, and in Africa, Mexico, and Syria.

ICRISAT Center is located on 1394 hectares near the village of Patancheru, 25 km northwest of Hyderabad on the Bombay Highway. The experimental farm includes two major soil types found in the semi-arid tropics: Alfisols (red soils), which are light and droughty, and Vertisols (black soils), which 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 characterize the Hyderabad area. The rainy season, also known as monsoon or *kharif,* usually begins in June and runs into September; more than 80% of the 800-mm average annual rainfall occurs during these months. The postrainy winter season of October through January, also known as postmonsoon or *rabi,* is dry and cool and days are short. The summer season, hot and dry with daily temperatures between 36 and 43°C, is from February until the rains begin again in June.

These seasonal variations affect differently the growing of the different crops. Cereal crops grown during the postrainy season rely on residual soil moisture or on irrigation. In the hot dry summer season, temperatures at flowering time are very high; short-season crops may be grown if irrigation is provided. Chickpeas are planted in October or November and grown 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 additional genetic material for the breeding program. The soil and climatic conditions are ideal for the groundnut research applicable to SAT agriculture. In addition to the major effort under rainfed conditions in the normal growing season, irrigated groundnut crops are produced during the postrainy and hot dry summer seasons to facilitate progress in the breeding program.

Acronyms and Abbreviations Used in this Annual Report:

AICMIP	All India Coordinated Millet Improvement Project
AICPIP	All India Coordinated Pulse Improvement Project
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
AW	Autorite des Amenagements des Vallees des Volta (Authority for the Development of the Volta Valleys)
AWF	available water fraction
CMMV	cowpea mild mottle virus
CNRA	Centre National de Recherche Agronomique (National Agricultural Research Center)
COPR	Center for Overseas Pest Research
CRISP	Crop Research Integrated Statistical Package
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAS	days after sowing
DEC PDP	Digital Equipment Corporation Programmable Data Processor
DM	downy mildew
EAAFRO	East African Agriculture and Forestry Research Organization
FAO	Food and Agriculture Organization of the United Nations
FESR	Federal Experimental Research Station, Puerto Rico
GAM	Groupe d'A melioration des Mils (Millet Improvement Group)
HYV	high-yielding variety
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in Dry Areas
IDMRS	ICRISAT Data Management and Retrieval System
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
IPMAT	International Pearl Millet Adaptation Trial
1PMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery
IPMSN	Internationa] Pearl Millet Smut Nursery
IRAT	Institute de Recherches Agronomiques Tropicales et des Cultures Vivrieres (Institute for Tropical Crops Research)
IRRI	International Rice Research Institute
ISGMN	International Sorghum Grain Mold Nursery
ISCRN	International Sorghum Charcoal Rot Nursery
ISPYT	International Sorghum Preliminary Yield Trials
ISRN	International *Striga* Resistance Nursery
LAI	leaf area index
LER	land equipment ratio
MTSLDR	Multilocation Testing of Sorghum Lines for Drought Resistance

OAU	Organization for African Unity
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (Overseas Scientific and Technical Research Office)
PAR	Photosynthetically active radiation
PEQIA	Postentry Quarantine Isolation Area
PMHT	Pearl Millet Hybrid Trial
PMST	Pearl Millet Synthetics Trial
Pre-IPMDMN	Pre-International Pearl Millet Downy Mildew Nursery
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	semi-arid tropics
SDM	sorghum downy mildew
SMIC	Sorghum and Millets Information Center
SEPON	Sorghum Elite Progeny Observation Nursery
TSWV	tomato spotted wilt virus
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
VLS	Village-Level Studies

Director's Introduction

The Consultative Group on International Agricultural Research at its meeting in November 1978 approved the establishment of an ICRISAT core program in Africa. This will enable us to make a long-term commitment to research to find new and improved technologies for the countries and people in semi-arid tropical Africa. Current projections show that these countries will have enormous cereal deficits by 1990 if improved technologies are not evolved and implemented. ICRISATcan now help to do something about this real and urgent need.

ICRISAT has established a core program in Africa. This will enable us to make a long-term commitment to research to find new and improved technologies for the countries and people in semi-arid tropical regions there.

The main building program for ICRISAT Center at Patancheru, near Hyderabad, India, was completed this year. ICRISAT staff who have been housed in 20 or more separate buildings around Hyderabad and Patancheru have now been brought together in our fine new buildings. Thanks are due to the donors; to our architects, Messrs. Doshi, Stein, and Associates, for their splendid design; and to the eight contractors who built the complex. Better staff communication leading to more effective and more innovative research will result from this consolidation. We even have our own post office—ICRISAT Patancheru P.O., Andhra Pradesh, India 502 324.

In recognition of the need to bring greater research resources to bear on our two major cereals, the Cereal Improvement Program is being divided into separate Sorghum Improvement and Millet Improvement Programs. Each program will be provided with the full complement of scientific and support personnel, except that the Microbiology subprogram located in Millet Improvement will also work on sorghum, and the Entomology subprogram located in Sorghum Improvement will also work on millets.

The various activities for the collection, maintenance, description, and distribution of the germplasm of our mandate crops have been consolidated into a single Genetic Resources Unit, which will also operate new long-term germplasm storage facilities when they are completed.

Advanced breeding material for pearl millet continues to lead the way in our crop improvement work. Some of the material first entered into the All India millet improvement trials 3 years ago is now reaching the stage of foundation seed increase. Virtually all the material released by ICRISAT is moderately or highly resistant to downy mildew, the most prevalent major disease of this crop. Male-sterile lines of pigeonpea that can be used in the production of high-yield hybrids represent an important breakthrough for this grain legume crop and are exciting the interest of pigeonpea breeders in national programs. Good progress is also being made on our other three mandate crops, and sorghum selections made by ICRISAT plant breeders are being multiplied for farmer use in Mali and Upper Volta.

The new farming systems package for rainy-season cropping of deep Vertisols has proved successful for a seventh year of experimentation at ICRISAT. The package will now be tested on farmers' fields in three of the six villages in India where our economists have been living for

The main building program for ICRISA T Center at Patancheru, near Hyderabad, India, was completed this year. Above is the administration building.

the past 3 years. In this first year of on-farm experimentation we tested crop combinations proposed by the farmers themselves and by the cooperating scientists in the local agricultural universities. Use of the ICRISAT package of practices on small watersheds will commence next year, taking account of these preliminary results.

Improvement of our research facilities continues. An additional 140 ha of arable land was developed and brought under cultivation at ICRISAT Center during the year, increasing the total cultivated area of the research farm to 725 ha. Drainage in the precision fields was improved, and the irrigation facility was extended from 200 ha to 300 ha in research areas demanding moisture control. Land improvements were also completed at two of our Indian substations, Hissar and Bhavanisagar.

We held workshops and conferences this year to improve our communications with scientists in participating countries and to sort out new directions for ICRISAT research. They included such subjects as intercropping, agroclimatology, the diseases of sorghum, and soilborne diseases of chickpea.

A workshop on socioeconomic constraints was held to determine the nature of our future program in Africa. It was preceded by two detailed, comprehensive surveys of the literature on production and marketing economics in Sahelian countries, conducted by Dr. David Norman of the Kansas State University and Dr. Barbara Harriss of the University of East Anglia. These social scientists were unanimous in their view that new technology, not just adapted technology, was essential to development in the Sahelian countries.

A major event of the year was the in-depth review of ICRISAT conducted by a panel of nine experts headed by Dr. Lloyd T. Evans acting on behalf of the Technical Advisory Committee of the CGIAR. I am pleased to report that the panel was highly commendatory of ICRISAT and its work and understood full well the tremendous

A major event of the year was the in-depth Quinquennial Review of ICRISAT by a panel of nine international experts. Here panel members review the progress made in developing new pearl millet male-sterile lines.

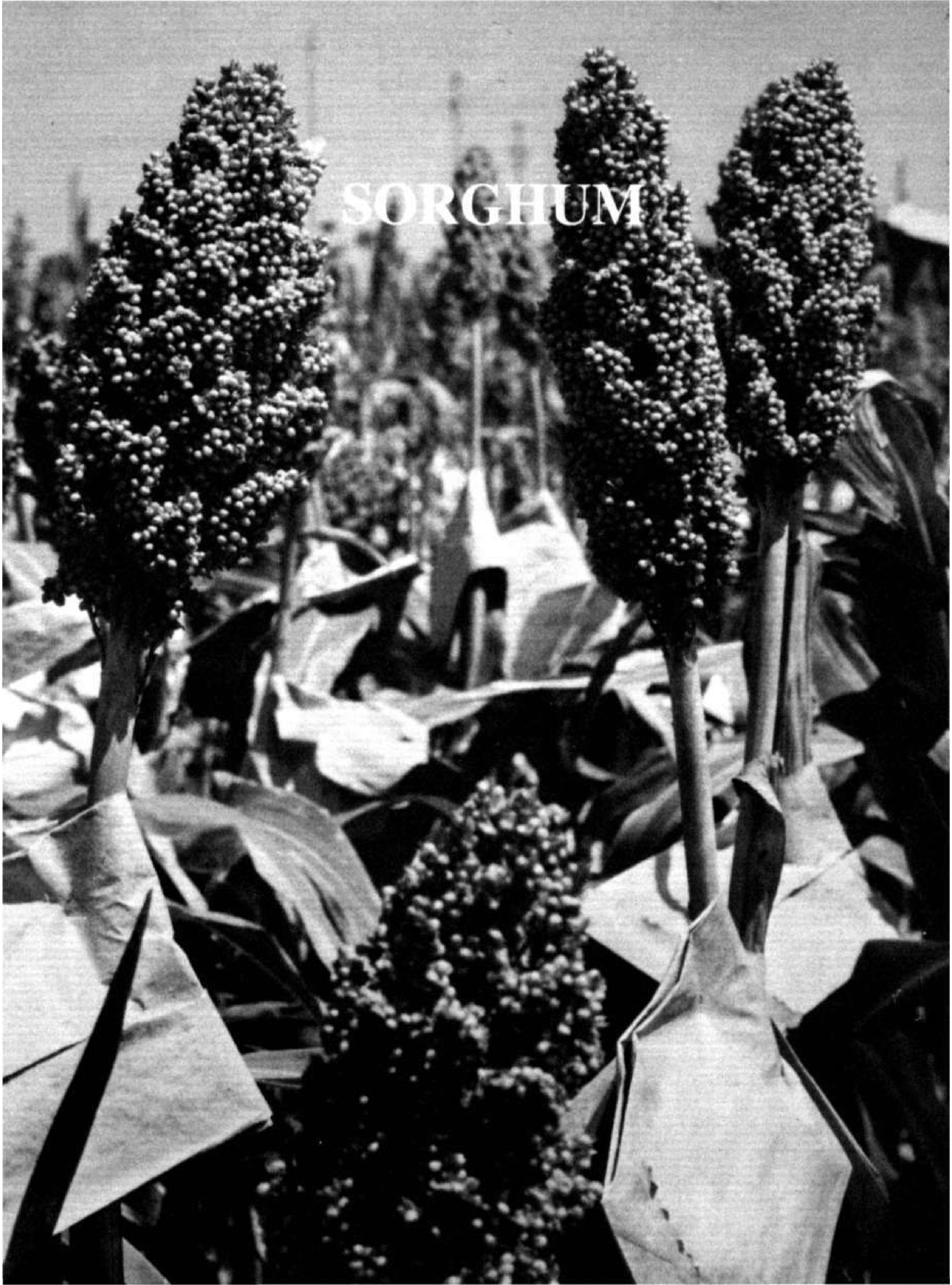
challenge we face in fulfilling our mandate towards improving the health, wealth, and way of life of the people of the semi-arid tropics.

Finally, I would like to record my thanks to our many collaborators and cooperators in India, in Africa, and other areas of the SAT and the developed world. Especially appreciated is the continuing strong commitment and support received from the Governments of India and Upper Volta and the State Government of Andhra Pradesh, India. Without their aid ICRISAT could not flourish.

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

SORGHUM



SORGHUM

Breeding

Population Breeding

To meet the long-term objective of providing improved breeding material to the national programs, a number of broad-based random-mating sorghum populations have been developed. Testing of selected lines in International Sorghum Preliminary Yield Trials (1SPYT) has indicated that with improvements in the base population there is improvement in the lines extracted from them. However, some high-yielding derivatives lack agronomically important traits. Therefore, a crossing program has been undertaken to improve these elite lines by pedigree methods of breeding.

Another important extension of the population improvement program has been the incorporation of additional useful variability into random-mating populations. During the past few years several good sources of resistances to grain mold, shoot fly, *Striga,* and stem borer have been identified. These sources of resistances have been crossed to random-mating populations in order to enhance the opportunity of selection for these traits.

Potential varieties of sorghum from ICRISAT are seed increased for international distribution.

International Sorghum Preliminary Yield Trials (ISPYT)

The ISPYT are composed of the most-advanced-generation elite lines derived from the random mating populations under recurrent selection at ICRISAT Center. During 1978, the lines were grouped into two maturity types for separate trials: early types that flowered in less than 60 days at ICRISAT Center were placed in ISPYT-1, and medium to medium-late maturing types that flowered after 60 days from planting were tested in ISPYT-2. Each of these trials was distributed to 28 locations in the semi-arid tropics.

ISPYT-1. This trial consisted of 30 early maturity lines. Data were returned from 17 locations, a substantially better return than that of the previous year, and more are expected from locations where the crop is grown at a different time of the year. At the 12 locations where it was possible to make an analysis of variance for grain yield, the coefficient of variation (CV) ranged from 14 to 46%, and was less than 20% at only six locations. The grain yield of some good entries is given in Table 1.

Several lines produced higher grain yield than the local check at each location. Diallel Pop-7 was outstanding at Nazareth in Ethiopia and at Rahuri in India; it averaged third in rank over 12 locations. Bulk-Y-398 ranked first at Hissar and Indore (India) and second at Dharwar (India) and Nazareth (Ethiopia). A nonrestorer line, US/B-292, performed better at almost all locations in Africa than in India. Similarly, Bulk-Y-138 was good in Africa.

On the basis of the mean performance over locations, FLR-53—a line from the Fast Lane-R population—gave highest grain yield, followed by SC-108, a check developed by Texas A & M .

ISPYT-2. This trial consisted of 60 medium to medium-late maturity lines. Data were reported from 20 of the 28 locations, but some locations did not report the grain yield. The analysis for grain yield was performed on data from 14 locations. The results from trials with coefficients of variation of 35% or less are reported in Table 2. Indian Syn-235 gave the highest mean yield, followed by Bulk-Y-1253. The variety GG-1483 performed well in West Africa and ranked first in Upper Volta, Mali, and Ghana.

S_2 Progeny Evaluation Trials

These trials were conducted for three random mating populations—US/R, US/B, and West African Early. This was the second cycle of S_2 testing for US/R and US/B populations and the first for the West African Early population. The tests included 195 S_2 lines from each population, along with five checks. All trials were conducted at ICRISAT Center, and at ICRISAT regional substations at Bhavanisagar and Dharwar. In addition, the US/R trial was conducted at Kobo, Ethiopia; the US/B trial at ICRISAT Cooperative Center in Sudan; and the West African Early trial in Upper Volta and Thailand. The mean grain yield in the US/R S_2 progenies ranged from 1819 to 6571 kg/ha, with an overall population mean of 4150 kg/ha; the best check, SC-108, yielded 3778 kg/ha. Based on overall performance of S_2 lines for grain yield and other agronomic traits, 30 S_2 lines, along with nine other lines selected as sources of resistance to pests and diseases, were recombined the following season to synthesize the population. Similarly, 31 lines were selected from the US/B S_2 progeny evaluation trial for recombination along with ten good nonrestorer lines.

The data on S_2 progenies of the West African Early population received from the five test locations showed many lines at each location with significantly higher grain yield than the local check. The mean grain yield of the entire population at all five locations was 3142 kg/ha. Thirty-seven lines with a mean grain yield of 3429 kg/ha were selected for recombination, thus providing a selection differential of 287 kg/ha. Since this population has good adaptation in West Africa, selection of the lines was biased towards those performing well there.

Table 1. Grain yield[a] and rank[b] of selected entries in ISPYT-1 (1978).

Pedigree	India: Dharwar	India: Bhavani-sagar	India: Indore	India: Rahuri	India: Pantnagar	India: Hissar	Sri Lanka[c]	Thailand[c]	Mali[c]	Nigeria[c]	Ethiopia[c]	Botswana[c]	Mean[c]
FLR-53	5999	2437	2901	5698	3795	1533	2650	3614	1055	1042	5360	4233	3360
	(3)	(20)	(13)	(4)	(5)	(13)	(24)	(4)	(14)	(17)	(3)	(3)	(1)
US/R-408	5366	2775	1512	5556	3225	1600	3638	3278	1047	660	4240	3667	3047
	(6)	(17)	(30)	(5)	(14)	(8)	(3)	(8)	(15)	(26)	(10)	(8)	(7)
US/B-292	4492	2850	2593	4843	2214	1617	3234	3366	957	1771	5020	3900	3072
	(15)	(12)	(24)	(16)	(22)	(7)	(13)	(7)	(18)	(4)	(4)	(7)	(6)
Rs/R-677	2625	3888	2670	5484	2059	1433	2964	3417	1813	1667	3413	3633	2922
	(30)	(2)	(22)	(7)	(25)	(17)	(18)	(5)	(2)	(6)	(16)	(9)	(12)
Diallel Pop-7	5250	3150	3256	6695	2939	791	3234	2152	1309	868	6953	2367	3247
	(7)	(9)	(7)	(1)	(16)	(22)	(12)	(28)	(7)	(21)	(1)	(23)	(3)
Bulk-Y-138	3733	1600	2824	4986	3496	625	3099	4197	1445	1076	3367	5567	3001
	(23)	(29)	(18)	(14)	(10)	(26)	(17)	(1)	(4)	(13)	(18)	(1)	(10)
Bulk-Y-351	4141	2625	2948	4416	3600	1458	3189	2922	1082	1042	4700	4000	3011
	(20)	(19)	(11)	(20)	(8)	(14)	(14)	(14)	(12)	(18)	(7)	(4)	(9)
Bulk-Y-127	4744	3088	3410	5271	3979	1600	3369	2973	1246	1424	4340	3300	3227
	(13)	(10)	(6)	(11)	(4)	(9)	(9)	(13)	(9)	(8)	(9)	(11)	(4)
Bulk-Y-398	6368	750	3858	4630	1741	2017	2628	3090	1129	1076	5427	2100	2926
	(2)	(30)	(1)	(18)	(28)	(1)	(25)	(10)	(10)	(14)	(2)	(25)	(11)
Indian Syn-398	4472	2038	3441	5199	4508	1708	3548	3371	1320	1007	3193	4600	3201
	(16)	(27)	(4)	(12)	(1)	(4)	(5)	(6)	(6)	(19)	(22)	(2)	(5)
SC-108	5541	3625	2840	5769	3761	1433	3638	3870	1328	1632	2827	3933	3350
	(4)	(3)	(17)	(3)	(6)	(16)	(4)	(18)	(5)	(7)	(26)	(5)	(2)
CSV-4	4628	3213	3580	5555	3574	283	3369	3083	914	556	1307	1967	2669
	(14)	(21)	(3)	(6)	(9)	(29)	(8)	(11)	(19)	(29)	(30)	(26)	(19)
Local Checks	5192	3225	2701	2137	2254	ND	2875	3071	234	1875	3247	2633	
	(8)	(7)	(20)	(30)	(21)		(20)	(12)	(30)	(3)	(20)	(10)	
Trial Mean	4515	2744	2843	4784	2965	1254	3034	2900	1015	1145	3751	2963	
CV (%)	14	25	19	16	17	37	19	18	22	46	21	26	
LSD at 5%	1338	1424	1098	1556	1062	939	1183	1069	462	1083	1617	1571	

a. Grain yield (kg/ha) based on plot size ranging from 3.6 to 7.5 sq m in different locations with two replications.
b. Figures in parentheses indicate rankings.
c. Station locations are as follows: Sri Lanka—ARS, Mahailuppallama; Thailand—Khonkaen; Mali—Morté; Nigeria—Kano; Ethiopia—Nazareth; Botswana—Sebele.
ND = No data

Table 2. Grain yield[a] and rank[b] of promising lines of ISPYT-2 (1978).

	India									
Pedigree	Dharwar	Bhavani-sagar	Indore	Hissar	Sri Lanka[c]	Thailand[c]	Upper Volta[c]	Mali[c]	Ghana[c]	Mean
Indian Syn-235	5970	2950	3781	1683	2515	4658	4817	2992	720	3343
	(2)	(8)	(17)	(4)	(16)	(8)	(3)	(14)	(5)	
Bulk-Y-1253	7330	2500	4830	1283	2560	2763	4633	2898	587	3265
	(1)	(22)	(5)	(17)	(14)	(51)	(4)	(16)	(21)	
GG-i482	5386	1938	3472	917	2336	3573	5750	4391	947	3190
	(5)	(43)	(22)	(35)	(26)	(30)	(1)	(1)	(1)	
Bulk-Y-1020	4997	2913	5015	1783	2560	4118	3208	2523	511	3070
	(13)	(9)	(3)	(1)	(15)	(18)	(33)	(23)	(33)	
Indian Syn-250	4744	1725	3410	1283	1999	5615	3017	3836	890	2947
	(17)	(51)	(24)	(15)	(41)	(2)	(37)	(3)	(2)	
Indian Syn-195	3990	1850	4877	1583	2358	3316	4375	2797	644	2866
	(38)	(46)	(4)	(7)	(23)	(40)	(7)	(17)	(17)	
Indian Syn-422	5192	2400	3472	1750	1752	3205	3900	2273	170	2679
	(8)	(24)	(21)	(2)	(48)	(42)	(16)	(37)	(59)	
SC-108	4511	3338	2994	1383	2381	3129	3283	3164	303	2721
	(23)	(5)	(38)	(12)	(22)	(43)	(30)	(8)	(54)	
CSV-4	4705	1875	3318	617	2785	4870	2192	2266	303	2548
	(18)	(45)	(27)	(47)	(7)	(6)	(58)	(38)	(54)	
Local	4511	3725	6250	ND	3369	3898	3500	3703		
	(22)	(1)	(1)		(1)	(23)	(22)	(4)		
CV(%)	17.2	31.2	20.7	27.0	18.6	19.2	30.5	35.0		
LSD at 5%	1410	1444	1362	1177	1361	1285	1515	375		

a. Grain yield (kg/ha) based on a plot size ranging from 3.6 to 7.5 sq. m at different locations and two replications.
b. Figures in parentheses indicate ranking.
c. Station locations arc as follows: Sri Lanka—ARS, Mahailluppallama; Thailand—Khonkaen; Upper Volta—Kamboinse; Mali—Cinzana; Ghana—Nyankpala.
ND = No data.

Breeding for Postrainy-Season Sorghum Types

Two trials conducted during the 1978 postrainy season consisted of entries that looked promising in the breeding nursery of population lines during the 1977 postrainy season. The crop ripened in moisture-stress conditions, and there was severe lodging due to charcoal rot. Also, there was heavy infestation of rust quite early in the growing period. This gave an opportunity to screen against charcoal rot and rust and also to measure the yield.

The promising lines with good yield and less susceptibility to charcoal rot and rust are presented in Tables 3 and 4. Several lines in both trials yielded significantly more than the checks, Maldandi (local) and CSH-8 (a released hybrid from the All India Coordinated Sorghum Improvement Project).

Grain Quality

Sorghum varieties that mature 2 to 5 weeks earlier than local ones are of great interest to breeders. Yields of early maturing varieties are usually better if the rainy season is shorter than expected. If the rains continue beyond expectation, the crop faces a severe problem of grain molding. A search for food-quality sorghums with grain mold resistance has been under way at ICRISAT for several years, and varieties with good levels of resistance to *Curvularia* and *Fusarium* molds have been identified. This material is now widely used in the SAT, while our research continues to seek yet higher levels of resistance to grain molds.

Sorghum Elite Progeny Observation Nursery (SEPON)

SEPON-1978, comprising 46 elite selections (F_6 and F_7 generations) from adapted x mold-resistant crosses, was dispatched to 21 cooperators in 15 SAT countries. The nursery was planted as a replicated yield trial in some locations only, while at others unreplicated observation plots were sown. Results on the overall performance were available from 18 locations in 12 countries, and 6 to 20 entries were selected by various cooperators. Table 5 presents the significantly better performers across locations out of 48 entries tested. A majority of the entries were relatively less susceptible to leaf diseases, although a few were highly susceptible to sooty stripe and anthracnose. Some of the entries did exceedingly well under low rainfall conditions in Botswana. In Mali, Entry No. 13 yielded 1300 kg/ha more than the local check. In Upper Volta, Entry Nos. 15 and 8 yielded much higher than the local check, while in Sudan, Entry No. 42 produced the highest yield. Mean yields across locations indicate entries 15 and 17 as the best.

Table 3. Grain yield[a] and rank of promising selections from sorghum Trial 1 conducted in the 1978 postrainy season.

Pedigree	Grain yield (kg/ha)	Rank
Indian Syn-387-1	2467	1
2KX17	2458	2
US/R-408-405	2433	3
Bulk-Y-1047	2308	4
GG-1483	2192	5
GG-1485	2133	6
Diallel-12-875	1917	8
Diallel-1008-771	1892	9
Diallel-1008-778	1850	12
CSH-8	1208	30
Maldandi	1017	34
CV(%)	19	
LSD at 5%	454	

a. Grain yield (kg/ha) based on 6 sq m with four replications.

Table 4. Grain yield" and rank of the promising Uses from sorghum Trial 2 conducted in the 1978 postrainy season.

Pedigree	Grain yield (kg/ha)	Rank
Indian Syn-405-2	2633	I
GG-1485	2608	2
Diallel-1008-761	2567	3
Indian Syn-395	2549	4
Indian Syn-315	2549	5
Diallel-12-876 Tall	2417	7
Diallel-465-813	2333	9
Diallel-1008-36	2317	10
Indian Syn-385-3	2233	11
CSH-8	1267	69
Maldandi	1400	61
CV (%)	12	
LSD at 5%	403	

a. Grain yield (kg/ha) based on 6 sq m with two replications.

Regional Tests

Yield trials comprising 145 F_6 and F_7 generation lines were conducted in the rainy season at ICRISAT Center, Dharwar, and Bhavanisagar. In Dharwar there was a good opportunity to assess leaf rust incidence, while at Bhavanisagar grain mold damage, particularly by *Phoma,* was scored. Grain yield ranged from 3500 to 6500 kg/ha. On the basis of overall

Table 5. SEPON-1978, grain yield (kg/ha) performance across locations of the significantly better performers out of 48 entries tested.

Entry	Pedigree	India				Sudan	Upper Volta	Mali	Kenya		Bots-wana	Thai-land	Mean
		Hydera-bad	Bhavani-sagar	Dharwar	Kovil-patti				Kampe-Ya Mawe	Katu-mani			
3	(SC-1-8-3 × CS-3541)-19-1	5549	5661	5849	1944	2410	1567		4955	3733	4373	1518	3756
5	" 29-1	3548	3737	3879	2055	3157	2300	3230	6155	6910	933	1609	3410
7	" 51-1	3896	4412	4238	2855	3638	1350		5408	4777	2133	1680	3439
8	(SC-108-4-8 × CS-3541)-13-1	6176	4437	6027	1555	2890	2342		6588	6622	2313	1865	4081
9	" 15-2	6764	3687	4999	550	2376	1170	2240	4577	5699	2940	1256	3296
13	(SC-108-4-8 × CS-3541-43-1	5424	5221	7187	2389	3244	1592	3600	6288	2778	4107	2106	3994
14	" 56-1	6353	4562	7189	1600	2984	1984	2830	7366	4611	2554	2044	4007
15	" 88-1	7650	6400	6740	1555	2609	3484		9210	4011	2160	2368	4619
17	(SC-108-4-8 × 2219B)-31-1	6481	4937	8453	1133	2754	2800		8921	4588	2866	2040	4497
28	(SC-108)-3 × E35-1)-29-2	5405	5455	5877	3111	3060	1350		5688	6055	400	1820	3822
29	(CS-3541 × IN15-2)-26-1	5462	5026	5333	3333	3377	833		4986	1678	2347	2038	3441
42	[(CS-3541 × 2KX6-2)9327]-20-1	4555	4217	4131	1778	5811	1192	2220	6377	4722	4640	1835	3771
43	" 23-1		3562	5671	933	2437	1250		5499	3289	267	1593	2722
47	CSH-6	6231	4017	5576	1500	2824	2359	2440	7433	378	3093	2065	3447
48	Local	4748	4056	2601	NA	718	1142	2300	7444	7577	3973	1412	3597

NA = Not applicable.

performance, six entries were selected from these experiments for the All India Coordinated Sorghum Improvement Project Preliminary Yield Trials (1979). The grain yield performance and other attributes of the six entries, along with one hybrid and two varietal checks are listed in Table 6.

Selection for Grain Mold Resistance

Selections in the field. A total of 3140 F_3, F_4, F_5, and F_6 progenies and 487 less susceptible checks from 1977 testing were screened for resistance to the two grain molds *Curvularia* and *Fusarium* in the rainy season in collaboration with the pathology unit. Plantings of these and susceptible checks were repeated frequently. All rows were evaluated for their reaction to *Curvularia* and *Fusarium* on a scale of 1 to 5. Relatively clean panicles (with a score of 3 or less) with good grain quality were selected. The results of selection are summarized in Table 7.

Efforts to diversify the genetic origin and plant morphology of the breeding material were intensified. Using resistant sources for grain mold, charcoal rot, shoot fly, stem borer, and interesting lines from the world collection with good grain quality, 1292 new crosses were made, of which 723 were single, 376 were double and three-way, and 193 were intercrosses. F_1 generation material from 1756 crosses made in previous seasons was also grown. The mold-resistant composite was backcrossed for the third time with less mold-susceptible selections from the rainy season.

In observation plots incorporating frequent checks, 1687 hybrids were evaluated. During the postrainy season, 922 hybrids with mold-resistant seed parents were inoculated with charcoal rot, 69 were found to beless susceptible. Seed of selected hybrids was increased for replicated yield testing in India in 1979. Sixteen entries were found to be nonrestoring and eight are being developed into male-sterile seed parents for hybrids.

Breeding for Charcoal Rot Resistance

The stalk rots, particularly charcoal rot, have caused severe grain losses in a number of

Table 6. Performance of some elite sorghum selections in India in the 1978 rainy season.

Pedigree	Days to flower[a]	Plant height[a] (cm)	Grain yield (kg/ha)[b] Hyder-abad	Dharwar	Bhavani-sagar	Mean	Rust	Grain mold	Char-coal rot	Food quality[c]
(SC-108-3 x 3541)-19-1	69	172	5 496	5849	5661	5668	2.0	2.5	3.0	1.0
(SC-108-3 x E-35-1)-29-2	71	181	5405	5877	5455	5579	2.5	2.0	2.5	1.5
(SC-108-4-8 x 3541)-40-l	73	182	4825	5527	5650	5334	2.0	2.5	2.0	2.0
(CS-3541 x IN-15-2)-26-l	67	174	5463	5333	5026	5274	2.0	2.5	2.5	1.5
(SC-108-3 x 3541)-51-1	68	154	3 896	4238	4400	4178	2.0	2.5	2.5	2.5
(SC-108-3 x 3541)-3-l	66	151	5 348	5817	4557	5240	2.0	3.0	3.0	2.0
CSV-3 (370)	70	176	4748	2601	4056	3801	4.5	5.0	4.0	5.0
CSV-4(3541)	73	141	4131	4460	3125	3905	2.0	3.0	3.0	3.0
CSH-6	64	167	6231	6576	4017	5608	3.0	3.0	4.0	2.0

a. Average across locations.

b. Grain yield data is quoted from replicated trials with plot size of 18.0,7.3, and 4.0 sq m in Hyderabad, Dharwar, and Bhavanisagar, respectively. Percent moisture of the grain from Hyderabad ranged from 10.0 to 11.5.

c. All characters were scored on a scale of 1 to 5 where, 1 = no molds, 2 = less than 10% grains moldy, 3 = 11 to 25% grains moldy. 4 = 26 to 40% grains moldy, and 5 = more than 40% grains moldy.

Table 7. Mold-resistant selections of sorghum obtained in the 1978 rainy season by screening 3627 F_3, F_4, F_5, and F_6 generation progenies (inoculated with *Curvularia* and *Fusarium*).

	Score[a]				
Origin	1.5	2.0	2.5	3.0	Total
1977 selections					
Single crosses	11	44	2	0	57
Three-way crosses	0	4	0	0	4
Segregating generations					
Single crosses	10	29	4	2	45
Double crosses	5	2	1	0	8
Three-way crosses	42	86	8	4	140
Total	68	165	15	6	254

a. Score. 1 = no molds. 2 = less than 10% grains moldy, 3 = 11 to 25% grains moldy, 4 = 26 to 40% grains moldy, and 5 = more than 40% grains moldy.

countries, including India, Ethiopia, Tanzania, Upper Volta, Mexico, Colombia, and Nicaragua. This disease, caused by *Macrophomina phaseolina* (Tassi) Goid, is generally associated with high temperature and stress, particularly drought stress.

Identification and development of source material is an important step in breeding for resistance to this disease. In cooperation with the pathology group, screening for resistance to charcoal rot began in the 1977-78 postrainy season.

Screening for Resistance to Charcoal Rot

The 28 lines selected from the 1977-78 postrainy season were organized into a nursery by our pathologists and screened at eight locations outside India and eight locations within India. Of these locations, the disease was most severe at Nandyal, Andhra Pradesh, India. Based on the disease score at Nandyal, 11 parental lines were found least susceptible to the disease. Several breeding materials (F_1 to F_5) were generated from these parental lines (Table 8). These were screened using tooth-pick inoculation technique in the 1978-79 postrainy season at Hyderabad.

The initial screening in the 1978-79 postrainy season included different sets of materials with the aim of diversifying potentially promising source materials. The nature of the materials and the number of lines screened and selected are given in Table 9. Fifty-one selections were made.

The 50 entries selected as less susceptible to the disease from the 1977 postrainy season initial screening were screened in the 1978 postrainy season at Hyderabad and Dharwar.

At Dharwar, the disease spread was greater than at Hyderabad (1.19 mean number of nodes crossed vs 0.39 in the early flowering, 1.24 vs 0.59 in the medium flowering, and 1.49 vs 0.74 in the late flowering group). The correlations for the mean number of nodes to which the disease spread within the stems at Dharwar and at Hyderabad were not significant in all three maturity groups. The coefficients of variations for the mean number of nodes crossed were large (43 to 65%), suggesting substantial environmental effects at each location. This may be partly responsible for the low levels of correlations. Efforts to improve the screening technique and to better understand the environmental influence on the expression of charcoal rot are in progress.

Under moisture-stress conditions susceptible varieties were devastated by charcoal rot. A resistant variety (background) was selected for use in our breeding program.

Table 8. Least susceptible parental lines and the number of various generations of sorghum breeding materials screened for charcoal rot at Hyderabad in the 1978-79 postrainy season.

	Number of					
Parental lines	F_1s	F_2s	F_3s	F_4s	F_5s	Total
(954063 x CS-3541)-30	172	80	48	11		311
(954068 x CS-3541)-II	163	24	15			202
(954068 x CS-3541)-64	106	53	6			165
SC-120-14	83					83
CS-3541	278	128	914	68	10	1398
IS-121	79	13	1			93
IS-1235	137	37	2			176
4-22	120	13				133
8-55	7	3				10
20-87	184	88	28			300
21-78	6	5				11
Total	1335	444	1014	79	10	2882

Table 9. Natare and number of sorghum Hues screened and selected from the charcoal rot 1978 79 postrainy season screening nursery.

Material	No. of Entries	
	Tested	Selected
MTSLDR[a]-1979-Early	52	15
—Medium	55	4
" — Late	45	3
Karper's Nursery	108	11
R-lines from B4 field 1978 rainy season	52	0
Shoot fly-resistant lines	12	1
Stem borer-resistant lines	21	0
Bijapur material	45	0
Rabi selections (germplasm)	53	7
Murty's classification (germplasm)	58	10
Population derived B-lines	79	0
Conventional B-lines	76	0
B-lines from B4 field 1978 rainy season	59	0
Total	715	51

a. MTSLDR-1979-Multilocation Testing of Sorghum Lines for Drought Resistance.

Breeding for Pest Resistance

Shoot Fly (*Atherigona soccata* Road.)

This year an effort was made to evolve a more effective and efficient screening technique for the shoot fly. All undamaged plants were identified within 4 weeks of emergence in order to avoid confusion among factors contributing to resistance.

One of several mechanisms contributing to resistance to the shoot fly is oviposition nonpreference; it was found to be associated with the presence of trichomes (microscopic hairs) on the leaves. At times, eggs are laid even on trichomed lines, but few deadhearts are formed. It appears that trichomes offer mechanical resistance by interfering with the migration of the maggot to the feeding point.

Observations for oviposition nonpreference and the presence or absence of trichomes were made on undamaged plants to sort out escapes and to categorize the identified resistant material. Material identified in one of four categories (Table 10) shows that contribution of trichomes and antibiotic factors to shoot fly resistance was in equal proportion, indicating that antibiotic factors are also important.

During the 1978 rainy season, 3223 undamaged plants were identified, but only 1089 agronomically superior ones were harvested. The number of escapes was less than 7%.

During the rainy season, 480 single crosses between resistant and agronomically elite lines were made, 109 single crosses were evaluated, and 26 agronomically superior crosses were selected.

During the 1978 postrainy season, 188 more single crosses were made. The 480 crosses made during the previous season were advanced, and 205 of the best crosses were selected.

In the 1978 postrainy season, the harvest from the 1978 rainy season was planted for retesting in the first week of January 1979. The shoot fly population at that time was low (about 70% damage on the susceptible checks). Several entries (mostly in F_6, F_5, and F_4 stage) were found to have more than 90% resistance with this pressure. Some entries identified as very good recovery lines had a high level of resistance.

In cooperation with physiologists, observations were made on the expression of the "glossy trait" (a light yellowish-green plant color and glossy leaf surface) in the seedling stage (see also Sorghum Physiology section). This trait was expressed more by trichomed lines than by nontrichomed ones (Table-11). Although the material was not bred to include this trait, it was frequently found in the more resistant lines. It was observed that shoot fly eggs were also laid on glossy plants, but fewer deadhearts resulted. If it proves to be a trait closely associated with shoot fly resistance it will make the screening operation easier. Plans for a more

Table 10. Sorghum breeding: shoot fly selections based on the presence or absence of trichomes.

Trichomes	Egg laying	Category	Number of selections made during 1977 postrainy		1978 rainy	
1. No	No	Escape	201	(39.8%)	73	(6.69%)
2. No	Yes	Antibiosis	123		515	
3. Yes	No	Ovipositional nonpreference	100	40:60[a]	106	50:50°
4. Yes	Yes	Mechanical	79		400	

a. Proportion of trichomed and nontrichomed material (nos. 3 and 4 are trichomed; 2, not trichomed; 1, not considered).

detailed study of this trait are under way. (Preliminary observation indicates that the glossy trait also contributes to reduce infestation by the flea beetle and the shoot bug *[Perigrinus maidis*].)

During the summer season (March sowing) a set of 2247 primary resistant progenies was planted at Hissar. Shoot fly attack was severe; each plant had 15 to 20 eggs. In this nursery only 17 entries had less than 30% damage. M35-1, a resistant check, had 50% damage.

Stem Borer (*Chilo partellus* Swin.)

The screening facilities for this pest were expanded substantially by the Cereal Entomology Unit during 1978-79. In the 1978 rainy season, 2.8 ha of breeding material were infested artificially with five to six larvae per plant. In the postrainy season, 2 ha of material were screened in the same way. Stem borer infestation was started 25 days after seedling emergence. Screening in the postrainy season proved more effective than in the rainy season (Table 12).

Midge (*Contarinia sorghicola* Coq.)

A search in 1978-79 to identify suitable locations and seasons for testing breeding material against midge under natural conditions indicated Dharwar to be a promising location for screening in the rainy season. Plantings were

Table 11. Sorghum breeding: shoot fly breeding material showing the glossy trait

Type of material	Number of entries showing trait	Percent
Trichomed	266 (328)	81.09
Nontrichomed	329 (483)	68.11
Very good and good recovery resistant lines	180 (309)	58.25
Recovery lines	679 (1330)	51.00

Figures in parentheses indicate the number of entries grown.

Table 12. Sorghum breeding: stem borer breeding material processed during 1978–79

Breeding material	Rainy season: Crossing block	Rainy season: Nursery		Rainy season: Screening selections (larval damage)						Postrainy season: Crossing block	Postrainy season: Nursery		Postrainy season: Screening	
	Crosses made	Planted	Selected	Screened	Slight damage	Larvae died	Free from damage	Damage at panicle	Damage at different nodes	Crosses made	Planted	Selected	Screened	Selected
F_1s	291	129	19							237	291	104		
F_2s				290	47	8	693	24	615				19	86
F_3s				133		1	49	2	26				1387	520
F_4s				182	2		40	1	7				78	172
F_5s				32			15	1					50	
F_6s													16	
BC_1F_2s														
BC_1F_3s				46	2		48	1	9					
BC_1F_4s				9			13						64	
BC_1F_5s													13	
Diallel F_2s				14	3		23		15					
Diallel F_3s													41	
Top crosses F_2s				22	8		60	6	34					
Top crosses F_3s													108	
2KX population				1			19							

delayed until the first week of August, and the incidence of midge was severe. At maturity, 412 separate promising plant selections were made for midge and some were common selections for both midge and *Calocorus.*

Earhead Bug (*Calocoris angustatus* Leth.)

During the 1978 rainy season, a substantial nursery of segregating material for midge resistance was planted 6 weeks later than normal sowing in hopes of a high midge population, which did not develop. However, during the grain-filling stage, this material was heavily attacked by earhead bugs. At harvesting time, 370 heads completely free of damage (though earhead bugs were present in these heads) were selected from a nursery of 3 ha. In order to confirm resistance, these selections were planted in separate progeny plots and artificially infested in the next season (1978 postrainy). Excellent grain quality and bug resistance was found in 36 entries, which are now in the F_5 and F_6 stage. This material will be further tested for midge reaction during the 1979 rainy season at Dharwar. There appears to be a good possibility of finding some lines with resistance to both midge and earhead bugs. The pedigree details of these lines are given in Table 13.

Table 13. Sorghum pedigrees found completely free of damage by earhead bugs in two tests in 1978-79.

Pedigree
(IS-3574C x SC-108-4-8)-11-4
(IS-12612C x PHYR)-4-I-4
(IS-12573C x 2219B)-4-2-I
(IS-12573C x 2219B)-19-2-I
(1S-12573C x PHYR)-2-I-I
(1S-12573C x PHYR)-2-2-1
(IS-12573C x PHYR)-2-2-2
(IS-12573C x SC-108)-2-2-3
(IS-12573C x SC-108-3)-4-3-1
(IS-12573C x SC-108-3)-4-4-2
(IS-12573C x SC-108-3)-7-3-I
(1S-12573C x SC-108-3)-18-I-I
(IS-12573C x SC-108-3)-18-2-3
(1S-12573C x SC-108-3)-18-3-1
(IS-12573C x SC-108-3)-18-3-2
(IS-12573C x SC-108-3)-18-5-3
(IS-12573C x SC-108-3)-19-I-I
(IS-12573C x SC-108-3)-19-I-2
(IS-12573C x SC-108-3)-19-I-3
(IS-12573C x SC-108-3)-19-I-5
(IS-12573C x SC-108-3)-19-2-I
(IS-12573C x SC-108-3)-19-2-2
(IS-12573C x SC-108-3)-19-2-4
(IS-12573C x SC-108-3)-19-2-5
(IS-12573C x SC-108-3)-19-2-6
(2KX6 x IS-12573C)-32-1-1
(EC-64734 x IS-2579C)-29-I-I
(EC-64734 x IS-2579C)-42-I-I
(A-30 x IS-12573C)-16-1-1
(A-30 x S-Girl-MR-I)-7-I-I
(Diallel (C_1)-465-2-S_8) x IS-2579C)-2-I-I
(Bulk-Y-S_6-55-2 x IS-2816C)-36-1-1
(Bulk-Y-S_6-55-2 x IS-2816C)-68-1-1
(Bulk-Y-S_6-55-2 x IS-12573C)-1-1-1
(Bulk-Y-S_6-55-2 x IS-12573C)-12-1
(IS-1082 x IS-2816C) x FLR-101-5-6-1

Breeding for *Striga* Resistance

Striga is a parasite of sorghum, maize, sugarcane, millets, and several grasses with a potential to cause severe damage to the host crop. *Striga hermonthica* in Africa; and *S. asiatica* in India, parts of S.E. Asia, Africa, and North Carolina (USA) are of significant economic importance.

Screening for Resistance to *Striga*

Laboratory screening for low stimulant production. It is generally understood that seeds of *Striga* will germinate only in the presence of a stimulant coming from the roots of the host plant. In the year under report, 4750 sorghum lines were screened for stimulant production.

They belong to various taxonomic groups {Table 14). Of the total, 370 were found to produce stimulant less than 10% of the control. Altogether, mote than 13 000 getmplasm entries have been screened and 730 lines have been identified as low stimulant producers in the past few years.

Field testing of tow stimulant lines. The laboratory technique of screening for low stimulant production has limited practical value as a selection tool unless it correlates well with field resistance to Striga. Field, trials were therefore conducted in the 1977 rainy season at Akola with a set of 50 germplasm lines and 40 F_3 lines. In these trials the field resistance and laboratory results did not correlate very well. The trial was repeated in the 1978 rainy season, and 96 low stimulant germplasm lines were planted in a Striga-sick field. A significant correlation coefficient of +0.43 was found between field resistance and laboratory results. The correlation was low, reducing the value of laboratory screening for low stimulant production as the practical tool previously anticipated for breeding against Striga. However, since the correlation was positive and significant, there is a need to refine the laboratory screening technique.

Field testing for Striga resistance. The International Striga Resistance Nursery (ISRN) has been a valuable tool to confirm resistance over locations. Two international nurseries were dispatched to ten locations in five countries of the SAT. However, data were useful only from eight locations, since Kobo in Ethiopia, and Mwanihala in Tanzania reported very low Striga infestations. Details of the 59 entries tested in two trials for Striga resistance are given in Tables 15 and 16. It is Clear from the results of Trial 1 that the response of varieties to S. hermonthica (African locations) and to S. asiatica (Indian locations) was different, indi-

Table 14. Sorghum material screened from July 1978 to June 1979 for low stimulant production for germination of Striga seeds.

Group	Total	Low types	Percentage
Caudatum—Kauras	119	16	13.44
—Guinea	19	4	21.05
—Bicolor	8	0	0.00
—Dochna	40	0	0.00
—Nigricans	225	3	1.33
—Zera Zeras	23	0	0.00
—Durra	87	2	2.29
—Conspicuum	45	0	0.00
—Membranaceum	3	0	0.00
Subglabresense	47	0	0.00
Subglabresense—milo	2	0	0.00
Milo—Kauras	78	0	0.00
Sudanense	103	4	3.88
Sudanense Durra	1	0	0,00
Sudanense Halepense	1	0	0.00
Grain-grass	256	10	3.90
Group unknown	3693	331	8.96
Total	4750	370	

Table 15. Results of ISRN-1 (rainy season, 1978).

Pedigree	India				Ethiopia-2 (Cheffa)	Sudan-1 (Abu Naama)	Sudan-2 (Abu Naama)
	Dharwar	Akola	Parbhani	Nandyal			
SRN-484	X	†	X	X	X	X	†
N-13	†	†	†	†	X	X	†
IS-1464	X	†	X	X	X	X	X
IS-4202	†	†	†	†	X	X	X
IS-6942	†	†	X	X	X	X	X
555	†	†	X	X	X	†	X
IS-52-18	†	†	†	†	X	X	X
16-3-4	X	†	X	†	X	X	X
NJ-1515	†	†	X	†	t	X	X
IS-9985	†	†	†	X	X	X	†
IS-5106	X	†	X	X	X	X	X
IS-2203	†	†	†	†	X	X	X
SRN-4882B	†	†	X	X	X	X	X
IS-8785	†	†	X	X	X	X	X
SRN-5790	†	†	†	X	X	X	X
Serena	†	X	X	X	X	X	X
IS-2643	†	†	t	X	X	X	X
IS-4242	X	†	t	X	X	X	X
SRN-6838B	X	†	X	X	X	X	X
(555 x 168)-22-I	t	†	X	X	X	X	X
(Framida x 148)-21-2	X	†	X	X	X	X	X
(BC-9 x Bonganhilo)-24-1	†	†	X	X	X	X	X
(A-2377 x 555)-31-I	X	†	X	X	X	X	X
(148 x 555)-13-3	X	†	X	X	X	X	X
23-4	†	X	X	X	X	X	X
(BC-9 x Bonganhilo)-25	†	†	X	X	X	X	X
(148 x 555)-31-I	†	†	X	X	X	X	X
IS-5603	X	†	†	X	X	X	X
(M35-1 x 5S5)-20	X	†	X	X	X	X	X
(555 x 168)-33-4	†	†	X	X	X	X	X
(148 x 555)-29-3	X	†	X	X	X	X	X
CSH-1 (Control)*	X	X	X	X	X	X	X
No of entries tested	32	32	32	32	32	32	32
No of entries selected	19	29	9	6	1	1	3

† - *Striga* infestation less than 10% of control.
x = *Striga* infestation more than 10% of control.
* = CSH-1 was used as the susceptible control and taken as 100% infested.

Table 16. Results of ISRN-2 (rainy season, 1978).

Pedigree	India		Ethiopia-2 (Cheffa)	Upper Volta (Ouagadougou)
	Akola	Dharwar		
IS-7227	X	*	†	X
IS-2404	X	*	X	X
IS-3962 x WABC 1022	*	X	X	X
IS-3968	X	**	DR x	*
IS-4270	X	**	X	X
Expt. 4/Ent-487	†	**	DR x	X
IS-2221	†	X	X	†
IS-2352	X	*	X	X
IS-2781	*	X	†	X
IS-2930	*	X	**	*
IS-3923	*	*	X	X
IS-3924	*	†	X	X
IS-4415	†	X	†	X
(Framida x IS-3691)-12-1	X	*	†	X
(NJ-2006 x Framida)-38-1	†	X	X	X
(148 x 555)-11	*	X	X	X
(M35-1 x 555)-21-3	X	X	X	X
(BC-9 x Boganhilo)-16-2	†	*	X	X
(M35-1 x 555)-16-l	†	†	*	*
(M-35 x 555)-21-2	†	†	X	X
(NJ-2006 x Framida)-18-2	*	X	†	X
(A2377 x 555)-12	*	X	X	*
(555 x 168)-9-l	*	†	X	X
(555 x 168)-9-3	*	X	X	X
S-1464	NT	NT	*	X
S-1510	NT	NT	*	X
S-1561	NT	NT	*	†
S-1488	NT	NT	X	*
S-1487	X	X	DR	X
CSH-1 (control)	X	X	X	X
No of entries tested	26	26	30	30
No of entries selected	7	4	5	2

Note: Upper Volta was drought-affected area. *Striga* infestation was not severe.
x = Less than 15% of control. OR = Drought resistant.
†. = Less than 10% of control. * = Less than 5% of control.
NT = Not tested. ** = Less than 1% of control.

eating the presence of a species-specific reaction of *Striga* on sorghum. Similar results were obtained in 1977. Within the Indian locations, the stability of resistance was poor. Only four entries (N-13, IS-4202, IS-5218, and IS-2203) showed *Striga* infestation less than 10% of control at all locations. In addition, SRN-4841, which exhibited resistance at all the locations tested last year, showed resistance only at Akola and one location in Sudan. However, it was susceptible in Sudan last year.

In Trial 2, only one entry showed resistance across locations: a breeding line derived from a cross between M35-1 and 555. Breeding is in progress to improve the resistance of source material to *Striga* and to other undesirable agronomic traits.

Breeding for Resistance to Drought

Efforts were made to screen for drought stress from the panicle initiation stage. Very low correlation was found between plant performance under stress and under adequate moisture conditions. This calls for development of a suitable experimental opportunity where drought can be expected and where adequate control of management is possible to reduce coefficients of variation (these tend to be higher in stress conditions). Useful material for the traditional farmer can be bred only if there is a good selection opportunity in drought conditions. The identification of needs and priorities to undertake this research improved considerably during the year.

Food Quality

In most regions where sorghum is utilized as a food, breeders select yellow or white grains with corneous endosperm. However, all such grains do not produce the desired food recipes satisfactorily. The complexity and diversity of sorghum foods popular across the SAT make it difficult for breeders to use empirical methods in the selection of quality grains suited for several different preparations. Obviously, much information is needed to define precisely the physical and chemical properties of the grain that contribute to the satisfactory making of the various sorghum recipes.

Evaluation of Chapati Quality

Chapati is an unleavened bread popularly made in India from whole sorghum flour. An ideal chapati should taste good and remain soft for at least 10 hours at room temperature.

Chapati evaluation using 13 physical attributes of the grain, dough, and the chapati itself have been standardized. Data collected on 1126 cultivars of diverse origin were analyzed statistically. The results reflect a broad range of variation for all the characters studied except grain density (Table 17). The kneading quality of the dough from various cultivars was classified subjectively into three grades by skilled women. Rolling quality of the dough, which varied from 15.00 to 27.87 cm, appeared to be a more reliable estimate of the dough property than the kneading score. Consistent differences were observed in chapati quality characters among cultivars. Environmental factors, such as soil, season, spacing, fertilizer, water availability, and percentage of moisture in the grain affect the grain properties, and consequently the chapati properties. It is important that comparisons be made only between entries sown at the same time and grown in a similar environment.

Generally, chapati color, aroma, and taste are affected by the pigmentation on the pericarp. The color of chapati can also bias the panelist against its taste and flavor, and tannins of colored grains may lead to a bitter taste. Therefore, a subsample of 520 pearly white grain varieties from the complete set of 1126 varieties was separately examined; it was found that within this group the range of variation for all the characters was as broad as that observed in the whole set of the material studied.

The study revealed that corneous grains, in general, exhibited more breaking strength, had more density, absorbed somewhat less water, and showed better kneading and rolling pro-

Table 17. Variability for some grain and chapati quality attributes in sorghum.

Attribute	Set[a]	Mean	±S.E	Range	
				Minimum	Maximum
Corncousncss score	I	2.410	0.02	1.000	5.000
	II	2.265	0.02	1.000	4.000
Grain wt (g/100 seeds)	I	3.520	0.02	1.529	7.115
	II	3.345	0.02	1.739	5.820
Breaking strength	I	8.714	0.05	3.530	18.800
	II	9.184	0.08	3.530	18.800
Grain density	I	1.228	0.00	1.072	1.437
	II	1.229	0.00	1.-112	1.437
Water absorption (%)	I	25.177	0.14	13.080	41.770
	II	25.967	0.20	13.080	41.770
Water for dough (ml)	I	28.320	0.06	20.580	36.910
	II	27.880	0.10	20.580	34.350
Kneading quality score	I	1.124	0.01	0.500	3.000
	II	1.085	0.01	1.000	3.000
Rolling quality (cm)	I	22.110	0.04	15.000	27.870
	II	22.270	0.07	16.250	27.650
Chapati taste	I	2.989	0.02	1.250	5.000
	II	2.870	0.02	1.250	4.500
Texture	I	2.608	0.01	1.000	4.500
	II	2.570	0.02	1.000	4.500
Flavor	I	1.217	0.01	1.000	4.000
	II	1.123	0.01	1.000	4.000
Keeping quality	I	2.929	0.02	1.000	5.000
	II	2.882	0.02	1.000	5.000

a. Set I had 1126 genotypes of various kernel colors.
Set II had 520 pearly white seeded genotypes.

perties. Taste, texture, flavor, and keeping quality of chapatis from grains with 65 to 70% corneous endosperm were most desirable. Chapatis from more highly corneous grains tend to be rough in texture, less soft, and poor in keeping quality, while the floury grains absorbed more water, kneaded poorly, and produced poor quality chapatis.

Correlation coefficients between grain, dough, and chapati properties were computed from the data obtained from 367 genotypes. Several of the characters were correlated at statistically significant levels, but the coefficients were weak. None of the characters was sufficiently correlated with chapati qualities to be used as an indirect assessment of chapati quality.

About 800 selections in the F_5 and F_6 generations from the grain mold resistance breeding program were screened to identify superior chapati-making lines, using M35-1 as the check. The 59 selections found to be comparable were evaluated in the rainy season when M3S-1 (a dry-season variety) becomes pigmented and moldy and is very poor in chapati quality. Seven lines from the wet season were found comparable to M35-1 grain produced in the dry season, paving the way to obtain M35-1 quality in rainy-season varieties.

Ugali Properties

Ugali is a dumpling popularly made in Kenya from coarse flour. It is made either from whole sorghum flour alone or mixed with that of maize. Ugali preparation procedures were standardized with the help of five trainees from Kenya, and ugali-making properties of 90 sorghum varieties were evaluated by them.

Cooking qualities of varieties showed significant differences. Mostly pale yellow or white ugali was preferred. Taste, texture, and keeping quality scores showed large differences for these characters among cultivars. In general, white corneous grains contributed to good ugali with less tackiness, a critical quality factor in ugali. M35-1, which makes excellent chapatis, was good for ugali also. However, E35-1, IS-5341, and IS-6928, which are more corneous and not particularly good for chapatis, exhibited the best ugali properties. The texture and keeping qualities of ugali from floury grains were very poor.

Uji

Uji is a porridge made in Kenya from fine sorghum flour. After overnight storage, the porridge forms a gel, and its keeping quality is rated very good if the stored uji is thick, viscous, and the gel can disperse uniformly without clotting when heated with water. The keeping quality is rated poor if water separates out of the stored uji and/or the consistency of the gel is thin or heterogeneous.

The keeping quality of uji could be quickly assessed by cooling the gel at 10°C for 3 hours. The gel was then removed from its container. The thickest gel retained the exact shape and nearly the diameter (58 mm) of the container (52 mm) when removed after cooling. Other gels varied in their shapes and extent of spreading, and their consistency could be expressed as the measured diameter on a linear scale.

Gel diameters of 75 varieties varied from 58 to 112 mm. Gel diameter measurements of cultivars were characteristic and consistent and reflected the uji keeping quality. An association between ugali textural properties and measured gel consistencies was also observed; the correlation coefficient was 0.74 and was statistically significant at 0.01 probability level. It appears that flours that make thick gels also tend to make ugali with acceptable texture (i.e., less sticky).

Selection Criteria for Improved Chapati and Ugali Qualities

Grains with 65 to 70% corneous endosperm frequently exhibited the best chapati-making properties. Flour particle size indices of such grains were around 60 to 65, and gel consistency measurements were about 62 mm, indicating a reasonably thick gel. Grains with more than 70% of the endosperm corneous, particle size index values over 70, and a very thick gel consistency seemed most suitable for making ugali.

Improvement for Lysine

The high-lysine breeding project started at ICRISAT in 1973 using the Ethiopian high-lysine lines IS-11758 and IS-11167 which have shrunken seeds and approximately 70% increased lysine in the protein (3 to 3.5%). The single recessive gene *hl* was found to condition high lysine in these lines.

Initially, selections with high lysine were recovered in normal-seeded segregates. However, selections in later generations resulted in very few lines with moderately high lysine.

It has not been possible to find-nbrmal-seeded selections containing the *hl* gene. It appears that the high lysine and the shrunken seeds are conditioned by the same *hl* locus. This may frustrate breeding efforts to recover agronomically elite lines with high lysine in normal seeds.

A second mutant source, P-721 (an opaque seed), came from Purdue University in 1975. It was found that this mutant Alone produced an increase of about 30% in lysine as percent of protein (2.5 to 2.7%), and that derivatives with this level of lysine could be easily recovered from crosses involving P-721. Howeyer, when this line and derivatives including it as a parent were grown in environments where soil nitrogen was limiting, no increase was observed in lysine percent of the protein.

Yields of P-721 were also low and not responsive to fertilizers and better management. The response of P-721 across environments that differ in lysine as percent of protein is shown in Figure 1. As most farmers in the SAT work with low fertility soils, it appears that the lysine percent of protein may be similar in normal and P-721-derived lines.

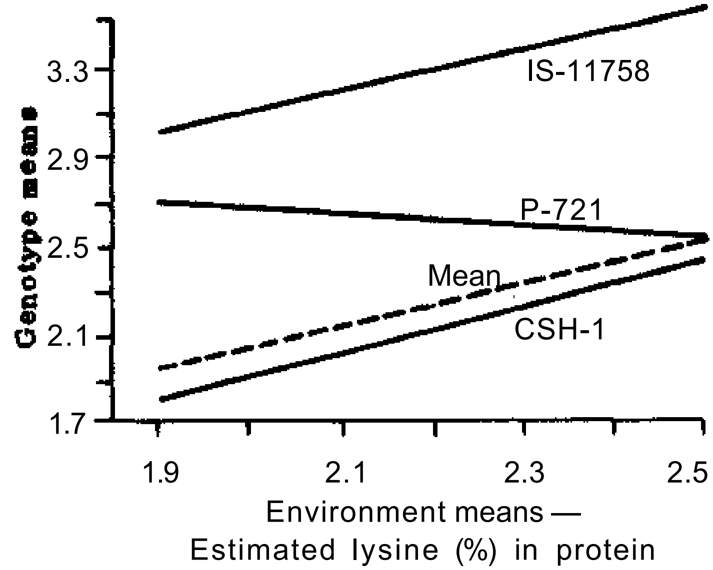


Figure 1. Regression of estimated lysine (%) in protein in 3 of 22 entries tested across 12 environments during the 1977-78 postrainy season.

Biochemistry

Village-level surveys were made in seven states of India to identify the kinds *of foods* that are prepared from sorghum. The states surveyed contribute more than 90% of the total area as well as production of sorghum in India. It was found that sorghum was used in breads, porridges, gruels, and as cooked, steamed, and fried foods, and snacks. The majority of people use sorghum to prepare unleavened bread called *roti* or chapati.

Physicochemical characteristics of flour and chapati-making qualities of 24 sorghum cultivars studied (Table 18) showed considerable variations, and preliminary results are reported in Table 19. Flour qualities (water absorption, stickiness, and spreading ability of dough) were also studied and were evaluated subjectively. Chapatis were made to the same thickness and diameter under identical conditions and their quality was assessed by trained taste panel members for color, texture, flavor, taste, and acceptability. The relationship between physical and chemical characteristics and chapati qualities have been worked out. It appears that the quantity of solubles, fat, and ash in the flour jointly influence and contribute to chapati characteristics (Table 20). Further analysis on the qualitative nature of other chemical parameters is in progress.

Proximate composition and mineral analysis were determined on 100 selected germplasm collections grown at ICRISAT farm during the same season. They represented the following types: with luster; with persistent subcoat; completely corneous; almost corneous; intermediate; almost floury; completely floury; waxy endosperm; and with white, yellow, straw, light brown, brown, reddish brown, light red, red, grey, and purple seed coat colors. The analysis revealed wide variation in the values for different constituents in these samples (Tables 21 and 22).

Grain maturation studies were conducted on

Table 18. Sorghum cultivars analyzed for physicochemical and chapati characteristics.

CSH-6	KARAD	CS-3541	M35-1	P-721	E35-1
M-32282	M-35082	M-35088	M-35528	M-35528	M-36135
	M-36406	BG-12	BG-30	IS-2328	IS-5090
IS-7943	IS-9742	IS-9985	IS-12611	MOTI	555

Table 19. Physicochemical characteristics of flour and quality of chapatis made from sorghum.[a]

Component	Range	Mean
FLOUR		
Swelling capacity		
v/v	4.5- 6.9	5.7
v/w	7.2-10.6	9.2
Flour solubles (%)	14.6-25.3	20.0
Starch (%)	66.0-74.1	70.0
Gelatinization temperature(°C)	65.5-69.0	66.4
Amylose (%)	21.9-30.0	27 .7
Water-soluble amylose (%)	3.1-10.5	6.6
Sugars (%)	1.2- 2.1	1.3
Protein (%)	9.3-15.6	11.8
Water-soluble protein (%)	0.5- 0.8	0.7
Fat (%)	2.6- 4.2	3.0
Ash (%)	1.4- 1.9	1.6
CHAPATI		
Water for dough (ml/100 g flour)	66.0-90.0	76.8
Moisture loss during baking (%)	16.9-39.6	28.0
Color and appearance [b]	1.0- 3.9	2.8
Texture [b]	1.2- 3.8	2.5
Taste [b]	1.5- 3.2	2.5
Flavor [b]	1.4- 3.2	2.5
Acceptability *	1.4- 3.3	2.5

a. Based on an analysis of 24 cultivars.
b. Ratings given by panelists (4 = excellent: 3 = good; 2 = fair; 1 = poor).

Table 20. Assessment of chapati qualities as a function of chemical characteristics.[a]

	Flour characteristics		
Chapati qualities	Solubles	Fat	Ash
Color	-0.33[b]	-1.39*	- 2.88[c]
Texture	-0.22[b]	-0.79[d]	- 1.00
Taste	-1.03*	-0.13*	-0.82
Flavor	-0.96*	-0.18[c]	- 1.21[d]
Acceptability	-1.62[c]	-0.16*	-0.91 [b]

a. Multivariate regression analysis: Chapati qualities as dependent variable tested against physicochemical characteristics as independent variables.
b. Significant at 0.01 c. Significant at 5%
d. Significant at 10%

Table 21. Proximate composition of selected sorghum germplasm samples.[a]

Constituent	Range	Mean
Starch (%)	55.6-75.2	70.8
Protein (%)	10.6-14.1	14.1
Sugars (%)	0.8- 4.2	1.3
Ether extract (%)	2.1- 7.6	3.3
Crude fiber (%)	1.0- 3.4	1,9
Ash(%)	1.6- 3.3	2.1
Lysine (g/100 g)	1.37-3.39	1.7
Tannin (%)	0.1- 6.4	0.6
100-seed wt (g)	1.3- 5.7	2.*
Grain hardness, force required to break (kg)	1.8-10.4	6.5

a. n = 100, moisture-free basis.

CSH-1, CSH-8, M35-1, P-721, CSV-3, Ry-49, IS-11167, and IS-11758. Samples from each of these eight cultivars were collected from 7 to 49 days following 50% flowering at weekly intervals and were analyzed for dry matter, starch sugar, protein, fat, and ash. Dry matter accumulation increased up to 28 days; then it declined in the cultivars tested. An increased rate of accumulation of starch was noted in cultivars M35-1 and CSV-3 up to 21 days, and did not change appreciably after that stage. While starch tended to accumulate, the sugar content decreased (Fig. 2). Protein accumulation was rapid in the initial stages for all the cultivars except Ry-49 and the two high lysine Ethiopian lines in which a very slow increase was observed.

Studies on soluble sugars using Biogel P-2 column were carried out on ten cultivars. Stachyose, raffinose, sucrose, and glucose 4-fructose were identified; their values ranged from 0.04 to 0.2, 0.1 to 0.4, 0.9 to 3.9, and 0.06 to 0.7%, respectively.

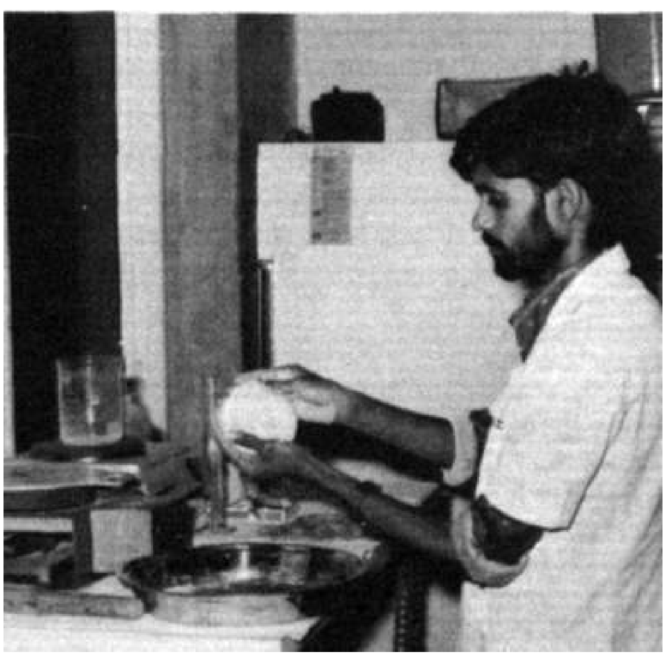
Studies on physicochemical and chapati characteristics will be continued using more cultivars in order to test our initial findings. Efforts will be made to improve our taste panel evaluation procedures.

Table 22. Mineral and trace element analysis of sorghum germplasm samples[a] (mg/100 g).

Element	Range	Mean
Phosphorus	388 -756	525.5
Magnesium	167.2 324.7	211.6
Potassium	363 -901	536.5
Iron	4.70- 14.05	8.48
Copper	0.39- 1.58	0.86
Zinc	2.49- 6.78	3.91
Manganese	0.68- 3.30	1.75

a. n = 99 on a moisture-free basis.

Promising sorghum varieties are evaluated for chapati quality in the laboratory at ICRISAT Center.



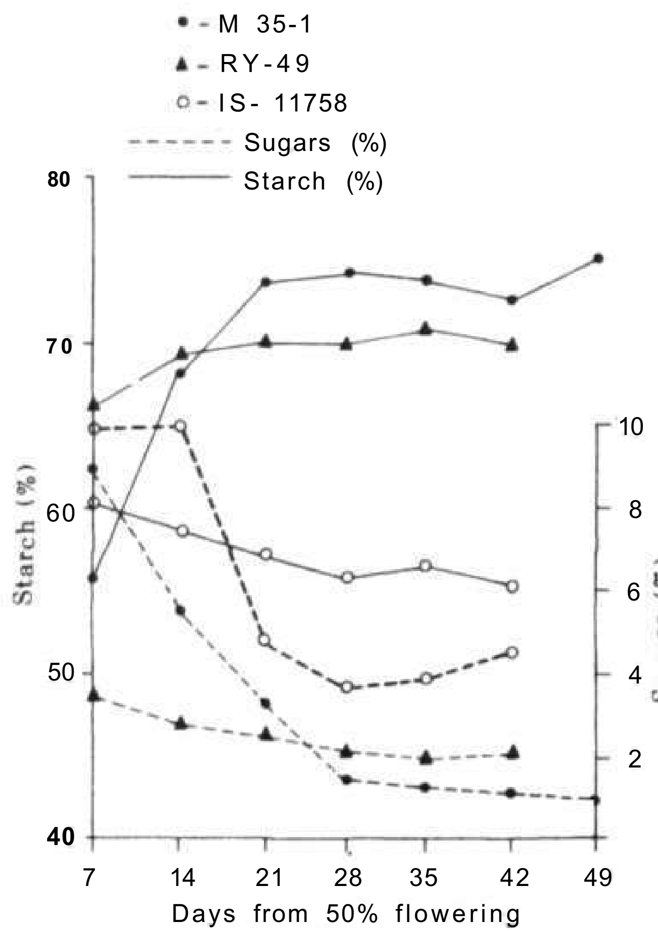


Figure 2. Changes in starch and soluble sugars content in maturing grains of three sorghum cultivars.

Physiology

Drought Resistance

Using the line source sprinkler irrigation technique (LS) we conducted experiments to evaluate

1. the relationships between soil-water (irrigation plus soil moisture) and crop growth, development and yield, and
2. the usefulness of the technique for screening sorghum genotypes for drought resistance.

Nine genotypes were sown in Alfisol during the postrainy season. Each side of the LS formed one replication, and these genotypes were randomized within each replicate. The field was uniformly irrigated (using perfo-spray) until the boot stage was reached in the genotype CSH-6. The LS was used at 50, 61, and 77 days after sowing to create a gradient of soil moisture (stress). The amount of water received across the plot was measured in catch cans placed at crop height. Measurements of growth, development, and plant height were also made during the treatment period, and the grain yield and total biomass were determined at harvest.

Environmental measurements, made in collaboration with the Farming Systems Research Program, included leaf-water potential, leaf rolling, and leaf temperature. Soil moisture and potential evaporation were also measured. Figure 3 shows the cumulative water applied using LS and the calculated evapotranspiration (Et) after the first LS irrigation until maturity. The effect of a continuously declining plant and soil water status on leaf-air temperature differences in CSH-6 is also shown.

The response of the different genotypes to the water stress gradient is shown in Figure 4. The genotypes within the same maturity class are shown by similar lines. A comparison of the genotypes in the early maturity group (CSH-1, CSH-6, and IS-1037) shows clearly that CSH-1 had the greatest yield potential tinder low stress conditions but that IS-1037 showed the least sensitivity to change in drought stress. In the medium group, CSV-5 and CS-3541 were not distinguishable but were higher yielding than V-302. In the later group, CSH-8 and SPV-86 were similar and showed a considerably better yield potential than M35-1, although the latter was less sensitive to changes in stress.

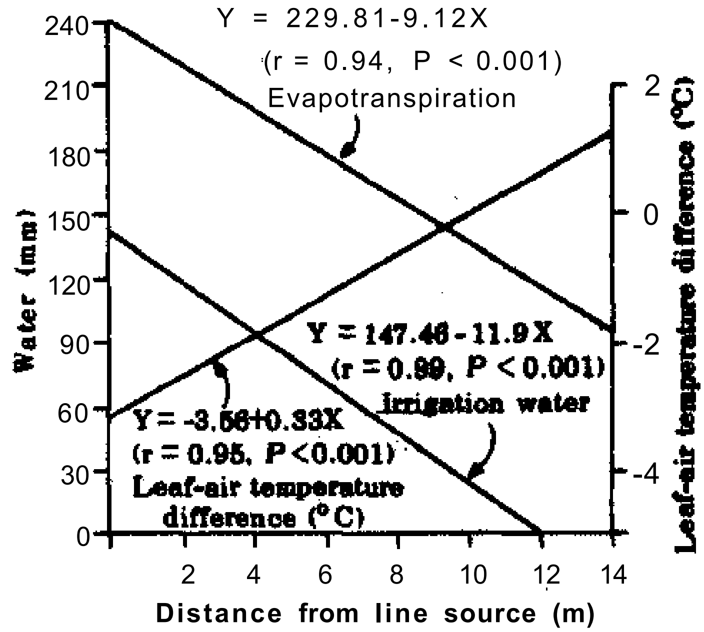
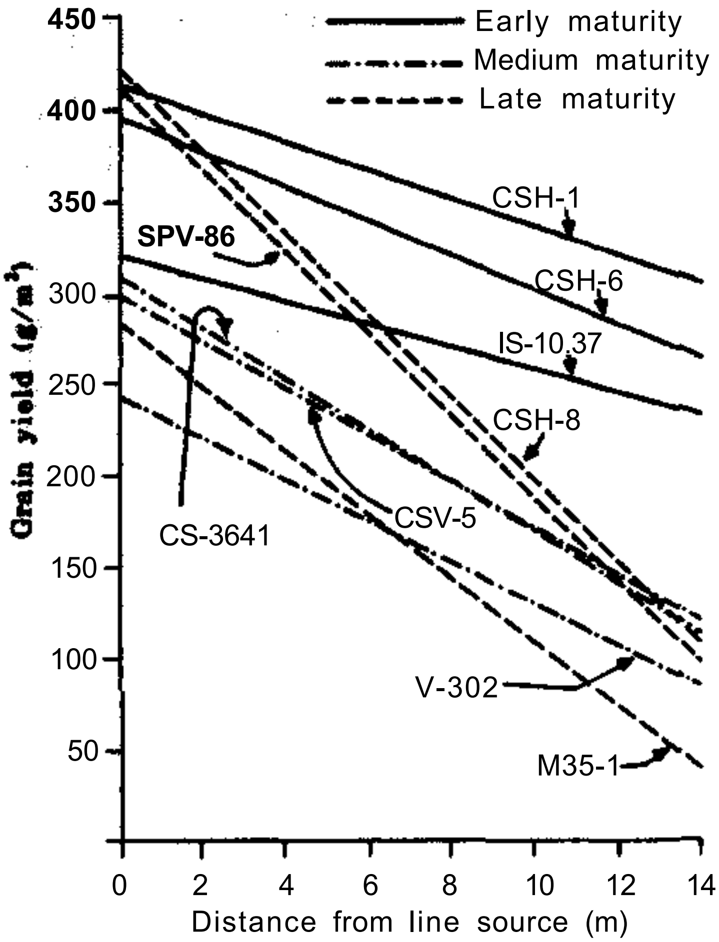


Figure 3. Total amount of irrigation water received, evapotranspiration (beyond 50 days until maturity), and leaf-air temperature differences at various distances from line source of sorghum (1978-79 postrainy season).

Charcoal Rot Resistance

The line source sprinkler irrigation technique was also used to study the effect of increasing soil moisture stress on charcoal rot incidence. Figure 5 shows that the disease increased with soil moisture stress.

Initial results from both experiments are encouraging and it is hoped that current experiments will confirm the usefulness of the LS technique and that it can be used subsequently by breeders and physiologists to select for drought and disease resistance. The possibilities of using this technique to study the interaction between fertility status and soil moisture will also be investigated with selected genotypes.



Intercept of regression line = yield potential
Slope of line = rate of yield change with water stress
Area under line = mean yield over range of stress

Figure 4. Effect of decreasing soil moisture on sorghum grain yield (line source; 1978-79 postrainy season),

Resistance to Shoot Fly

Earlier it was found that most of the cultivars possessing some field resistance to shoot fly have trichomes on the abaxial leaf surface. Further experiments, with a wider range of germplasm and breeding lines, confirmed these observations. A substantial number of comparisons, ranging from low (20% deadhearts) to very severe (over 90% deadhearts) levels of shoot fly attack, showed that trichomed lines suffered less damage than trichomeless lines. Under severe shoot fly pressure the difference between trichomed and trichomeless lines was reduced (e.g., 85% vs 95% deadhearts), but differences were statistically significant in all cases. Under lower and more realistic levels of attack, the differences between the two groups were both agronomically and statistically significant (e.g., 18% vs 35% deadhearts).

The presence of trichomes on the leaf surface appears to confer an advantage in two ways: (1) by reduction in the amount of egg-laying on the leaf, and (2) by a reduction in the frequency with which the presence of eggs results in the death of the shoot (Fig. 6). The ultimate percentage of plants with deadhearts was 24 and 54 for the trichomed and trichomeless lines, respectively.

A field evaluation of the leaves of trichomed lines showed certain distinctive characteristics in the seedling stage. They tended to be erect and narrower with a yellowish green, glossy appearance. Such leaves are referred to as "glossy." These traits are evident in the first 3 weeks following emergence; later, however, leaves do not show these distinctive characteristics.

Approximately 8000 lines of the world sorghum germplasm collection were screened for the presence of this glossy seedling trait. Only 70 such lines were found, and these are largely of South Indian origin. Of these 70, more than

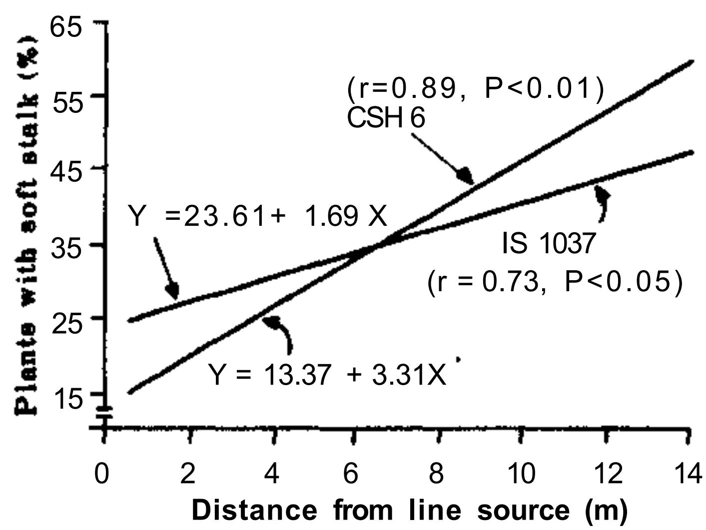


Figure 5. Effect of decreasing water supply on charcoal rot incidence in sorghum (line source; 1978-79 postrainy season).

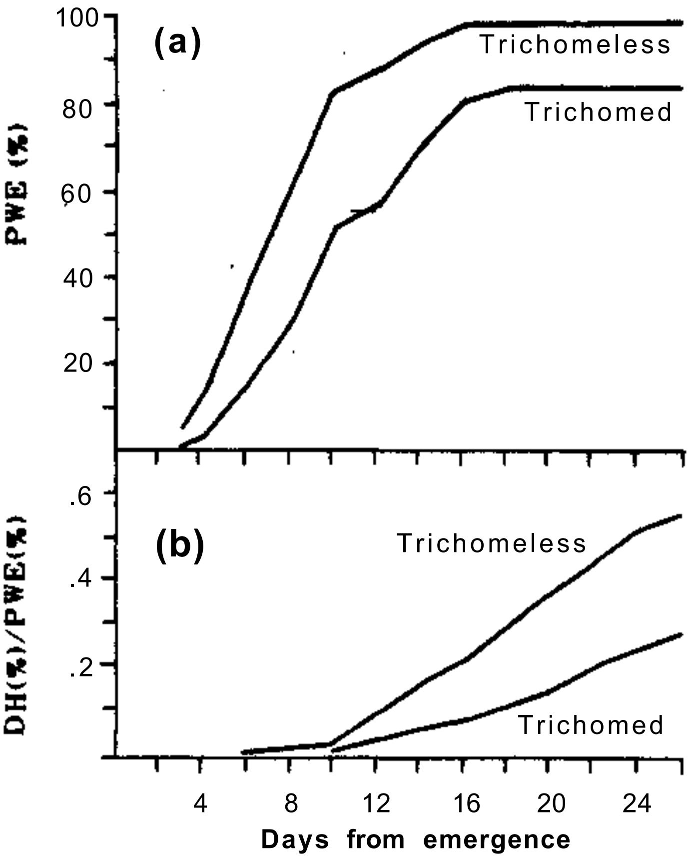


Figure 6. Effect of time on the mean percentage of plants with eggs (PWE) and the ratio of percentage of deadhearts to percentage of plants with eggs (DHI PWE) for trichomed (n = 32) and trichomeless (n — 35) lines of sorghum.

80% were trichomed, confirming our earlier observations of the high frequency of association between trichomed and glossy traits.

The world germplasms could be classified into four trichome-glossy combinations: trichome glossy, trichome nonglossy, trichomeless glossy, and trichomeless nonglossy. The first three are of rare occurrence. A set of lines representing these four groups was tested for degree of resistance/susceptibility to the shoot fly under variable shoot fly pressure. A cluster analysis procedure (Gates, C.E., and Bilbro, J.D. 1978 *Agronomy Journal* 70: 462) was used to group lines with statistically different levels of shoot fly damage. The frequency of trichome-glossy lines in each group was calculated. Figure 7 shows that the highly tolerant group was invariably trichomed with glossy leaves, and the highly susceptible group was mostly trichomeless and nonglossy.

In order to investigate the individual or additive effects of the glossy trait and the presence of trichomes, a set of 40 lines with an equal number from all combinations was selected from the original lines. These were field-tested for shoot fly tolerance. The results show clearly that the presence of trichomes and the glossy trait have independent and apparently additive effects in reducing shoot fly damage, even under heavy shoot fly pressure (Table 23).

We strongly believe that the addition of both the traits into sorghum breeding lines will result in an improvement of shoot fly resistance. The glossy trait can be easily identified in the seedling stage and should prove a useful selection criterion for the sorghum breeders. The physiologists are providing this service to the breeding section on a large scale, examining about 30 000 leaf samples a year, at the rate of 900 per day.

Seedling Drought Resistance Screening

An experiment has been designed to examine the effects of water stress on seedling development in a wide range of genotypes.

Wooden boxes (60 x 110 x 22 cm) were filled

Table 23. Mean percentage of deadhearts among an array of sorghum lues for all combinations of glossy and trichomed characteristics.

Category	Mean Percent DH
1. Trichome glossy	60.7 ± 3.2
2. Trichomeless glossy	70.9 ± 3.6
3. Trichome nonglossy	83.5 ± 2.9
4. Trichomeless nonglossy	91.3±1.6
Whole set	76.6 ± 2.4

"t" test 2 vs 4 5.17(*P* > *0*.01)
3 vs 4 2.35 (*P*> 0.05)
1 vs 2 + 3 7.02(*P*> 0.61)

with red soil (Alfisol) up to 5 cm from the top. The soil was saturated at sowing and then allowed to slowly dry out. Portable shelters were used to keep out the rain. The lines were rewatered when they appeared to be wilting; only 50% of them showed chances of recovery on rewatering. A visual score on a 1 to 5 scale for severity of wilting was made prior to rewatering the plants. This was repeated 1 and 5 days later, so as to assess the ability of the different lines to recover. Preliminary results from 82 lines showed significant differences in tolerance to water stress at the seedling stage. The results also suggest that there is scope for selection for genetic improvement.

Entomology

During the year under review it was possible to provide graded levels of shoot fly attack on breeders'material. Studies on the biology and

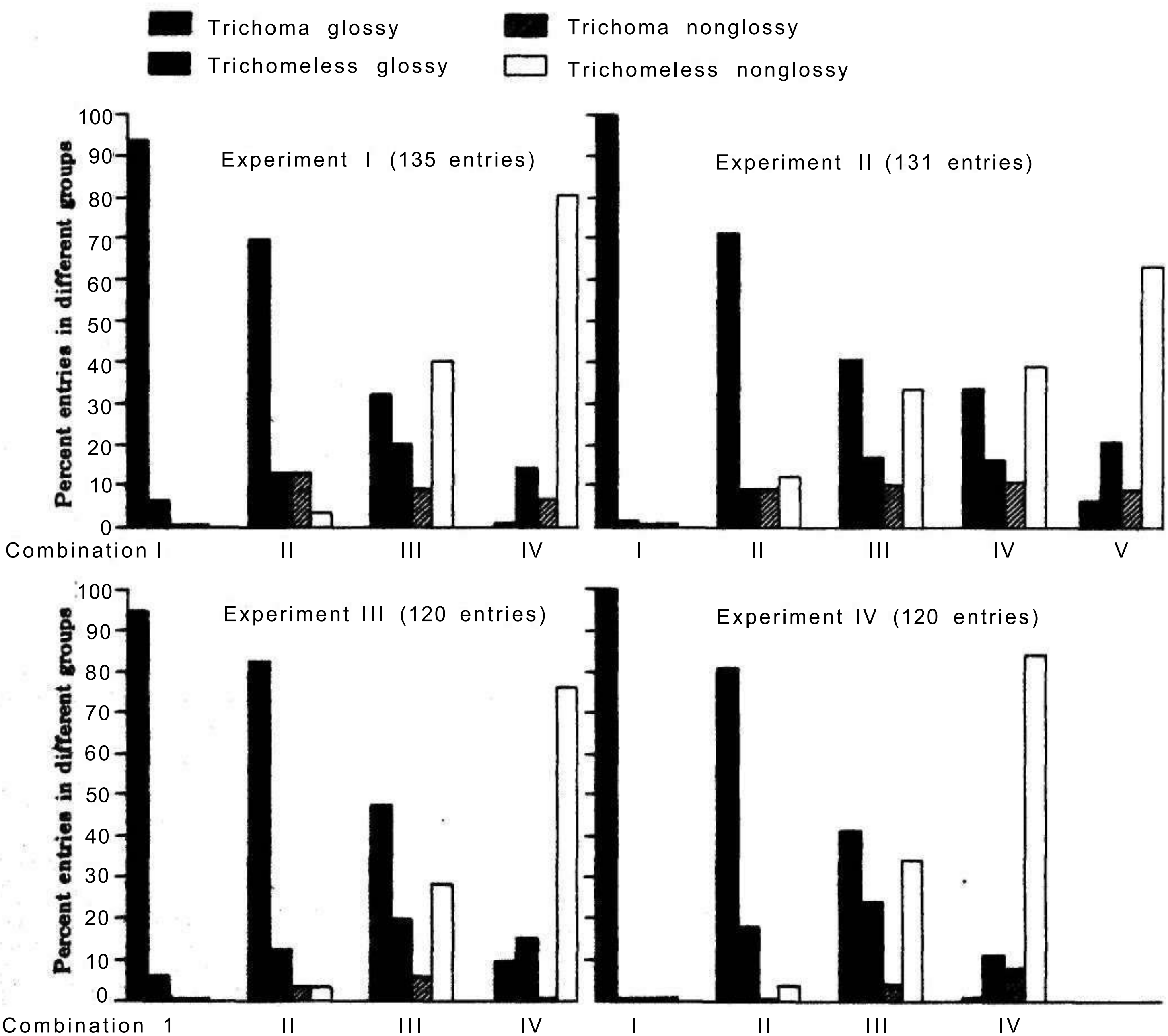


Figure 7. Distribution pattern of various trichome-glossy combinants indicating level of shoot fly tolerance in different experiments on sorghum.

ecology of the shoot fly and stem borer were continued. A full-scale laboratory for stem borer rearing on an artificial diet was started, and a large group of materials was screened successfully using the dispenser technique developed by CIMMYT. Further studies on stem borer pheromones were carried out.

Pest Incidence and "Carryover" Studies

Observations on pest incidence and carryover of pests from the previous season were made both at ICRISAT Center and on farmers' fields. The standard observation plots consisting of a range of cultivars were grown in the pesticide-free area of ICRISAT Center in both the rainy and, for the first time, postrainy seasons. Shoot fly (*Atherigona soccata*) was severe in the rainy season, and there was a heavy stem borer attack by two species, *Chilo* and *Sesamia,* in the post-rainy season. Observations on the stalk residues of sorghum from the rainy season confirmed that some larvae could survive up to 250 days and that 44% of the larvae entering diapause produced adult moths. Parasitism in larvae was low (about 5%). The number of larvae present in stalks was proportionally far higher at ICRISAT Center than on farmers' fields, and there was an indication that, as a percentage, more of the larvae from farmers' fields survived to produce adults. Although no parasites were obtained from larvae from farmers' fields a large number of parasite pupal cases were present.

Sorghum Shoot Fly

Work continued on shoot fly population dynamics using galvanized square pan metal traps with fishmeal at 20 different sites at ICRISAT Center *for* sampling *of cropped* and grassland areas. The results from these studies were similar to those obtained in 1977-78; 30 species of the genera *Atherigona* and *Acritochaeta* were recovered. Trap catches in April, May, and June were extremely low, but a significant proportion of the flies caught were *A. soccata.* Detailed examination of 45 female *A. soccata* caught in June indicated that most were spent; however, 38% had a second or third batch of developing eggs. No gravid females were found in the sample but 20% were virgin or with a first egg batch. An examination of 2936 *A. soccata* females trapped in July showed that 47% had well developed ovaries and that 4% were gravid. A significant number (46%) were spent. Only 3% were virgin or with a first batch of developing eggs. These figures therefore did not indicate any lack of attraction to older flies, but there was strong evidence that flies with maturing ovaries were highly attractive.

The fact that the low May population was capable of producing a high number of eggs was confirmed by studies in which sorghum was sown at eight sites at ICRISAT Center on three different dates in the summer season (May) and irrigated. The mid-May sowing was heavily attacked by shoot fly (21% of seedlings with eggs). Activity was apparently stimulated by an unseasonal rain (about 77 mm) on 11 and 12 May 1979.

Studies on 17 species of grass at ICRISAT Center showed that although a very extensive range of shoot fly species was present, only seven species of grass carried *A. soccata* and the number of flies bred from these was extremely low. The tendency for a particular fly species to be associated with relatively few grass species was confirmed. Three of the 13 fly species bred from grasses remain undescribed (Table 24). A preliminary attempt to determine if shoot fly moved over long distances indicated that there was little movement from sorghum fields when a trap was placed in the middle of a lake 1 km from the nearest sorghum for 2 months at the peak sorghum shoot fly season. Only four A. *soccata* were caught in 2 months of observation. In a study in which five species of wild sorghum and sudangrass *were sown in* the postrainy season, *A. soccata* was the dominant species present in damaged plants (Table 25). Three other fly species *Atherigona atripalpis, A. bidens,* and *A. oryzae,* were bred in very low numbers. The work on breeding shootflies from cultivated sorghum continued and again 98% of the male flies bred (13 222) were *A, soccata.* Six other species were bred from sorghum, including one unidentified species, but the numbers were extremely low; *Atherigona falcata* and *Acritochaeta orientalis* were more numerous. From these studies, it is clear that carryover of *A. soccata* between seasons is closely related to the presence of sorghum, either wild or cultivated.

Preliminary studies on fishmeal fractions continued, in association with the Max Planck

Table 24 Shoot flies and their host plant records (other than sorghum) from 1 June 1978 to 31 May 1979.

Name of the host	Total flies	No. of females	No. of males	*soccata*	*falcata*	*punctata*	*bidens*	*oryzae*	*pulla*	*reversura*	*eriochloae*	*atripalpis*	*laeta*	SP III	SP VII	SP XIV
Bothriochloa pertusa	10	4	6				6									
Brachiaria distachya	54	25	29			4									1	24
Brachiaria eruciformis	69	41	28			28										
Brachiaria ramosa	42	26	16		2	12		1	1							
Brachiaria reptans	102	57	45		2	42				1						
Cynodon dactylon	129	69	60	1				1		51			7			
Dichanthium annulatum	12	9	3	1	1	1										
Digitaria adscendens	307	180	127		5			121				1				
Echinocloa colonum	1798	990	808	16	782	1		6			3					
Echinocloa crusgalli	563	334	229	1	227				1							
Eragrostis japonica	172	115	57	5	1			50						1		
Eriochloa procera	272	141	131	1	2	1		2	71		54					
Panicum repots	12	2	10						9			1				
Setaria glauca	27	19	8	1		2		1	1			3				
Setaria intermedia	' 23	12	11					1				10				
Setaria italica	9	4	5			5										
Unidentified grass	3	3	0													
Grand Total	3604	2031	1573	26	1022	96	6	183	83	52	57	15	7	1	1	24

Table 25. A range of shoot flies bred from wild sorghums and sudangrass during postrainy season 1978-79.

Name of the host	Total flies	Females	Males	*soccata*	*bidens*	*oryzae*	*atripalpis*
Sorghum almum	66	33	33	32	1	—	—
Sorghum halepense	204	101	103	102	-	1	-
Sorghum virgatum	55	23	32	31	-	-	1
Sorghum verticilliflorum	111	68	43	43	-	-	-
Sorghum arundinaceum	2	2	0	-	-	-	-
Sorghum sudanense	35	27	8	8	-	-	-
Grand Total	473	254	219	216	1	1	1

Institute. To date the catches with different tractions have been lower than with whole fishmeal.

Screening of germplasm lines collected recently in India under high levels of fly attack continued. In all, eight trials were conducted in the rainy season and four in the postrainy season. In addition, in the postrainy season when fly attack is naturally high, several trials were carried out without spreader rows and fishmeal. Lines were evaluated on the basis of oviposition nonpreference, deadheart percentage, tillering ability, and head production. Eighty-five lines from the rainy season and 194 from the postrainy season were selected for further testing.

Stem Borer

The spotted stem borer, *Chilo partellus,* is an important pest of sorghum in India and in the lowland areas of East Africa. The distribution and biology of the pest species have been worked out.

In addition to the "carryover" studies, regular monitoring of *C. partellus* at ICRISAT Center was continued using light traps and pheromones. Two periods of activity were identified—one in August/September and the other, far more important, in January/February/March. The increase of catches of male moths in the pheromone traps in April is probably associated with the harvest of the postrainy season crop (Fig. 8), but this needs further investigation. Many of the pheromone traps were sited near sorghum fields.

In spite of the large numbers of moths present in March/April, "carryover" was contained, possibly by enforcement of a closed season. Further studies on the pheromones of C. *partellus* were carried out. The pheromone was found to be composed of aldehyde (major) and alcohol (minor) components. The studies indicated that very low dosages (5 *μg)* of the alcohol and aldehyde components were inferior to a load of 50 *μg.* The aldehyde component was the major attractant: the treatments not including the alcohol component caught far more moths. A preliminary study of moth activity at night, with

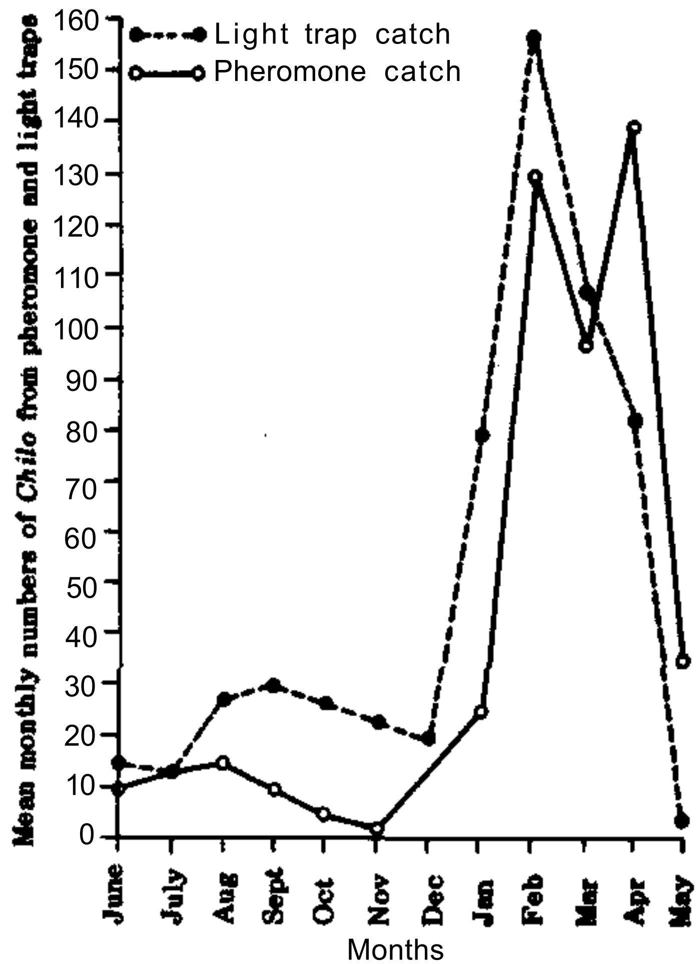


Figure 8. Mean monthly catches of male* Chilo partellus *moths at light (3) and pheromone (14) traps at ICRISAT Center, June 1978 to May 1979.

pheromone and virgin female moths, was carried out for seven nights in the postrainy season (February). It was found that the moth activity was greatest between midnight and 0300 hours. Some activity, however, was also observed as early as 2100 hours (Fig.9).

The maximum calling activity of females was between 0100 and 0200 hours. Interestingly, in the period immediately prior to this (midnight to 0100 hours), the synthetic pheromone attracted more moths indicating that males were receptive, but that females were just beginning to "call" and probably not producing sufficient pheromone to dominate. Further work in this area is required since temperature effects are undoubtedly important.

Some 258 germplasm entries were screened for resistance to stem borer in both the rainy

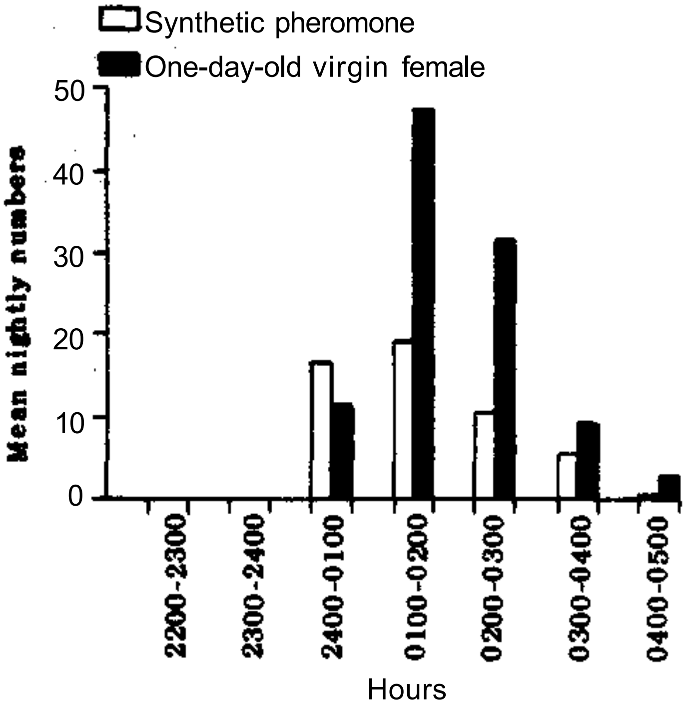


Figure 9. Mean nightly catch of Chilo partellus *male moths with synthetic pheromone and virgin female attractant over seven nights (14 to 20 February 1979; totals of three replicates)* .

and postrainy seasons. Larvae produced on artificial diet were used for field screening. The newly established rearing laboratory allowed 4 ha of breeders' material to be infested. In all, 85 lines representative of India, Kenya, Ethiopia, and Sudan were selected for further screening.

Other Pests

Levels of midge attack were low at ICRISAT Center and selection pressure was insufficient for adequate screening of the midge nursery. Lines S-Girl-MR-1 and AF-28 were, however, retained for further testing.

Of the 101 lines found to be less susceptible to earhead bug, *Calocoris angustatus,* in the previous monsoon season, most were eliminated by a field-screening technique dependent on the high natural levels of infestation obtained on July-sown material. Only 14 were retained for further study.

Pest Nurseries

The 1978 pest nurseries were distributed to cooperators within India and overseas. The shoot fly nursery was sent to 13 locations, the stem borer nursery to 12 locations, and the midge nursery to 8. The number of successful returns was not encouraging, but at sites where records had been adequately taken, it was clear that the entries selected by our program showed higher degrees of resistance than local check entries. Some of the midge lines, in particular, were promising in Mali and Upper Volta.

Pathology

The major emphasis in sorghum pathology was on the identification and utilization of stable host-plant resistance to grain molds (species of *Fusarium, Curvuiaria,* and *Phoma),* charcoal rot (*Macrophomina phaseolina* [Tassi] Goid.), downy mildew *(Peronosclerospora sorghi* [West & Uppal] C. G. Shaw), and the leaf blight (*Exserohilum turcium* [Pass.] Leo & Sugg.) and rust (*Puceiniapurpurea* Cooke). Grain molds are a major problem of widespread occurrence, particularly on short-cycle sorghums, which often mature under wet conditions.

Considerable progress was made in developing elite sorghums with mold resistance. These materials are contributing to national and regional programs in SAT areas. Good sources of resistance to charcoal rot, downy mildew, leaf blight, and rust were identified. Multilocational testing was conducted for the third year for grain molds, downy mildew, and leaf diseases at many locations in Asia, Africa, and the Americas.

Grain Mold Resistance Screening

At ICRISAT Center. Artificial inoculation and natural infection were both used in screening for resistance to grain molds. In artificial inoculation a mixture of *Fusarium moniliforme* Sheld., *F. semitectum* Berk & Rav., and *Curvuiaria lunata* (Wakker) Boedijn was used as inoculum. These were the most prevalent fungi previously isolated from molded grain. Figure 10 shows the steps used in grain mold resistance screening.

Field screening. Of 30 entries screened in the 1978 International Sorghum Grain Mold Nursery (ISGMN), 12 entries were selected (Table 26). Eighty-two singlehead selections from progeny in the advanced screening program were evaluated in the laboratory; of these, 17 were rated as less susceptible. Other than the 12 entries selected in the ISGMN, only 4.6% of the lines in the 1978 International Sorghum Disease Nurseries (ISDN) were selected since they were not developed on a mold resistance background. Among the source material, a group of seven entries (IS-14332, IS-2327, E35-1, IS-9225, IS-2328, IS-2261, and IS-2435) performed consistently better than others during the past 3 years.

Laboratory screening. Field screening for grain mold resistance allows only one screening in a year and the success of the screening is dependent on favorable weather conditions during

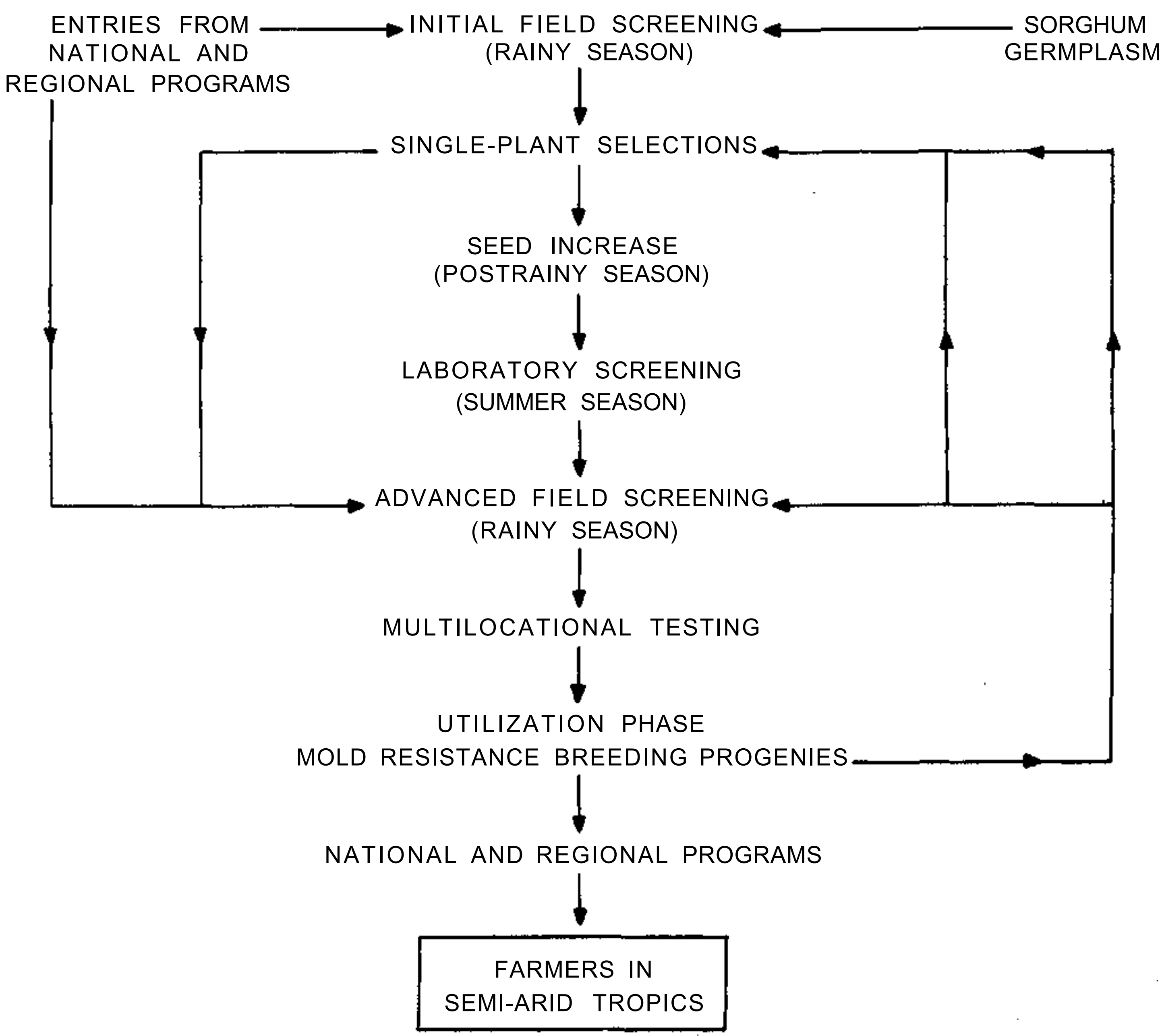


Figure 10. Flow chart of sorghum grain mold resistance screening activity at ICRISAT Center.

Table 26. **Summary of the grain mold resistance screening activities on sorghum at ICRISAT Center during** rainy **season 1978.**

Material	Entries screened	Entries selected	Percent entries selected[a]
ISGMN 1978'	30	12	40.0
SEPON 1978[c]	48	6	12.5
Less susceptible lines from laboratory screening	82	17	20.7
International nurseries other than ISGMN-1978	109	5	4.6
Elite selections from mold resistance breeding project	111	11	9.9
Single head selections from rainy season 1977	564	112	19.9
Mold resistance breeding progenies F_3 and F_4	2096	223	10.6
Total	3040	386	12.6

a. Based on field head mold ratings of 2.
b. The 1978 International Sorghum Grain Mold Nursery.
c. The 1978 Sorghum Elite Progeny Observation Nursery.

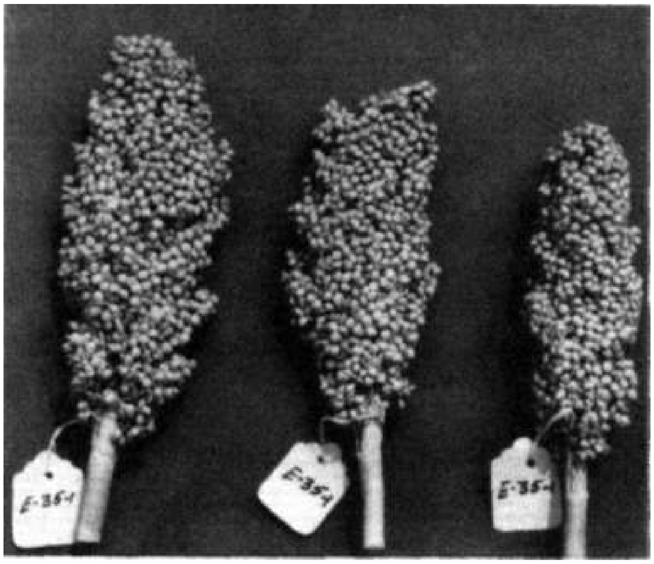
flowering and maturity. Therefore we tested a laboratory screening technique to differentiate the grain in the laboratory for apparent low and high susceptibility to grain molds. The technique involves incubation of postrainy-season-harvested grain in petri-plate moist chambers at 25°C for 4 days and measurement of three grain mold infection parameters: (1) percent mold (percentage of molded grain after incubation), (2) severity (moldiness of each grain on a 1 to 5 scale), and (3) visual scoring (assessment of moldiness on the incubated grain).

Among the 659 entries screened in the laboratory in summer 1978, no single entry was completely free of mold infection, although 77 entries had visual scores of 2 or less.

Multilocational testing. The objective of this program is to develop stable grain mold resistance, to distribute source material to interested scientists, and to promote the development of a cooperative international network of scientists. In the 1978 ISGMN (Table 27), no entry was highly resistant, and eight entries—IS-14332, IS-9225, E35-1, IS-2328, IS-2327, JP-2579, M-36284, and M-36285—were consistently better than others at most locations. The two M-lines are derivatives from SC-108-3 and E35-1. Grain molds are greatly influenced by humidity at the time of flowering. Late flowering entries generally tend to escape mold infection. However, several of these entries performed substantially better than the susceptible check (IS-9991), even though they flowered earlier or about the same time.

Charcoal Rot (*Macrophomina phaseolina*)

At ICRISAT Center. Using the toothpick-inoculation technique, 540 sorghum germplasm lines and 1501 breeding progenies were screened for resistance to charcoal rot. Individual



Heads of the mold-resistant variety E35-J. This variety was seleeted from the ISGMN and is performing well in Upper Volta.

plants were split open at maturity and the internal spread of the pathogen from the internodal point of inoculation near the base of the plant was assessed on the basis of number of nodes crossed. There were 399 lines that had no node crossed in any plant; 644 lines had up to 50% of the plants showing one node crossed.

In the advanced screening of 2918 F_3 charcoal rot resistance breeding progenies, 2281 single plants were selected by breeders as having good agronomic traits (Table 28). When the selected plants were split open, 567 had one node crossed and only 26 plants showed no spread of infection from the point of inoculation. All other plants showed spread of infection within the inoculated internode.

The toothpick-inoculation technique causes physical injury to plants and is therefore unsatisfactory for disease resistance screening. Better inoculation methods are under investigation. Problems have also been encountered at ICRISAT Center with occasional rains in November and February that disturb the moisture stress conditions essential for infection and development of charcoal rot. A more suitable location for initial screening of a large volume of sorghum material is being sought.

Table 27. The rank values of 30 ISGMN-1978 entries based on across-location means for three grain mold assessment parameters.

Entry	Field rating"	Lab ranking[b]	Lab rating[c]
IS-14332	1	1	4
1S-9225	2	4	2
E35-1	3	7	3
IS-2327	5	3	1
M-36284	6	6	7
IS-2328	8	8	5
M-36285	10	2	6
JP-2579	9	9	10
IS-2435	7	5	13
1S-2261	4	12	18
M-36368	11	16	16
M-36471	12	15	17
M-36423	13	17	8
M-36533	14	20	9
IS-472	15	14	10
M-36348	16	11	14
M-36049	17	18	11
M-36046	18	22	22
M-36619	19	10	12
CS-3541	20	24	23
M-35052	21	13	15
M-36109	22	25	26
M-36113	23	19	25
M-407-15	24	23	20
M-35175	25	28	28
M-36333	26	26	24
M-4337-2	27	27	27
M-4397-1	28	21	21
IS-9991 (check)	29	30	30
PP_2B (check)	30	29	29

a. Based on data from 12 locations scored on a 1 to 5 basis.
b. Based on data from 9 locations- based on a simple ranking.
c. Based on data from 8 locations based on estimated percentage of molded surface of threshed grain.

Multilocational testing. The International Sorghum Charcoal Rot Nursery (ISCRN) was initiated to identify sources of stable resistance to charcoal rot and to distribute resistant genotypes to scientists in national and regional

Table 28. Number of single-plant selections in each charcoal rot reaction category for no node crossed and one node crossed in charcoal rot resistance breeding progenies of sorghum.

Group of material	Total entries screened	No. of single plant selections	Reaction category (No node crossed) X	Y	Z	One node crossed
Rabi* sorghum breeding progenies (F_3s)-I	568	133	2	1	89	41
Charcoal rot resistance breeding progenies (F_3s)-I	352	950	5	21	623	301
Rabi sorghum breeding progenies (F_3s)-II	1000	337	9	20	231	77
Charcoal rot resistance breeding progenies (F_3s)-III	998	861	10	59	664	148
Total	2918	2281	26	101	1587	567

a. No node crossed plants were again subdivided into three categories X, Y. and Z based on extent of stalk colonization within inoculated node, where X = no spread from inoculation point. Y = about half of internodal area covered and Z = extending up to one internode but not crossing any node.
b. Rabi = postrainy season.

programs. Based on the mean performance of entries at seven locations in Africa and Asia, eight entries had a minimum mean number of nodes crossed of less than one (Table 29), but the maximum mean number of nodes crossed for these entries ranged from 2.4 to 8.4. The known high susceptibles had up to seven nodes crossed. At Nandyal, where the maximum disease pressure was recorded, four entries—(SC-108-4-8 x CS-3541)64, CSV-4, (SC-108-4-8 xCS-3541)-II, and IS-121-performed better than other test entries based on mean number of nodes crossed and percent soft-stalked plants. The check entries at Nandyal had a mean of up to seven nodes crossed.

The total rainfall received during the period from flowering to maturity at various locations was found to influence the expression of charcoal rot symptoms (Fig. 11). In a study of known high and low susceptibility entries, two interesting points, observed in comparison of total rainfall received, days to 50% flowering, and charcoal rot reactions (mean number of nodes crossed), confirmed earlier observations:

1. Resistant and susceptible entries flowering around the same time differed in their charcoal rot reactions at locations where the rainfall received was low (10 to 40 mm).
2. Resistant and susceptible entries showed almost the same reactions at locations where the rainfall received was high during flowering to maturity (110 to 196 mm), with the exception of one replication at Parbhani. The low susceptible entry at Parbhani had no nodes crossed in one replication and in another replication up to three nodes were crossed.

Leaf Blight (*Exserohilum turcicum*) and Rust (*Puccima purpurea*)

Large-scale field screening for resistance to leaf blight and rust was carried out at ICRISAT Center. Inoculum grown on autoclaved sorghum grain was used to promote leaf blight incidence, and severe natural incidence was relied on for rust screening. Of the 930 lines in preliminary screening, 125 were blight-free and 40 rust-free. An additional 480 entries had trace to 5% blight, and 303 entries had up to

Table 29. Charcoal rot reactions (mean number of nodes crossed) of the 1978 ISCRN entries at seven locations.

Entry	Mean days to 50% flowering	Mean number of nodes crossed		Nodes crossed[b] < 1
		Min[a]	Max[a]	
(SC-108-4-8 x CS-3541)-64	63	0.6	3.3	10
20-87	63	0.8	3.2	8
1-30	68	0.8	4.4	9
(SC-108-3 x CS-3541)-30	73	0.8	3.0	8
CSV-4	70	0.8	3.3	8
8-55	63	0.8	5.2	9
(SC-108-4-8 x CS-3541)-11	65	0.9	3.3	7
IS-121	58	0.9	2.4	10
IS-1235	69	1.0	4.0	6
4-45	64	1.0	8.2	8
SC-120-14	65	1.0	3.9	5
6-39	66	1.1	4.8	8
5-33	69	1.1	5.0	8
15-36	61	12	6.6	8
4-20	67	12	5.5	6
IS-12666 C	56	1.3	4.8	6
18-10	69	1.3	4.8	6
4-22	66	1.3	3.8	5
23-94	65	1.3	5.0	7
2-86	65	1.4	7.6	8
21-78	62	1.4	5.0	7
20-67	67	1.4	6.2	8
1-52	69	1.5	4.6	7
IS-84	65	1.5	8.4	7
SC-120	64	1.5	5.4	6
25-98	63	1.6	5.2	7
21-82	64	1.6	6.6	6
IS-410	58	2.1	5.8	3
CSH-6[c]	61	2.2	7.4	5
A-2268[c]	71	2.4	5.8	3

a. Data based on seven locations—Wad Medani, Tarna. Kamboinse. Parbhani. Dharwar, Nandyal,and ICRISAT Center.
b. Two replications at each of the seven locations, *c.* Known high susceptibles.

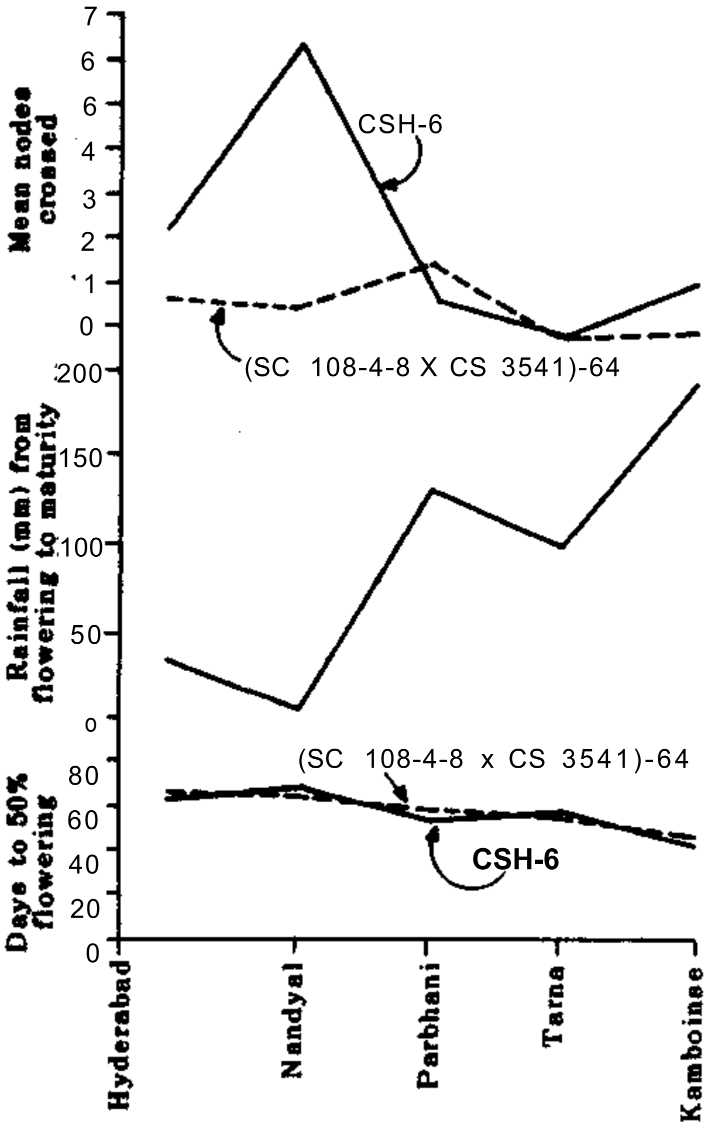


Figure 11. Total rainfall received from flowering to maturity; days to 50%flowering and charcoal rot reactions (mean nodes crossed) of a known highly susceptible —CSH-6—and a less susceptible—(SC 108-4-8 x CS-3541]-entry of sorghum in the 1978 1SCRN at three Indian and two African locations.

5% rust. Only 14 entries-IS-2007, IS-3679, IS-3872, IS-3911, IS-6958, IS-9836, IS-10803, IS-9928, IS-1201C, IS-3579C, IS-3818C, IS-684SC, IS-7254C, and IS-7994C-were free from both blight and rust when scored at the soft dough stage.

International Sorghum Leaf Disease Nursery. The International Sorghum Leaf Disease Nursery (ISLDN) has three objectives: (1) to identify stable resistance sources to various leaf diseases of which the most important are anthracnose (*Colletotrichum graminicola* [Cesati] Wilson), grey leaf spot (*Cercospora sorghi* Ellis & Eberhart), leaf blight (*Exserohilum turcicum* [Pass] Leo. & Sugg.), rust (*Puccinia purpurea* Cooke), sooty stripe (*Ramulispora sorghi* [Ellis & Eberhart] Olive & Lif.), rough leaf spot (*Ascochyta sorghina* Sacc.) and zonate leaf spot (*Gloeocercospora sorghi* Bain & Edg.), (2) to identify "hot-spot" locations for screening under natural infection for these diseases, and (3) to distribute the leaf disease resistance source to cooperating scientists in countries of the SAT.

Table 30 shows the results of the 1978 ISLDN. IS-7254 was the best entry (it has been for 3 successive years), but none of the entries showed a high level of resistance to a particular disease at all locations.

Downy Mildew (*Peronosclerospora sorghi*)

We continued efforts at ICRISAT Center to develop an effective screening technique for sorghum downy mildew (SDM). In order to provide continual sporangial inoculum, several cultivars of maize *(Zea mays)* and teosinte (*Euchlaena mexicana*) were tried as infector rows. Although a considerable number of plants in these cultivars developed systemic infection, the conidial production was not sufficient to serve as an effective source of inoculum.

Preliminary studies were conducted with sorghum (known high susceptibles CSV-2, DMS-652, and IS-2550), maize (CM-500), and sweet corn. These plants were grown in trays with sterilized soil and placed between previously sown infector rows. Young seedlings developed high levels (67 to 88%) of systemic infection. However, this infector row technique was not effective for large-scale field screening because we could not control shoot fly attack in the latersown test entries.

Mixtures of oospores and soil with farm-yard manure (approximately 1:10-oospore:soil by volume) produced SDM infection of 60% in the known highly susceptible DMS-652 sorghum cultivar. The combination of oospores applied in the soil and later inoculation with conidia may help in obtaining high levels of SDM infection.

Up to a mean of 53% systemic infection was obtained when conidial suspension was injected into 29 to 34-day-old plants of DMS-652.

Microbiology

Ninety-eight cultivars of sorghum were screened for their nitrogenase activity using an acetylene reduction assay during the rainy season and the irrigated winter (postrainy) season of 1978—79. Nine out of the 65 cultivars planted in the winter season stimulated nitrogenase activity of more than 30 µg N/15-cm dia core per day (Table 31). Only two lines had above 235 *µg*

Table 30. Flowering data and maximum reactions[a] of 23 sorghum entries to seven leaf diseases* at various locations[c] in the 1978 ISLDN.

Entry	MDTF[d]	Blight	Grey	Anth.	Zonate	Rust	Rough	Sooty
IS-7254	91	3	3	2	3	2	1	3
IS-7322	100	3	3	3	4	2	2	2
IS-2276	72	3	4	5	4	2	2	2
CS-3541	69	3	3	3	3	3	2	2
IS-2225	64	4	5	5	4	3	2	2
BRANDES	79	4	4	4	3	2	3	2
SC-120-4	67	3	3	3	5	2	4	2
IS-10240	66	2	4	4	4	3	3	3
IS-4150	76	3	3	4	4	3	2	3
IS-3925	72	4	4	4	3	3	2	3
IS-115	73	3	4	3	3	3	4	2
SC-326-6	83	3	3	3	4	2	4	3
IS-2419	60	3	4	3	4	3	3	4
IS-10262	60	3	4	4	4	4	3	3
IS-517	61	4	3	4	3	3	3	3
IS-460	56	3	3	3	4	3	3	3
IS-158	65	3	4	4	3	3	4	3'
IS-152	61	3	4	4	3	3	3	3
TAM 428	73	3	5	3	3	3	3	4
IS-2223	60	4	3	5	4	3	4	3
IS-3390	62	3	5	4	4	3	3	3
IS-8171	98	3	5	4	3	3	3	3
IS-2232	62	3	3	5	3	3	3	3

a. 1 = highly resistant and 5 = highly susceptible on a scale of 1 to 5.
b. Leaf blight, grey leaf spot, anthracnose, zonate leaf spot, rust, rough leaf spot, and sooty stripe.
c. Eight locations in India (Indore, Navsari, Kovilpatti, ICRISAT Center), Thailand (Khon Kaen), Niger (Seha), Nigeria (Samaru). and Upper Volta(FarakoBa).
d. Mean number of days to 50% flowering.

Table 31. Sorghum cultivars stimulating nitrogenase activity[a] in the irrigated postrainy season 1978-79.

Cultivar	Origin	μg N fixed/ core per day	Active seasons	Total tested	Max. activity in other seasons μg N/core per day
IS-239I	S. Africa	256	2	2	66
IS-1050	India	235	2	3	54
IS-3756	Ethiopia	86	2	2	56
IS-2663	Uganda	82	2	3	82
IS-15162	Cameroun	69	2	2	50
19/10[b]	USA	61	1	1	
IS-2207	India	51	2	4	158
IS-2318	Sudan	31	3	5	130
IS-2333	Sudan	30	2	5	325

a. Plants were assayed during the grain filling stage 108 days after planting.
b. Tested for first time.

N/core per day. Eight of these nine cultivars were found to be active in both seasons.

Large increases in dry-matter production and nitrogen uptake were 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, inoculated plants accumulated as much as 108 mg N/plant, without addition of any nitrogen fertilizer (Table 32).

The response of sorghum CSH-6 seedlings to inoculation with *Azospirillum lipoferum, A. brasilense, Azotobacter chroococcum,* and *Derxia* spp was examined for plants grown in 25 x 200-mm test tubes with washed, sterilized vermiculite as the root medium. The tubes were inoculated at sowing and the plants were assayed for their nitrogenase activity 8 days later. The highest activity of 364 nmol C_2H_4/plant per 24-hr incubation period was obtained with plants inoculated with *Azotobacter chroococcum.* The activity in the uninoculated control plants was 1.2 nmol C_2H_4/plant per 24-hr incubation period. We are exploring whether this technique will be useful for studying host cultivar-bacterial strain interactions in nitrogen fixation associated with sorghum.

Looking Ahead

Breeding. The promising sorghum varieties with good grain quality that we have identified will continue to be supplied to various national programs. Elite varieties and hybrids will be increasingly tested in India in collaboration with the All India Coordinated Sorghum Improvement Project. Search for nonrestorers has been successful, and a diverse array of seed parents or A lines will be developed in the next few years.

Interdisciplinary activities among breeders, physiologists, pathologists, and entomologists will be intensified in order to evaluate breeding material against various stress factors such as drought, stalk rots, and insect pests. Having achieved success on techniques of rearing stem borer larvae and inducing artificial infestation, we plan to screen germplasm and breeding material for resistance to this major pest. The value of traits like glossiness and presence/absence of trichomes in breeding for insect resistance will be more critically examined. Breeding activities at ICRISAT regional substations in India will be expanded. Certain problems in breeding cannot be researched in

India (for example, *Striga hermonthica* and *Busseola fusca);* therefore major efforts on *Striga* are being shifted to Africa (Upper Volta). Identification and utilization of resistance to grain molds like *Curvularia* and *Fusarium* were rewarding, and our future efforts will be to combine resistance to other important molds like *Phoma.*

Having established some procedures to evaluate food quality of breeding material, we will be giving more attention to this area of research, particularly in collaboration with scientists in Africa.

Biochemistry. Studies on the relationship of physicochemical and chapati characteristics of sorghum will be extended to more sorghum cultivars in order to test our initial findings. Efforts will be made to improve our taste-panel evaluation procedures.

Entomology. Our screening efforts for shoot fly resistance will concentrate increasingly on the material emanating from the breeding programs in addition to any newly added material from the germplasm collections. Attempts to determine the chemical and physical bases for resistance to sorghum shoot fly will be intensified in collaboration with the scientists at ICIPE, Nairobi. Studies on the fly larval movement, adult migration, and pupal diapause, if any, will be carried out. Efforts will be made to develop an effective artificial diet for the fly. The chemicals responsible for attraction in fish meal will be tested in collaboration with the Max Planck Institute, West Germany. Work on chemicals responsible for host-plant resistance will be carried out in collaboration with COPR, London, and ICIPE, Nairobi.

To evaluate resistance, a special midge-screening area will be developed at Dharwar,

Table 32. Nitrogen balance as mg N/pot of sorghum CSH-5 grown in vermiculite in pots for 49 days.

Fertilizer N[a] (kg/ha)	Inoculated/ uninoculated	Initial N in vermiculite"	Final N in vermiculite mgN /pot	Total N in plant material[c]	Overall N gain
0	Inoculated with Napier bajra root enrichment culture	7	180	369	541
	With isolate from *Sorghum halepense*	10	158	187	335
	With boiled composite	7	113	152	258
	Uninoculated	6	68	99	161
	Unplanted	0.5	45		44.5
20	Inoculated with Napier bajra root enrichment culture	60	23	140	103
	With isolate from *Sorghum halepense*	63	-10	173	100
	With boiled composite	60	214	89	243
	Uninoculated	59	68	127	136
	Unplanted	54	45		-8
120	Uninoculated	323	233	248	158

a. N fertilizer addition as NH_4SO_4, calculated on a surface area basis.
20 kg N/ha = 53 mg N/pot, 120 kg N/ha = 318 mg N/pot.
b. Includes initial N in vermiculite, fertilizer inoculum, and seed. *c.* For five plants per pot.

which is a midge-endemic area in South India. Subsequently, material emerging from the breeding programs incorporating identified resistances will be screened. More information will be obtained on the biology, carryover, host plants, and natural enemies of the midge fly.

Detailed work will be carried out on the biology and ecology of the earhead bug complex. Attempts will be made to develop screening techniques, which will be utilized to screen material generated from the breeding programs. Material emerging from the screening programs for all major pests will be put in pest nurseries in India and overseas.

Work will be carried out on the armyworm (*Mythimna separata*), shoot bug (*Peregrinus maidis*), and headworm complex. Studies on pest biology, carryover, population dynamics, host-parasite relationships, and evaluation of attractants and pheromones will be intensified.

Pathology. Our efforts in sorghum pathology will include: (1) identification and utilization of lines with resistance to *Phoma;* (2) screening new germplasm collections to identify diversified source material resistant to grain molds; downy mildew; and leaf, stalk, and root diseases; (3) analysis of molded grain for mycotoxins; (4) characterization of various components in sorghum grain deterioration; (5) identification and utilization of source material consistently less susceptible to charcoal rot, leaf diseases, and downy mildew; (6) investigations on the development of a possible screening technique for charcoal rot resistance in the seedling; (7) investigations on the role of various stress factors in the development of charcoal rot; (8) identification of stable sources of resistance to ergot; (9) identification of more "hot-spot" locations for screening leaf diseases, charcoal rot, and sorghum downy mildew under natural infection conditions; and (10) improvements in screening techniques for resistance to leaf diseases and charcoal rot.

Microbiology. Nitrogen fixation associated with sorghum roots will be studied in nitrogen balance experiments in pots, in lysimeters, and in the field, using isotopic ^{15}N.

The response of sorghum to inoculation with nitrogen-fixing bacteria will be characterized, using bacterial cultures obtained from plants in traditional sorghum-growing areas in the SAT.

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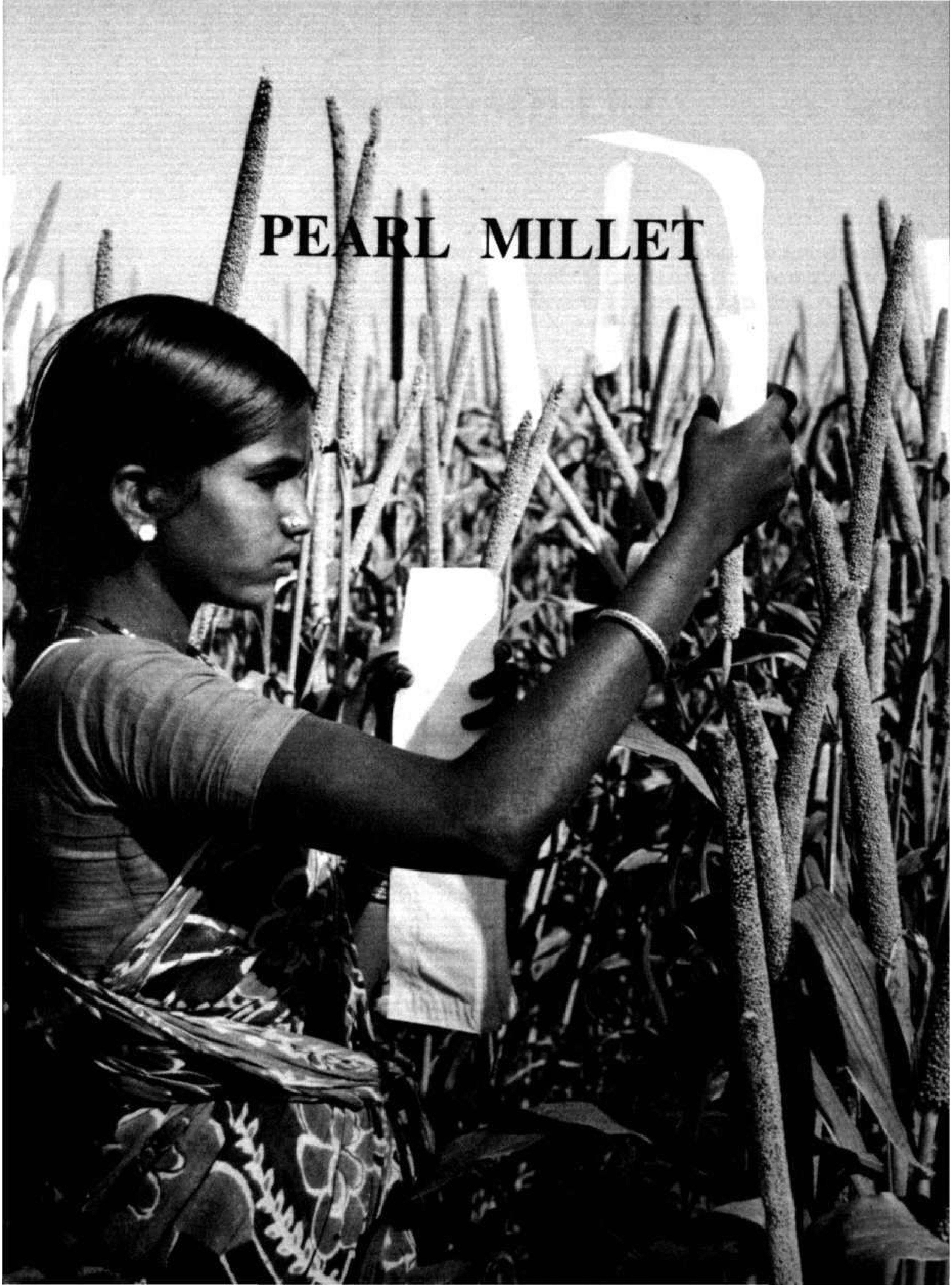
PEARL MILLET



Contents

PEARL MILLET

The basic objective of the pearl millet improvement program is to develop and disseminate technology that will enable consistently higher levels of on-farm pearl millet yields than at present. The technology includes techniques, breeding procedures, and improved genotypes having stress resistances and high-yield potential. This report is structured by discipline, but as in other ICRISAT crop improvement programs, there is considerable interdisciplinary interaction in project formulation, management, and execution.

Breeding

The primary aims of the breeding activities are the development and distribution of novel and improved genotypes capable of producing high, stable yield, and possessing good grain quality and resistance to major diseases and other stress factors. To achieve these aims the program emphasizes close integration of activities at ICRISAT Center and multilocational testing of breeding material in India and West Africa, including testing in downy mildew nurseries. Recurrent selection in composite populations and variety-cross approaches are emphasized equally in generating hybrids, synthetics, experimental varieties, and inbreds, as well as an array of breeding lines to be distributed to cooperating breeders in various countries.

Source Material

Inflow of new variability is essential to continuous progress in a crop improvement program. The basic source material is the germplasm collection, which contains a rich diversity of genotypes (see Genetic Resources Unit section of this report). In our source material project, selected germplasm accessions, as well as source populations developed by breeders outside ICRISAT, are maintained and utilized. These germplasm accessions have been crossed to adapted lines and progenies have been selected for use in the hybrid as well as the variety-cross program. Of the nine source populations in this project, eight originated in West Africa, and four contain appreciable amounts of photosensitivity. These populations are being improved by progeny evaluation, and good progenies have been crossed to male-sterile lines to identify potential pollinators and seed parents for hybrids. Crosses have also been made to elite material to move desirable characteristics into more agronomically advanced backgrounds.

In the 1978 rainy season, S_2 progenies of three West African dwarf populations (3/4 Heine Kheri, 3/4 Ex Bornu, and Saria Synthetic) were grown at Bhavanisagar in South India (UN). Mean yields were 3418 kg/ha for 3/4 Heine Kheri progenies, 4163 kg/ha for Ex Bornu progenies, and 3689 kg/ha for Saria Synthetic progenies. Eight progenies from Ex Bornu, five from 3/4 Heine Kheri, and five from Saria Synthetic were chosen to develop experimental varieties, and selection differentials for grain yields were about 20%. Recombinations of the selected progenies to form experimental varieties were done in summer 1979 in the ICRISAT Center downy mildew nursery.

Several good progenies with a wide range of diversity were generated from source populations and source x adapted crosses. An F_3 progeny nursery (837 lines), derived from crosses involving West African dwarf populations (S_2 progenies) and established Indian inbreds, was grown at ICRISAT Center in the rainy season of 1978. About 450 individual plants from 17 different crosses were selected to enter the 1979 Uniform Progeny Nursery and for developing experimental varieties. A large number of test crosses were also made using these progenies.

Trials in 1978 identified several potentially useful products from this project. The hybrid ICH-241 (5141A x Serere 38-142), of which the pollinator is derived from the Working Collection, and two synthetics derived from source populations (ICMS-7819 and ICMS-7820) performed well in advanced trials. In the Source Material Hybrid Trial, three new hybrids were identified for testing in the Advanced Hybrid Trial of 1979. These were 5141A x 7173 (2880 kg/ha), 5141A x 7177 (2819 kg/ha), and 5141A x S38-36 (2794 kg/ha). In this trial, the check hybrid BJ-104 yielded 2236 kg/ha.

Source material progenies proved to be a valuable source for resistances to downy mildew and smut. Six progenies, all originating from Ex Bornu, were moved from the 1978 Pre-International Pearl Millet Downy Mildew Nursery (Pre-IPMDMN) into the 1979 IPMDMN. Three progenies from Ex Bornu (EB 137-1-1, EB 74-3, and EB 24-1) were smut-free in the 1978 advanced smut screening trials.

Composite Breeding

Intrapopulation Improvement

The number of composites under intrapopulation improvement was reduced from 13 to 11 in 1978 by merging certain composites with similar phenotypes. Early Composite was merged with Dwarf Composite to form D_1 Composite; Late Composite and Nigerian Composite were merged to form the new Late Composite; and D_2 Composite was developed by merging GAM-75, GAM-73, and a few other dwarf D_2 lines. One new composite, Elite Composite, was formed by combining high-yielding, downy mildew resistant, and agronomically superior lines selected from all composites under recurrent selection at ICRISAT in 1977.

By the beginning of the 1979 postrainy season we had completed four cycles of selection in one composite, three cycles in three composites, two cycles in three composites, and one cycle in one composite. The first cycle of S_2 progeny selection was started on the three new composites derived from composite merging. Selection within individual composites was based on performance of 200 to 300 progenies, replicated twice and tested in three to five environments, with an additional replication in downy mildew nursery at ICRISAT Center for within-line selection and seed multiplication. Composite progenies have also been tested in West and East Africa since 1977 with the assistance of ICRISAT breeders at those locations.

From the composite progeny trials conducted in 1978, 22 to 40 progenies per composite were selected for recombination, and the average selection differential for grain yield was 23.6%. Recombination was effected in the downy mildew nursery using only disease-free plants. Based on visual score, disease rating, and grain yield, four to eight progenies from each composite were selected for developing six across-location and 15 location-specific experimental varieties. In merging the Early Composite and the Dwarf Composite, line-to-line crosses were made and evaluated along with their parents. Based on the performance of the crosses and the general combining ability of their parents, three experimental varieties were developed from six crosses.

To assess the genetic gain from selection in these composites, comparisons of C_0, C_1, and C_2 bulks were made in six composites in five environments in India and West Africa. Based on Indian locations where composite progenies were tested during the process of recurrent selection, an average gain in seed yield of 4.2% per year was recorded, although the differences from cycle to cycle were not statistically significant, except for Medium Composite, which showed a 12.5% gain in seed yield per year. Most of the composites improved in India did not show any improvement in West Africa. 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, indicating that the selection methods employed had not rapidly diminished the potential for improvement.

The practical products from the composites are experimental varieties and individual best progenies generated in each cycle of selection. The advanced cycle bulks of composites are not intended for release (except to other breeders on request).

Composite products tested at several locations in India and Africa in 1978 included 45 experimental varieties and 79 best progenies. The 1978 Experimental Variety Trial included, for the first time, experimental varieties derived by recombining progenies selected at ICRISAT's West African locations in 1977. Thirty-four experimental varieties had grain yields equivalent to the commercial hybrid check BJ-104 (2580 kg/ha), and all were superior in downy mildew resistance. One experimental variety, WC-B77, was significantly better for grain yield (3110 kg/ha) than BJ-104. Three experimental varieties, WC-B77, 1VS-P77, and MC-K77, were selected for further testing; the first two were also entered in the All India Coordinated Millet Improvement Project (A1CMIP) trials to be conducted in 1979.

All five ICRISAT experimental varieties in the 1978 AICMIP trials did well. Among those entries tested for 3 years, WC-C75 was the highest yielder, with a mean yield of 1731 kg/ha; this was equal to 94% of the yield of the commercial hybrid BJ-104. This variety will be entered in minikit trials in 1979 and will be included as the check entry in the population trials. The remaining entries (IVS-A75 and MC-C75 in Advanced Population Trial, and SSC-H76 and MC-P77 in Initial Population Trial) were the best-yielding entries in their respective trials.

Of the 79 individual progenies tested, 62 gave the same yield level as the hybrid check BJ-104 (2413 kg/ha), and the majority recorded a lower incidence of downy mildew. One progeny, IVS-7190, gave a significantly higher yield (3158 kg/ha) than BJ-104. Ten progenies were selected for advanced testing in the 1979 Elite Varieties Trial.

A trial to assess inbreeding depression in experimental varieties and in individual progenies by comparing Syn 0, Syn 1, and Syn 2 indicated a slight but nonsignificant increase in grain yield from generation to generation. However, there was a significant yield loss in two out of four experimental varieties and one out of eight individual progenies. It seems that the varieties need to be considered individually; some yield losses may occur in certain varieties, but the majority will maintain the same yield levels in successive generations.

A dwarf "side-car" program was devised to convert seven tall (normal) composites with plant height ranging from 170 to 230 cm, into dwarf d_2 versions by backcrossing, using largely GAM-73 and GAM-75 (which measured below 140 cm) as the d_2 gene donors. The third and final backcross was completed in the rainy season of 1978, and the F_2 populations were generated in the 1979 summer season. Twenty-five promising dwarf F_3 progenies, derived from the first backcross generation, were selected for entering in the Uniform Progeny Nursery and were used in developing six d_2 dwarf synthetics.

Interpopularion Improvement

One cycle of reciprocal full-sib recurrent selection was completed in the 1R/1B composite pair, and the second selection cycle commenced. Based on the results from the first cycle of selection, two experimental varieties of different heights (165 cm and 182 cm) were developed, and 22 test-cross hybrids, some of which produced higher grain yield than the commercial hybrid BJ-104 by as much as 31%, were selected for further evaluation in the Initial Hybrid Trial The third and final round of random mating was completed in another complementary pair of populations—2R and 2B, and S_1 progenies and test-cross hybrids were generated for the evaluation of agronomic traits and restorer reactions.

ICRISAT plant breeder examines a new pearl millet hybrid generated in the interpopulation improvement program.

Based on a diallel study of 16 ICRISAT composites, two additional complementary composite pairs (GAM-75 x 3/4 Ex Bornu and Serere Composite 2 x Nigerian Composite) were identified for reciprocal recurrent selection. Following the reciprocal full-sib method of recurrent selection, GAM-75 x 3/4 Ex Bornu entered the second cycle of selection, and two experimental varieties were generated from selected progenies of 3/4 Ex Bornu. The Serere Composite 2 x Nigerian Composite pair is being improved by the reciprocal inbred tester method. These populations have mixtures of both restorer and maintainer plants, and the possibility of converting one population into a restorer type and the other into a maintainer type is being examined.

Comparison of Population Improvement Methods

In order to provide pearl millet breeders with information on the relative values of different methods of recurrent selection, a 7-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_2 PS). The World Composite was chosen for this study, and the same selection intensity (10%)

and selection criteria were used in all methods. At the end of 1978, the S_2 PS was in the second cycle and the other methods were in the fourth cycle of selection. Random-mated bulks, selfed bulks, and test crosses (using four testers) produced from the individual methods of selection will be compared.

Variety Crosses and Synthetics

In the variety-cross project, new inbreds and partial inbreds are generated each year by crossing two or more complementary lines, mainly Indian x African, followed by pedigree selection for two or three generations. These lines are evaluated for performance per se, for use in making synthetics, and for potential as hybrid parents. To provide the national programs with new sources of clear-cut variability, selected lines with a range of diversity are distributed to cooperating breeders annually in the form of Uniform Progeny Nurseries.

In the 1978 rainy season, the F_1s and F_2s grown at ICRISAT Center, Hissar, and Bhavanisagar included 2000 variety-cross F_1S and 450 F_2 populations. F,s with obvious defects were rejected and those remaining were selfed to produce F_2 populations. Individual plant selections were made from the F_2 populations for further evaluation as F_3 lines. A variety-cross progeny nursery of about 2000 entries (F_3s, F_4s, and F_5s) was grown at ICRISAT Center, and selections were made for further advance and evaluation.

The F_4 (200 entries) and F_5 (100 entries) Uniform Progeny Nurseries were sent to 12 locations in six countries and eight locations in three countries, respectively. Several lines were selected for use in national breeding programs.

Synthetics were formed by combining the individual sets of lines selected on the basis of performance per se and/or combining ability. They were first tested in the Initial Synthetics Trial at a limited number of locations (ICRISAT Center in, low and high fertility, Hissar, and/or Bhavanisagar) and in the ICRISAT Center downy mildew nursery. Promising entries were moved to the Advanced Synthetics Trial for testing at a larger number of locations, including some in Africa.

The 1978 advanced Pearl Millet Synthetics Trial (PMST-1), consisting of 22 synthetics and three checks, was grown at four locations in India and two locations in Africa. Mean grain yields and downy mildew incidence of selected entries are shown in Table 1. ICMS-7806 was the top-yielding entry at Indian and African locations, and also had a low incidence of downy mildew.

Hybrids

Inbreds or partial inbreds generated from the source material, population improvement, and variety-cross projects are channeled into hybrid development and testing activities. They are crossed to three male-sterile lines (5054A, 5141 A, and 111A), and the resulting test-cross hybrids are initially evaluated in unreplicated trials at ICRISAT Center. Selected hybrids are entered in the initial replicated hybrid trial at several locations, including the ICRISAT Center downy mildew nursery. Promising entries with downy mildew resistance and satisfactory agronomic characters are then entered in the advanced hybrid trial at a larger number of locations in an international cooperative trial. The best hybrids from the advanced trial are more intensively evaluated in the International Pearl Millet Adaptation Trial (IPMAT) and in national testing programs.

In the 1978 Pearl Millet Hybrid Trial (PMHT-1), 23 ICRISAT hybrids were tested at three locations in India and two locations in West Africa along with two commercial hybrids included as checks. The four top-yielding hybrids at Indian locations were ICH-105, ICH-241, ICH-220, and ICH-206. All produced higher grain yields and had lower downy mildew incidence than the hybrid checks BJ-104 and PHB-14 (Table 2). At the African locations, ICH-162, ICH-211, ICH-165, and ICH-238 were the best-yielding entries; and ICH-162,

Table 1. Grain yields and downy mildew incidence of selected entries in PMST-1,1978.

Entry	Mean grain yield (kg/ha)			DM incidence (%)		
	Four Indian locations[a]	Two African locations[b]	All locations	ICRISAT Center	Tarna (Niger)	Bambey (Senegal)
ICMS-7806	3094	2355	2847	0	1	4
ICMS-7703	2928	2039	2631	4	2	1
ICMS-7816	2893	2079	2622	4	3	2
ICMS-7818	2925	1977	2609	0	3	1
ICMS-7805	2812	2195	2606	1	3	1
ICMS-7819	2707	2042	2485	0	1	2
BJ-104 (Hybrid check)	3059	1621	2580	22	6	1
PSB-3 (Variety check)	2197	1056	1848	12	6	14
WC-C75 (Variety check)	2752	1814	2439	1	3	1
Mean (25 entries)	2705	1788	2400	NA	NA	NA
LSD (0.05)	234	408	213			

a. ICRISAT Center high and low fertility, Hissar, and Bhavanisagar.
b. Tarna (Niger) and Bambey (Senegal).
NA = Not averaged.

Table 2. Grain yields and downy mildew incidence of selected entries in PMHT-1,1978.

Entry	Pedigree	Mean grain yield (kg/ha)			DM incidence (%)		
		Three Indian locations[a]	Two African locations*	All locations	ICRISAT Center	Tarna (Niger)	Kano (Nigeria)
ICH-105	5054A x B282	3115	2384	2822	0	11	23
ICH-162	111A x 700429-14	2506	2981	2696	0	2	5
ICH-206	5141A x NW 15-18	2776	2566	2692	3	10	24
ICH-238	111A x (T 166-2 x 700594-10-3-4) (7651)	2557	2716	2621	0	8	9
ICH-165	111A x SC 14(M)	2501	2734	2594	2	3	7
ICH-211	5141A x NC-SN 38-1	2329	2919	2565	0	2	8
ICH-241	5141A x S-38-142	3060	1560	2460	4	5	26
ICH-220	5054A x (SD_2 x E x B-2) (D-1088)P-1	2924	1579	2271	2	17	32
BJ-104'	5141A x J104	2667	1725	2290	13	8	21
PHB-14[c]	111A X PIB-228	2252	1769	2059	5	1	8
Mean (25 entries)		2595	2313	2482	NA	NA	NA
LSD (0.05)		382	475	262			

a. ICRISAT Center high and low fertility, and Hissar.
b. Tarna (Niger) and Bambey (Senegai).
c. Check entry.
NA = Not averaged.

ICH-238, ICH-165, and ICH-211 had low levels of downy mildew. Some of these hybrids were not sufficiently uniform and need reselection in the pollen parent before retesting.

In three other initial hybrid trials, 35 hybrids were identified for retesting in 1979. Pollinators of these hybrids included inbred varieties as well as population progenies.

Development and Improvement of Seed Parents

Only a few male-sterile lines have been developed; of these, some have major defects such as unstable sterility and are not utilized commercially. Progress in hybrid breeding has been restricted to the improvement of male parents, which combined well with these male-sterile lines. To widen the scope of generating better hybrids, we have been involved in breeding new male-sterile lines, including male-sterile lines suitable for African conditions.

Three approaches are being used to develop and improve seed parents for hybrid production:

Conventional backcrossing. Sterile cytoplasm of the A_1 system is being introduced into maintainer lines, using the conventional backcrossing technique. These lines were derived from variety crosses and crosses involving B-lines (tested for maintenance ability in F_3 generation) and source material. During the 1978 postrainy season, four inbred lines (Ex Bornu 18-1, Casady Dwarf 5-1, 3/4 Heine Kheri 207, and Casady Dwarf 67-1), and corresponding sterile hybrids, were planted for the third backcross. Plant-to-plant crosses of these inbreds were found to be sterile in both rainy and postrainy seasons. The fourth backcross will be attempted in the rainy season of 1979 in the disease nursery, and also initial test crosses will be made to assess the combining ability using a set of standard restorers.

Exploitation of residual variation. Considerable residual genetic variability occurs in the existing male-sterile lines and their maintainer counterparts, and in morphological characters, seed set, downy mildew resistance, and the frequency of pollen shedders in the A-line. Variability for these undesirable characters is being minimized in four male-sterile lines and their corresponding maintainers ($126D_2$,67,66, and Serere 10L) by making a large number of plant-to-plant crosses and subsequent testing in the disease nursery. The defects include fertile sectors in 67A, high frequency of pollen shedders in 66A, poor seed set and grain color in $126D_2$ A, and a high proportion of fertiles and segregation for bristling in Serere 10LA. Individual plant-to-plant pairs with improvements of their respective defects were selected in 67, 66, and $126D_2$. However, we failed to identify a good A and B pair in Serere 10L, though we grew more than 600 plant-to-plant crosses.

Induction of disease resistance. One major factor limiting the use of male-sterile lines is their susceptibility to downy mildew (DM). An example is the male-sterile line $23D_2A$, a dwarf and good combiner developed in USA. This line is highly susceptible to DM both in India and Africa. To induce downy mildew resistance, seed of $23D_2B$ was treated with gamma rays (30 kr), and from the M_2 generation onwards, disease-free plants (in the ICRISAT Center downy mildew nursery) were selected and backcrossed to the A line, using pedigree selection. In the 1978 rainy season, the fifth backcross was made and three pairs were selected for multiplication in 1979, based on DM reaction and morphological uniformity. Initial test crosses made with selected dwarf inbreds were evaluated in summer 1979. Results are presented in Table 3. The improved $23D_2$ progenies took between 48 and 66 days to flower, and were resistant to DM but highly susceptible to smut. To incorporate earliness and smut resistance, crosses were made in the postrainy season of 1978 using 23DB (received from Dr. Glenn W. Burton, USA) as the source of earliness and smut-resistant lines EB-24-1, EB-74-3, EB-137-1-1, WC-FS-148, and SSC-FS-252. The F_2 populations will be grown in 1980 to screen for dwarfs with low smut susceptibility and earliness.

A highly DM-resistant version (right) has been developed from a highly DM-susceptible line, 23D$_2$B (left) through irradiation-induced mutation, followed by selection in the DM-screening nursery at ICRISAT Center.

International Trials

In 1978, the fourth International Pearl Millet Adaptation Trial (IPMAT-4) comprising 20 entries, contributed by cooperators and ICRISAT, was sent to 51 locations in 20 countries. The entries included hybrids, synthetics, experimental varieties, population bulks, and a local check. Data were received from 37 locations in 13 countries ranging from 28 40'S to 30"41' N, of which 36 locations reported data on grain yield.

The highest location mean grain yield was recorded at Serere, in Uganda (4213 kg/ha) and the lowest (227 kg/ha) at Anantapur in India. The mean grain yield over all locations was 1992 kg/ha. The highest-yielding entry over all locations was the hybrid MBH-110, contributed by the Maharashtra Hybrid Seed Company, India, and the lowest was Ex Bornu Bulk. The top grain yields at individual locations ranged from 659 kg/ha (PHB-47 at Anantapur) to 5061 kg/ha (ICMS-7703 at Serere). Mean yields of the test entries were higher than the yields of the local checks at 18 locations.

The mean grain yields of each entry for all locations, Indian locations, and African locations are presented in Table 4. In Africa, six of the seven top entries were bred using either totally or partly African germplasm (exception: GHB-27).

Rank correlation between entry mean yields for all locations and for Indian locations, and for all locations and for African locations were positive and significant (0.83 and 0.74, respectively). However, the correlation for rankings

Table 3. Performance of some selected dwarf test crosses of pearl millet derived using improved $23D_2$ A, summer 1979.[a]

Field Code	Pedigree	Days to 50% bloom	Plant height (cm)	Grain yield (kg/ha)	1000-grain weight (g)
321	$23D_2A$ x F_4(PIB 228 x 3/4 HK-119-35)	52	130	2866	4.6
336	$23D_2A$ x F_4(PIB 228 x 3/4 HK-119-35)P1	55	140	3333	6.7
339	$23D_2A$ x F_4(PIB 228 x 3/4 HK-119-35)P3	55	148	3600	6.2
343	$23D_2A$ x F_4(PIB 228 x 3/4 HK-119-35)PC	52	145	3333	6.5
353	$23D_2A$ x F_4(PIB 228 x 3/4 HK-119-74)P5	50	125	3466	6.0
391	$23D_2A$ x F_4(PIB 228 x 3/4 HK-113-4)PC	50	150	3800	5.3
394	$23D_2A$ x F_4(PIB 228 x 3/4 HK-113-4)P2	54	145	4000	6.3
	Mean (of 29 selected test crosses)	52	133	2972	5.7
	Range: Minimum	49	110	1800	3.7
	Maximum	55	150	4000	7.6
	GHB 1399[b] (dwarf hybrid check)	48	117	2260	
	BK 560[c](commercial hybrid check)	41	145	3222	
	PHB-14[c] (commercial hybrid check)	48	163	3572	

a. Planted 12January 1979, harvested 13 April 1979. Fertilizer dose: 120 kg N, 60 kg P/ha; plant population 125 000 plants/ha.
b. Mean of ten observations.
c. Mean of three observations.

of entry means at Indian locations and at African locations was not significant. This nonsignificance was apparently due to the contrasting performances of entries MBH-110, ICH-105, and BJ-104, which are adapted to India but are highly susceptible to downy mildew in West Africa.

The downy mildew incidences were much more severe on several entries in certain West African locations than in India, and some entries showed distinct differential reactions among West African locations. Hybrids ICH-118 and ICH-165 had relatively stable levels of downy mildew resistance across locations.

Several other multilocational trials of composite progenies and products, inbreds, synthetics, and hybrids were also grown by cooperators in India and other countries. Distribution of these trials is shown in Table 5.

In 1978, 19 ICRISAT entries were tested in the All India Coordinated Millet Improvement Project (AICMIP) multilocational trials. Two new hybrids (ICH-154 and ICH-165) were in the Initial Pearl Millet Hybrid Trial, and the hybrid ICH-105 was retained in the Advanced Hybrid Trial. Two new experimental varieties (SSC-H76 and MC-P76) and one synthetic (ICMS-7703) were accepted to the Initial Pearl Millet Population Trial, and three experimental varieties (WC-C75, IVS-A75, and MC-C75) were in the Advanced Population Trial. Ten elite restorers were contributed to the parental trial. Hybrid ICH-154 gave higher yield (1993 kg/ha) than the mean yield of the Initial Hybrid Trial (1950 kg/ha at 28 locations) and was promoted for advanced testing in 1979. All experimental varieties and synthetics did well in their respective trials. SSC-H76 and ICMS-7703 ranked first and second among the test entries in the Initial Population Trial, with yields of 1952 kg/ha and 1932 kg/ha, respectively, compared with the trial mean of 1744 kg/ha over 21 locations. Experimental varieties WC-C75 (2073 kg/ha) and IVS-A75 (2008 kg/ha) were the top-yielding varieties in the Advanced Population Trial (trial mean over 33 locations was 1945 kg/ha). Among the varieties that have been tested for 3 years, WC-C75 ranked first

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The downy mildew incidences were much more severe on several entries in certain West African locations than in India, and some entries showed distinct differential reactions among West African locations. Hybrids ICH-118 and ICH-165 had relatively stable levels of downy mildew resistance across locations.

Several other multilocational trials of composite progenies and products, inbreds, synthetics, and hybrids were also grown by cooperators in India and other countries. Distribution of these trials is shown in Table 5.

In 1978, 19 ICRISAT entries were tested in the All India Coordinated Millet Improvement Project (AICMIP) multilocational trials. Two new hybrids (ICH-154 and ICH-165) were in the Initial Pearl Millet Hybrid Trial, and the hybrid ICH-105 was retained in the Advanced Hybrid Trial. Two new experimental varieties (SSC-H76 and MC-P76) and one synthetic (ICMS-7703) were accepted to the Initial Pearl Millet Population Trial, and three experimental varieties (WC-C75, IVS-A75, and MC-C75) were in the Advanced Population Trial. Ten elite restorers were contributed to the parental trial. Hybrid ICH-154 gave higher yield (1993 kg/ha) than the mean yield of the Initial Hybrid Trial (1950 kg/ha at 28 locations) and was promoted for advanced testing in 1979. All experimental varieties and synthetics did well in their respective trials. SSC-H76 and ICMS-7703 ranked first and second among the test entries in the Initial Population Trial, with yields of 1952 kg/ha and 1932 kg/ha, respectively, compared with the trial mean of 1744 kg/ha over 21 locations. Experimental varieties WC-C75 (2073 kg/ha) and IVS-A75 (2008 kg/ha) were the top-yielding varieties in the Advanced Population Trial (trial mean over 33 locations was 1945 kg/ha). Among the varieties that have been tested for 3 years, WC-C75 ranked first with a mean yield of 1731 kg/ha, which was 94% of the commercial hybrid BJ-104 (Table 6). This variety was recommended for minikit trials in 1979, and was included as a check entry in the AICMIP Initial and Advanced Population Trials.

Distribution of Seed Material

During 1978-79, more than 2700 seed items of breeding and source material including inbreds, restorers, hybrids, synthetics, population progenies, experimental varieties, and disease resistance sources were distributed to breeders in 21 countries.

Biochemistry

Protein and Lysine Study

During 1978, protein content was estimated on grain samples of 21 entries of IPMAT-4 grown at four locations. Results indicated a weak relationship between yield and protein content, and between protein content and seed size, confirming results obtained in the previous years. Data for protein content at several locations again showed relatively less variation among locations as compared to variation in yield (Table 7).

Data gathered from analysis of various trials conducted at several locations over the past 3 years indicated the following:

1. In pearl millet, the relationship between (a) grain yield and protein content is weak and mostly negative, (b) grain yield and DBC/g protein (reflecting the basic amino acids content) is weak and mostly negative, (c) grain weight and protein content is weak and can be either negative or positive, (d) grain weight and DBC/g protein is weak and mostly negative, and (e) protein content and DBC/g protein is strong and negative.
2. The genotype-environment interaction for protein content is not significant, indicating that breeding for improved protein con-

Table 6. Performance of selected pearl millet populations in the AICMIP trials.

Population	Grain yield (kg/ha) 1976	1977	1978	Mean	BJ-104[a] (%)	Downy mildew (%) 1976	1977	1978	Mean
WC-C75	1490	1631	2073	1731	93.6	0.2	2.2	2.8	1.7
DC-3	1490	1579	1986	1685	91.1	1.5	4.9	3.4	3.3
PSB-8	1530	1532	1795	1619	87.6	5.3	4.5	6.6	5.5
PSB-3	1330	1574	1898	1601	86.6	2.0	8.9	12.2	7.7
New Vijay	1510	1560		1535	83.1	4.2	10.8		7.5
Local	1135	1302	1916	1451	78.5				
BJ-104		1727	1971	1849	100.0	1.8	8.3	9.8	6.6
HB-7	1640	1482	2084	1735	93.8	2.0	6.7	5.8	4.8
Trial Mean	1330	1540	1945	1605		41.6*	93.5'	67.9[b]	67.7[b]

Source: The coordinators review, AICMIP workshop 1979.
a. Commercial hybrid check.
b. HB-3, a susceptible hybrid check.

Table 7. Grain yield (kg/ha) and protein content (%) of IPMAT-4 (1978) entries at four locations.

	Grain yield				Protein content			
Entry	1	2	3	4	1	2	3	4
ICH-105	2097	2249	2355	2943	9.8	11.0	11.9	9.5
ICH-118	2826	1518	2607	3330	10.9	11.2	12.5	10.7
ICH-154	2701	2043	2120	3650	10.2	11.2	12.3	10.1
ICH-165	2204	1633	2871	2762	10.0	11.7	12.3	9.3
GHB-27	2742	1420	2706	2896	12.0	12.0	12.7	10.8
MBH-110	2402	2171	2119	3361	11.5	10.6	13.5	10.8
PHB-47	2282	1422	2164	2649	10.9	11.7	12.1	10.4
BJ-104	3046	1440	1826	2626	10.5	13.2	12.2	1.9
NHB-3	1417	1607	1461	2554	10.6	11.7	11.9	10.0
SSC-H76	2313	1753	1767	3086	9.0	10.5	11.6	9.2
WCB-76	2251	1730	2418	3051	10.3	10.4	12.5	10.3
MCP-76	3060	1417	2091	2810	10.4	10.3	12.4	10.3
RF-A76	1865	1481	2575	2963	9.5	11.4	12.5	10.7
IVS-A75	2644	1924	1703	2604	10.6	10.9	10.8	9.0
WC-C75	2809	1670	2026	2462	11.0	10.5	11.4	9.5
MC-C75	2345	1583	2323	3345	9.6	11.1	11.8	9.6
ICMS-7703	2506	1608	1689	3043	10.2	10.4	10.6	9.6
DC-3	2531	1738	1989	3032	10.2	12.1	12.4	10.3
SSC(C_1) Bulk	2272	1684	1761	2484	10.1	11.3	11.5	10.8
Ex Bornu Bulk	1893	1020	2041	2675	8.8	10.0	12.3	9.3
Local check	2874	1567	2610	2748	9.7	11.1	11.7	10.1
Mean	2432	1651	2153	2908	10.3	11.2	12.1	10.0
CV (%)	17.9	34.2	25.4	18.6	9.8	8.1	5.6	8.5
LSD (0.05)	721	933	906	893	1.7	1.5	1.1	1.4
Range: Minimum	1417	1020	1461	2464	8.8	10.0	10.6	1.9
Maximum	3060	2249	2871	3650	12.0	13.2	13.5	10.8

1. ICRISAT (high fertility), 2. ICRISAT (low fertility). 3. Hissar, 4. Bhavanisagar.

tent could be carried out using single location results.

3. Protein contents of the same material grown at different locations do not differ much, although grain yields vary substantially.

Thus selection for increased protein content in pearl millet should be possible without detrimental effect to yield or seed size. Breeding work is now under way on a limited scale to examine the possibility of improving both yield and protein content together, using both the conventional approach and recurrent selection. World Composite was chosen for the recurrent selection approach since it has the highest level and good range of protein content among the current composites in the program. Selection will be effected on yield, protein content, and other agronomic characters simultaneously. Progenies from crosses involving two of the high protein lines (identified in 1976) with elite breeding lines are now in the F_3 stage. Additional crosses have been made among lines with high protein, low protein, high lysine, and high grain weight to study the inheritance of protein and lysine content and subsequent selection in segregating progenies.

During this period 5394 samples of pearl millet were screened for protein, using rapid methods; the range was 5.8 to 16.5 and the mean was 10.6. Sixty-five samples were also screened for lysine, using ion exchange chromatography; the range was 2.1 to 3.8, with a mean of 2.7.

Food Product Study

Surveys on consumer preferences in pearl millet were carried out in seven Indian states (Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Tamil Nadu) that account for 80% of total area and 73% of pearl millet production in the country. Several food products commonly prepared from pearl millet were identified: breads, porridges, gruels, and boiled, steamed, and fried foods, and snacks. Depending on the product, whole grain, flour, grits, or batter is used as the starting material. Chapati, an unleavened bread made from whole flour, was found to be the most commonly used.

Physicochemical studies for chapati characteristics were carried out with 16 pearl millet cultivars, comprising local types and popular Indian hybrids. The ranges and means of various physical and chemical characteristics of these cultivars are indicated in Table 8. In addition to evaluation of several flour qualities, the water absorption, stickiness, and spreading ability of dough were also studied and evaluated subjectively. Chapatis made under standardized conditions were evaluated by a trained taste panel for color, texture, flavor, taste, and acceptability.

Chapati quality may be governed by several factors of flour, either physical or chemical, that complement each other. Physical factors such as grain density and swelling capacity, and chemical characteristics of flour such as water-soluble protein, nonreducing sugars, amylose, and fiber were found to be related to taste as evaluated by the chapati taste panel. Results of multivariate regression analysis indicated that most of the above factors had some influence on chapati quality (Table 9). Further work is in progress to understand the factors that influence chapati quality.

Table 8. Physicochemical characteristics of pearl millet flour and chapati quality.[a]

Component	Range	Mean
	Flour	
Swelling capacity		
v/v	3.8- 6.0	5.0
v/w	7.6-10.8	9.2
Flour solubles (%)	22.6-32.4	27.9
Starch (%)	63.1-70.5	66.9
Amylose (%)	21.9-27.4	24.6
Water soluble amylose (%)	3.6- 7.6	5.0
Sugars (%)	2.0- 2.6	2.4
Protein (%)	10.8-17.4	13.7
Water-soluble protein (%)	1.0- 1.3	12
	Chapati	
Water for dough (ml/100 g flour)	64.5-77.3	73.5
Moisture loss during baking (%)	21.3-32.0	27.4
Color and appearance[b]	1.6- 3.6	2.6
Texture[b]	1.6- 3.8	2.8
Taste*	1.6- 3.0	2.5
Flavor"	1.8- 3.2	2.6
Acceptability[b]	1.2- 3.2	2.5

a. Based on 16 cultivars and hybrids.

b. Ratings given by 'panelists (4 = excellent, 3 = good, 2 = fair, 1 = poor).

Sugar Content Study

Sugar fractionation of millet flour of eight cultivars was done using Biogel P-2 column. The total sugars content ranged from 2.2 to 28%

Estimations of stachyose, raffinose, sucrose glucose and fructose were made and their values ranged from 0.06 to 0.1%, 0.7 to 0.8%, 1.3 to 1.8%, and 0.08 to 0.2%, respectively.

Physiology

Evaluating Genotypes under Drought Stress

Millet is grown mainly under conditions of low and erratic rainfall. Therefore, testing for drought resistance is an essential part of the Pearl Millet Improvement Program. For the past 3 years, selected breeding materials have been screened for resistance during the dry summer season as a joint project of the breeders and physiologists. The method used—described fully in the 1976-77 ICRISAT Annual Report — involves comparing genotype performance in midseason (panicle initiation to flowering) and terminal (flowering to maturity) stress treatments. Determination of resistance is based on the performance of the cultivars in the stress treatment relative to that in the nonstressed treatment.

Data from 3 years of such testing have been analyzed to determine the factors that influence performance (yield) under stress conditions and to develop appropriate methodology for assessing drought resistance independently of other factors that influence grain yields in the stress treatments.

Factors affecting yield in stress treatments. Flowering dates for the genotypes ranged from 38 to 60 days. With the use of single midseason and terminal stress treatments, some genotypes escaped severe stress, and others, stressed at the designated stage, suffered severely. In the midseason stress, the earlier- and later-flowering genotypes yielded less than others (Fig. 1). In the early-flowering genotypes the midseason stress overlapped with flowering, and yields were severely reduced because of spikelet sterility and poor grain set. Lower yields in the later-flowering genotypes may have been related to a general reduction in yields with late flowering in the summer season rather than to specific interaction with the stress treatment.

Table 9. Assessment of chapati qualities as a function of physical and chemical characteristics.[a]

	Chapati qualities				
Characteristic	Color	Texture	Taste	Flavor	Acceptability
Swelling capacity of flour	0.19	ND	0.39***	0.23***	0.46**
Amylose	0.23**	- 0.20**	0.13*	0.21***	0.08
Water-soluble amylose	- 0.32**	ND	-0.11	-0.27**	-0.11
Nonreducing sugars	1.69	2.67 ***	ND	0.97***	ND
Fat	0.52*	0.35	-0.31*	-0.41***	-0.29
Ash	- 1.41*	- 1.16**	- 1.10**	-1.21***	- 1.41***
Crude fiber	2.13*	0.95	ND	0.78*	ND

a. Multivariate regression analysis—chapati qualities as dependent variable tested against physicochemical characteristics as independent variables.
ND = No data: variable was not included.
*Significant at 0.10.
**Signiflcant at 0.01.
***Significant at 0.01.

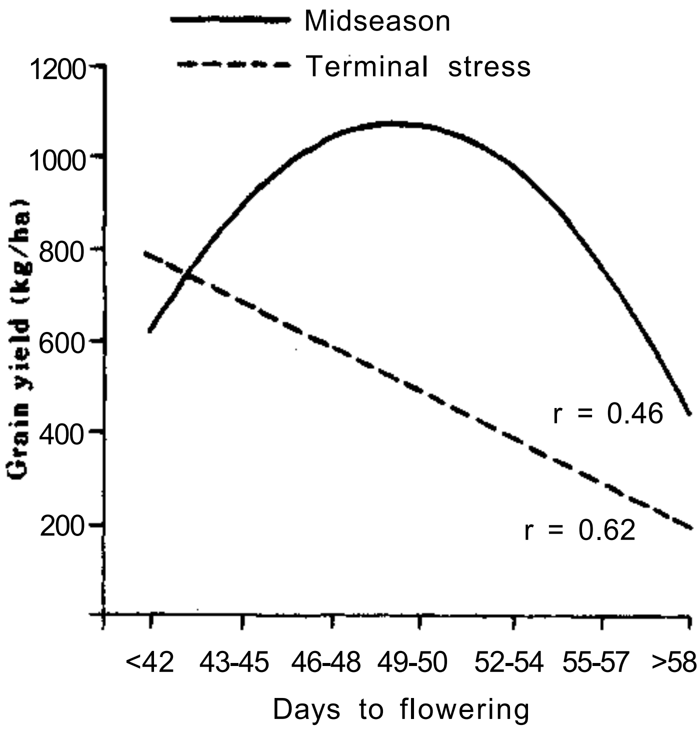


Figure 1. Grain yields in the midseason and terminal stress treatments in relation to days to flowering.

In the terminal stress treatment, the earlier-flowering genotypes were less affected than the later-flowering ones (Fig. 1), owing to the use of a single general stress that allowed the early-flowering genotypes to escape.

In addition to the effects of time of flowering, yields in both stress treatments were linearly related to yields in the nonstress treatment (for the midseason stress, r = 0.58, and for the terminal stress r = 0.44).

The individual and the combined contributions of these two factors (drought escape and yield potential) to actual grain yield in the stress is presented in Table 10 for the 1978 experiment. It is clear that both of these factors had a substantial effect on grain yields under stress. It is, therefore, necessary to remove these effects while evaluating breeding materials for drought resistance per se.

Method of evaluation. The effects of drought escape and yield potential were removed by use of a regression approach to predict the yields under stress as a function of date of flowering and yield potential. As the flowering date response in midseason stress is a second order polynomial, the equations used under the two stresses were different. These two factors accounted for 40 to 60% variation in yield under stress (Table 10). The remaining 40 to 60% constituted drought index (resistance or susceptibility) and experimental error.

Standard normal residual, after removing the yield potential and escape factors, was used as an index of drought resistance/susceptibility. Cultivars with values of the residuals falling below the 10% and above 90% quantiles of the normal distribution were considered suscepti-

Table 10. Correlation coefficients between grain yield of pearl millet under drought stress and grain yield of nonstressed cultivars and between gram yield under stress and days to flowering in 1978.

	Yield in control (YC)	Days to flowering (bl)	bl + $(bl)^2$	YC + bl	YC + bl + $(bl)^2$
Grain yield in midseason stress	0.58**	-0.04	0.46**		0.65**
Grain yield in terminal stress	0.44**	-0.62**		0.74**	

** < 0.01

ble and resistant, respectively. For many cultivars, the variation in yield under stress was largely explained by these two factors (e.g., BJ-104 and BK 560). There were, however, a few cultivars that did appear to be resistant (eg., WC-B76, SSC-C75, and ICH-165) or susceptible (Casady) to one or the other of the stress treatments.

Grain Yield, Grain Number, and Kernel Weight

Variation in grain number and kernel weight. Grain yield response to variation in grain number and kernel weight was examined in 19 rainy- and postrainy-season crops of AICMIP hybrid BJ-104 over the past 3 years, and in two rainy season crops of a set of 40 different cultivars grown at ICRISAT Center in 1978.

The mean grain yield of BJ-104 crops was 229 g/m^2, with a range of 106 to 355 g/m^2. Variation in grain yield was very strongly related to variation in grain number ($r^2 = 0.80$; $P < 0.01$) in the range of 19 000 to 64 000 grains/m^2 (Fig. 2). For the 40 cultivars, mean grain yield was 210 g/m^2 within the 100 to 331 g/m^2 range. Variation in grain yield was again directly related to variation in grain

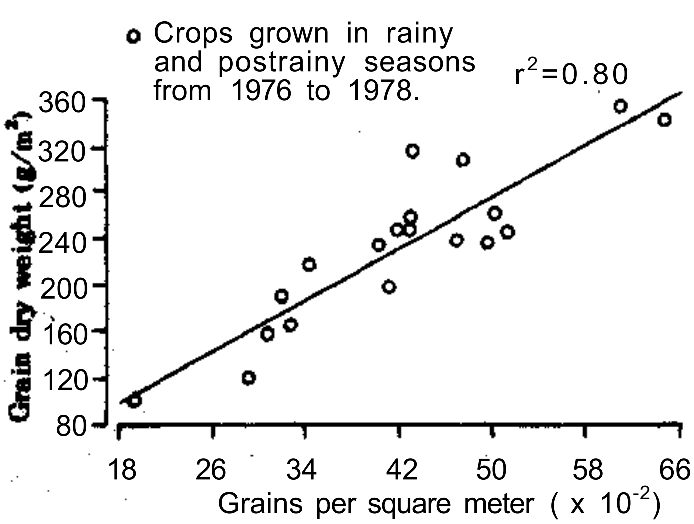


Figure 2. Grain yields in AICMIP hybrid BJ-104 in relation to grain numbers.

number ($r^2 = 0.54$; *$P<0.01$*) in the range of 17 000 to 52 000 grains/m^2 (Fig. 3).

Kernel weight was unrelated to grain yield in the BJ-104 crops ($r^2 = 0.19^{NS}$), despite some variation (4.9 to 6.5 g/1000 seeds). Kernel weight did significantly influence grain yields in the 40-cultivar set ($r^2 = 0.30$; $P < 0.01$) as the range of kernel weight was larger (3.2 to 9.0 g/1000 seeds), but was a lesser determinant than grain number.

Grain number and preflowering growth. Within BJ-104 crops, grain number/m^2 was directly related to crop dry matter at flowering ($r^2 = 0.58$; $p<0.01$) resulting in good correlation of grain yield with preflowering growth ($r^2 = 0.63$; $p < 0.01$). This underlines the importance of growing conditions prior to flowering, particularly the sensitivity of an individual cultivar to variations in these conditions.

These relationships were much weaker in the 40-cultivar set; preflowering growth explained only 26% of the variability in grain number and 36% in grain yield. Thus individual cultivars differed considerably in their ability to develop reproductive sites per unit of growth made during the preflowering period.

Considerations for yield improvement. Since grain number per unit area is the major yield determinant, several studies were initiated to evaluate possible ways to increase grain number. These included: (1) selection of lines from a West African population for increased number of productive tillers, (2) prolonging the vegetative period (by daylength extension), thus increasing meristem size at floral initiation, and (3) study of the relationships between grain number and the length of vegetative and reproductive periods in lines selected from photosensitive materials.

In contrast to most other cereals, increase in grain number did not reduce kernel weight in this set of 40 lines ($r^2 = -.01^{NS}$). Therefore, direct breeding for grain number while holding grain size constant may be another possibility for increasing yield. A project will be initiated to test this hypothesis using lines from Serere,

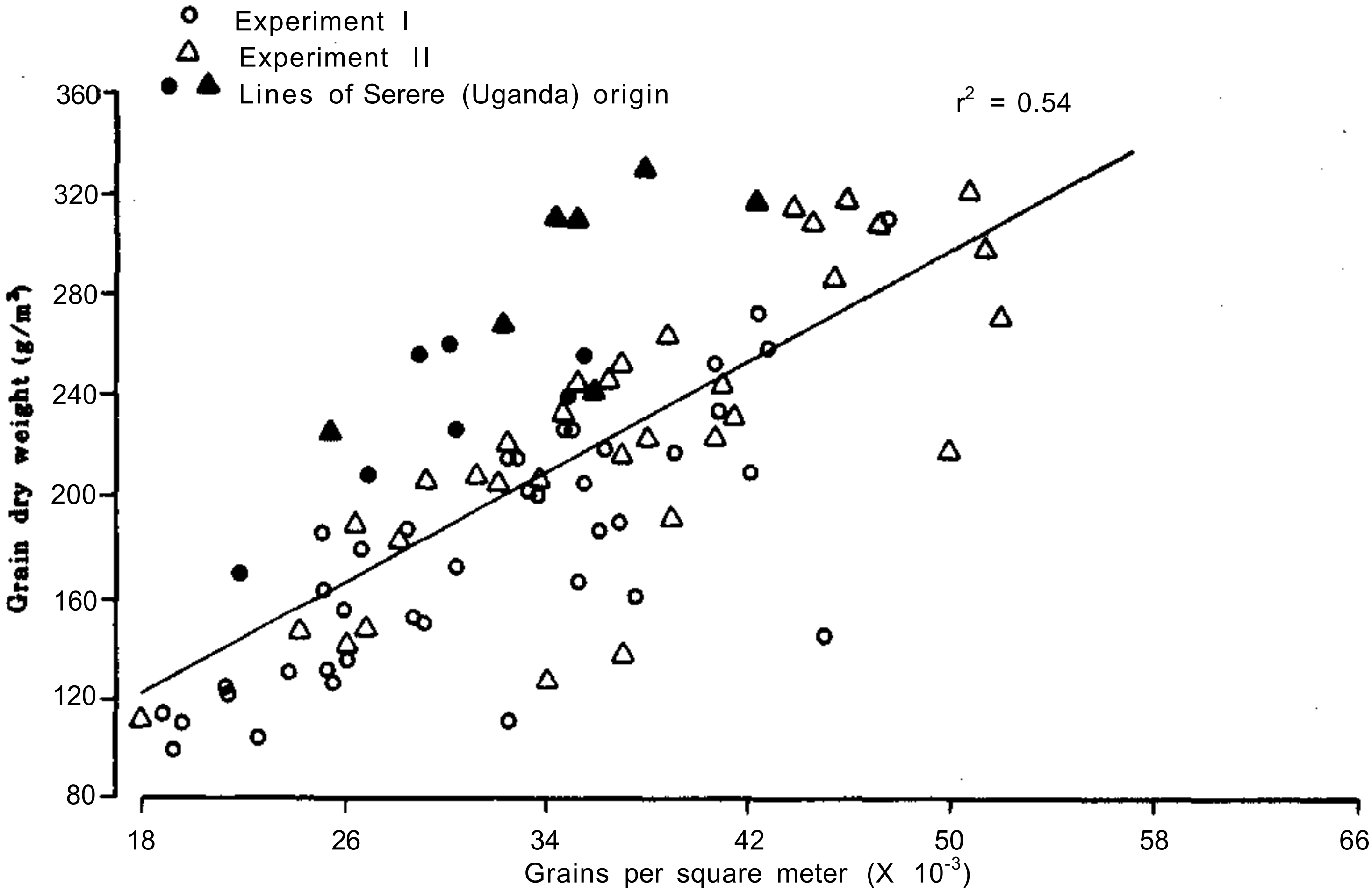


Figure 3. Grain yields in a set of 40 genotypes in relation to grain numbers.

Uganda (solid symbols in Fig. 3), as recurrent parents in a backcrossing program designed to increase grain numbers. These lines have a considerably larger seed size (8 g/1000 seeds) than the average for the entire set (6.2 g/1000 seeds) while maintaining average grain numbers.

Leaf-Water Potential in Pearl Millet

Diurnal changes. Diurnal variation in leaf-water potential and stomatal conductance were monitored on a number of days in stressed and adequately watered millet crops in order to compare the environmental response of millet with that of better-studied cereal crops. Data for a typical summer-season (February-April) day for a pearl millet crop at the grain-filling stage are presented here.

The stomatal conductance of the penultimate leaf in the adequately watered crop followed the diurnal irradiance pattern closely, although there may have been some reduction of conductance in the afternoon (Fig. 4). Conductance in the stressed crop responded initially to irradiance, but once leaf-water potential fell below approximately -15 bars, conductance declined steadily, reaching sunrise values by shortly after midday (Fig. 4).

Water potentials declined steadily from predawn values as conductance increased in both crop (Fig. 4). Leaf-water potential in the adequately watered crop stabilized at approximately -15 bars by 1100 hours; the water potential fell to a minimum of -25 bars in the stressed crop, despite the decrease in conductance,

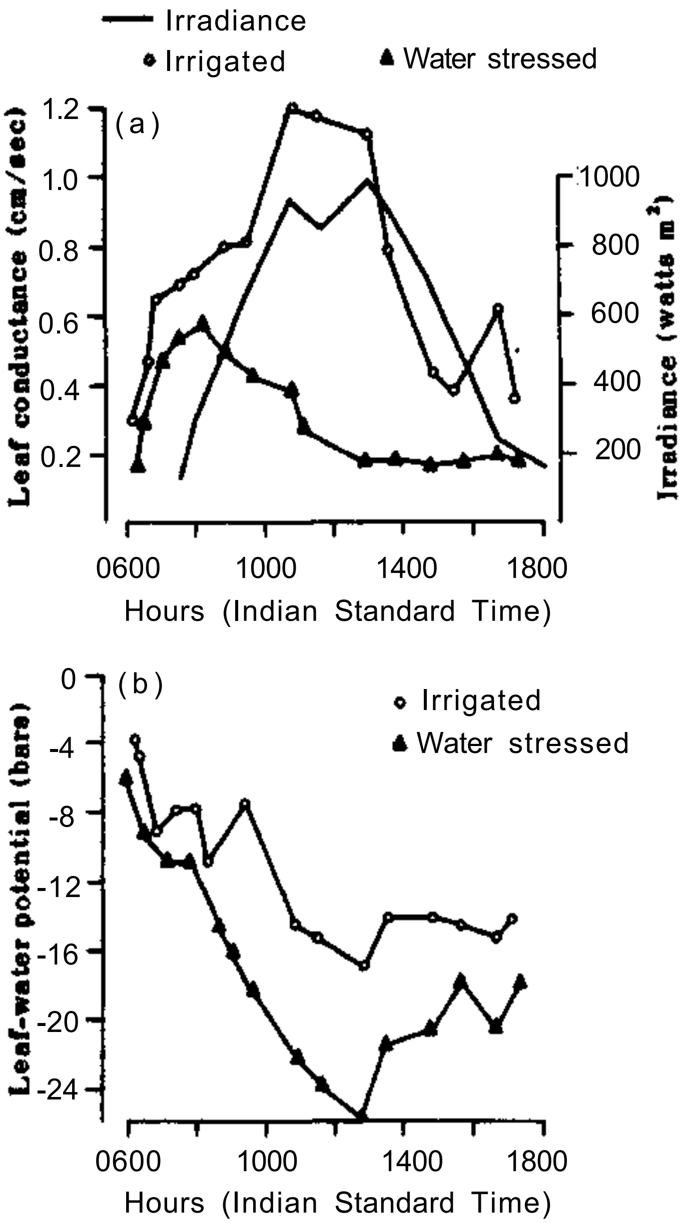


Figure 4. Diurnal changes (a) in irradiance and leaf conductance (abaxial plus adaxial surfaces) and (b) in leaf-water potential for irrigated and stressed crops of AICMIP hybrid BJ-104.

which limited water loss by this crop.

Control of leaf-water potential. Leaf-water potential is considered to be a function of the transpiration flux from the leaf (the rate of water loss from the leaf) and the rate of resupply of the plant with water from the soil (essentially the availability of soil water). Leaf-water potential was plotted against an estimate of transpiration flux (the vapor concentration gradient between leaf and air, multiplied by the leaf conductance) for both crops (Fig. 5). In the stressed crop, leaf-water potential declined linearly with increasing transpiration flux. The decline in stomatal conductance (Fig. 5) in this crop reduced transpiration flux considerably; but due to the limited available water in the soil, leaf-water potential was directly dependent upon the rate of water loss from the crop ($r^2 = 0.74$; $p < 0.01$).

In the nonstressed crop, by contrast, leaf-water potentials responded curvilinearly to the transpiration flux. As the rate of water loss increased, the rate of water supply to the leaf increased, allowing the crop to maintain a relatively constant leaf-water potential of -14 to -16 bars over a two to three-fold range in estimated transpiration flux (Fig. 5). This

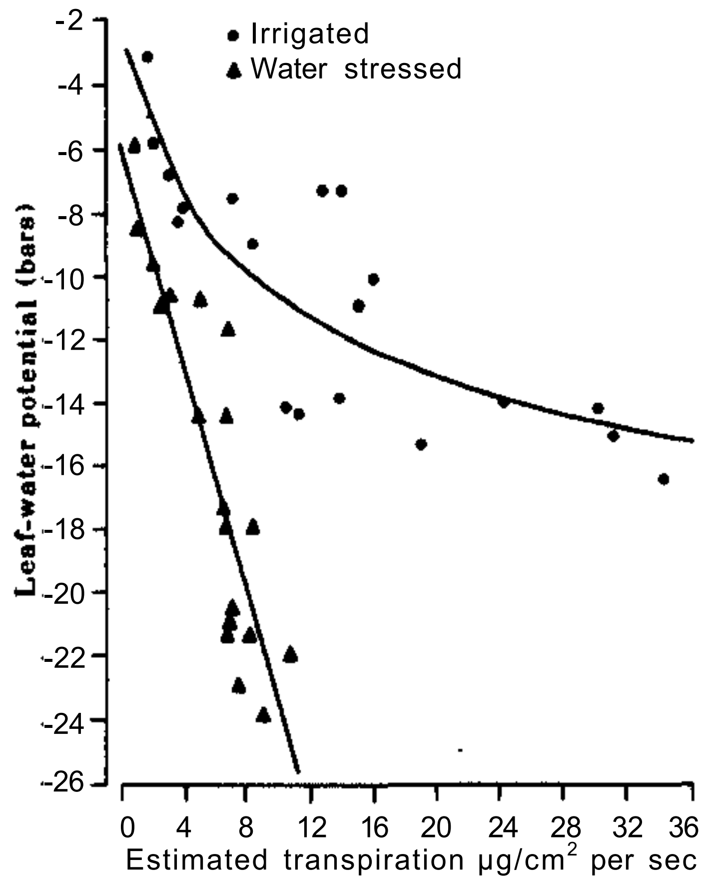


Figure 5. Leaf water potential as a function of estimated leaf transpiration for irrigated and stressed crops of AICMIP hybrid BJ-104.

implies a variable internal resistance to water movement from the soil to the leaf, because absorption of water must be approximately equal to transpiration for water potential to remain constant in a herbaceous plant.

Thus millet seems to be well adapted to conditions of high transpiration flux, provided adequate soil water is available. The ability to maintain stomata open, in spite of the high transpiration rates, allows the leaves to maintain normal transpiration cooling and carbon assimilation. Under conditions of limited soil water, stomata close early in the day, which reduces water loss significantly, but water potentials do fall to low levels and normal physiologic processes are not maintained.

Entomology

Observations on pearl millet pests at ICRISAT Center continued to show that other than sporadic pests such as cutworms, which are general cereal feeders, there were only minor problems. An important observation was that there was more wireworm attack on the pearl millet seedlings when the crop was sown immediately after the preceding groundnut crop.

During rainy season 1978, hybrid ICH-105 was sown to determine the range of pest species present, and destructive sampling was carried out up to harvest. Shoot fly eggs were laid on 1% of the plants, while *Chilo* damage was low (0.3%). By the 9th week, there was 21.7% aphid incidence, and 15% of the heads were infested by earhead bug. At the 11th week, *Heliothis* and webbers were seen on 3% of the earheads.

During June 1978, a survey was made on farmers' fields near ICRISAT Center. On one field, where pearl millet was grown for fodder purposes under well irrigation, 12.7% of the plants had deadhearts caused by shoot fly. Of the 99 flies that emerged from these plants, 65 were females and 34 males. Of the males, 33 were *Atherigona approximata* and one was *A. soccata,* giving additional support to the hypothesis that *A. approximata* is the dominant shoot fly species on pearl millet.

During the rainy season 1978, a set of 22 lines provided by the breeders was planted late (2 August 1978) to determine the relative susceptibility to shoot fly. Deadheart incidence 28 days after planting ranged from 4.6% (MBH-110) to 42.1% (ICH-105).

Pathology

The aim of the pathology projects is to identify and to help the breeders utilize sources of stable and durable resistance to the important diseases of pearl millet. A modest effort is also made to evaluate alternative control measures that may be feasible technically, economically, and sociologically for the peasant farmer.

Downy Mildew (*Sclerospora Graminicola* [Sacc] Schroet)

Resistance Screening at ICRISAT Center

More than 7000 pearl millet breeding lines, test hybrids, experimental varieties, and germplasm entries were screened for downy mildew (DM) resistance in a 6 ha DM-screening nursery in the rainy season 1978 and again in the post-rainy season 1978-79, employing the infector-row inoculation system. Consistently high DM incidence occurred in the frequently planted susceptible checks, indicating adequate inoculum pressure on the test entries.

Of the 300 germplasm entries tested, 84 were classed as low DM-susceptible (< 10% DM incidence); 54 of these were from the 700 000-series of lines from northern Nigeria. Pearl millet germplasm entries from locations with low rainfall, such as oases of Mauritania and Chad, were generally highly susceptible to DM at ICRISAT Center.

Of the 90 entries in five trials of the All India Coordinated Millet Improvement Project (AICMIP) screened for DM resistance during the 1978 rainy season, ten F_1 hybrids, two population products, and one local cultivar

Part of the 6-ha DM-screening nursery at ICRISAT Center, showing lines in their first screening (foreground), and lines that have undergone several generations in the screening nursery (background). The bagged heads indicate breeding activities going on in the DM-screening nursery.

had less than 10% DM incidence in two replications.

The DM incidence in commercial hybrids BJ-104, BK-560, and PHB-14, planted as checks, averaged 61, 28, and 26%, respectively.

Breeding activities were carried out in the DM nursery in the population improvement projects. The use of this screening system for two seasons per year for 3 years has resulted in the development of a high level of DM resistance in most of the ICRISAT breeding materials.

Multilocational Testing

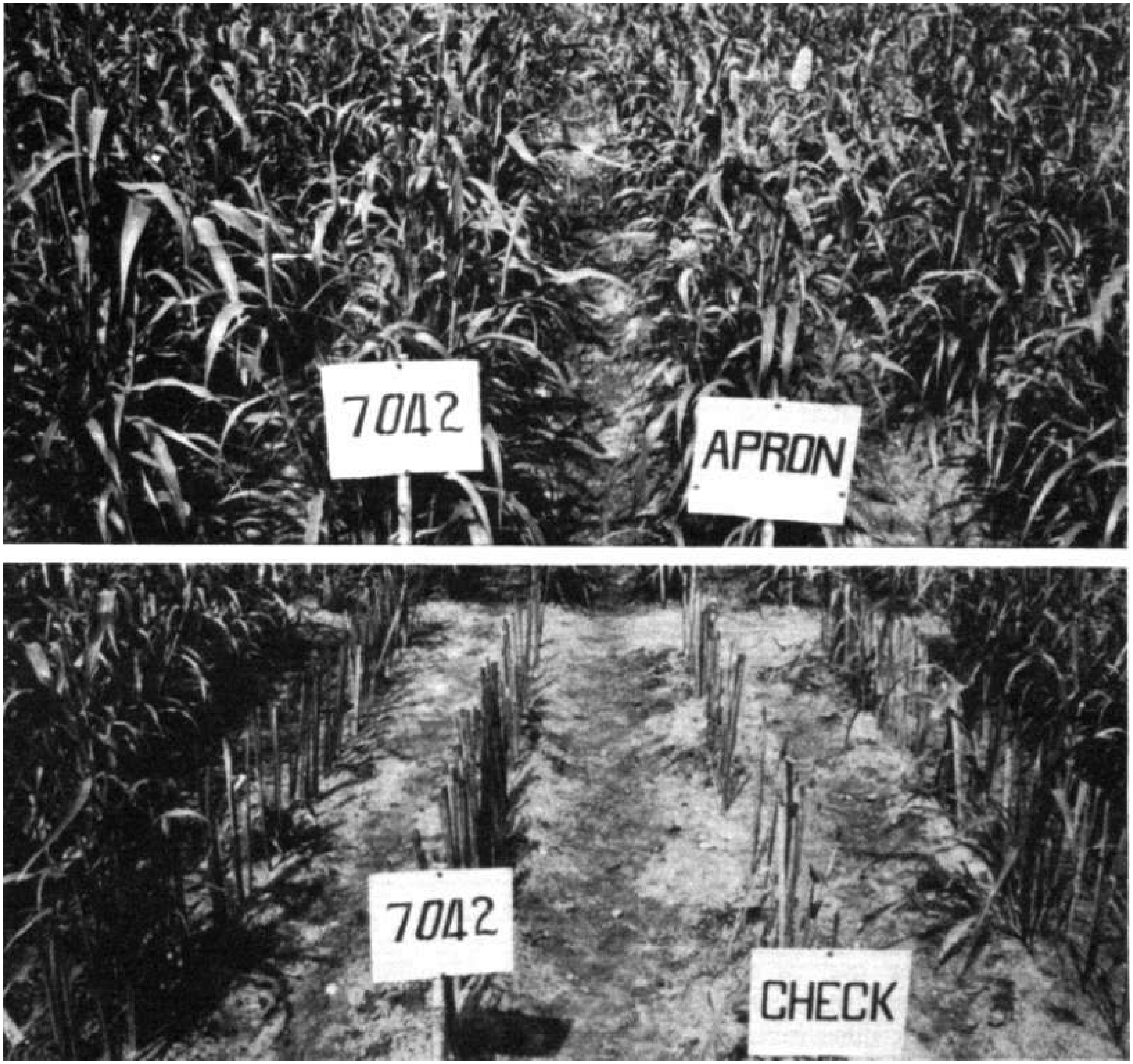
The stability of DM resistance is examined through cooperative multilocational testing, with the participation of scientists in national and regional programs in Africa and Asia. Promising entries are first tested at a few key DM "hot-spots" in West Africa and India in the Pre-International Pearl Millet Downy Mildew Nursery (Pre-IPMDMN). Good performers in the Pre-IPMDMN tests go forward into the IPMDMN in the following year for further testing in many countries.

The 1978 Pre-IPMDMN. Results were obtained for the 150-entry trial from Upper Volta (Kamboinse), Nigeria (Samaru), and India (Hissar and ICRISAT Center). No entry was DM-free at all locations, but 16 entries had no more than 10% DM incidence at any location (Table 11). Distinct location-specific reactions were apparent for some entries.

The 1978 IPMDMN. The 45-entry 1978 IPMDMN was sent to cooperators at 27 locations in ten countries, and results were received from 16 locations in four countries. Forty-two of the 45 entries had across-location infection-index values of less than 10%. One entry SDN-503, had no more than 10% infection index at any location. Eight entries combined an across-location mean of less than 5% with a maximum of no more than 12% at any location (Table 12). Entries, that performed particularly well in 3 years of IPMDMN tests are SDN-503, 700251, 700516, P-7, and P-10.

Alternative Control

As a follow-up to the promising results with the fungicide metalaxyl (Ridomil, Ciba Geigy Ltd) at ICRISAT Center during 1977 (ICRISAT 1977-78 Annual Report), a multilocational trial was organized during the 1978 rainy season. The fungicide was used to dress seed of highly-DM-susceptible hybrid NHB-3 at 0.5, 1, and 2 g active ingredient (a.i.) per kg seed. Complete results were received from cooperators at ten locations. At all locations the lowest DM-infection index values were obtained from seed treated with 2 g a.i./kg



Pearl millet cultivar 7042 (above) grown from seed treated with a seed-dressing formulation of the systemic fungicide metalaxyl (Apron, Ciba Geigy Ltd.) compared with a plot planted with nontreated seed of the same cultivar (helow). The DM killed most 7042 plants in the nontreated plot (pegs mark the position of infected plants that died and disappeared).

seed. In comparison with the nontreated check plots, overall mean reduction of downy mildew at 0.5, 1, and 2g a.i./kg seed was 11, 29, and 41%, respectively, and corresponding values for yield increases were 13, 46, and 64%, respectively (Table 13). The fungicide would be expected to give even better control in farmers' fields where, unlike in the DM-screening nursery, there would be no continually high inoculum pressure throughout the crop growth. It is likely that the fungicide will control almost all initial infection and there would be little or no secondary inoculum to infect the later-formed tiller primordia.

Table 11. Doway mildew (DM) infections indices (%) averaged over two replications for Hissar, ICRISAT, and Kamboinsc, and 30-day DM incidence (%) from one replication at Samaru, for selected entries in the 1978 Pre-IPMDMN.

Entry	Hissar	ICRISAT	Samaru	Kamboinse
700042	0	0	0	8
MPP-7147-2-1	2	8	4	2
7124-3	0	1	5	5
J-2220	0	6	4	1
IP-2058	4	7	0	4
IVS-7041	0	1	8	8
NC-7158	0	5	0	7
NC-7174	0	1	0	3
EB-79-2-2 x 59-3-1	0	3	0	3
EB-17-1-6	0	1	5	1
2989-109-1	0	6	4	5
B-Senegal-2-5	0	5	0	2
WC-7209	0	3	0	0
2287-ME	0	3	10	6
IP-1360	1	7	9	4
MC-7044	1	4	3	8
2778-22ME	0	2	50	60
DC-7116	0	2	63	56
700270	0	5	63	10
700404	0	12	93	10

lit a cooperative trial in Senegal with hybrid CN-74, treated with metalaxyl at the same rates as in the other trial, DM control was observed during the first 3 weeks of crop growth, but by final scoring all plots were severely infected. The reasons for such non-effectiveness of the fungicide need investigation.

Ergot (*Claviceps fusiformis* Lov.)

Resistance Screening at ICRISAT Center

The bask technique. In order to avoid the pollen-based escape mechanism, all tillers to be inoculated were bagged at the boot-leaf stage so that the inflorescences emerged into a pollen- and inoculum-free environment. When the inflorescences were at the protogyny stage, visible through the parchment bags, the bags were removed, a fresh honeydew conidial suspension was sprayed onto the inflorescences, and the bags were replaced. Overhead sprinkler irrigation was used thrice daily on nonrainy days during the period of inoculation and incubation. The bags were removed 15 days after inoculation to assess the severity of ergot development.

Initial screening. During the 1978 rainy season, ten randomly selected plants in a single 5 m row of each of 716 West African and Indian germplasm lines, 84 F_1 hybrids and population products from AICMIP trials, F_1 and F_2 progenies of crosses of ergot low susceptible parents, and 133 Pre-IPMDMN entries, were inoculated as described above. The results are shown in Table 14. Two hundred and eighteen single heads with little or no ergot were selected from germplasm lines and 657 were selected from F_2 progenies for advanced screening.

Advanced screening. Seed from single-head selections from the initial screening was planted in two 5 m rows, and subsequently 20 randomly selected inflorescences were inoculated as described earlier.

During the 1978 rainy season, 19 of 202 advanced lines had no more than 20% mean ergot severity, and 500 heads with little or no ergot were selected for further evaluation (Table 14).

During the 1978-79 postrainy season, 53 of 657 F_3 families (selections from the 1978 rainy season tests) had mean ergot severity of less than 20%, and 25 of these had desirable agronomic traits. A total of 258 ergot-free heads were selected from 25 families for evaluation of their reactions to ergot, DM, and smut during the 1979 rainy season (Table 14).

Multilocational Testing

In an attempt to identify stable ergot resistance, a cooperative International Pearl Millet Ergot Nursery (IPMEN) has been established in which materials identified as having low susceptibility in the ICRISAT Center ergot nursery (in initial and advanced screenings) are exposed to many populations of the ergot pathogen in a wide range of environments.

The 26-entry 1978-IPMEN was tested at 13 locations in India and West Africa. No entry was ergot-free, but eight entries (700626, Ex Bauchi 700638-3-2-1, 700708-1, 700526, J797-

Table 12. Percent infection indices" of the eight best entries at 16 locations in the 1978 IPMDMN compared with infection indices of local susceptibles and the location means for all entries.

	Locations																	
Entry	1[b]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Max	Mean[c]
SDN-503	0	1	0	0	0	4	2	0	5	3	6	4	5	6	10	<1	10	2.7
700251	0	0	0	0	1	0	0	0	<1	0		3	6	7	11	5	11	2.2
IVS-5216	0	0	0	0	<1	0	5	1	0	9		0	3	8	11	8	11	2.9
WC-6086	0	2	<1	0	2	2	1	7	0	0		7	0	10	11	9	11	3.2
700516	0	0	<1	0	0	0	<1	1	0	0	<1	2	12	7	10	3	12	2.3
P-7	0	0	0	0	<1	0	3	1	11	0		5	1	8	12	10	12	3.4
ICI-7611-(F4)	0	0	0	0	3	6	<1	<1	6	8	6	2	0	12	11	5	12	3.7
P-10	0	0	0	3	0	<1	3	5	5	0	7	3	5	10	12	12	12	3.9
Location mean for all test entries	1	<1	<1	<1	2	2	2	4	5	5	6	8	10	11	12	12		
Local susceptibles mean	41	29	70	68	98	24	61	96	28	100	90	48	71	2	23	6		

a. Means rounded off to nearest whole number except for < 1.
b. 1. New Delhi, 2. Kovilpatti, 3. Hissar, 4. Jamnagar, 5. Coimbatore, 6. Hyderabad, 7. Ludhiana, 8. Pune, 9. Durgapura, 10. Bambey, 11.ICRISAT, 12. Kamboinse, 13. Mysore, 14. Samaru, 15. Kudumiamalai, and 16. Kano.
c. Means calculated before the location means were "rounded off."

Table 13. **Downy mildew infection indices and grain yield in plots of NHB-3 grown from seed treated with metalaxyl 25% w.p. at three rates[a] expressed as percentages of the infection index and of grain yield values from the entreated check plots at 14 locations in the 1978 International Trial for the Fungicidal Control of Pearl Millet Downy Mildew.**

	Infection index			Grain yield		
Location	0.5	1	2	0.5	1	2
Kovilpatti	117	107	128	ND	ND	ND
Kudumiamalai	97	94	85	83	123	115
Samara	204	92	34	ND	ND	ND
Durgapura	(63)[b]	(40)	(17)	ND	ND	ND
Ludhiana	70	60	43	137	151	151
Hissar	43	20	15	141	264	364
Jamnagar	92	89	78	108	137	122
Pune	104	81	65	111	116	141
ICRISAT Center	37	24	16	124	146	169
Kamboinse (Upper Volta)	65	36	21	117	132	158
Aurangabad	74	64	56	127	127	149
New Delhi	83	81	76	ND	ND	ND
Coimbatore	84	83	77	108	123	140
Kano (Nigeria)	94	89	69	76	141	128
Mean	89	71	59	113	146	164
Mean ex-locations 1, 2, 3[c]	75	63	52	117	148	169

a. 0.5, 1, and 2 g a.i./kg seed by dry dust treatment.
b. Incidence values are from 25 days-after-planting scoring and are not used in the production of the across-location mean.
c. DM levels were low at these locations and there were no significant differences.
ND = No data reported.

1-1, 700457, 3/4 Ex Bornu 74-2-1, and SC-2[M]5-4) had mean ergot severity scores of no more than 15% (Table 15).

Alternative Control

Control of ergot through pollen management. A first attempt was made to determine whether the pollen-based escape mechanism could be utilized for ergot control in pearl millet hybrids under field conditions. Hybrid ICH-118 was planted in 10 m x 10 m isolated plots (at least 500 m from another pearl millet crop), alone or in a 4:1 mixture with cultivar SC-2(M)5-4, an early-flowering line less susceptible to ergot, that would serve as a pollen donor. Plots were either not inoculated or were inoculated by spraying conidial suspensions of the ergot pathogen on three occasions at 2-day intervals during the early flowering period of ICH-118.

The inoculated ICH-118 plot, without the pollen donor, had 73% plants infected with mean severity of 8.3%. The inoculated ICH-118 plot, with the pollen donor, had 34% ergot incidence with mean severity of 0.5%. It thus appears that pollen management is a possible means of ergot control in hybrids in the field, but the results of this nonreplicated one-season

ICRISAT plant pathologist examines pearl millet heads, on right from highly susceptible line, and on left from one of the ergot-resistant lines recently developed.

trial need careful checking in different environments. If the effects are confirmed, the application of the technique to farmers' field situations will need examination.

Smut (*Tolyposporium penicillariae* Bref.)

Resistance Screening

The smut-resistance screening activities were divided, in the same way as the ergot-screening activities, into initial, advanced, and multilocational testing. The initial and advanced screening trials were conducted at Hissar in northern India during the 1978 rainy season (the second successive year of smut-screening tests there).

Smut development was successfully promoted by bagging tillers at the boot-leaf stage and leaving the bags in place until grain maturity. Ten randomly selected plants per 4-m row were bagged for each test entry, a procedure known to promote smut, and percent smut severity was estimated on each head after grain maturity. Smut-free heads from promising lines were selected for further evaluation. Results of initial and advanced screening are shown in Table 16.

Multilocational Testing

The 1978 International Pearl Millet Smut

Table 14. Number of pearl millet lines in various categories of mean ergot severity at ICRISAT Center from June 1978 to April 1979.

	No. of entries	No. of entries with ergot (%) 0	<10	<20	<30	>30
1. Initial screening[a]						
Germplasm lines	716	0	11	51	127	589
F_1 crosses	394	0	31	78	136	258
Pre-IPMDMN AICMIP	33	0	1	5	12	21
IPMHT-I	31	0	0	0	0	31
APMHT-II	23	0	0	0	0	23
IPMPT-IV	19	0	0	1	1	18
APMPT-V	11	0	0	0	0	11
II. Advanced screening[b]						
Advanced Screen II	202	0	4	19	45	157
F_3 families[c]	657	0	15	53	125	532

a. Baaed on 10 inoculated inflorescences per line.
b. Based on 20 inoculated inflorescences per line.
c. Based on 50 inoculated inflorescences per line.

Table 15. Summary performance of the eight superior 1978 IPMEN entries and the local checks.

Entry	Number of locations (max 13) where the mean percent ergot infection was <10%	< 20%	<30%	Across-location mean[a] (%)	Entry vs location means[a]
700626*	8	11	13	8	12
Ex Bouchi 700638-3-2-1	7	11	13	10	12
700708-1[b]	8	10	12	11	12
700526*	6	8	13	13	12
3 797-1-1	6	9	12	14	9
700457*	6	7	11	15	10
3/4 EX 74-2-1[b]	5	10	12	15	8
SC-2(M)5-4	6	8	11	15	9
Local checks	2	3	5	42	2

a. The number of locations where the individual entry mean was less than the mean for all entries at that location.
b. New entry in 1978 {others are either 1977 entries or selections from them).

Nursery (IPMSN), consisting of 34 lines selected from previous advanced screening at Hissar, was tested for smut resistance at Bambey in Senegal, Samaru and Kano in Nigeria, and Hissar and Jamnagar in India. No entry was smut-free at all five locations, but ten entries had mean smut severity of less than 10% at all locations (SSC-FS-252, EB-54-1-1, J-2238, P-20, EB-137-1-1, P-10, ICI-7517, IP-2253, EB-74-3, EB-237-3-1). SSC-FS-252 was smut-free at Kamboinse and Hissar, and developed only 1% smut at Bambey and Jamnagar. Smut severity was generally greater at Kano and Samaru in Nigeria, as a result of inoculation of smut spores into the developing boot, but EB-54-1-1, SSC-FS-252, and J-2238 performed well at these locations.

It is encouraging that smut resistance selection using the bagging technique at Hissar is effective at other smut "hot spots." However, in order to eliminate escapes and to ensure more uniform inoculum pressure, inoculation procedures will be evaluated at Hissar in the 1979 rainy season.

Rust (*Puccinia penniseti* Zimm.)

Initial Resistance Screening

During the 1978 rainy season, 215 germplasm entries were screened for rust resistance at the rust "hot spot," Bhavanisagar. Under severe pressure, 18 entries were rust-free and 47 entries had no more than 10% rust on the upper four leaves.

Multilocational Testing

A 45-entry International Pearl Millet Rust Nursery (IPMRN) was sent to cooperators at eight locations in India and one in Kenya. Results were received from eight cooperators in India. Rust reactions at one location, Kudumiamalai, were much more severe than at the other locations (Table 17); this will be rechecked during 1979. The five entries listed in Table 17 had a maximum of 10% rust at any location in the 1977 preliminary rust multilocational testing nursery.

Microbiology

Major emphasis continued to be placed on examining the potential for exploiting nitrogen fixation by bacteria associated with pearl millet roots. Work was carried out on evaluating genotypic differences between millet lines in

Table 16. Number of pearl millet lines in various categories of mean smut severity following screening for smut resistance at Hissar during the 1978 rainy season.

Trial	No. of entries	No. of entries with mean smut infection (%)			
		0	1-10	11-20	>20
Initial screening[a]					
Germplasm lines	727	0	24	6	697
F_1 lines	249	11	189	21	28
Advanced Screening I					
Selections from 1977[b]	512	58	439	14	1
PMSN[c]	25	0	24	1	0

a. Based on 10 bagged inflorescences per line.
b. Based on 20 bagged inflorescences per line.
c. Based on 20 bagged inflorescences in each of two replications.

Table 17. Estimated rust coverage (%) on the upper four leaves of five IPMRN entries at eight locations in 1978.

	Location"							
Entry	1	2	3	4	5	6	7	8
SC-1 (S)-4-4-5	0	0	0	6.3	9	5	7.3	42.3
700481-7-5	0	0	0	0	3.8	10	2.6	38.8
700481-23-14	0	2.5	0	0	6.5	5	4.3	17.0
700481-27-2	0	2.5	0	0	10	10	5.4	43.0
700481-27-5	0	8.8	0	0	6.8	5	7.9	14.8
Susceptible check	11.5	42.5	79.0	22.5	39.9	52	39.1	50.2

a. 1. Bhavanisagar, 2. Ludhiana set-1, 3. Ludhiana set-2,4. ICRISAT Center, 5. Pune, 6. Hissar, 7. Bangalore, 8. Kudumia-malai.
b. Mean of five replications.

stimulating nitrogen fixation, on identifying the microorganisms involved, and on increasing the potential for nitrogen fixation by inoculation.

Several lines of pearl millet have consistently stimulated nitrogenase activity in their rhizospheres over several seasons. The activity of 15 of these lines ranged from 59 to 235 µg N/18-cm diameter core per day in the rainy season of 1978, with the inbred line PIB-155 from Punjab, India, and the GAM-73 population from Senegal fixing more than 200 µg N/core per day. More than half of the 84 lines tested during the rainy season of 1978 had some activity (> 25 µg N/core per day), but only 8 of the 79 lines tested in the irrigated summer season were active. Cultivars of the minor millets *Eleusine coracana, Panicum miliaceum, P. miliare, Panicum* sp., and *Setaria italica* showed more consistent activity than pearl millet.

Blue green algae were present in mats on the soil surface of many fields. Their extent and nitrogen-fixing activity under pearl millet was generally low, but under tropical grasses, such as *Pennisetum purpureum,* the mats maybe very active, depending on the wetness of the soil surface and the extent of the plant canopy. Nitrogenase activity of these algal mats ranged from 24 to 119 mg N fixed/m^2 per day, compared with only 0.5 to 1.6 mg N/m^2 per day for surface soil without visible algal growth. Nitrogen fixation of this order contributes significantly to the soil-nitrogen balance. Activity declined rapidly as the soil surface dried out.

Thirty-four nitrogen-fixing bacterial cultures, isolated from pearl millet roots, were identified. Thirteen isolates were from the Spirillaceae, 13 from the Enterobacteriaceae, 5 from the Azotobacteriaceae, and 3 from the Bacillaceae. Of the 10 different media tested for suitability for counting nitrogen-fixing bacteria from soils, a sucrose medium with 100 µg extract added per liter gave the highest counts.

The nitrogenase activity associated with pearl millet seedlings grown in vermiculite in 25 x 200 mm test tubes varies with the culture of organisms used. At 14 days after sowing, a maximum activity of 21 µmoles C_2H_4/plant per day was obtained with a culture of *Derxia* sp. The variability among plants in this system was much less than for field-grown plants. It may be possible to screen pearl millet lines more reliably for differences in their ability to stimulate nitrogenase activity in such a system.

The pearl millet hybrid BJ-104, grown in washed vermiculite with nitrogen-free nutrient solution and inoculated with nitrogen-fixing bacteria, gained 34 mg N/plant in 48 days, and for each pot of five plants there was a nitrogen gain of 211 mg. At harvest, nitrogenase activity associated with the roots was 79 µmoles C_2H_4/g root per hour, and no activity was found in the vermiculite without roots.

Looking Ahead

Breeding. The program will continue to generate and test new hybrids, 'synthetics, experimental varieties, and breeding lines to identify higher yielding genotypes with stable performance and disease resistance to supply to national programs. More of the germplasm accessions and promising breeding material from the West African Cooperative Programs will be utilized to maintain a continuous inflow of new variability.

Now that the techniques for screening ergot and smut resistances have been standardized and the resistance sources have been identified, more emphasis will be placed on incorporation of ergot and smut resistances into high-yielding lines.

Work will be intensified to develop new seed parents for producing better hybrids. The possibility of improving yield and protein content simultaneously will also be examined.

Biochemistry. Analysis of selected germplasm accessions for protein and lysine content will be carried out. Laboratory analysis to determine relationship between physicochemical characteristics of grains and chapati quality will continue. Attempts will be made to improve our taste panel evaluation procedures.

Physiology. The drought resistance project will be expanded into a cooperative project with the breeding subprogram to investigate the feasibility of breeding directly for resistance to drought stress under field conditions in drought screening nurseries managed by the physiology team.

A project to investigate the basis of adaptation in millet will be initiated in 1979. This will involve direct measurement of crop growth and environment in three locations in India and reanalysis of selected IPMAT data from past years, utilizing additional site data on soil moisture, heat unit accumulation, daylength, etc.

Work will continue on the development of genetic materials to test hypotheses on means of increasing yield potential in millet (some of these projects were outlined in the report on grain yield response to grain number and grain weight). In order to properly evaluate such hypotheses, materials from a common genetic background, incorporating the desired characteristics, must be bred or selected.

Entomology. To date, activities in Millet Entomology have been mainly observational to obtain an understanding of the insect problems on this crop. Our future emphasis will be to determine the relative abundance and importance of different pests, identification of insects with a potential for becoming pests, and changes in the relative importance of different insects in relation to varieties, farming systems, and other practices. Observations will be made on the relative susceptibility of germplasm and breeders' elite material to different pests. Sampling techniques will be standardized and biology of insects found to be important studied. If considered necessary, resistance screening will be initiated against the key pests. Preliminary observations will also be made on the extent of losses due to insects, to determine the importance of insect pests on pearl millet.

Cooperative links will be developed with entomologists in other countries of the SAT, and close links will be maintained with scientists working in All India Coordinated Millet Improvement Project.

Pathology. The large-scale DM screening nursery will continue at ICRISAT Center and the cooperative international Pre-IPMDMN and IPMDMN programs will continue.

Evaluation of the causes of differential reactions among test locations will be intensified through a joint project with the University of Reading (England) and the Overseas Development Administration.

New seed dressing formulations of Ridomil will be evaluated multilocationally.

The ergot resistance breeding materials will be tested at the F_4 and F_5 generations, and plans will be made to utilize the developed resistances. The potential for ergot control through pollen management will be further examined.

Smut-resistance screening will be intensifed at Hissar, with evaluation of inoculation methods. The IPMSN program will be continued at a few key smut "hot spots." The rust screening and testing program will continue with activities similar to the 1978-79 period.

Microbiology. A long-term nitrogen balance study will be conducted in the field, using pearl millet lines that have shown potential for high nitrogen uptake and nitrogen-fixing activity. This will permit the estimation of the amount of nitrogen fixation associated with those lines.

The association between nitrogen-fixing bacteria and pearl millet will be examined for specificity and to see whether this varies with location. The nitrogen-fixing activity associated with pearl millet and related tropical grasses will be examined in different environments and soil types.

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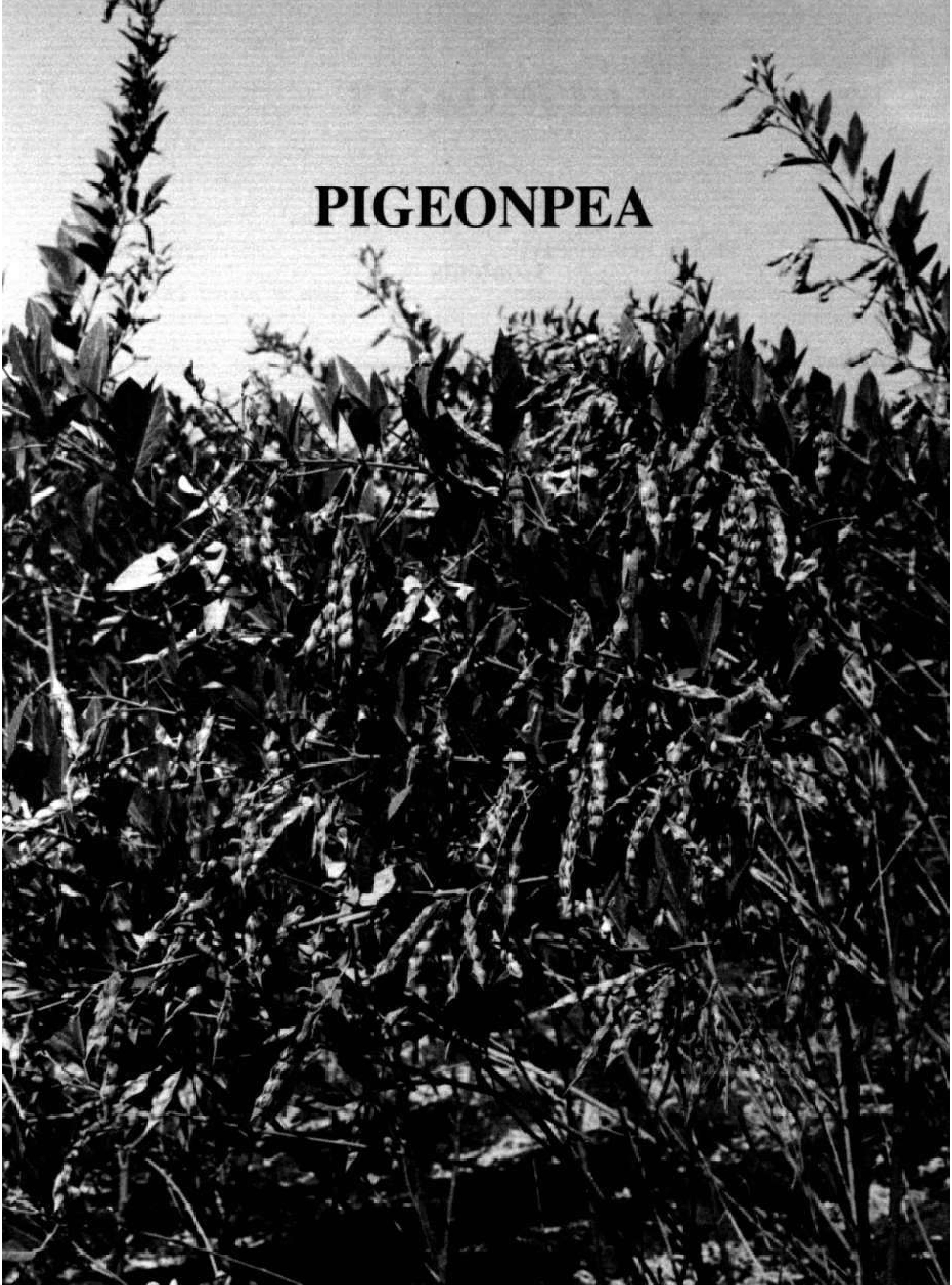
PIGEONPEA



Contents

PIGEONPEA

Breeding

At ICRISAT Center, breeding for improvement of medium maturity (160-170 days) genotypes of pigeonpeas receives major emphasis. These are usually grown as intercrops, with low inputs. The major breeding objectives for increasing yields in such production systems are the incorporation into promising genotypes of disease resistance, lower levels of susceptibility to pod borers, and increased genetic potential for yield.

Breeding for improved late-maturing genotypes adapted to traditional production systems typified by northern India is in progress at Gwalior, India. The objectives are the same as above.

The development of genotypes suitable for nontraditional systems largely involves short-season cultivars. For these, our core program is located at Hissar in northern India, and contract research is in progress at the University of Queensland in Australia. In addition to disease resistance and high yield, emphasis has been on photoperiod insensitivity and on improving consumer acceptability (chiefly seed size and color).

In our role of providing breeding material for selection for local adaptation, we must continually reevaluate our objectives and the environments under which we select. For example, the traditional material is grown as a sole crop as well as an intercrop, and if hybrids should become available, sole cropping might increase substantially. There is an increasing interest in, and research effort on, the planting of pigeonpeas as a dry-season crop. To date there has been no breeding effort in this environment. Production of pigeonpeas as a sole crop under irrigation in dry areas is expanding.

Development of Lines

Last year we reported encouraging results with inbred lines derived from existing cultivars. Lines of T-21, entered in the 1978 All India Coordinated Trials, had comparatively high yields at Badnapur, Junagadh, Rahuri, and Varanasi, giving an indication of satisfactory adaptation of inbred lines.

Our tests indicated superior yield performance of several new lines, and eight of medium maturity (two resistant to sterility mosaic) were submitted to the Indian program for testing. Ten early-maturing lines were submitted to the All India Coordinated Trials.

Two international trials of vegetable-type lines (for green pea harvest) were conducted, one of 26 early-maturing lines and the other of seven medium-maturing experimental lines. Results were received from 6 of 15 locations. Some experimental lines were superior to the local checks (in Puerto Rico and Kenya).

Observation nurseries of early- and medium-maturity new lines were furnished to national program breeders. On the basis of cooperators' reports, 17 of the medium-maturity lines were advanced to replicated multilocation tests.

Development of Populations

We are advancing some populations using mass selection for yield, and several others (composite populations involving male sterility, dual populations, and single-cross advanced generation bulks) without selection. Mass selection appears to be ineffective for increasing yield, so far. The mean performance and variance of some of the other populations will be determined by deriving lines and testing them in the S_2 generation. Currently two F_4 populations, advanced by single-pod descent, are being evaluated for variance of the population and heterozygosity of F_5 lines. The mean performance of 38 such F_4 bulks are to be tested in multilocation trials. Local breeders can then derive lines from the highest-yielding bulks, screen the progenies in F_6; and conduct yield trials in F_7, thus having material advanced enough to increase for release after only 3 years.

Development of Hybrids

The genetic male-sterile lines in hand are from two germplasm lines, one from Andhra Pradesh (MS-3A) and the other from Maharashtra (MS-4A). They are of medium-late maturity, susceptible to the major diseases, and non-uniform. Inbred lines are being produced from them. Backcrossing is also being done to transfer male sterility to good lines of different maturity and to transfer disease resistance to the sterile lines. We are also actively searching for cytoplasmic sterility and are studying the nature of apparent cytoplasmic sterility in intergeneric derivatives with *Atylosia scarabaeoides* cytoplasm.

We have now completed 2 years of tests of F_1 hybrids, from crosses of particular cultivars and breeding lines with the two sterile populations MS-3A and MS-4A. Cases of specific combining ability were observed, as would be expected from the results of diallel studies. The highest percentage of heterosis was generally found in hybrids with low-yielding pollen parents, and a generally lower percentage heterosis was found in those with higher-yielding pollen parents (Fig. 1). The maximum

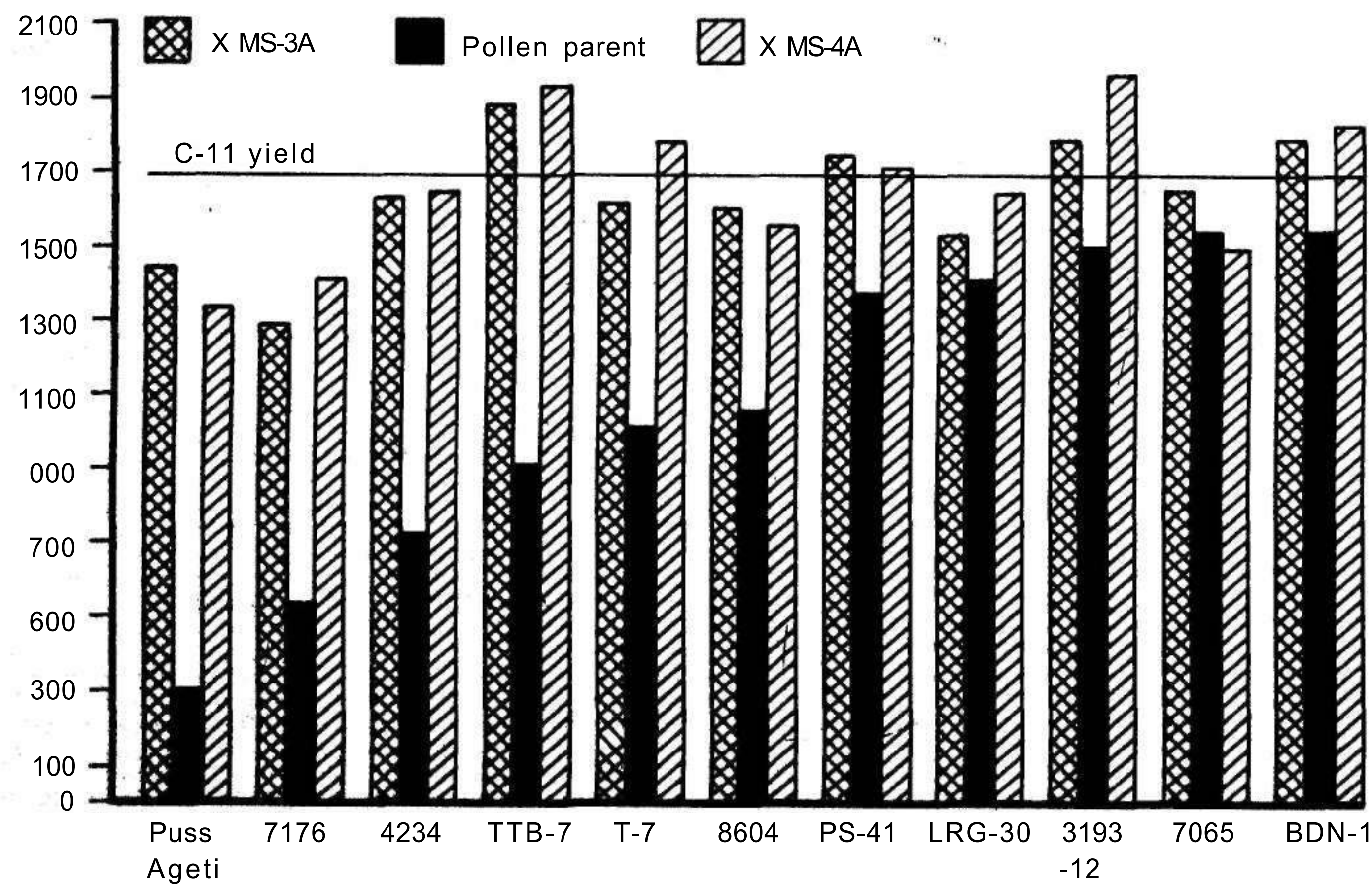


Figure 1. Grain yields of pollen parents and their hybrids with MS-3A and MS-4A intercropped with eowpeas at ICRISAT Center in 1978 compared with high-yielding cultivar C-11 (yield of Pusa Ageti from second flush only).

A wilt-resistant line of pigeonpea stands in contrast to a susceptible line at ICRISAT Center.

yield advantage of a hybrid compared with the highest-yielding cultivar was 31.5% in the first year's test and 17% in the second.

Two hybrids, MS-4A x C-11 and MS-4A x BDN-1, were entered in the All India Co-ordinated Trials. We will have seed production blocks of two hybrids, MS-3A x C-11 and MS-4A x BDN-1, in the coming year, to test the production system developed in small-plot trials. Seed of the male-sterile lines has been distributed to local breeders for hybridization with locally adapted cultivars, and more new hybrids will be included in preliminary tests at ICRISAT Center.

Breeding for Disease Resistance

Several breeding lines possessing resistance to sterility mosaic have been selected. Tests of 15 resistant lines were furnished to six locations in 1978-79. Observations were obtained from only two locations, and yield differences were nonsignificant.

Genetic studies indicate that four allelic genes are involved in the control of resistance and susceptibility to sterility mosaic. In the material tested, there apparently were two alleles for immunity, one for tolerance (ring-spot symptom), and one for susceptibility. Susceptibility was dominant to all of the resistance genes.

Progress in breeding new lines with wilt resistance has been slow, even with excellent sources of resistance available from the pathologists. The inheritance of wilt resistance appears to be complex. In 1979-80, we will be screening for seed yield among single-plant progenies derived from 36 progenies that have survived 3 or more years of screening in the wilt nursery.

Selections resistant to *Phytophthora* blight were made in the F_3 and F_4 generations, and their progenies will be screened in the blight nursery.

We now screen lines for resistance to sterility mosaic, wilt, and *Phytophthora* blight, in a multiple disease nursery. Of the 886 progenies tested, 20 showed promise; 121 single-plant progenies from these will be retested. Some lines from the other disease nurseries will also be tested.

Breeding for Insect Resistance

Screening for reduced susceptibility to pod borers in pigeonpeas is carried out in the entomology section. A collaborative project on transfer of resistance (or perhaps reduced susceptibility) from particular *Atylosia* species is under way. Promising plants in F_2 populations of intergeneric crosses were intermated. Plants selected in the intermated F_1s will be tested as progenies, and the best ones will be intermated again. This work is relatively long term, and it is likely to take many generations to derive pigeonpea lines having sufficient desirable characteristics to be acceptable.

Natural Outcrossing

The floral biology of the pigeonpea favors 100% self-pollination, but in fact there is usually some hybrid seed produced on unprotected plants as a result of bee visits to the flowers. Our earlier observations revealed that several species of wild bees visit the flowers and that species of *Megachyle* are the most important pollinators. We take advantage of the bee pollination in the production of hybrid seed on male-sterile plants and in population improvement breeding schemes, but natural crossing poses problems in developing pure lines and in maintaining purity of seed of released cultivars. We continue to study several aspects of this phenomenon to better capitalize on it and more effectively control it.

We have observed pod-set on male-sterile plants and normal fertile plants grown in a mixed population at ICRISAT Center. The average number of pods per plant and the distribution of numbers of pods per plant were almost the same in both types (Fig. 2). This indicates an equal opportunity for pollination in both kinds of flowers, even though the male-steriles were entirely dependent on the pollen deposited by visiting bees.

To determine the applicability of results from ICRISAT Center to other areas, a standard field layout of green-stem and purple-stem plants was planned for 12 locations in India this year. At ICRISAT Center, under insecticide-sprayed conditions, the average percentage of hybrid seeds produced on the green plants was 21 (Fig. 3). At Varanasi, the only

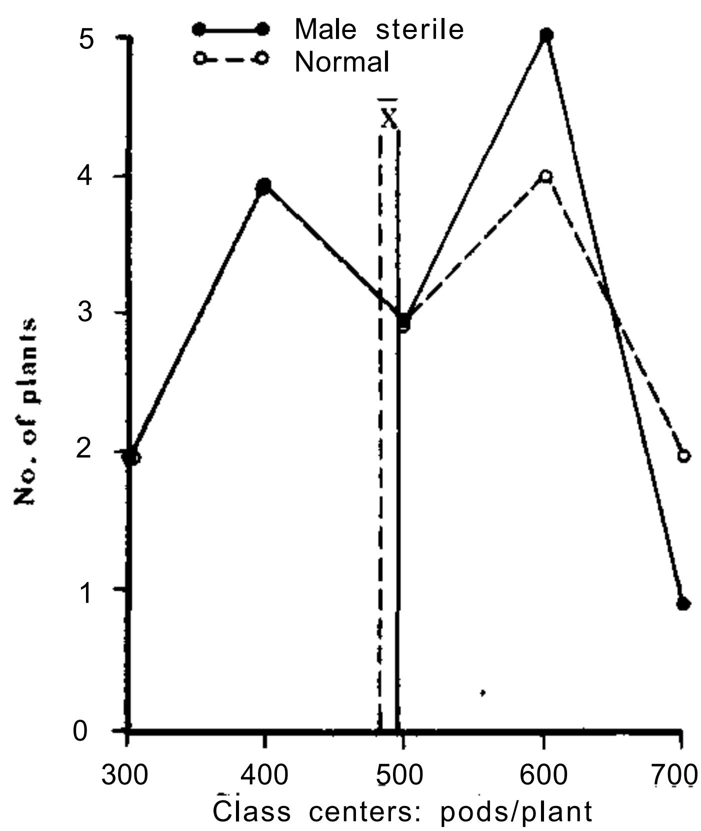


Figure 2. Frequencies of numbers of pods per plant on male sterile and normal plants under open pollination at ICRISAT Center.

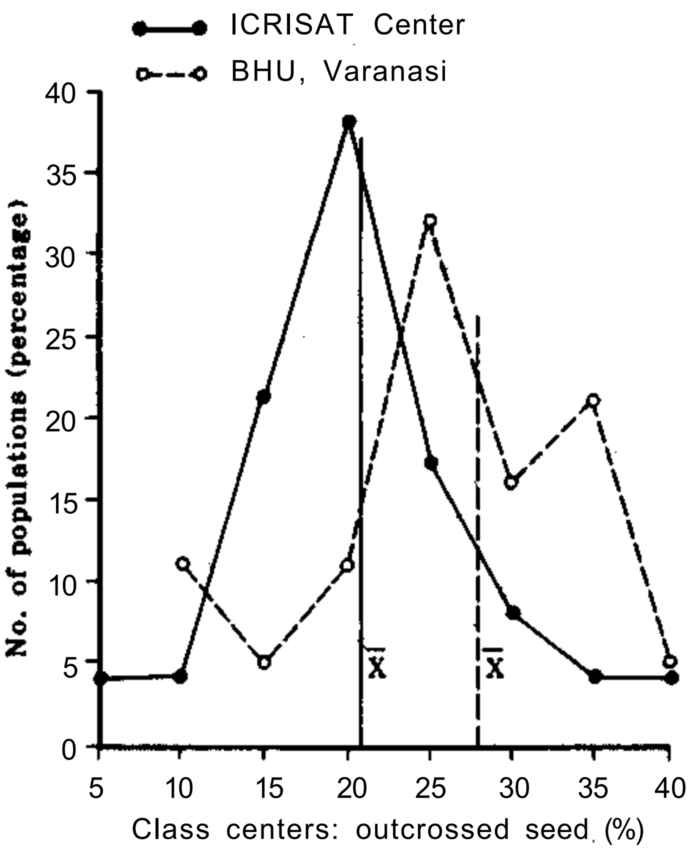


Figure 3. Frequencies of plants with different percentages of outcrossing in tests at ICRISAT Center and at BHU, Varanasi.

other location for which data are available, the mean outcrossing was 27%. Figure 3 shows that crossing by bees on normal fertile flowers was not constant from plant to plant; the range was from 7 to 38% at ICRISAT Center and 10 to 41% at Varanasi.

These results suggest that possibilities of exploiting natural crossing, and coping with the problems caused by it would be similar at the two locations. Continued research is needed on this problem, particularly at other locations and in different seasons. We are also investigating different ratios of sterile females to pollinator rows for hybrid seed production and effects of distance and barriers on intercrossing between fields.

To avoid random crosses by bees on hand-pollinated flowers, the parent lines were enclosed in a mesh-covered cage. To reduce plant size, planting was delayed until September. Compared with crossing July-sown parents in the open, we recorded an increased percentage of crosses set and a lower incidence of pod borer damage.

Breeding for New Plant Types

The extension of pigeonpea to new systems of production might be possible through the development of new plant types. Specific objectives toward this end exist in the breeding program; for example, development of vigorous, spreading, many-branched plants for intercropping with cereals. We are also attempting to combine high yield with unusual plant types, and then to evaluate the usefulness of such types.

Dwarf plants have several advantages, including easier application of insecticide, partitioning of more photosynthate to pods in the absence of large, woody main stems, and better suitability to mechanical harvest. Figure 4 illustrates the five genetic dwarfs that are used as parents. D_1 to D_3 appeared in the F_2 population from two normal parents. The simplest hypothesis was that two recessive genes controlled dwarfness and that each normal parent carried one. In crosses with five parents, monogenic inheritance was observed, indicating that the normal parents carried one gene for dwarfness in the recessive condition. Of the hundreds of crosses made to date, only one has produced these dwarf plants. This observation, together with the evidence that five random parents carry one dwarf gene each, suggests that the frequency of the second dwarf gene must be extremely low. Dwarf selections from hybrids are being advanced and evaluated as progeny rows.

Figure 4 also shows that one of the lines, ICP-7952, branched very profusely. Three such lines were selected in recent germplasm collections. Since the number of secondary branches is usually positively correlated with the grain yield, these lines are of interest.

Conversely, a single-culm nonbranching plant type is also being used in crosses to produce nonbranching lines of different matur-

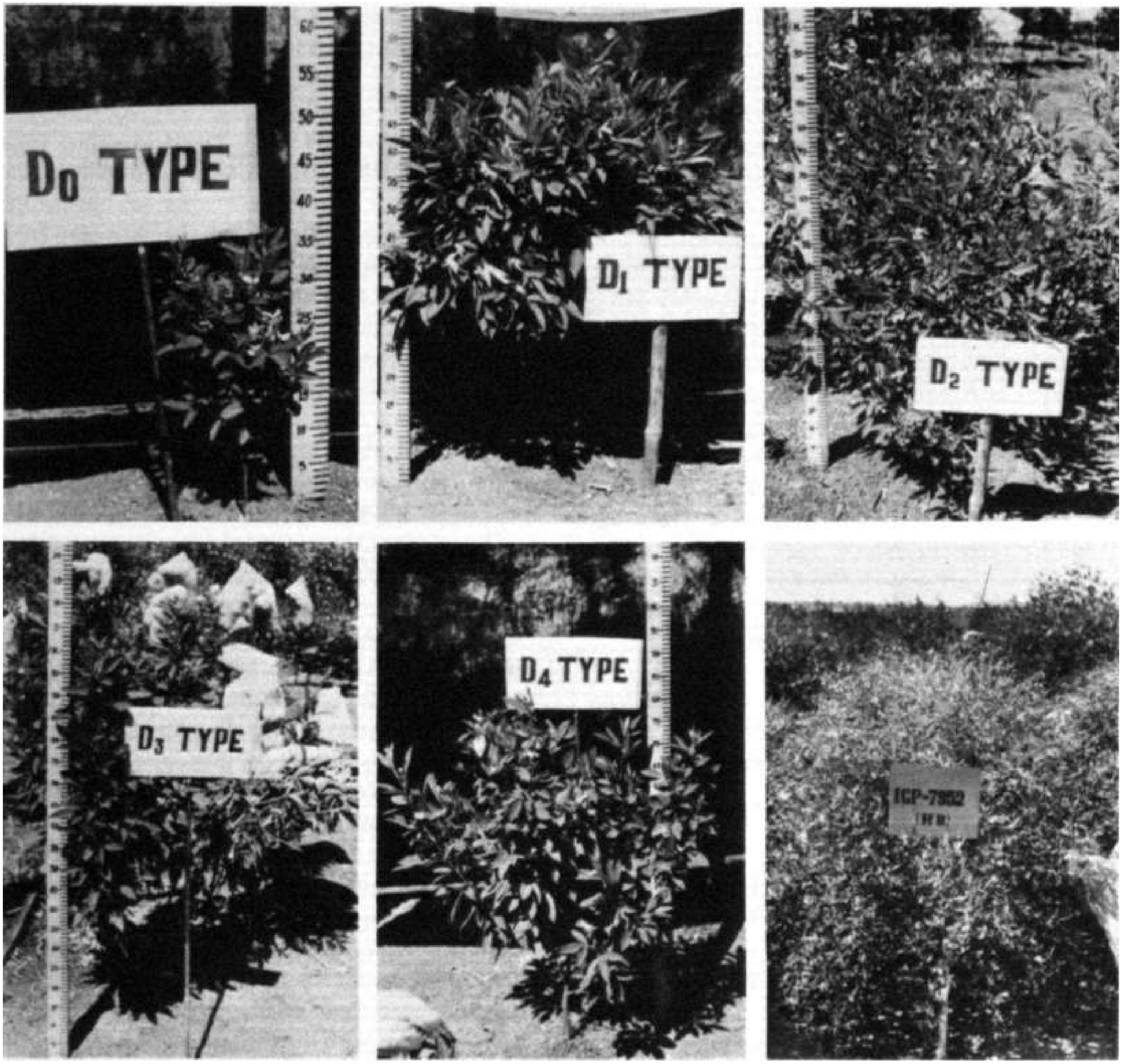


Figure 4. Five genetie dwarf plant types (D_0 to D_4), and ICP-7952, characterized by high branch number.

ities; these may give a yield advantage when sown at closer spacings.

Research in Australia

A significant portion of northern Australia consists of semi-arid tropics. Because the requirements of this area could not be met at ICRISAT Center's research farm, cooperative research with the University of Queensland, Australia, was formalized in 1977. The primary objective has been the development of short-season pigeonpea genotypes and production systems suitable for mechanical harvesting in extensive dryland agriculture. Agronomic and breeding studies of photoperiod-insensitive material continued in 1979. We now know that this material is capable of high seed yields, with some lines producing up to 4500 kg/ha from the plant crop and 6500 kg/ha total from the plant and first ratoon crops in experimental plots. Lines differ in time to flowering and maturity, and we have selected those that appear to be quite synchronous in flowering and podding. These lines will be evaluated in regional trials in Australia and have been supplied to a number of cooperators internationally.

A photoperiod-sensitive cultivar, Royes, has been released in Australia, and commercial production is expected in 1979-80. The adaptation of this cultivar is limited by the incidence of frost, and earlier-maturing Royes-type breeding lines have been developed and introduced. They will be evaluated regionally in 1979-80. An active program of plant introduction is continuing, particularly from ICRISAT Center.

During 1979, hybridization has been carried on with photoperiod-insensitive material for three main objectives: to transfer desirable seed and pod characters into the insensitive genetic background, to study the inheritance of insensitivity, and to commence quantitative breeding analyses of short-duration pigeonpea populations. In addition, we are conducting growth analysis and light interception studies of insensitive canopies to guide our agronomic research. Growth cabinets are being used to study the effects of photoperiod-temperature interaction on floral development, and studies on germination of immature seed have commenced. The last two programs are directed, in part, towards accomplishing rapid generation turnover in this crop.

Biochemistry

During 1978-79, in addition to routine screening of samples, studies were carried out on the cooking quality of *dhal* (dried split seeds), determination of amino acids, and biochemical changes in seeds during maturation.

Evaluation of Cooking Quality Characteristics

Dhal samples of 25 cultivars were evaluated for their cooking time, and were analyzed for various physicochemical characteristics (Table 1). Variation (24-68 min) in the cooking time of these cultivars was large in comparison with that of 20 market dhal samples, which ranged between 22 and 28 min. A negative and highly significant correlation ($r = -0.81$, $P < 1\%$) was observed between the cooking time and the

Table 1. Physicochemical characteristics of dhal samples of pigeonpea.[a]

Component	Range	Mean
Cooking time (min)	25 -68	38
Solids dispersed (%)	20.80-54.7	37.9
Water absorption (w/w)		
(a) Soaking at room temp, for 24 hr	0.61- 1.08	0.88
(b) Heating at 80°C for 1 hr	1.21- 2.06	1.54
(c) Boiling at 100°C for 25 min	1.69- 2.65	2.25
Increase in volume (v/v) during boiling at 100°C for 25 min	1.18- 1.86	1.51
Gelatinization temperature of isolated starch (°C)	73 -81	76
Water soluble amylose (%)	7.3 -12.0	9.8
Starch content (%)	51.5 -63.4	58.6

a. n = 25.

amount of solids dispersed during the cooking process. The quantity of water absorbed (w/w) by dhal samples when heated at 100°C for 25 min was negatively and significantly correlated (r = - 0.81, *P*<1%) with cooking time. These preliminary results show that the percentage of solids dispersed and water absorption during the cooking process are important parameters to be considered in developing rapid methods for evaluating the cooking quality characteristics of pigeonpea dhal samples; our observations agree with those reported by the Central Food Technological Research Institute, Mysore, India.

Total Sulphur and Sulphur Amino Acids

Sulphur amino acids, methionine, and cystine were analyzed in 25 dhal samples after performic acid oxidation in a Beckman 120-C amino acid analyzer. Total sulphur was also estimated in these samples by the wet digestion method. The mean values of these 25 samples revealed that sulphur in cystine and methionine together accounted for 68.7% of the total sulphur in the meal. Methionine (g/100 g protein) and cystine (g/100 g protein) when considered together or individually were positively correlated (Table 2) with total sulphur (g/100 g meal). The significant correlation of methionine with cystine suggests that estimation of one of these two amino acids in a screening program might be sufficient to identify lines with high sulphur amino acids. The observed relationship between total sulphur and sulphur amino acids is encouraging, and further work will be carried out in this area.

Tryptophan

Another amino acid of nutritional importance in pigeonpea is tryptophan, but due to its destruction during acid hydrolysis, it cannot be estimated along with other amino acids. We have compared three methods of tryptophan estimation in our laboratory. Dhal samples of ten cultivars were analyzed for tryptophan in an amino acid analyzer after alkaline hydrolysis and by two different colorimetric procedures. Tryptophan (g/100 g protein) estimated by using the amino acid analyzer ranged between 0.47 and 0.63, with an average value of 0.53; these values were slightly lower than with the colorimetric procedures. Further work is in progress to study the suitability of these techniques.

Biochemical Changes During Maturation

In order to understand the accumulation of principal grain constituents of pigeonpea dur-

Table 2. Correlation coefficients between protein (%) total sulphur, and sulphur amino acids in 25 cultivars of pigeonpea.

Component	Protein (%)	Cystine	Methionine	Cystine +Methionine
Protein (%)		0.269 "	0.489[a]*	0.392 *
		- 0.308 [b]	-0.262[b]	-0.214*
Total sulphur	-0.150	0.554[a]**	0.453 *	0.534°**
(g/100 g meal)		0.616[b]**	0.612"**	0.651 **

*Significant at 5% level. *a.* g/100 g meal.
**Significant at 1% level *b.* g/100 g protein.

ing the course of development, we studied the levels of soluble sugars, starch, soluble nitrogen, protein nitrogen, and amino acids at different stages of maturation of cultivars HY-3C, ST-1, and ICP-1 grown during the rainy season of 1977-78 at ICRISAT Center. Percent soluble sugars increased up to 14 days after flowering; thereafter a sharp decline was observed. Rapid accumulation of starch was observed between 14 and 21 days after flowering (Fig. 5). Protein nitrogen expressed as a percentage of dry weight decreased during development, whereas soluble nitrogen increased during the early stages of maturation and then sharply decreased and became more or less constant as the grain matured (Fig. 6). Sulphur-containing amino acids, methionine, and cystine, when expressed as percentage of protein, declined with maturation. Polyacrylamide gel electrophoresis of salt-soluble proteins revealed that seed storage proteins are formed 14 days after flowering and do not change much during the later stages of maturation.

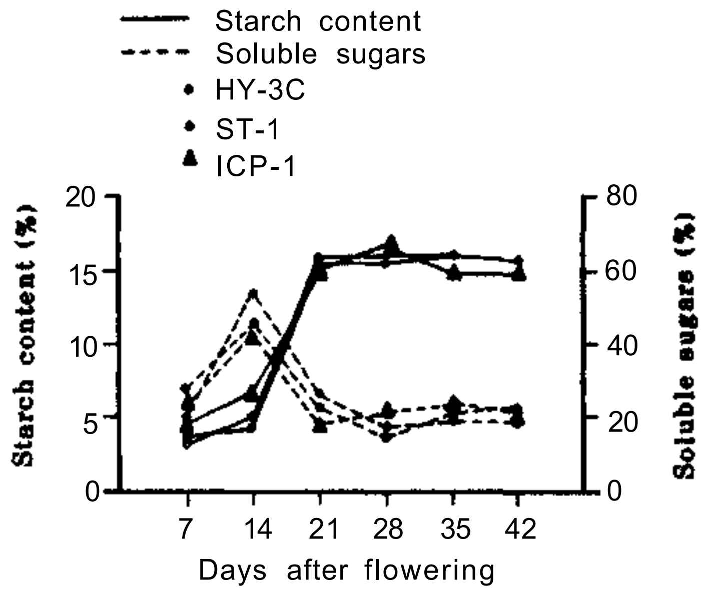


Figure 5. Soluble sugars and starch content at different stages of pod maturation of pigeonpea.

Physiology

Research continued on screening for waterlogging and salinity tolerance, as well as on compensation for damage to developing pods. Results in these areas were similar to those reported last year. Some investigations that gave interesting leads are summarized below.

Growth Analysis

Determinate versus indeterminate cultivars. Growth characteristics and yield of four determinate and four indeterminate cultivars within each maturity class were compared for 2 years. The cultivars were taken from the available germplasm and were assumed to be random representatives of their respective types.

Last year we reported higher total drymatter production of indeterminate types within each maturity class, and we observed the same difference this year. However, there were no consistent differences in grain yield between the two types, and these tests did not demonstrate an inherent yield advantage in either type. Further information on this question could be readily obtained by comparison of isopopulations derived in breeding programs.

Cultural Practices in Pigeonpea

Response to plant population. Our studies with postrainy-season pigeonpeas have demonstrated the importance of high plant population in compensating for low yield per plant associated with the small plant size in this season. This year we initiated experiments on the effect of plant population on rainy-season-planted pigeonpeas. Most studies in the literature report higher yields with higher plant populations, but very few studies have given a response curve in which the highest populations resulted in reduced yields.

In an experiment to test only the effects of plant spacing within the row, an early cultivar (T-21) was planted in rows 75 cm apart and a medium maturing (C-11) and a late cultivar

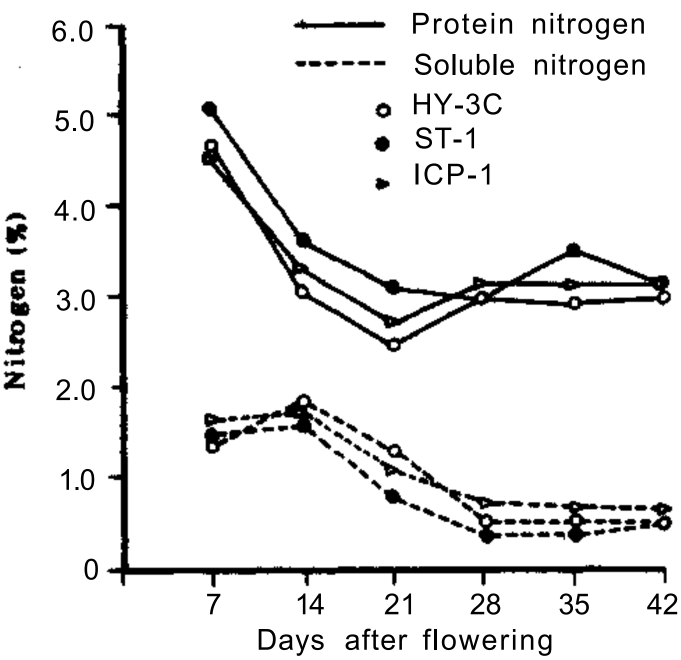


Figure 6. Protein nitrogen and soluble nitrogen at different stages of pod maturation of pigeonpea.

(NP[WR]-15) in rows 150 cm apart, with plant-to-plant spacings of 2.5, 5, 10, 20, 30, and 50 cm. T-21 gave higher yields with increased population, with the highest yield at the closest spacing; while the later cultivars appeared to reach a plateau—C-11 at 5 cm spacing, and NP(WR)-15 at 20 cm spacing (Fig. 7). Yield levels were highest for C-11, which is of the maturity considered best for the ICRISAT Center environment.

The tremendous response of yield to plant spacing in the intermediate range tested is of great importance. Many yield trials are planted with a spacing of 25 or 30cm between plants, and our results indicate that loss of part of the stand could greatly affect yield estimates. Our observations of farmers' crops, on the other hand, suggest that where row planting is used close spacing of plants is usual and yield is not restricted by limited population within the row.

In order to get more information on questions emerging from these studies we will test different plant spacings in experiments with varying row spacings also.

Response with Aiming for forage harvest. On a hypothetical basis, it should be possible to plant a thick stand of pigeonpeas to get early ground cover, remove some of the plants during the rapid growth phase of the crop, and harvest a satisfactory grain crop from the remaining plants. Earlier, we tried to take a forage yield by ratoonmg, but found two difficulties: (1) when rain fell on a recently ratooned crop, many plants died, and (2) ratooning delayed the production of the grain crop, which could result in increased water stress during pod filling.

Two cultivars, BDN-1 and C-11, were planted in rectangular spacings of 30 x 12, 50 x 20, and 75 x 30 cm on both Vertisols (black soils) and Alfisols (red soils). Forage harvests (Fig. 8) consisted of removing one-half and one-third of the rows. The closest spacing and 50% thinning gave the highest forage yields on both Alfisols and Vertisols.

Grain yield did not respond significantly either to plant population or thinning on Vertisols or Alfisols (Fig. 9). There was an apparent response to increased population in the unthinned plots of BDN-1 on both soils, but differences were not statistically significant. In C-l 1 such a trend was not evident.

We plan to extend the treatments in this trial to find the limits of thinning that are possible without reducing grain yield, and to incorporate appropriate plant spacings.

Effect of foliar nutrient sprays. The soils at ICRISAT Center are generally low in phosphate. Experiments with soil-applied fertilizers have not given encouraging results. We investigated foliar sprays during the past 2 years as a means of providing additional nutrients. The spray treatments were applied during pod filling, starting 2 weeks after 50% flowering, with two applications on Vertisols and three on Alfisols. There was no response to the nutrient application in any of the characters measured.

Sprays used included urea and potassium polyphosphate alone and in combination, and both of these with potassium sulphate. In retrospect, it seems logical that these spray treatments were applied too late in the develop-

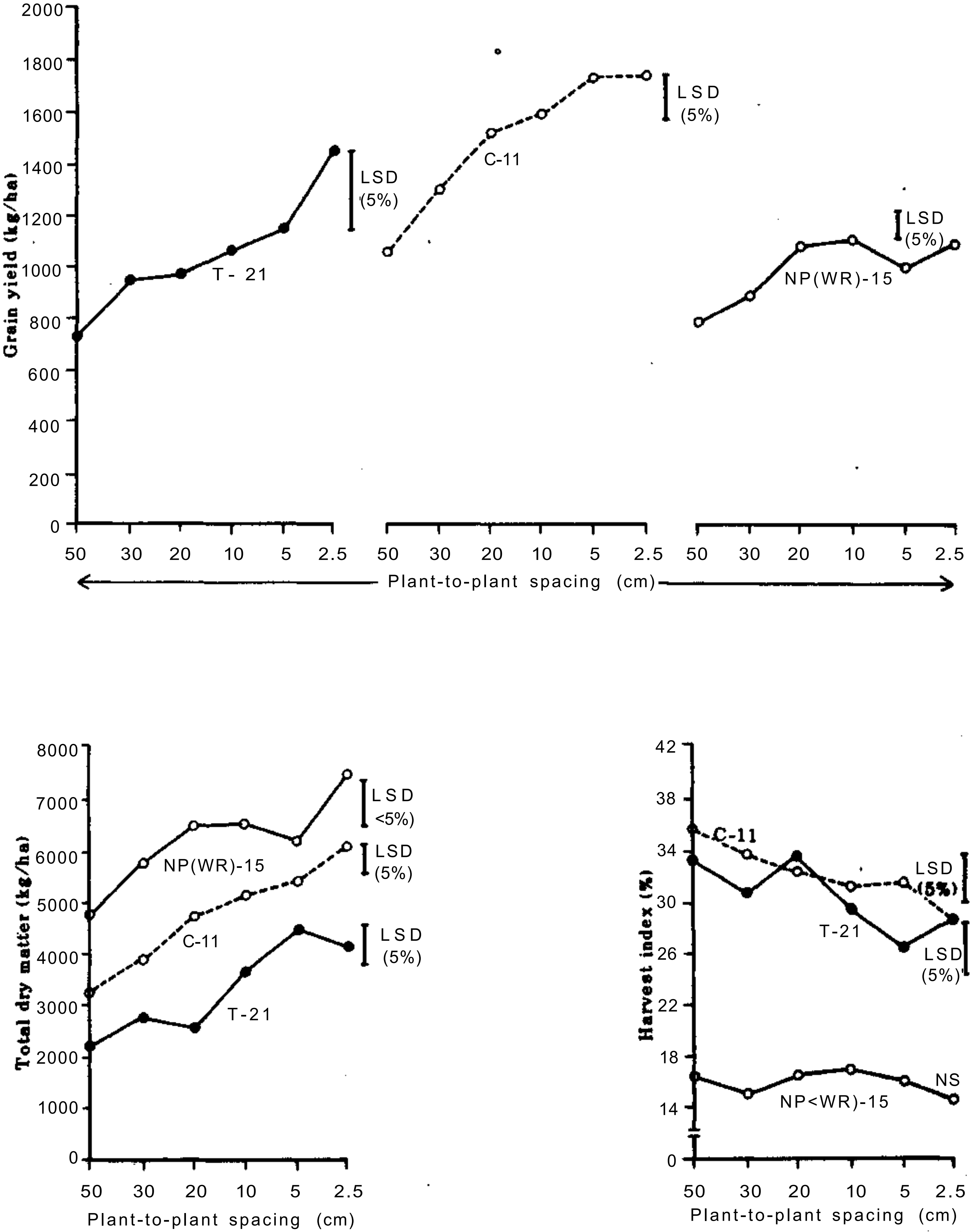


Figure 7. Response of three cultivars to varying plant-to-plant spacing in constant row spacings.

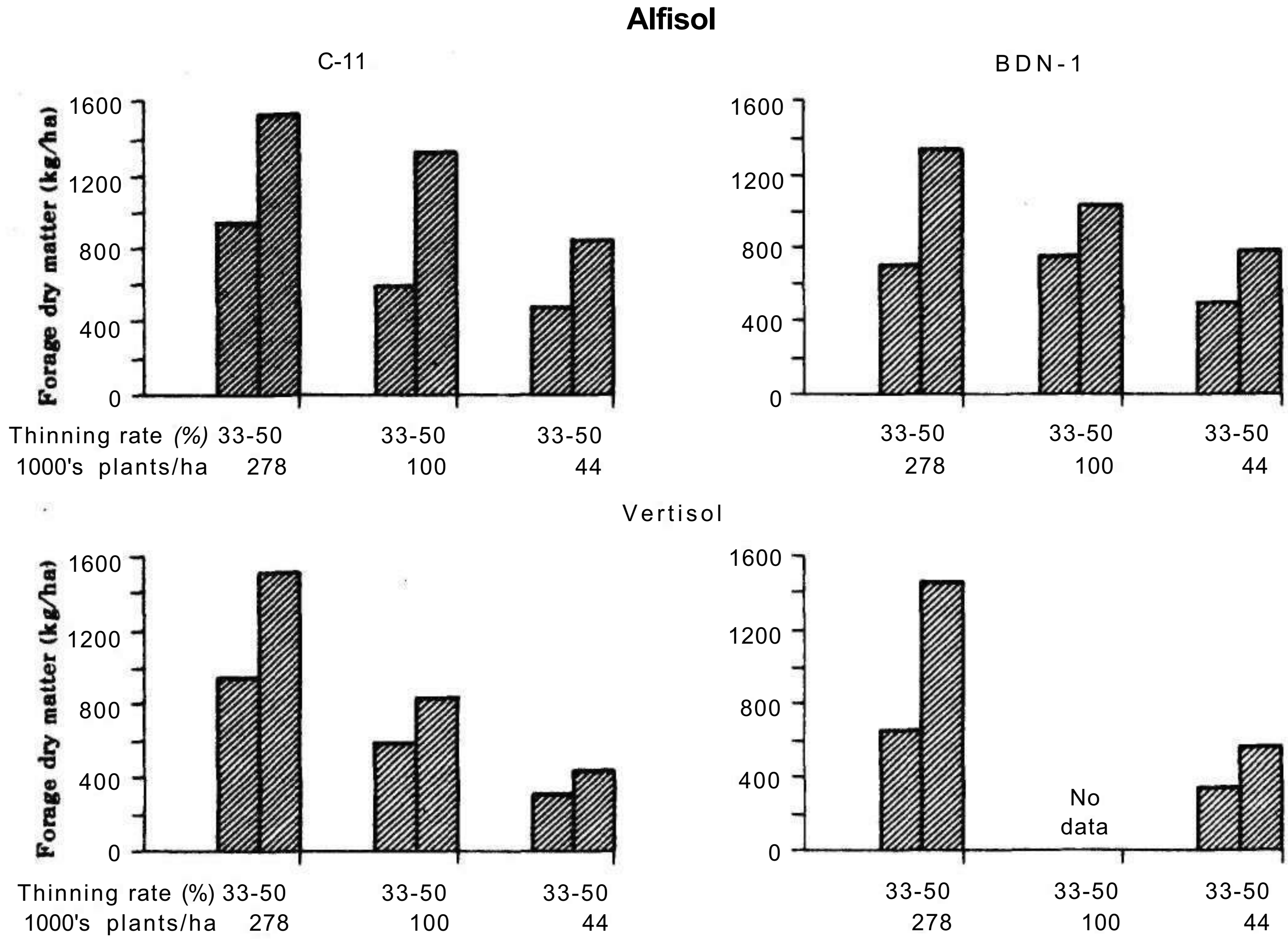


Figure 8. Yields of forage dry matter of C-11 and BDN-1 at three populations and two rates of thinning on Vertisols and Alfisols.

ment of the plant. Further experimentation on time of application is needed.

Entomology

Survey of Insect Pests

We continued our surveys of the pest damage on pigeonpea in farmers' fields with tours through seven states of India. Some districts that had been surveyed in previous years were revisited in an attempt to obtain information on year-to-year variation. This year also, some of the surveys were planned to coincide with the flowering and green-pod stage of the crop so that we could see the pests, rather than the final pest damage that we normally record from pod samples taken from the mature crop.

As in previous years, *Heliothis armigera* was the most damaging pest in most of the areas surveyed, particularly in the more southerly states. Although the overall attack by this pest was not so severe as in the previous year, more than 50% of the pods were destroyed by these larvae on many farms. There is great variation in intensity of damage, not only from year to year and area to area, but also among farmers' fields within single villages. Thus, in one village in which ten farmers' fields were sampled, the total percentage of insect pest damage in the pods ranged from 35 to 82%, with a mean of 62%. Of the several other pests on this crop, *Melanagromyza obtusa,* the podfly, was again generally recorded as the second most common, while in the more northern states it was often the most damaging pest. *Exelastis atomosa,* a plume moth, was also more prevalent in the

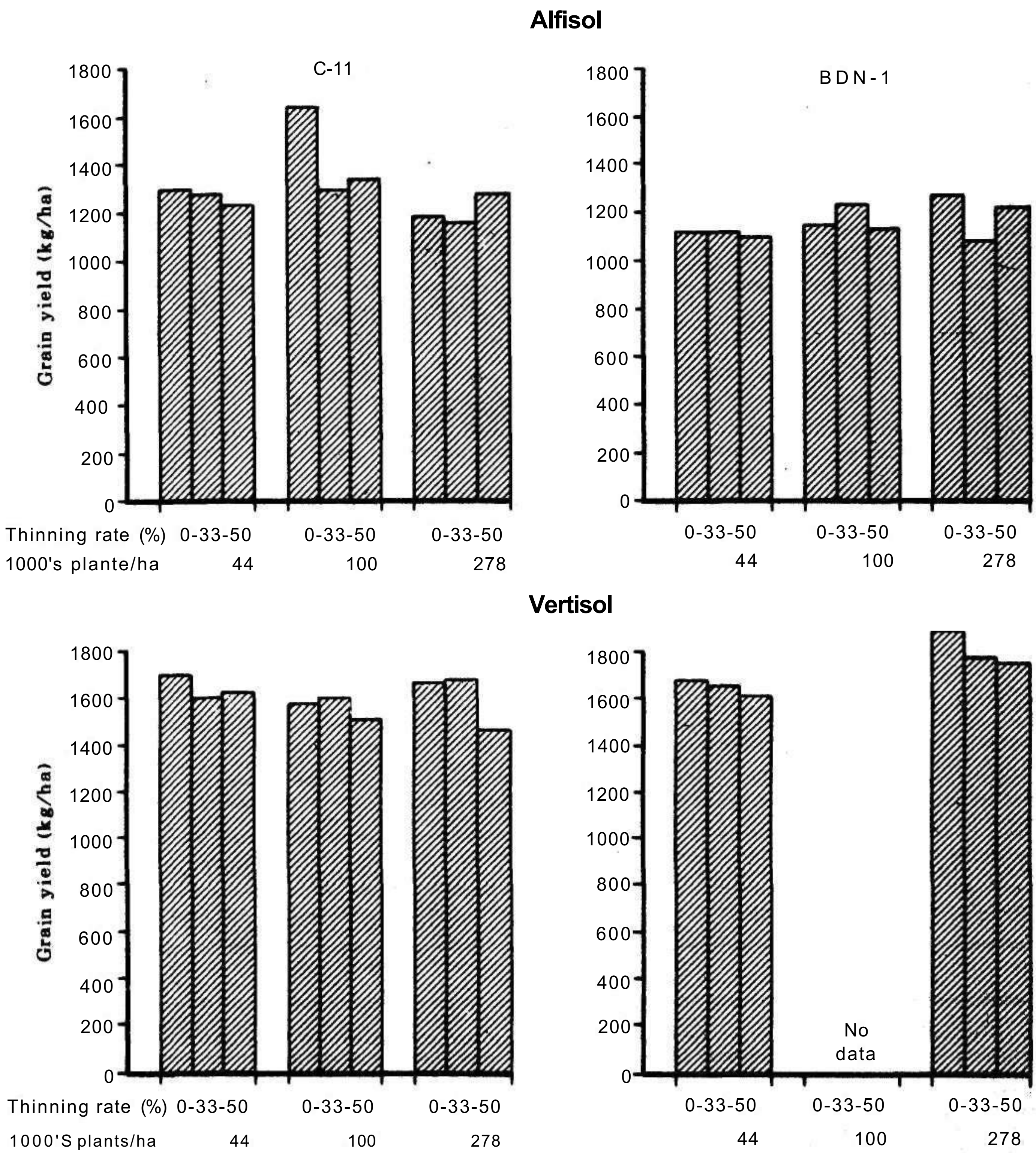


Figure 9. Grain yields of C-11 and BDN-1 at three populations and three rates of thinning on Vertisols and Alfisols.

north, replacing *Heliothis* as the most common borer in many fields. Sucking bugs, particularly *Clavigralla* spp., were also common and we found them to be more damaging to the crop than generally believed.

We also recorded information on soil type, field size, cropping pattern and pesticide use during these surveys. During the year under report, 28% of the fields visited were of sole crop pigeonpea, a much higher proportion than had been recorded in our previous surveys. The most common intercrops were sorghum, pearl millet, cotton, groundnuts, and other legumes. Of the 320 fields visited where the farmer or one of his family was able to supply us with definite information, only 13 (4%) had been treated with any pesticide. These, in the states of Karnataka, Maharashtra, and Madhya Pradesh, were all treated with BHC or DDT (dusts or wettable powders). The less polluting endosulfan is commonly recommended for use on pigeonpea, but in our surveys we did not find a single farmer using this pesticide. The relatively low cost and ready availability of the organochlorine insecticides are the obvious reasons for their popularity.

Host-Plant Resistance

The steady progress in selection of less susceptible plants and populations was maintained. Adequate populations of the major pests occurred naturally in our fields again this year, so open-field screening was effective. In our large pesticide-free area, the *Heliothis* populations were too abundant for selective screening, particularly at the normal flowering time of the midmaturing cultivars. By mid-November the larvae had devoured every available bud. flower, and pod, and then turned their attention to the leaves, even on the much less susceptible *Atylosia* relatives of pigeonpea, There are no pigeonpeas that are anywhere near immune to. this pest, and such enormous populations overwhelmed the levels of resistance that we have available. Although the first flush of flowering in the midmaturing cultivars was completely destroyed, the plants produced a second flush at a time when the *Heliothis* populations had subsided, so reasonable yields were obtained from some cultivars (Table 3). This ability to compensate for earlier damage differs markedly among cultivars and is of great importance to the farmer who does not use pesticides in areas where *Heliothis* can destroy the first flowering flush; thus it forms one of our more important selection criteria in the early and midmaturing cultivars. The data in Table 3 are from pesticide-free and sprayed trials of midmaturity selections. It can be seen that the yield performance of the selections under protected conditions had little correlation with the yields obtained in the pesticide-free trial ($r = -0.16$).

One of the major objectives of this project is to ensure that the materials generated and selected by our breeders, and other scientists, are not extra-susceptible to insect pest damage. We already have some evidence to show that selection of pigeonpeas for yield in pesticide-protected trials may produce materials with greater pest susceptibility. Lines found promising by the breeders and pathologists in the sprayed fields are subsequently screened in our pesticide-free areas to determine their susceptibility to insect pests and to select from them for reduced susceptibility.

Balanced lattice-square design trials were used for testing some of the more advanced selections, and these again gave increased efficiencies when compared with randomized block design analyses. This year the gains were relatively small, ranging only up to 40%, but as the major problem encountered in our screening work is that of high coefficients of variation, even small increases in efficiency are useful.

In cooperation with the All India Coordinated Pulse Improvement Project (AICPIP), we participated in multilocation tests of promising cultivars in trials designed to compare the relative susceptibility of the entries to insect pest damage. Four such trials were conducted and the results from these, when compared with those from similar trials from

Table 3. Percentage of insect-cawed pod damage and yield from a pesticide-free trial of less susceptible selections of pigeonpea compared with the yields from the same selections in a trial protected from the pests.

	Pesticide-free		Sprayed
Entry	Pods damaged (%)	Mean plot yields (g)[a]	Mean plot yields (g)[a]
1	58	884	1711
2	54	782	1070
3	36	421	1453
4	44	732	1430
5	66	786	1322
6	77	605	1605
7	64	709	1536
8	57	622	992
9	47	743	1275
10	47	707	1428
11	63	688	1541
12	62	409	1340
13	58	326	618
14	54	1076	987
15	49	529	950
16	46	448	1273
17	35	410	1282
18	72	805	1443
19	54	721	1453
20	45	501	1104
21	48	568	1098
22	58	1013	1387
23	66	662	1297
24	44	995	644
25	57	863	718
26	57	778	972
27	50	1004	932
28	47	993	525
29	63	894	895
30	40	880	1181
31	48	805	1639
S.E.±	4.3	64.9	190.0
cv%	13.7	16.1	27.4
LSD at 5%	12.1	183.4	540.1

a. Plot size = $9m^2$.

other locations in India, gave very useful data. We are fortunate in enjoying excellent cooperation from the national pulse entomologists in a number of projects with great mutual benefits.

Attempts to transfer the pest resistance found in *Atylosia* spp. into useful pigeonpea types continued, but we have not yet succeeded in selecting any intergeneric derivatives that match the combined resistance and yield performance that is available in some of our selections from pigeonpea. In general, the intergeneric derivatives are less susceptible to podfly, moderately susceptible to *Heliothis* and highly susceptible to *Tanaostigmodes,* the hymenopteran pest, but all are relatively low yielding.

We supplement our field trials with laboratory studies in an attempt to identify mechanisms of resistance. Our studies of antibiosis to *Heliothis* were again hampered by a virus that killed many of the larvae, but we hope to overcome this problem when we move to new laboratories.

The effect of pod washing on the incidence of podfly was again studied, and it is now apparent that there are marked differences in attraction to podfly egg laying after pod washing among different cultivars. In some cultivars there was a large increase in infestation after pod washing; in others there was little or no measurable increase.

In preliminary studies on the structure of young pods there were indications that those from some of the less susceptible cultivars had a concentration of a tannin-like substance in the subcutaneous cell layer. We intend to follow up these and other promising leads with more intensive studies.

Biological and Ecological Studies

Practical pest management can best be built upon a secure foundation of knowledge of the biology and ecology of the pests and their natural enemies. We monitor the populations of the pests and their natural enemies throughout each year, not only upon the pigeonpea crop but also on the alternative crop and weed hosts. During the period under report, the parasitoid incidence on *Eucosma critica,* the leaf webber, proved to be of particular interest, as illustrated in Figure 10. The leaf webbers and their parasitoids were common on pigeonpea through the vegetative stage, but there was a slump in the parasitoid incidence in November. We recorded a similar pattern in the previous seasons. It is probable that the slump was a result of the parasitoid population being diluted across the huge populations of *Heliothis* larvae that suddenly appeared on the flowering pigeonpea at that time, for we know that at least two species of parasitoids are common to the leaf webber and *Heliothis.*

The improvement of our methods for monitoring pests is an important facet of our research, and we allocated some of our time to trap development. This year we further developed the use of virgin female traps, with success in the case of *Exelastis* and *Eucosma.* but still with little reward for *Heliothis.* We continue to cooperate with the Tropical Products Institute in London in the search for effective *Heliothis* pheromone attractants.

Insect Damage to Nodules

In a cooperative study with the microbiologists, the entomologists have been studying the insect damage to nodules, which in some samples has exceeded 50% and so may have a major influence on the nitrogen-fixing efficiency of this crop. We have now established that the larvae of a fly identified as *Rivellia angulata* are the major cause of the damage. Species of this genus have also been reported to feed on legume nodules in the USA, Africa, and Australia. We have succeeded in rearing this insect in our laboratory and have monitored the populations of the fly with the aid of sticky traps at ground level in our fields.

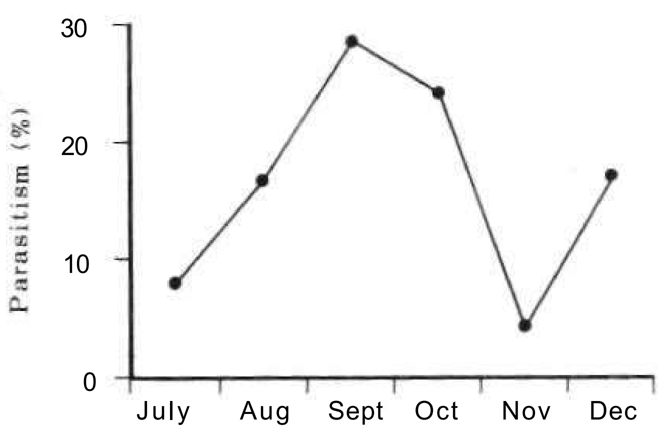
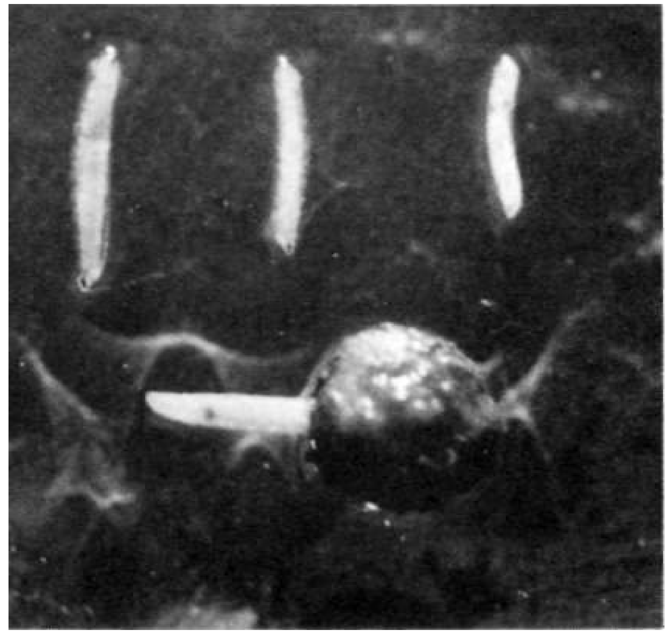


Figure 10. Mean percentage of parasitism recorded in* Eucosma critica *larvae collected from pigeonpea at ICRISA T from July to December, 1978.



***A pigeonpea nodule being damaged by the larva of* Rivellia angulata.**

Pest Management Studies

We continued to study the interaction of a number of factors with the pest populations on tKe crop. Research station farms are not ideal for such studies, for atypical patterns of crops and practices tend to produce pest populations that differ markedly from those found in farmers' fields. We hope to develop more of our observations off' the research farm in the future.

This year again we found that there were more *Heliothis* larvae per unit area with closer plant spacing in the rainy-season crop. In the postrainy-season crop, however, where plants are much smaller and much greater plant populations are needed to adequately utilize the available space, the number of *Heliothis* larvae per unit area decreased with closer spacing (Table 4). The plume moth *Exelastis atomosa* was much more common and damaging on the postrainy than on the rainy-season crop.

The components of any practical pest management exercise on this crop will include synchronous sowing of a less susceptible cultivar of appropriate maturity, geared to the climatic conditions of the area and the expected pest population peaks, together with the judicious use of a pesticide applied according to count of the pests on the crop. We hope to be ready soon to suggest the trial of such a package in farmers' fields in cooperation with national programs.

Table 4. The mean number of *Heliothis armigera* larvae recorded per m^2 in pesticide-free spacing trials of pigeonpea in the rainy and postrainy seasons on ICRISAT farm.

	Heliothis larvae/m^2	
Plants/m^2	Rainy	Postrainy
50.0	ND	1.8
25.0	ND	6.0
10.7	5.2	ND
4.4	4.0	ND
1.4	2.6	ND

ND = No data.

Pathology

Wilt (*Fusarium udum*)

Development of sick plots/sick pots. Four plots two each in an Alfisol and a Vertisol, have now been developed in a total area of 3.5 ha, and the germplasm and breeding material is being screened. To supplement field screening, soil in 1000 pots has been made sick. Material showing promise in the sick plots is evaluated in sick pots.

Developing "sand culture" technique for screening. When the pulse pathology program was initiated in 1974, we made unsuccessful attempts to adapt the well-known "sand culture" technique for screening against pigeonpea wilt. We intensified our efforts and have now worked out a procedure. Briefly, it involves multiplying *Fusarium udum* on potato-dextrose broth by incubation for 10 days on a shaker, dipping roots of pigeonpea seedlings (raised in autoclaved sand) in the fungus suspension, and then transplanting the seedlings to pots containing autoclaved sand. The wilt develops in susceptible cultivars in a month.

Screening for resistance. A large amount of breeding material in various generations was screened. Promising (less than 20% wilt) progenies in F_3 and F_4 generations were identified. Further selections were made by breeders, and new progenies will be screened again. All six male-sterile lines were highly susceptible to wilt.

Among the 58 All India trial entries, only BDN-1 showed less than 10% wilt, thereby confirming its low susceptibility to wilt. Of the 39 entries tested in the All India trial for wilt resistance, 8 entries (out of 12) from ICRISAT and 2 from other centers were found highly promising. The 12 entries from ICRISAT were tested at nine locations in India. The ICRISAT entry ICP-8863 showed resistance at all the locations.

Several lines with resistance to both wilt and sterility mosaic have been identified.

Sterility Mosaic

During the year, severe and widespread occurrsnce of sterility mosaic was reported from several areas in India, particularly from eastern Uttar Pradesh and Bihar. The availability of many sources of resistance gives us confidence that the problem can be overcome through breeding for disease resistance.

Studies on the mite vector. Preliminary studies revealed that the inoculation access period for file mite vector (*Aceria cajani*) was only 5 min. The vector could move with wind and spread the disease up to 35 m from the source of infection. It appears that the mite vector does not move very long distances.

Screening for resistance. A large number of breeding materials and newer additions *to* the germplasm collection were screened in the field using the infector-row system. After four generations of rigorous screening and selection, 29 out of 30 single-plant progenies of four germplasm accessions showed uniform resistance. A total of 2092 single-plant progenies of resistant plants selected during 1976-78 were screened, and 931 were uniformly resistant.

A large amount of breeding material from F_3 to F_5 generations was screened. Of 841 F_5 progenies screened, five were selected by the breeders for a yield trial.

All six male steriles were susceptible. Of the All India Coordinated Trial entries, 1234 and NP(WR)-15 showed low infection, and HY-2 showed the ring-spot reaction.

In a multilocation test, the 12 resistant entries from ICRISAT showed resistance at Faizabad (Uttar Pradesh) but susceptibility at Dholi (Bihar). This indicates the possibility of a different strain of the virus or the vector.

Phytophthora Blight

Identification of the fungus. Two species of *Phytophthora* had been reported on pigeonpea from New Delhi, India. These were *P. drechsleri* f. sp. *cajani* and *P. cajani. In* order to confirm the identity of the five *Phytophthora* isolates collected from various locations in India, Dr. J. Kannaiyan of ICRISAT worked in the laboratory of Dr. D.C. Erwin at the University of California at Riverside. Study of the growth rate at different temperatures, morphology, mating behavior, and host range resulted in the conclusion that all five isolates were of *P. drechsleri* f. sp. *cajani.*

Media for growth. Five growth media (cornmeal agar (CMA). CMA + Pimaricin-Vancomycin-PCNB, potato-dextrose agar, V-8 juice-agar, and pigeonpea stem extract-dextrose-agar) were compared. All five isolates of *P. drechsleri* f. sp. *cajani* showed best growth on CMA.

Pigeonpea *Phytophthora* does not attack roots. Therefore, to learn *if* the roots contained any inhibitors, we prepared media using pigeonpea leaf, stem, or root extracts with dextrose and compared them with the standard V-8 juice broth. The root extract medium did not inhibit the growth and the leaf or stem extract media did not stimulate it.

Optimum temperature for storing the fungus cultures. We faced some difficulties in storing pure cultures at lower temperatures. Therefore a simple experiment was conducted to find the optimum temperature for storing cultures. The P_2 isolate (ICRISAT isolate) grown on V-8 juice-agar was stored at four temperatures — 10°, 15° 22°, and 28° C. The viability of the cultures was tested weekly. At 15 C the fungus remained viable up to 133 days, whereas at 10° it was viable for 14 days only. At the other two temperatures, the viability was lost between 60 and 80 days.

Fungicidal seed dressing to control blight. Recently a group of acylalanine derivatives, which systemically control various diseases caused by fungi of the Oomycetes, has become available from Ciba-Geigy under the trade name Ridomil. A seed treatment trial was conducted by following the "pot culture" technique. Seeds of HY-3C were dry-dressed at five rates—0.1, 0.2, 0.3, 0.4, and 0.5% by weight of the commercial formulation. These were sown in pots and 6-day-old seedlings were inoculated by pouring the inoculum around the base of seedlings, followed by watering. Another inoculation was done 15 days later. Seedlings from untreated seed were inoculated likewise and used as checks. Whereas 99% of the seedlings from untreated seeds blighted within 15 days after the first inoculation, no seedling blight occurred with 0.4 and 0.5% seed dressings. However, 15 days after the second inoculation, 10.4 and 6.8% of the seedlings had blight with 0.4 and 0.5% seed dressings. The results clearly indicate that seed dressings with Ridomil can give complete blight control up to at least 3 weeks. We must remember, however, that the disease develops in nature at any time up to 2 months after sowing.

Screening for resistance. A large number of germplasm accessions and breeding materials were screened mainly in the field but also in pots. Of the 1400 germplasm accessions screened during the year, 52 were found promising (less than 10% blight). Many F_3 and F_4 progenies showed resistance. The six male-sterile lines showed low blight incidence in the field but were found susceptible when tested in pots. MS-4A, however, showed less blight than other male-steriles. Of the 58 entries in the All India Coordinated Trials, nine were found to possess resistance to both blight and sterility mosaic.

Surveys

Roving surveys in the Indian state of Uttar Pradesh were made in cooperation with the state agricultural universities. In all, 108 locations in 44 districts were surveyed. The average incidence of wilt and sterility mosaic for the whole state was 8.2 and 15.4%, respectively. In farmers' fields, wilt ranged from 0 to 86% and sterility mosaic from 0 to 93%.

Macrophomina stem canker, *Phytophthora* blight, and yellow mosaic were severe in some fields.

Interaction between Sterility Mosaic and Powdery Mildew

During the year we observed severe incidence of powdery mildew (*Oidiopsis taurica*) in the sterility mosaic screening nursery at ICRISAT Center. Detailed investigations established that the infection of pigeonpea plants by sterility mosaic predisposes them to severe incidence of powdery mildew.

Multiple Disease Resistance

In order to identify pigeonpea lines resistant to the three major diseases—wilt, sterility mosaic, and *Phytophthora* blight—we have developed a nursery where screening for resistance to these three diseases can be done. One hectare has been made wilt-sick. The infector-row system is used to spread sterility mosaic, and all plants are artificially inoculated with the P_2 isolate of *Phytophthora.* During the year we screened 866 F_4 and F_5 progenies from four crosses involving parents with resistance to at least one of the three diseases. Seed from 121 single plants that showed no disease was collected for further screening.

Microbiology

Soil Populations of Rhizobia

During the year several soil samples were collected from various fields at and around ICRISAT Center and analyzed for their population of the cowpea miscellaneous group of *Rhizobium* that also nodulate pigeonpea, using a serial dilution-plant infection technique (most probable number method). Forty-eight samples were taken from four different fields to follow seasonal changes in numbers, and 156 samples from eight locations in the Hyderabad area to study the distribution with depth through the soil profile. *Rhizobium* populations varied among sites and with soil depth. In one Alfisol (red soil) field cleared for cultivation after at least 6 years of grass fallow, the population was largest in the top 30 cm, then gradually declined to zero at 150-cm soil depth. In another Alfisol field the population remained high throughout the profile with 3.6 x 10^3 rhizobia/g soil even at a depth of 150 cm. Soil samples collected at another site had uniformly low numbers of less than 100/g soil.

There was a marked rhizosphere effect of pigeonpea on cowpea rhizobia, with numbers increasing from 1.3 x 10^3/g in the bulk soil to 9.1 x 10^4/g in the rhizosphere (Table 5).

Table 5. Population of cowpea group *Rhizobium* expressed as most probable numbers (MPN) in the rhizospbere of pigeonpea ICP-1[a] grown in a Vertisol during the rainy season in 1978.

Soil depth (cm)	Log_{10} MPN/g soil	
	Rhizosphere	Nohrhizosphere
0-20	5.71	4.01
20-30	7.27	2.29
30-40	6.15	4.28
40-50	4.34	3.60
50-60	4.73	3.79
70-80	4.34	2.89
80-90	4.31	2.29
90-100	2.90	2.66
100-110	5.19	3.17
Mean over all the depths	4.96	3.12

a. Inoculated with *Rhizobium* at sowing time and sampled 180 days later.

Rhizobium Growth Characteristics

Most of our isolates that nodulate pigeonpea are slow-growing rhizobia, taking more than 5 days for colonies to grow on agar. This is characteristic of most of the strains described for the cowpea miscellany of *Rhizobium.* However, we also have several fast-growing isolates that nodulate pigeonpea, with 2 mm diameter colonies appearing after 2 days. These fast-growing isolates are more similar to *Agrobacterium,* a soil bacterial species related to *Rhizobium,* than to the slow-growing cowpea rhizobia, in their reaction to several tests, including the ability to grow with 2% salt in the agar medium, utilize citrate and calcium glycerophosphate in growth media, and grow on manganese lactose medium. Unlike *Agrobacterium* they did not form galls when inoculated on the test plant *Kalanchoe.*

Pigeonpea Response to Seed Inoculation

Fifteen *Rhizobium* strains found to be highly effective in fixing nitrogen (page 112, 1977-78 Annual Report) were further tested in an inoculation experiment in both Vertisol and Alfisol fields during the rainy season 1978-79. Seeds of the medium duration pigeonpea cultivar ICP-1 were inoculated before sowing with peat cultures containing more than 10^9 rhizobia per gram. Inoculated seeds carried about 1.8 x 10^5 rhizobia per seed. At 30 days after planting, there were differences in nodulation, nitrogenase activity, and shoot dry weight between fields and between strains within the same field. The strain IHP-35 forms black nodules on pigeonpea, and this characteristic was used in studying its competition with the indigenous soil popula tion of *Rhizobium* in forming nodules. More black nodules were found after inoculation with IHP-35 than on uninoculated plants, particularly in the Vertisols (Table 6). This strain was originally isolated from a Vertisol. Four strains including IHP-35 produced significantly more grain yield (16 to 27%) than uninoculated control plants in a Vertisol field (Table 7).

In an Alfisol field, the increases in grain yield of up to 25% as a result of inoculation with different strains were not statistically significant.

Table 6. Black nodule formation on uninoculated control plants of pigeonpea cultivar ICP-1 and plants inoculated with strain IHP-35 (rainy season 1978).

Field	Soil type	Total nodules/plant		Black nodules/plant		Percent black nodules/plant	
		IHP-35	Control	IHP-35	Control	IHP-35	Control
RA26	Alfisol	30	31	6	0.2	20	0.6
RA32	Alfisol	28	22	3	1	11	5
B9	Vertisol	23	24	10	2	43	8
G5	Vertisol	21	22	8	4	38	18

In a Vertisol, seed inoculation with five single strains and one composite culture did not influence pigeonpea grain yield. Another inoculation trial was conducted in the pesticide-free area at ICR1SAT Center, using five single strains and a mixed culture of *Rhizobium.* At 30 days there was no difference between treatments in either nodulation or nitrogenase activity. *Heliothis* and podfly attack was so severe that very little grain was harvested in the first picking. Three pickings were done in all. The yield levels of around 600 kg/ha were low but are comparable to those obtained in farmers' fields. There was no significant response to inoculation.

Table 7. Effect of seed inoculation with *Rhizobium* on grain yield of pigeonpea cultivar ICP-1.

Rhizobium strain	Grain yield (kg/ha)	Percent increase over control	Rank
IHP-35"	1749	27.4	1
IHP-147[a]	1716	25.0	2
IHP-71[a]	1679	22.3	3
IHP-195[a]	1588	15.7	4
IHP-7	1568	14.2	5
IHP-70	1565	14.0	6
IHP-24	1558	13.5	7
IHP-100	1541	12.2	8
IHP-38	1524	11.0	9
IHP-215	1514	10.3	10
IHP-88b	1473	7.3	11
Uninoc Control	1373		12
IHP-229	1339		13
3958	1339		14
1HP-194	1331		15
3857	1243		16
CV (%)	9.5		
LSD at 0.05	206		

a. Significantly greater than the uninoculated control at 5% probability.

Screening Pigeonpea for Symbiotic Characteristics

Twelve lines tolerant of wilt, 8 *Phytophthora* blight resistant lines, 30 sterility mosaic resistant lines, 38 lines from the breeders' crossing block, and 97 germplasm selections from our previous field screening were sown in an Alfisol field and harvested 45 days later. There was much variability in all the characters observed (Table 8). Some sterility mosaic resistant lines had particularly good nodulation, nitrogen-fixing activity, and dry-matter production. We have selected some high and low nodulating lines from each category to follow the correlation between early observations on nodulation and final dry-matter production and grain yield.

Growth of Pigeonpea in Pot Culture

A comparison was made of different root media: Alfisol, Vertisol, sand, and a sand-vermiculite-

Table 8. Screening pigeonpea lines for nodulation characteristics[a] (Alfisol, rainy season 1978).

Group	Nodule no./ plant		Dry wt nodules/ plant (mg)		Nitrogenase activity: μm C_2H_4/ plant/hr		Nitrogenase activity: μmC_2H_4/g dry nodule/hr		Shoot dry wt/plant (g)		Root dry wt/ plant (mg)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Wilt-resistant lines	5	27	5	123	0.3	15.1	53	209	.65	3.90	100	571
Phytophthora-resistant lines	3	21	14	109	1.3	18.6	72	172	.73	3.20	187	607
Sterility mosaic resistant lines	8	41	16	208	1.0	30.4	50	318	.36	8.13	119	1104
Crossing block lines	2	30	3	118	0.4	15.4	57	235	.33	2.75	82	462
Germplasm selections	3	52	2	148	0.1	20.8	42	319	.24	3.89	58	563
Breeders' selections advanced lines in variety purification	16	37	28	71	2.3	12.0	46	225	.94	1.75	222	370

a. Average of 10 plants.

grit mixture supplemented by various nutrient amendments. Pigeonpea seeds of cultivar ICP-1 were inoculated with a peat culture of an effective *Rhizobium* strain and sown in 15 cm diameter plastic pots on 3 November 1978. They were harvested after 6 weeks and their nodulation and plant weight were observed (Table 9). Addition of farmyard manure (FYM) stimulated shoot development, although nodulation was reduced, with virtually no nodules formed with the addition of 30% v/v FYM to sand. Addition of 80 kg P_2O_5/ha stimulated nodulation and nitrogen fixation with a 92% increase in dry matter over plants grown in unamended Alfisol. The increase in the Vertisol was 22%. Adding zinc sulphate to the Alfisol increased nodulation and plant growth.

When nutrient solution containing 25 ppm N was used to water pots there was no effect on nodulation and nitrogen fixation in sand, but nodule weight and plant growth were stimulated in soil. Surprisingly, nodules were formed even in the presence of continuously supplied nutrient solution containing 200 ppm N. Nodulation and plant growth was much better in a sand-vermiculite-grit mixture than in sand or soil alone.

Looking Ahead

Systematic multilocation testing will be expanded for identification of superior populations and advanced lines. The hybrid program will be strengthened through development of additional lines carrying genetic male sterility, investigation of possible cytoplasmic male sterility, and evaluation of a wider range of parent lines in crosses.

Possibilities of utilizing quality factors in selection of vegetable types will be investigated.

Cropping practices for maximum production will be investigated further. Water relations will be studied. Screening for tolerance to soil salinity and waterlogging will be expanded.

Work will be intensified on developing multiple-disease-resistant lines, and the stability of resistance to individual diseases will be evaluated in expanded multilocation trials.

Selection for insect resistance will be intensified; research related to pest management, including the ecology and bionomics of the pests and their natural enemies, the biochemical basis of resistance, and host-pest interactions,

Table 9. Effect of different culture media on nodulation and growth of inoculated pigeonpea cultivar ICP-I grown for 6 weeks in pots.

Medium	Nodule (no./plant)	Nodule dry wt (mg/plant)	Root dry wt (mg/plant)	Shoot dry wt (mg/plant)
Alfisol alone	28	23	177	377
Alfisol + 80 kg P_2O_5/ha[a]	44	58	250	812
Alfisol + 25 ppm N "	44	50	178	642
Alfisol + $ZnSO_4.7H_2O$ (25 kg/ha)[a]	51	40	174	492
Alfisol+10% v/v FYM[d]	38	24	329	997
Vertisol alone	34	61	175	581
Vertisol + 80kg P_2O_5/ha[a]	36	84	206	720
Vertisol + 25 ppm N[b]	31	81	189	701
Vertisol + 10% v/v FYM[d]	22	38	253	734
Sand[c] alone	21	31	165	408
Sand + 25 ppm N[a]	21	25	164	402
Sand+ 200 ppm N[a]	16	11	157	369
Sand + 10% v/v FYM[d]	6	51	269	1042
Sand + 30% v/v FYM "	1	1	280	1552
Sand + vermiculite + grit[e]	57	75	247	767
CV%	31.6	25.2	14.8	12.9
LSD at 5%	10	11	31	88

a. P_2O_5 added as single superphosphate incorporated in the top 8 cm of soil in the pots. Amount calculated on a surface-area basis.
b. Pots were watered throughout with a nutrient solution containing 25 ppm nitrogen as ammonium nitrate.
c. $ZnSo_4.7H_2O$ was dissolved in water and added to wet soil on the top of the pots. Amount was calculated on a surface-area basis.
d. FYM—Farmyard manure incorporated throughout the soil or sand.
e. All sand treatments were watered with a nutrient solution containing nitrogen as ammonium nitrate as indicated

will be further developed.

Further work on development of a non-destructive assay for nitrogen fixation will be done. The search for efficient host and *Rhizobium* genotypes and breeding to improve nitrogen-fixation efficiency will continue.

Publications

Institute-level publication

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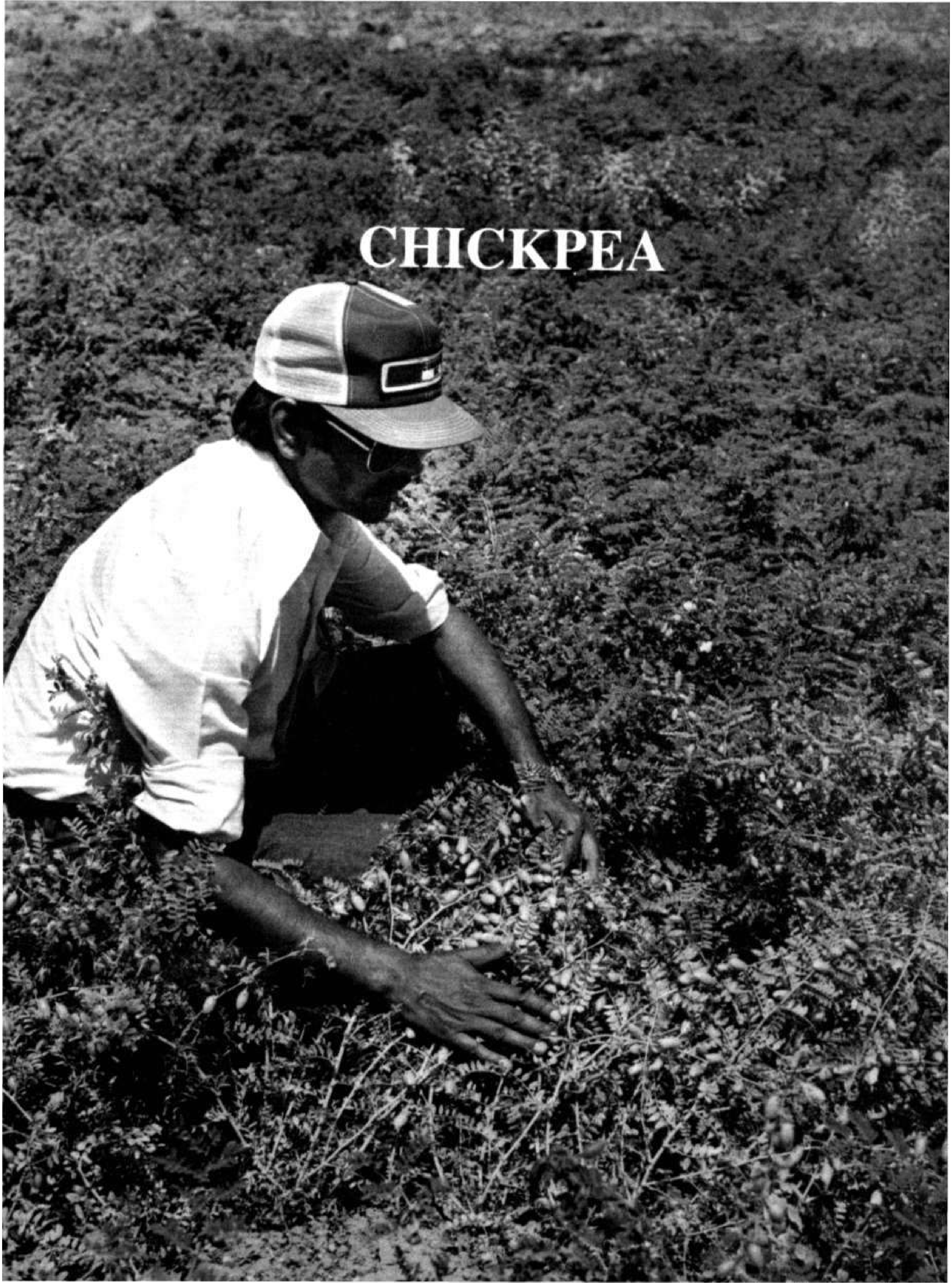
CHICKPEA



Contents

Chickpea

Breeding

The chickpea breeding programs at ICRISAT and ICARDA (see "International Cooperation" section of this report) were integrated in 1978—79, providing more effective coordination of chickpea improvement. ICRISAT is concentrating on breeding early *desi* (small; colored seed coat) types at Hyderabad and late desi and *kahuli* (large; white seed coat) types at Hissar.

Accelerated Generation Turnover

In chickpeas, a cycle of breeding can take ten or more generations. Chickpea breeding at ICRISAT has been restricted largely to one generation per year for various reasons, and this adversely influences its cost, effectiveness, and responsiveness to new problems. Two approaches have been adopted to accelerate the turnover of generations off-season nurseries and environmental modification.

Off-season nurseries. Chickpea growth during summer at Hyderabad is suppressed by high temperature, and foliar diseases are generally serious in hot, wet conditions. In 1978 79, breeding material was sown in the open field at ICRISAT Center in late June and was largely unsuccessful. The plants in a portion of the field under plastic cover showed reasonably

Plastic shelters are used for raising chickpea in the rainy season at ICRISAT Center; these shelters reduce disease incidence.

normal growth, although flowering and podding was suppressed. The use of such rain-shelters for growing an off-season chickpea nursery will be examined further next year.

Following 2 years of investigation at several locations, a site at Tapparwaripora in Kashmir has been chosen for off-season summer culture. In 1978 79, 21 cultivars were sown in late May, early June, and mid-June to determine the optimum sowing time to allow harvest prior to mid-October. Insect and disease problems occurred but were controllable using endosulfan and Dithane Z-78, respectively. The late-May and early-June sowings gave the highest yields; the early-June sowing date is regarded as the most suitable because there is a high probability of rain in May. One hectare of land at Tapparwaripora has been acquired for advancement of breeding material in the future.

Environmental modification. Since chickpea was thought to be a long-day plant, we conducted several experiments with artificial extension of daylenglh to 24 hours using incandescent lighting in the field in an effort to induce earlier flowering and maturity. An early desi cultivar, CPS-1, sown at Hyderabad (18 N) on 15 December flowered 10 days earlier under 24-hour days than in the normal daylengths. A further gain of 3 days was achieved using foliar fertilization with nitrogen and phosphorus (Fig. 1). In a second experiment on 18 cultivars sown at Hyderabad on 17 January, all cultivars flowered in 32 to 35 days in the 24-hour daylength and produced normal seed. Under normal daylengths, only the early cultivars flowered and matured, while the later cultivars remained vegetative and were killed by high temperatures in March. A similar trial under

ICRISAT's off-season nursery in Kashmir, India, whieh permits growing a second generation of chickpea each year.

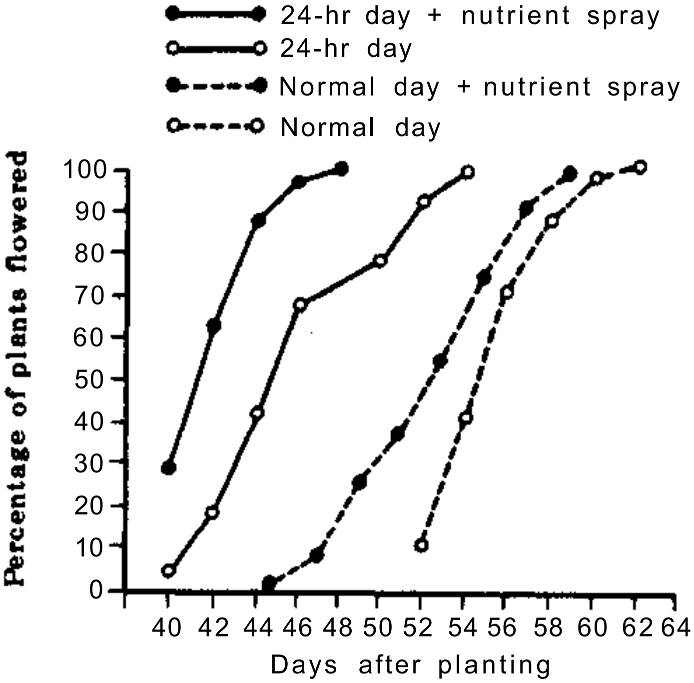


Figure 1. Effect of 24-hr daylength and nutrient spray on flowering in chickpea (cultivar CPS-1).

plastic covers at Bangalore (13°N) sown on 17 April also exhibited earlier flowering and maturity under 24-hour daylengths.

These studies made it clear that the life cycle up to flowering of most chickpeas can be reduced substantially by exposure to 24-hour days. This will allow four generations to be grown annually at Hyderabad—two during autumn/ winter in the field, and two in spring/summer, possibly in a glasshouse. Investigations are continuing on the intensity, duration, and timing of artificial light required to achieve early flowering in chickpeas.

Quantitative Breeding for Adaptation

Prior to 1978-79, classical pedigree breeding procedures involving emphasis on selection of single plants were used almost exclusively in chickpea breeding at ICRISAT. We have now concluded that single-plant selection for seed yield is ineffective. Because of this and the high magnitude of genotype-environment interaction and local adaptation in chickpeas, a quantitative breeding approach has been adopted. This will involve multilocational testing of crosses as early-generation (F_2, F_3) bulk populations. The objectives include the identification of the value of parents in breeding and of crosses with potential at individual locations or across locations, and the provision of an opportunity for national program breeders to select within the most promising crosses locally.

In 1978-79, ICRISAT sowed 164 bulk populations at Hyderabad, Hissar, and Gwalior, and 46 of these were also sown at other sites in India (Delhi, Kanpur, Jabalpur, and Rahuri). Disease, unseasonal rain, and waterlogging caused heavy damage at some sites, and only Gwalior, Kanpur, and Rahuri reported complete data. Nevertheless, useful selection was possible, e.g., 20 populations showed resistance to *Fusarium* wilt at Jabalpur, and high-yielding populations were selected at Rahuri. Similar tests of bulk populations will be distributed annually, and we plan to distribute an elite bulk test including the best three entries from each site plus the best three entries averaged over all sites.

Selection within populations for seed yield will now be based on progeny testing. In general, elite F_2 or F_3 populations will be sampled in space-planted F_4 bulks, for evaluation of F_4-derived lines in the F_5 and F_6 generations.

Extending Adaptation of Chickpeas

The chickpea is relatively poorly adapted to high temperatures and is susceptible to various foliar diseases, such as *Ascochyta* blight, which are accentuated by wet conditions during growth. It is normally grown on land fallowed to conserve moisture, as a spring-sown summer crop in the temperate areas (west Asia, North Africa, South America, and southern Europe), and as an antumn-sown crop in the subtropics (Indian subcontinent, Ethiopia, Sudan, and Mexico). Considerable expansion of the area of adaptation of the crop may be possible by improving tolerance of stress factors, and by developing plant types required for new production systems.

Early sowing in lower latitudes. Chickpea growth and yield in peninsular India (Hyderabad, 18°N) is considerably lower than in northern India (Hissar, 29°N), and this is related in part to the shorter crop duration in the lower latitudes, possibly due to high temperatures and/or moisture stress during late growth. Chickpea is normally sown in October, but sowing in September after the end of the wet season may result in improved germination, better utilization of conserved moisture, and a longer growing season. However, early sowing will necessitate cultivars tolerant of high temperatures and wet conditions in the seedling stage.

In 1978-79, some 350 breeding and germplasm lines were sown in September at Hyderabad to determine their performance under early sowing. The lines varied widely in days to flowering and maturity. Good seed yields were obtained from lines with a range of flowering times(35 to 80 days to flowering), and the highest yielding lines were from the mid-maturity group (115 to 130 days to maturity). The highest yielding lines will be retested next season along with additional germplasm lines.

Late sowing in higher latitudes. Chickpea yields in North India are generally greatest from sowings in mid-late October, with later sowings resulting in a decline in seed yield. However, considerable areas are double cropped, with sowing in mid-late November after the harvest of a wet-season crop of sorghum, pearl millet, maize, or paddy rice. There is an urgent need for chickpea cultivars adapted to and capable of high seed yields under late sowing.

Screening of germplasm lines for performance under tote sowing was conducted at Hissar in 1977-78 and 1978-79. However, both seasons were atypical in that the late-sown crop was higher yielding than the October sowings. This occurred because unseasonal heavy rain in February-March resulted in excessive vegetative growth and heavy lodging of the October-sown crop. The trials will be repeated.

Winter sowing in temperate areas. Studies in west Asia have shown that winter crops of chickpea can produce higher seed yields than the normal spring-grown crop, provided disease (particularly *Ascochyta* blight) is controlled or avoided. Winter culture offers the possibility of exploiting a longer growing season and improved moisture availability, and may allow expansion of chickpea into lower rainfall areas. Germplasm has been screened by ICARDA at Terbol (Lebanon) and Tel Hadia (Syria) using winter sowings. Genetic resistance to *Ascochyta* blight is required for this change in season of culture, and breeding for resistance has commenced.

Developing new plant types. Most chickpea cultivars have a short, bushy, and spreading habit, and are difficult to harvest mechanically. Mechanized farming and harvesting requires medium to tall erect plants, with high seed yields and responsiveness to high-input cultural practices.

Selection has been practiced for several years within the progeny of crosses of tall germplasm lines from USSR and Greece with elite chickpea cultivars. Some advanced F_5 lines have been bulked in 1978-79 and will be evaluated under various cultural practices at both Hyderabad and Hissar next year.

A program to introduce the double pod and multiseed characters into breeding populations has commenced.

Breeding for Disease and Insect Resistance

The major diseases of chickpea are *Fusarium* wilt, *Ascochyta* blight, and chickpea stunt. We are breeding chickpea lines resistant to each of these, and with combined wilt/stunt resistance.

Screening for wilt resistance is conducted in a wilt-sick plot at ICRISAT Center, Hyderabad and another wilt-sick plot is being developed at Hissar. A number of F_5 to F_7 lines, which were apparently resistant to wilt in 1977-78, were bulked and retested this season. Of these, 68 desi and seven kabuli were promising agronomically, and are being increased in the off-season nursery for further testing and possible distribution to national programs. We are also backcrossing to transfer wilt resistance into superior cultivars.

Lines resistant to *Ascochyta* blight and stunt have been crossed to high-yielding cultivars. The F_2 populations will be screened in the next season for blight resistance at ICARDA, and for stunt resistance at Hissar.

Lines with lower degrees of susceptibility to, or ability to recover from, attacks by *Heliothis armigera* have been identified and used in crossing. Some advanced lines in the F_5 and F_6 generations have been identified as less susceptible, and will be retested.

Inheritance of Male Sterility

In 1976 77, two apparently male-sterile plants (MSP-1, MSP-2) were observed in the F_2 of Annigeri x PM-L 550 (peduncle mutant). They remained green as other plants matured. Crosses were made on both plants using G-130 pollen. In 1977-78, the F_1 plants were fully fertile and had normal meiosis. In the F_2 generation (246 of MSP-1, 260 of MSP-2; 1978-79), there were no visible differences among plants in external floral morphology, and most plants appeared fully fertile and had high percentages of pollen stainability. However, some plants exhibited very low pod set, shrivelled and semitranslucent anthers that appeared to be nondehiscent, and/or degrees of pollen stainability ranging to less than 5%.

While male sterility has now been demonstrated in chickpeas and appears to be a recessive character, the inheritance is complex and will be studied further in the F_3 generation. Meiosis was normal in several F_2 plants with low pollen stainability, suggesting that pollen inviability was not due to meiotic upset.

A wilt-sick chickpea plot at ICRISAT Center with breeding material segregated for resistance.

Collaborative Events

In 1978-79, ICRISAT coordinated various international trials and nurseries, distributed to national programs breeding lines with specific characteristics, participated in exchanges of visits and information, and organized an international workshop on chickpea improvement.

Five different types of trials and nurseries for desi chickpeas, including the early-generation bulk tests of crosses, were distributed to 39 locations in 12 countries. Cooperators from several locations reported that they had soleeted some of these entries for advanced local testing and/or for seed multiplication for possible release.

Twenty-seven advanced kabuli lines were submitted to ICARDA for the international nurseries, and 1017 F_1 to F_7 breeding lines were also sent there for use in selection. We distributed 1746 samples of parental lines, 1367 advanced lines, and 309 segregating bulk populations to breeders in 17 countries.

Of the five ICRISAT lines included in the All India Coordinated Pulse Improvement

Project (AICPIP) trials in 1977-78, two were promoted to the Gram Coordinated Varietal Trial (GCVT). Eight other lines, which performed well in the international nurseries, have been submitted for the Gram Initial Evaluation Trial (GIET) in India in 1978-79.

The) report of the third international trials was prepared and distributed to cooperators and other scientists internationally. Combined analyses of line performance over locations and over 3 years of testing revealed substantial interaction among entries, years, and locations. The cultivar x year interaction is illustrated in Table 1. P-324 and K-468 had relatively low yields in 1 of the 3 years of test. The results suggest that specific adaptation may be important in chickpeas. However, the yield comparisons are of considerable value in identifying differences in adaptation of cultivars.

An International Workshop on Chickpea Improvement held at ICRISAT Center in February, is reported in the "Workshops, Conferences, and Seminars" section of this report.

Biochemistry

Studies were conducted in the areas of cooking quality evaluation, amino acids determination, chemical analyses of desi and kabuli chickpea cultivars, and biochemical changes in seeds during maturation.

Evaluation of Cooking Quality of Chickpea

Dhal (dried split seeds) samples of 15 cultivars of chickpea were evaluated for their cooking time and analyzed for physicochemical characteristics. The procedures of open vessel cooking and pressure cooking were compared to determine the cooking time. The procedure involving open vessel cooking that is most commonly employed by the village folks was followed because it is easy to perform, and the results are reproducible. Samples were tested at different stages of cooking by pressing them between the thumb and index finger. Of all the physicochemical characteristics studied (Table 2), the percent solids dispersed into cooking water ($r = -0.88$, $P < 0.01$) and the amount of water absorbed during the cooking process ($r = -0.69$, $P < 0.01$) were observed to be best correlated with the cooking time of the chickpea cultivars.

Table 1. Mean seed yields (kg/ha) of desi cultivars of chickpea tested for 3 years in international trials.

Cultivar	1975-76	1976-77	1977-78	Mean
P-324	1431	1897	2095	1808
K-468	2038	1438	1769	1748
C-214	1910	1527	1771	1736
B-108	1598	1599	2000	1732
P-436	1474	1928	1656	1686
P-946	1641	1729	1688	1686
P-3552	1439	1736	1871	1682
T-3	1514	1616	1872	1667
NEC-240	1740	1541	16%	1659
P-182	1596	1497	1710	1601
G-130	1730	1389	1584	1568
P-4235	1252	1511	1454	1406
No. oftrials	13	11	14	

Table 2. Physicochemical characteristics of chickpea cultivars.[a]

Component	Range	Mean
Cooking time (min)	26 -50	35
Solids dispersed (%)	20.8 -32.6	26.8
Water absorption (w/w)		
(a) Soaking at room temp for 24 hr.	0.71- 0.%	0.89
(b) Heating at 80°C for 1 hr	1.17- 1.74	1.43
(c) Boiling at 100°C for 35 min	1.69- 2.13	1.90
Increase in volume (v/v) during heating at 100°C for 35 min	1.08- 1.79	1.47
Gelatinization temperature of isolated starches (°C)	65 -69	67
Water-soluble amylose (%)	8.0 -10.5	9.0
Total amylose (%)	20.8 -24.6	22.4
Starch content (%)	53.3 -60.6	57.0

a. Based on an analysis of 15 cultivars.

Chemical Differences between Desi and Kabuli Cultivars

Whole-seed and dhal samples of chickpea cultivars of desi and kabuli type grown at Hissar (29°N) and at ICRISAT Center (18°N), were analyzed for protein, starch, soluble sugars, ash, crude fiber, and seed coat contents. The results are shown in Table 3. Of all the constituents analyzed, seed coat percentage and fiber content can be considered as the only two constituents that could be used to distinguish the desi and kabuli types of chickpea cultivars. The results obtained indicate that it would be desirable to monitor the seed-coat content of desi types and breed for varieties having lower seed-coat percentage.

Whole-grain, dhal, and seed-coat samples of these cultivars were also analyzed for minerals and trace elements. Of all the elements, calcium appeared to be the predominant mineral of the seed coat in both kabuli and desi cultivars and it was higher in the kabuli cultivars. Therefore, calcium and other elements from the seed coat are lost during the processing to obtain dhal. No clear-cut differences between the kabuli and desi cultivars were observed in the levels of calcium or other elements in whole-grain and dhal samples.

Limiting Essential Amino Acids

Following performic acid oxidation, 30 cultivars (dhal) were analyzed for methionine sulfone and cysteic acid using an amino acid analyzer. They were also analyzed for total sulphur by the wet digestion method and by use of the Leco sulphur analyzer. Total sulphur (g/100 g meal) was positively correlated (0.476, $P < 0.01$) with percent of meal protein (Table 4). Methionine and cystine expressed as g/100 g protein did not show any relationship either together or individually with total sulphur (g/100 g meal). Therefore, from the limited number of samples used in this study, it appears that total sulphur content may not be a reliable indicator of sulphur-amino acids in chickpea.

Tryptophan is the second limiting essential amino acid of chickpea. We have tried three different procedures to identify a technique

Table 3. Average values of constituents of deal (based on an analysis of eight cultivars) and kabuli (based on an analysis of seven cultivars).

	Whole seed		Dhal	
	ICRISAT Center	Hissar	ICRISAT Center	Hissar
Protein (%)				
Kabuli	22.4	24.0	24.0	25.0
Desi	22.0	22.4	25.9	26.8
Starch (%)				
Kabuli	49.2	48.6	56.0	55.6
Desi	45.6	43.7	56.3	54.4
Sugars (%)				
Kabuli	6.1	6.1	5.2	5.4
Desi	5.3	5.4	4.6	5.2
Fiber (%)				
Kabuli	2.7	3.2	1.0	1.2
Desi	8.4	9.2	1.1	1.1
Fat(%)				
Kabuli	5.4	4.7	6.0	5.3
Desi	4.6	4.1	5.8	4.8
Ash(%)				
Kabuli	3.1	3.2	3.1	3.1
Desi	3.4	3.3	2.7	2.9
100-seed wt (g)				
Kabuli	23.4	22.7		
Desi	18.1	17.6		
Seed coat (%)				
Kabuli	6.4	7.1		
Desi	16.2	16.0		
Seed coat N (%)				
Kabuli	0.86	0.95		
Desi	0.46	0.59		

that can be adopted to estimate tryptophan for screening large numbers of samples. Due to its destruction during acid hydrolysis, tryptophan cannot be determined along with other amino acids. Therefore, tryptophan was analyzed following alkaline hydrolysis in the amino acid analyzer, and the results were compaved with the two different colorimetric methods. Ten cuttivars of chickpea (dhal) were analyzed. Slightly higher values for tryptophan were obtained by the colorimetric procedures than in the amino acid analzer.

Chemical Changes in Developing Chickpea Seeds

Chickpea cultivars G-130, L-550, and 850-3/27

Table 4. Correlation coefficients between protein (%), total sulphur, and sulphur amino acids in 30 cultivars of chickpea.

Component	Protein (%)	Cystine	Methionine	Cystine + Methionine
Protein (%)		0.719"**	0.895"**	0.809"*
		- 0.309"	- 0.645[b]**	- 0.487 **
Total sulphur	0.476**	0.402"*	0.578[a]**	0.494"**
(g/100 g meal)		0.043"	0.094"	- 0.016*

a. g/100g meal; *b.* g/100g protein.
* Significant at 5% level; **Significant at 1% level.

grown under field conditions were sampled at different stages of maturation and analyzed for protein, starch, soluble sugars, soluble nitrogen, and amino acids. Rapid starch accumulation was observed during the period between 14 and 28 days after flowering (Fig. 2). The level of soluble nitrogen continuously decreased up to 28 days after flowering and thereafter remained constant as the grain matured. Protein nitrogen decreased up to 14 days after flowering and after a slight increase became constant during the later stages of maturation (Fig. 3). The percentage of salt soluble proteins decreased with maturation of grain,

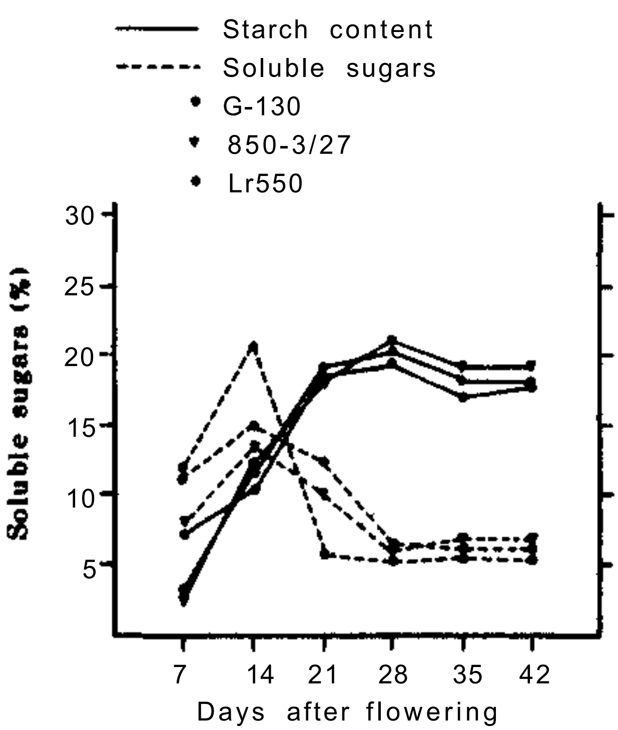


Figure 2. Soluble sugars and starch content at different stages of maturation of chickpea.

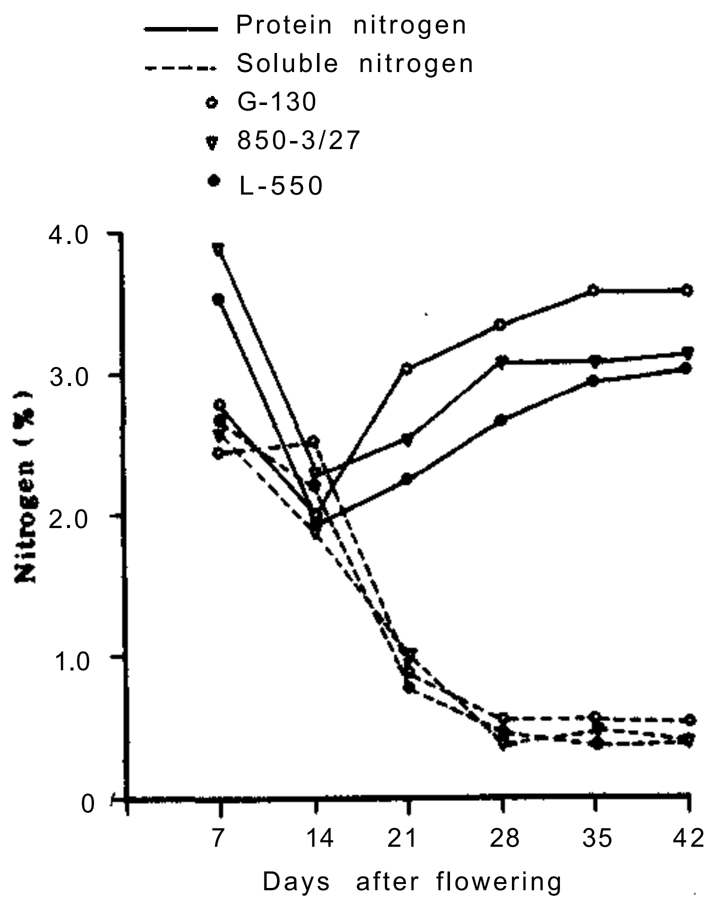


Figure 3. Protein nitrogen and soluble nitrogen at different stages of maturation of chickpea.

suggesting that other protein fractions accumulate during later stages of maturation. SDS-polyacrylamide gel electrophoresis revealed that deposition of seed storage protein in cotyledons started 14 days after flowering. The levels of methionine and cystine when expressed as g/100 g protein decreased as the grain matured.

Routine Screening

Screening of germplasm for protein content was continued. About 2000 accessions were analyzed for protein content using the rapid dye-binding capacity method; the values varied between 17.3 and 28.3%. Several cultivars and their crosses grown at different locations during postrainy season of 1977-78 were also analyzed for protein content. Large differences were observed in the protein content of cultivars grown at different locations.

Physiology

Response to Irrigation

The yield of chickpeas is typically lower in peninsular India than in northern India. Hissar, in northern India, is characterized by a prolonged winter, resulting in longer growth duration of chickpeas. It has been assumed that growth duration of chickpeas in southern India is limited by high temperatures. The effect of declining moisture supply is very likely also a factor, but definitive research on the effects of the two factors and their interaction has not been done.

An experiment was conducted at ICRISAT Center with four, two, and no irrigations. Large replicated plots were used. The cultivar was Annigeri, well adapted to the area, planted at the recommended time. The response to irrigation at Hyderabad was very encouraging (Table 5). With four irrigations, the yield and total dry matter production were more than doubled, and were similar to that of good crops in northern India. Two irrigations, given early in the season, increased yield by 56%. The factors that contributed to increased yield were increase in growth duration, larger LAI, better status of water as reflected in maintenance of high water potential, and average higher net assimilation rates in the irrigated than in the nonirrigated treatments. The yield components that were positively affected were-pods per plant and seeds per pod, whereas the hundred-seed weight declined slightly but not significantly with increased irrigation.

The essentially linear increase in yield with increasing irrigation clearly indicates the need for further research on conditions for maximum yield.

Response to Nutrients

Responses to soil-applied nutrients (both N and P) have been inconsistent and generally absent in our experiments. Even on those soils low in available phosphorus (2.5 ppm) there was no response to soil-applied phosphorus, either broadcast or banded. Responses to foliar fertilization were investigated this year. Fertilizers were applied at the rate of 50 kg nitrogen and approximately 20 kg P/ha in the form of urea and single superphosphate in six split doses at weekly intervals. The first spray was given at the time of flowering. The controls received water sprays.

In treatments where nitrogen was included in the spray solutions the plants generally remained green a week longer than in other treatments. Responses to both nitrogen and phosphorus were positive. At Hissar the increase in yield was of the order of 200 kg (15 to 19%), but it was not statistically significant. Foliar spray treatment containing urea + single superphosphate (SSP) solution increased yield at ICRISAT Center by 15 to 26%, depending upon the cultivar. The average response over cultivars is given in Figure 4. The greatest response was from the application of urea in combination with potassium polyphosphate (organic source of P). This nutrient solution also contained potassium. Responses to foliar application of diammonium phosphate (DAP)

Table 5. Effect of irrigation on yield, total dry matter, harvest index, yield components, and growth duration of chickpea,

Treatments	Yield (kg/ha)	Total dry matter	Harvest index	Pods per plant	Seeds per pod	100-seed wt (g)	Days to maturity
Nonirrigated	1347	2272	59	35	1.12	17.2	87
Irrigated two times[a]	2102	3556	60	45	1.20	16.2	96
Irrigated four times[b]	3042	6065	51	64	1.32	15.1	127
CV(%)	20.7	38.7	15.2	19.5	2.5	4-3	
LSD at 0.05	586.9	2008.5	NS	21.1	0.07	1.59	

a. 31 and 43 days after sowing.
b. 31, 43. 65, and 92 days alter sowing.
NS = Not significant.

were about equal to those with Urea + SSP treatment. Higher concentrations of DAP resulted in scorching of foliage and reduction" in yield.

Pod Set at Hissar

The phenomenon of "ineffective flowering" (a period during which flowers are formed but fail to develop into pods) is well-known in chickpeas grown in northern India. By contrast, in chickpeas in southern India, where winter temperatures are higher, pods develop from the first flowers. While it is impossible to determine the critical temperature for pod set under field conditions, and the specific developmental functions that fail are yet to be identified, our observations on cultivars at Hissar (Fig. 5) provide some insight into the problem.

Fifteen cultivars initiated podding over a period of 12 days, suggesting differential response to the environment. The range in length of period of ineffective flowering was from 30 to 52 days, with a logical tendency for later flowering cultivars to have the shorter periods. However, correlation between days to flower and days to pod set was not very close, further suggesting genetic differences in the environmental requirements for pod development.

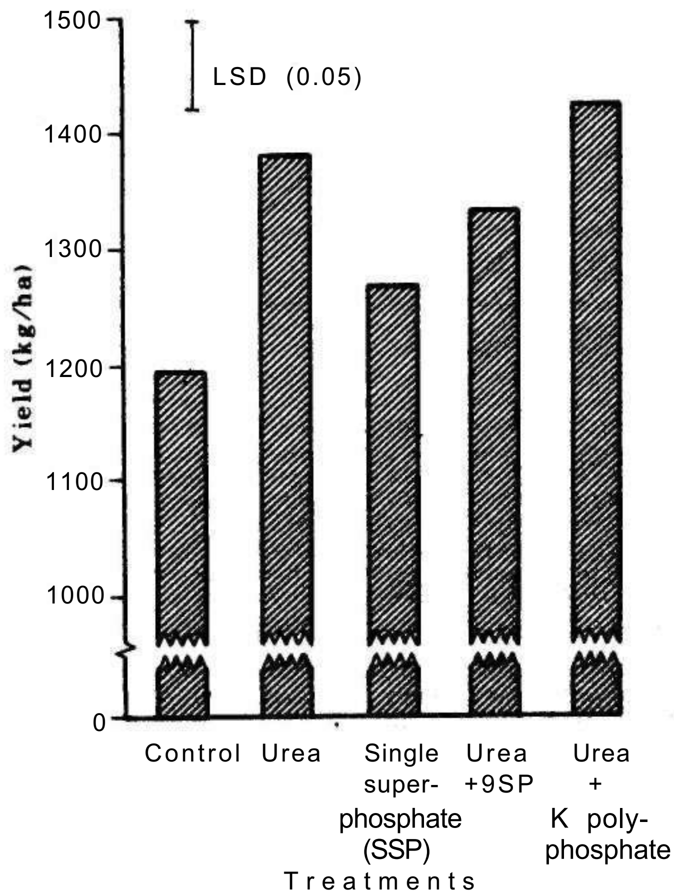


Figure 4. Effect of foliar fertilization on the yield of chickpeas at ICRISAT Center.

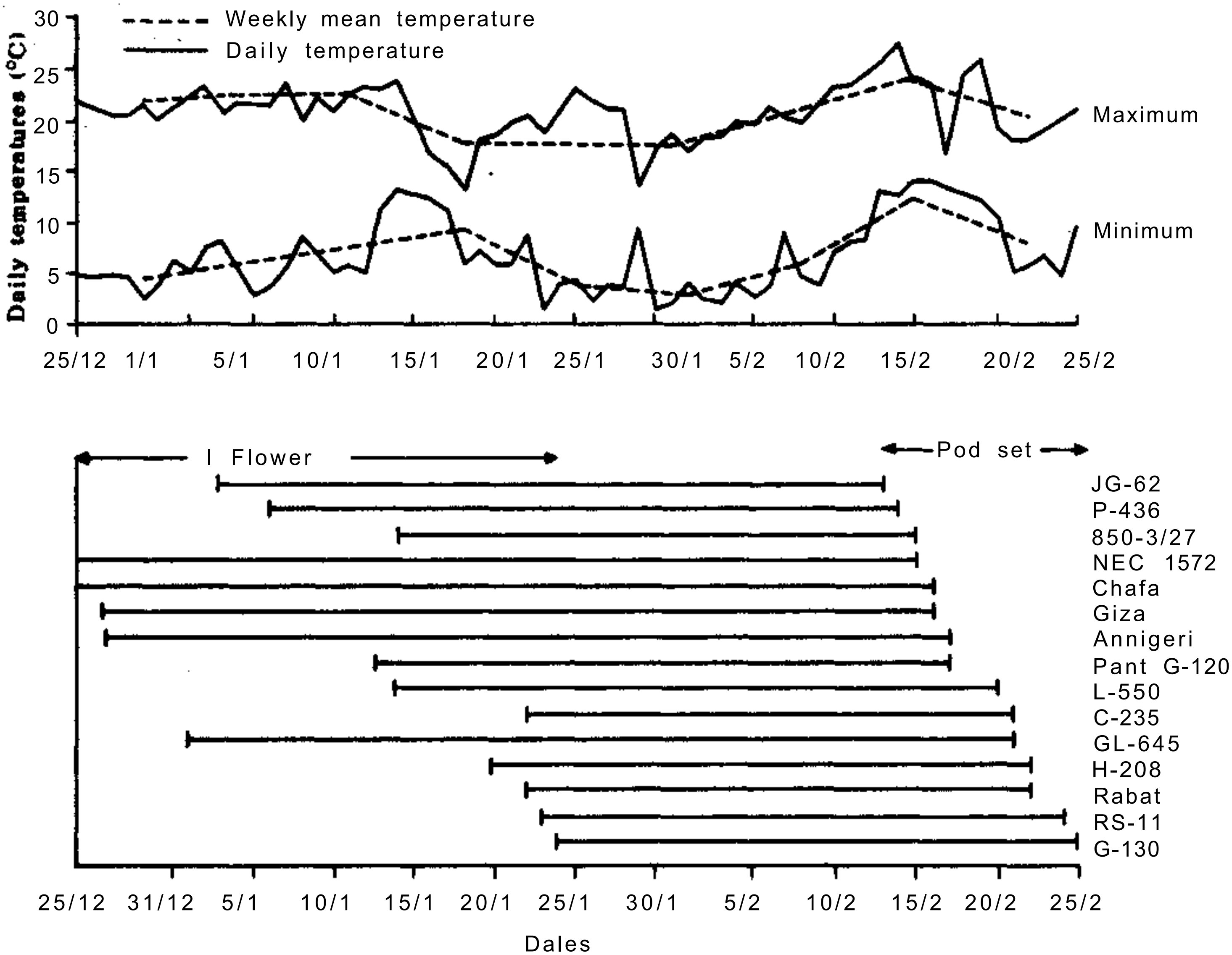


Figure 5. Dates of first flower and first pod set (period of ineffective flowering) in 15 cultivars at Hissar. Maximum and minimum temperatures are shown above.

Daily and weekly mean temperatures in Figure 5 show a marked rise in minimum temperature beginning about February 1. While our present hypothesis is that low temperature is the major factor preventing pod set, critical studies under controlled conditions are required to determine whether heaf unit accumulation as well as a minimum critical temperature controls the pod set.

Availability of genetic variation in pod set at cooler temperatures will be very useful in selecting for extension of the reproductive growth duration in such environments and may possibly contribute to yield.

Entomology

Insect Pest Surveys

We continued our survey of pest attacks on chickpea and visited farmers' fields in 85 districts across ten states in India. Observations during the vegetative stage of the crop showed that termite damage was an important factor in reducing plant populations, particularly on the lighter soils in the more northerly areas. Cutworms, including *Agrotis* spp, were recorded as sporadic pests in some areas and also killed plants in the seedling stage. Our records of plant populations in Punjab, Haryana, and Rajasthan ranged from 18 to 28 plants/m^2 during the vegetative stage, but these figures fell to 9 to 17 plants/m^2 in our survey at the maturity stage, indicating substantial plant loss, some of which was probably caused by diseases.

Our surveys at the maturity stage showed the greatest contributor to pod damage was *Heliothis armigera,* but this year the incidence of this pest in the more northerly states was relatively low. *Plusia* spp were the only other insect pests commonly noted, but damage caused by birds, rats, and rabbits was also recorded in many fields.

Of the 232 fields visited where definite information on the farm operations could be obtained, only 12 (5%) were treated with pesticides. Of these, 11 were treated with DDT/BHC dusts.

In a survey trip through the chickpea-growing areas of Jordan, Syria, and Turkey in late May, we found the leaf miner, *Liriomyza cicerina,* to be common in every field that was visited, even in Central Turkey where the crop was then in the seedling stage. Damage by *Heliothis* spp was sporadic but tended to be more severe in the south, with up to 40% of the pods damaged at one location in Jordan. Aphids were also found in damaging populations in some fields in Jordan and Syria.

Host-Plant Resistance to Insect Pests

Progress continued in the selection of materials that are less susceptible to losses caused by *Heliothis.* Although we can now advance our materials through at least two generations each year by taking an off-season crop, we can usually screen only one generation against *Heliothis* in our fields because of insufficient pest buildup in the off-season crop. This year again our attempts to use cages to ensure adequate pest attacks showed little promise, but the natural infestations of *Heliothis* were sufficient to give adequate screening with little chance of escape. We continued to cooperate with the All India Coordinated Pulse Improvement Project in multilocation screening.

We have no lines that are anywhere near immune to *Heliothis* attack but we do have selections that in 3 years of testing have suffered relatively less damage and have given greater yields when compared with commonly used check cultivars in unprotected field trials.

Results obtained from one of our trials this year are shown in Table 6. These data provide a good illustration of some of the problems encountered in this research. Entry 3 was recorded as a "high borer" line last year, but this year the pod damage recorded was the second lowest in the trial. This was probably because *Heliothis* severely damaged this line at the vegetative stage, delaying flowering. When this line did manage to set pods the *Heliothis* attack had diminished, so the percentage of damage in the relatively few pods that were set was low, but its yield was the lowest. Entry 1 did well for the third year, substantially outyielding the check. This entry and other promising lines are now being utilized by our breeders in their crossing programs. This trial was of balanced lattice square design and gave an increased efficiency over the randomized block design of about 20% for both damage and yield data. We now use such designs for all of our advanced selection trials.

Most of our screening so far has been from among the many cultivars available in our germplasm collections. We are also investigating the utility of selecting for resistance within cultivars. The potential for such selection would appear to be low, for this crop is self-pollinated. However, results from preliminary observations indicated that heritable differences could be detected. This year we selected plants with more and less damage from within large blocks of four of our more promising cultivars. The progenies of these will be tested in the coming season.

The mechanisms of resistance to *Heliothis* in chickpea are of obvious interest. In cooperation with the Max Planck Institute for

Table 6. Comparison of promising early desi chickpea selections in a balanced lattice square design trial in pesticide-free conditions, ICRISAT Center, 1978- 79.

Entry	Selection	Borer damage in 1977-78	Days to flower-ing	Mean pod damage (%)	Mean plot yield (g)"
1	ICC-506-EB-EB	Low	50	8.0	550
2	ICC-1381-EB-EB	Low	54	15.2	470
3	ICC-3928-EB-EB	High	80	10.9	262
4	ICC-5690-EB-EB	Moderate	50	22.7	406
5	IC-73167-5-3-BP	Moderate	65	12.5	360
6	ICC-928-EB-EB	Moderate	65	20.5	358
7	IC-7394-18-2-2P-LB-BP-EB	Low	54	12.2	383
8	IC-73129-16-1-1P-LB-BP-EB	Low	57	19.8	374
9	Annigeri-1 (Check)	High	53	31.2	343
	SE of mean ±			1.7	38
	CV(%)			20.3	19
	LSD at 0.05			5.6	123

a. Harvested plot = 6.48 m^2.

Biochemistry at Munich, we are continuing our studies of the very acid exudate produced by the foliage and pods of this crop, for we think that differences in the quantity and composition of the exudate may account for some of the susceptibility differences. There also appear to be differences in pod wall hardness. Another factor of obvious importance is the ability to recover from extensive damage incurred during the vegetative stage, and we are recording cultivaral differences in this aspect. Such ability to compensate for early loss is of particular interest in the early-maturing cultivars that tend to yield best in the relatively short growing season at Hyderabad.

Insecticide Use

As in previous years, striking differences were observed between the pesticide-treated and pesticide-free plots of our spraying trial. The unprotected plants were severely damaged by *Heliothis* during the vegetative phase and far more of the harvested pods from the untreated plots were damaged. However, the untreated plots matured at least ten days later than the sprayed ones, and the extra growing time allowed substantial compensation for earlier losses in the untreated plots (Table 7). The extra yield obtained from the sprayed plots was not found sufficient to pay for the pesticide used.

Last year we found an increase in the number of *Heliothis* larvae per unit area with greater plant populations in an unprotected trial. This resulted in a reduction in yield at the closest spacing. This year we conducted unprotected and protected spacing trials (Table 8). In the untreated trial, we again found much greater numbers of *Heliothis* larvae/m^2 in the closer-spaced treatments. However, closer spacing this year did not result in an obvious yield reduction, but there appeared to be no yield advantage in plant densities greater than 8/m^2 in either unprotected or protected conditions. In these trials there were much greater differences in yield between the protected and unprotected trials than were evident in the in-

Table 7. Data from a trial[a] comparing pesticide-treated and pesticide-free chickpea at ICRISAT Center, 1978 79.

	Desi (Annigeri)		Kahuli (L-550)	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Days to 70% maturity	105	95	132	121
Damaged pods (%)	16.4	1.5	12.7	1.8
Grain yield (kg/ha)	879	955	632	914

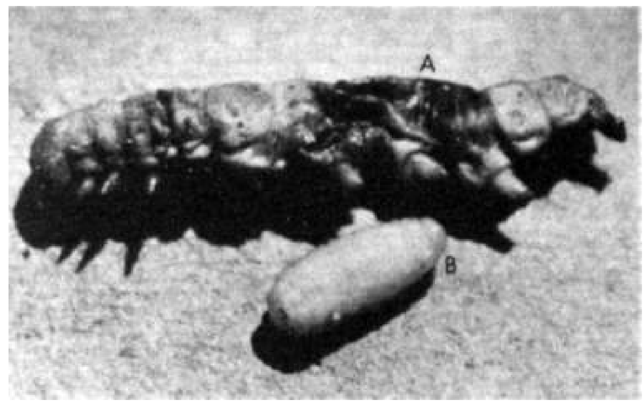
a. Two replicates, main plot size 342 m^2.

secticide use trial; the reason for this could be a site difference or a result of interplot effects.

Natural and Biological Control

In our studies of the natural control of *Heliothis.* we collected thousands of larvae from the fields and reared them (until death or pupation) in the laboratory, recording the incidence of parasitoid emergence. This year the overall parasitism rate was low, averaging less than 5%. Larvae collected from pesticide-free fields averaged 5.4% parasitism, but in sprayed fields the incidence was reduced to 3%. We recorded increased rates of parasitism in plots with lower plant densities, and larvae from kabuli plants had a greater parasitoid incidence than those from desi. The large majority of the emerged parasitoids were hymenopteran, but there is still some confusion over the identity of *Diadegma* sp, which was predominant.

In cooperation with the Biological Control Unit of the Plant Protection Directorate of the Government of India and the Commonwealth Institute of Biological Control, Bangalore, we conducted laboratory and field cage studies of *Eueelatoria* sp, a dipteran parasitoid of *Heliothis* that was imported to India from the USA. We had no problems in multiplying this parasite in our laboratory, but it did not establish easily in field cage trials. Problems with virus in our laboratory cultures of *Heliothis* resulted in the loss of our stock of this parasitoid. In the coming season we hope to obtain a fresh stock of the fly for field release studies.



A Heliothis armigera *larva (A) killed by* Eucelatoria (*B*)*, a parasite imported to India from the Americas.*

Pathology

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

Screening for Resistance

We continued screening of the germplasm and found 140 of the 1800 screened accessions to be highly promising. Two lines resistant to wilt, ICC-2616 and ICC-3782, were found resistant to chickpea stunt also. In the breeding material screened, a large number of progenies in the F_3 and F_4 generations were resistant.

Table 8. Data from insecticide-treated and untreated plant density trials on chickpea at ICRISAT Center, 1978-79.

		Plant density /m^2				
	Treatment	4	8	33	67	SE(m)
Heliothis/m^2	Sprayed	3.7	2.0	2.7	3.8	± 0.7
	Unsprayed	11.1	17.8	39.5	41.5	± 16.0
Pods damaged (%)	Sprayed	2.1	0.6	0.3	0.7	± 0.4
	Unsprayed	17.8	18.9	18.6	23.7	± 2.7
Grain yield (g/m^2)	Sprayed	157	201	200	207	±24.8
	Unsprayed	86	112	92	85	± 8.9

Symptomless Carriers (Hosts)

Laboratory as well as field studies were used to identify symptomless carriers of the wilt pathogen. Isolations from apparently healthy lentil, pea, and pigeonpea grown in wilt-sick soil yielded *F. oxysporwn* f. sp. *ciceri.* Its pathogenicity was proved. The pathogen, however, did not colonize black gram, brinjal, chilli, cowpea, cucumber, climbing bean, green gram, groundnut, lucerne, maize, okra, pearl millet, French beans, radish, sorghum, soybean, tomato, or watermelon. The fact that some crops are symptomless carriers of the wilt pathogen is important from the viewpoint of planning rotation of crops with chickpea.

Age of Chickpea Plant and Wilt Incidence

Two cultivars were planted in wilt-sick soil in pots to determine the number of days of exposure required for infection to take place. The susceptible cultivar JG-62 required at least 4 days of root exposure to inoculum before wilting was observed. A 5-day exposure of roots to inoculum was sufficient to kill all the plants. Cultivar 850-3/27 required more than 6 days of root exposure to inoculum before plants wilted, and it took nearly 23 days for 100% mortality in 850-3/27 as compared to 13 days in JG-62.

When plants of varying ages of highly susceptible cultivar JG-62 and the "late wilt" cultivar 850-3/27 were transplanted from autoclaved soil to the wilt-sick soil in pots, they succumbed to the disease irrespective of the age of seedlings. The results indicated that plants did not develop ability to resist the pathogen even after they were 50 days old.

Existence of Physiologic Races

Preliminary studies conducted last year provided evidence for the existence of races in *F. oxysporum* f. sp. *ciceri.* These studies were continued further. The chickpea wilt pathogen was isolated from wilted plants collected from different locations in India. The cultures were purified, single spored, and their pathogenicity proved. We now have isolates from most of the chickpea-growing areas of India.

Wilt isolates tested were from ICRISAT Center, Hissar, Jabalpur, Kanpur, and Gurdaspur, and ten genotypes—four desi types resistant to wilt at Hyderabad and six susceptible types (four desi and two kabuli—were used as differentials. The test was conducted three times and reactions in most cases were consistent. However, to further confirm the findings, a trip was made in December 1978 to Hissar and Kanpur to collect wilted plants. These isolates were also single spored and their pathogenicity was proved. They were then used in repeating the study. The cultivars reacted differentially to the isolates, confirming the earlier findings. Summarized results are presented in Table 9.

Hissar and Jabalpur isolates appeared to be identical and can be considered nearer to the ICRISAT isolate. The Kanpur isolate was more aggressive and quite distinct. It appears to be a different physiologic race. The Gurdaspur isolate gave a distinct reaction on C-104 and can be considered a separate race.

Root Rot (*Fusarium solani*)

Pathogenicity

Black root rot caused by *F. solani* is not widespread but can be important locally. It has been reported more frequently from areas where chickpeas are irrigated. ICRISAT bulletin "Diagnosis of some wilt-like disorders of chickpea (*Cicer arietinum* L.)" gives a description of a number of root rot diseases. Since we had not been able to diagnose black root rot under field conditions, we carried out artificial inoculations in a net-house to study the development of the diagnostic symptoms.

An isolate of *F. solani* from Delhi was used to inoculate 15-day-old seedlings. Some of the seedlings were injured at their collar portion with a sharp scalpel. The following symptoms were observed:

Ten days after inoculation: Plants showed slight stunting and older leaves were pale. A black lesion was seen in the hypocotyl region. The fungus was present in the cortex. Cotyledons were unaffected.

Fifteen days after inoculation: Stunting was conspicuous. Older leaves were yellow. The root lesion had extended downwards accompanied by rotting of roots.

Twenty-one days after inoculation: External symptoms were conspicuous. Several seedlings had collapsed after turning yellow. Blackening was evident at the base of the seedlings. The tissues at and below soil level were black and

Table 9. Reaction of chickpea cultivars 40 days after inoculation to five isolates of *Fusarium oxysporum* f. sp. *ciceri,* in four repetitions of pot tests.

	Reaction to isolate																			
	ICRISAT				Hissar				Jabalpur				Kanpur				Gurdaspur			
Cultivar	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
JG-62	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	M	M	M	M
C-104	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	R	R	R	R
BG-212	R	R	R	R	M	M	M	M	M	M	M	M	S	S	S	s	M	M	M	M
JG-74	R	R	R	R	R	R	R	R	R	R	R	R	S	M	S	M	R	R	R	R
CPS-1	R	R	R	R	M	M	M	M	S	M	M	M	S	S	S	S	S	S	S	S
WR-315	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	S	M	M
Annigeri	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chafa	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	M	M	M
L-550	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	M	M	M	M
850-3/27	S	S	S	S	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

R = Resistant (0 to 20% wilt). M = Moderately susceptible (21 to 50% wilt).
S = Susceptible (51% and above wilt). Seedling number of each cu ltivar varied from 20 to 25 in different tests.

were at different stages of rotting. Cotyledons were rotting.

Thus it appears that black root rot can be identified by (1) wilting followed by yellowing of foliage, and (2) black discoloration of rotting roots.

Stunt

Identification

Attempts were made to identify the virus using the following techniques.

Purification. Even though the virus is not mechanically transmissible, efforts were made to purify it to test its serological relationship and get pictures on the electron microscope. The work was carried out at Hissar in collaboration with Dr. J.P. Verma, and at ICRISAT Center.

The procedure developed by Dr. J.W. Ashby, Division of Scientific and Industrial Research (DSIR), Plant Diseases Division, Christchurch, New Zealand, for purifying "luteo" viruses was followed with slight modifications.

Batches of up to 200 g of shoot and root portions from infected plants were used, both separately and together. Fresh tissues were always thoroughly washed with tap water before extraction. Homogenization was done in the Waring blender for 4 to 5 min with 0.1 *M* phosphate buffer pH 7.4, four times the weight of the tissue; 2-mercaptoethanol (0.1%) was added to the buffer. In case of extraction of shoots, 0.01 *M* EDTA was added. The extract was filtered through a layer of muslin cloth and was clarified by low speed centrifugation at 8000 rpm for 10 min. To the clarified sap 8% PEG and 3% NaCl were added, thoroughly stirred in the cold, and kept overnight in the cold.

The pellet was collected by centrifuging at 10 000 rpm for 15 min and was resuspended in 1/12 volume of the original buffer. It was thoroughly resuspended by stirring in the cold for 1 hour, and to it was added 1/4 volume of 1:1 n-butanol-chloroform. It was kept cold for 1 hour, and the phases were separated by centrifugation at 8000 rpm for 10 min. The aqueous phase was collected and stored in the cold overnight. Then it was subjected to two cycles of centrifugation (36 000 for 120 min; 45 000 for 60 to 90 min). After the first high speed, the pellet was suspended in 0.05 *M* phosphate buffer pH 6.5 without 2-mercaptoethanol. The final pellet was dissolved in 2 ml buffer.

UV absorption. The absorption spectra of the purified virus preparation were studied using the Beckman D.B.G.T. Spectrophotometer and showed typical absorption spectra of a nucleoprotein. No such absorption was seen in healthy preparations. Preparations from roots; shoots; shoots and roots; and phloem portions gave typical absorption spectra, indicating that the purification procedure followed was successful.

Serology. The serological relationship of the purified preparation with the antiserum of pea leaf roll virus obtained from Dr. J.W. Ashby was studied using the Ouchterlony agar double diffusion test. Sharp precipitation zones developed with the preparations from diseased plants but not with the healthy ones, indicating the positive serological relationship of the causal agent of chickpea stunt with the pea leaf roll virus. This relationship was repeatedly proved with the isolates from Hissar and Hyderabad.

These studies along with those reported earlier on aphid transmission, host range, etc. indicate that chickpea stunt is caused by the pea leaf roll virus.

Screening for Resistance

Screening is being carried out at Hissar in field conditions where susceptible checks such as WR-315 show over 80% natural incidence of stunt. So far, 21 lines have been identified that remained disease-free for three consecutive years. These lines have been sent for testing to Sudan where stunt incidence is high.

Ascochyta Blight (*Ascochyta rabiei*)

Since this disease does not occur naturally at Hyderabad, screening of germplasm is done in Isolation Plant Propagators. Promising lines are then tested in international nurseries. During the period under report, over 800 germplasm accessions were screened but none was found to be highly resistant. Only three lines, ICC-3259, ICC-3277, and ICC-3531, had a rating of 3 on a 9-point scale. F_2 and backcross-1 progenies involving the wild *Cicer reticulatum* showed promise and seed from resistant plants was saved for further evaluation.

Blights in Kashmir Off-Season Nursery

Our off-season nursery in Kashmir was visited on 4 August 1978 for investigation of a report of a "serious disease situation in chickpea" on 27 July. Blights were seen in patches, particularly in C-214, JG-74, F-378, and 850-3/27 in the first planting (29 May), and on Chafa and NEC-1572 in the second planting (4 June). Wilt was observed in JG-62. Some plants showed typical symptoms of *Ascochyta* blight, but others did not. Infected plant parts were brought to Hyderabad for further investigations.

The fungi isolated were: *Alternaria alternata, Ascochyta rabiei, Colletotrichum dimatium,* and *Phoma medicagenis.* The pathogenicity of all four fungi was proved. The symptoms produced by *Ascochyta rabiei* and *Phoma medicagenis* were strikingly similar. All four fungi could be isolated from surface-sterilized seed collected from blight-affected plants; *Ascochyta* was the most frequent one.

International Nurseries

An International Chickpea Root Rot/Wilt Nursery (ICRRWN) was sent to 32 cooperators in 18 countries. The nursery was sent for planting at 37 locations and had 63 entries. Likewise, the International Chickpea *Ascochyta* Blight Nursery (ICABN) was sent to ten cooperators in eight countries. The nursery was sent for planting at 13 locations and had 46 entries. A separate report will be prepared.

Consultants' Group Discussion on Soilborne Diseases

In January 1979, ten scientists from Australia. India, the Netherlands, U.K., and USA participated in a group discussion at ICRISAT Center on soilborne diseases of ICRISAT's three legume crops, and developed recommendations for ICRISAT's research priorities leading to better control of diseases of these legume crops. Invited consultants were Drs. G.S. Abawi (USA), J.S. Chohan (India), D.J. Hagedorn (USA), N. Hubbeling (the Netherlands), J.M. Kraft (USA), G.S. Purss (Australia), H.K. Saksena (India), J.B. Sinclair (USA), R.S. Singh (India), and R.K.S. Wood (U.k). Dr. David Allen, IITA, Nigeria, also participated as a special invitee. A comprehensive review of the ICRISAT work on soilborne diseases of pigeonpea and chickpea and a field visit to review experiments at ICRISAT served as stimuli for in-depth discussions. Consultants' papers and recommendations are to be published, and will serve as guidelines for future research on soilborne diseases at ICRISAT.

Microbiology

Chickpea *Rhizobium* Strain Collection

We now have more than 500 authenticated isolates of chickpea *Rhizobium* originating from the major chickpea-growing areas of India and six other countries. Nodules collected in the field are dried over calcium chloride for transporting and storing. A procedure has been developed for isolating *Rhizobium* from these nodules in the laboratory, with a 70% success rate. Isolates are authenticated as *Rhizobium* if they nodulate chickpea plants grown under axenic conditions in test tubes. The plants are dwarfed by cutting off their cotyledons. Authenticated strains are then tested for their nitrogen-fixing ability by inoculating chickpea plants grown in pot culture in a sterilized, nitrogen-free, sand medium. Some of the strains seem tolerant of saline soil conditions in their ability to form nodules and fix nitrQgen. Strains held at ICRISAT are available to any user and we have sent strains and inoculants to 11 different countries.

Chickpea *Rhizobium* Populations

We are studying the effect of paddy on chickpea *Rhizobium* populations using the specific *Rhizobium*-counting technique reported in the ICRISAT Annual Report 1977-78 (p. 134). Paddy fields where chickpea had not been grown previously had very few chickpea *Rhizobium* (< 100/g soil). After inoculated chickpea was grown in these fields the number increased to about 10^4/g soil in the root zone of the plants. After one crop of paddy the numbers declined to 7.4 x 10^2/g soil. We wish to see how long it takes to establish chickpea rhizobia in paddy soils and whether there is a need to inoculate each time a chickpea crop is taken after paddy.

Chickpea *Rhizobium* populations were estimated in some fields at ICRISAT Center. In a Vertisol field the population was about 8 x 10^3/g soil; this should be adequate for satisfactory nodulation. *Rhizobium* numbers decreased slightly with the increase in soil depth (Table 10). Nodulation in chickpea is usually restricted to the top 15 cm of soil. Virtually no nodules are recovered below 30 cm depth although a large population of *Rhizobium* lives there, indicating that some factor other than *Rhizobium* numbers limits nodulation at these depths. In an Alfisol field, which was only 300m away from the Vertisol field examined and where chickpea was not normally grown, there were fewer than 100 chickpea rhizobia per gram of soil. Seed inoculation of chickpea increased this number to the level found in the Vertisol (Table 10) and the nodulation pattern also resembled that obtained in the Vertisol.

Nodulation and Nitrogen Fixation

Chickpea is usually grown on residual moisture. In the 1978-79 winter season, under Hyderabad conditions, nearly all the nodules on a plant were formed in the first 2 to 3 weeks after sowing. After an irrigation or after a rain, a new flush of roots and nodules was formed. Under residual moisture conditions nodules were most active 2 to 3 weeks after their formation. Nodule size continued to increase with age but specific nitrogenase activity of the nodules declined, and was very low 8 weeks after sowing. Nodules usually stopped growing by this stage and senesced very quickly, with no nitrogen fixation detected after 9 weeks (Fig. 6). There was a large difference in nodulation and nitrogenase activity between the medium-duration cv 850-3/27 and the longer duration, less active cv G-130. However, they followed a similar pattern of activity (Fig. 6). This pattern varied with the season; in 1976-77, nodules remained active on cv 850-3/27 until 89 days after planting, and activity was at least double that throughout the two subsequent seasons.

Nitrogenase activity as measured by acetylene reduction varied greatly over locations. At Hissar in North India, nodules remained active even during the mid-pod-fill stage (Fig. 7), when the specific activity of the nodules (nitrogenase activity per gram nodule tissue) was three times greater than that found at ICRISAT Center at flowering. During the night, nitrogenase activity at Hissar and Hyderabad was about 50% of the average day-time activity (ICRISAT Annual Report 1977-78, p. 137). The similar ambient temper-

Table 10. Changes in chickpea *Rhizobium* population with soil depth and crop history at ICRISAT Center, Hyderabad.

Field	Depth (cm)	Log_{10} MPN[a] 1st Sampling (Jan 1979)		Log_{10} MPN[a] 2nd Sampling (May 1979)
Paddy soil	0- 5	0.43		3.94
No chickpea history	5- 15	0.32	Chickpea[b]	4.06
	15- 30	1.25		3.57
	30- 60	ND		3.08
R_2 Alfisol	0- 5	4.87		4.81
Chickpea in 1977-78 season	5- 15	4.83	Groundnut"	4.61
	15- 30	4.36		3.89
	30- 60	ND		3.69
B8-Vertisol	0- 5	3.49		4.62
Chickpea in 1976-77 season	5- 15	3.49		5.34
	15- 30	3.32	Chickpea[b]	3.85
	30- 60	ND		3.81
	60- 90	ND		2.53
	90-120	ND		2.13

a. MPN = Most probable number, estimated by a soil dilution-plant infection technique.
b. Crop grown during the period between first and second sampling.
ND = No data observations not made.

ature conditions of 11 to 30°C at Hyderabad and 11 to 34°C at Hissar during the assay periods suggest that it is not the differences in the ambient temperature that cause this difference in the nitrogenase activity. A marked diurnal variation in nitrogenase activity has been observed at Hyderabad over two seasons and at 30 and 45 days after planting.

Our studies indicate that the better plant growth and yields obtained at Hissar compared with those at Hyderabad result in part from better nitrogen fixation.

Genetic Variability for Nodulation

We reported large differences among cultivars in nodulation characteristics (ICRISAT Annual Report, 1977-78), and some of these have been further tested in the field at three different locations. Some cultivars gave consistently good or poor nodulation over location and season but a few were inconsistent.

A 3 x 3 diallel cross has been made between low and high nodulating lines in collaboration with the breeders to determine the heritability and inheritance of nodulation. If the heritability turns out to be high we will undertake a breeding and selection program to increase nitrogen fixation.

A visual-scoring technique for nodulation, taking into account nodule number and mass, has proved useful when large numbers of plants are to be scored, and we are using it for our survey of germplasm entries. The visual score was highly correlated with nitrogen-fixing activity.

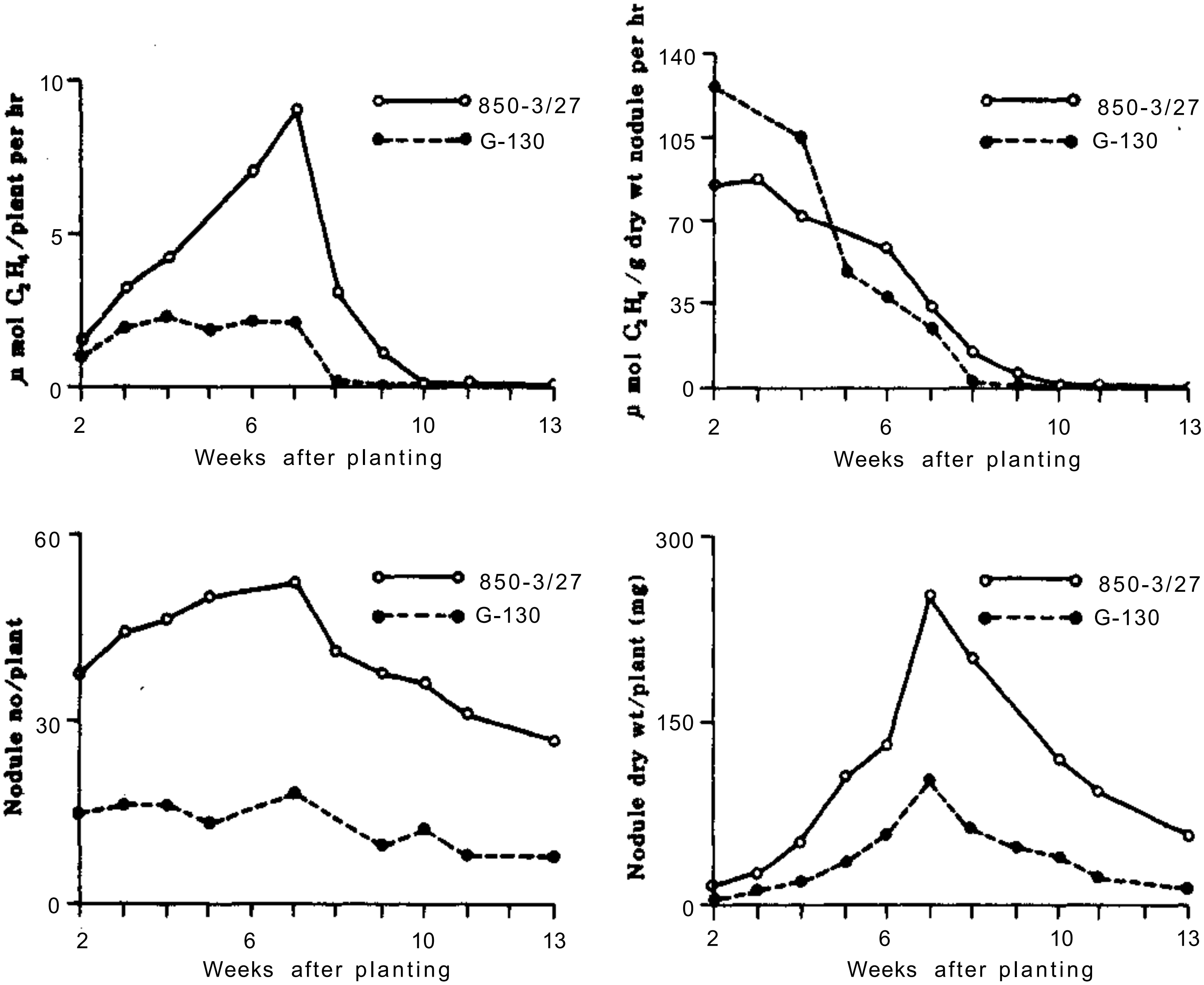


Figure 6. Seasonal variation in nodule number and weight per plant, nitrogenase activity per plant, and per gram nodule weight in chickpea cv 850-3/27 and G-130 during the dry winter season 1978-79 at ICRISAT Center.

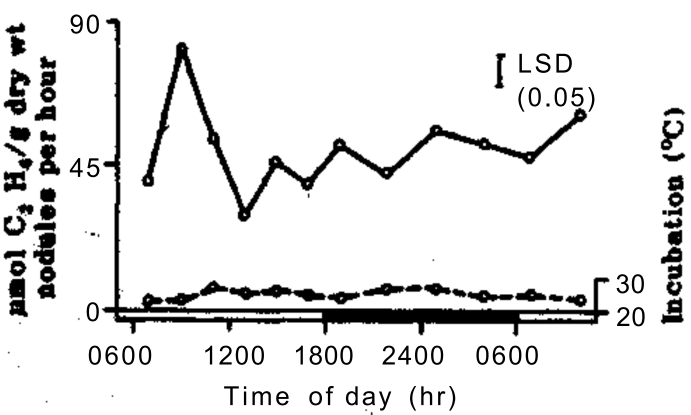


Figure 7. Diurnal variation in nitrogenase activity of chickpea at Hissar.

Looking Ahead

Breeding for disease resistance, including multiple-disease-resistant lines, will be intensified and breeding methodologies will be devised to take advantage of the rapid generation turnover capability recently developed. International testing of early generation bulks as well as advanced material will be continued and expanded. Screening for germination capability under low moisture and emergence from extreme planting depths will be expanded. Modification of limits of adaptation will be attempted through continued screening of germplasm at suboptimal planting dates.

Research, on yield-limiting conditions and yield-maximizing conditions will be intensified, with special reference to nutrition, water, and temperature effects. Lines found to have reduced levels of pest damage will be tested in multilocational trials. Methods developed for screening for nodulation will be applied to breeding populations.

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GROUNDNUT

Contents

GROUNDNUT

Breeding

Coordination with National Programs

Coordinated trials. During the 1978 rainy season, 11 yield trials sponsored by the All India Coordinated Research Project on Oilseeds (AICORPO) were conducted on Alfisols at ICRISAT Center. All of the trials were grown without protection from pesticides, and yields were low due to severe attacks by rust, leaf spots, and bud necrosis disease although rainfall totalled over 1000 mm during the season and the distribution was good.

Distribution of segregating material. From the postrainy-season harvest of 1978-79, we supplied to breeders in India 1897 F_2, F_3, and F_4 populations from the rust resistance, high yield, and quality and earliness projects.

Genotype x Environment Interaction

Groundnut is primarily a rainy-season crop in India, but a substantial area under this crop is also grown using the same varieties in the postrainy season under irrigation, when shelling percentages and 100-kernel weights are significantly improved over those of the rainy season. A set of 22 cultivars was grown in a randomized block design with four replications in the postrainy season of 1977-78 and in the rainy season of 1978. The season x cultivar interaction component was found to be highly significant for all the yield characters, indicating that cultivars behaved differently at the same location in different seasons. The mean performance of the cultivars and their ranking in different seasons is presented in Table 1. Cultivar *x* season interaction indicates the need for separate evaluation programs for the two seasons.

Breeding for Earliness

During the year two more sources of earliness (cultivars 91176 and 91776), which are claimed to mature in 75 days, were incorporated into the hybridization program. During the 1978 rainy season, 97 F_1, 78 F_2, and 7 F_3 pedigrees were planted. In the F_2 generation 180 plant selections with good yield, 59 bulk selections with good yield, and 58 bulks with average yield were made in crosses with the early-maturing Chico parent. The outstanding F_2 plant selection, with 260 g pods/plant, came from the cross Robut 33-1 x M-13. In the F_3 populations several individual plant selections and bulks were made based on earliness, yield, and plant vigor.

The material selected in the rainy season of 1978 was advanced in the postrainy season, and 186 plant selections and 171 bulk selections were made. Some of the early-maturing plant selections in the F_2 generations were as follows:

Parent 1	Parent 2	Plant Selection
2-5(119)	Chico (109)	P1 (117)
Tifspan(119)	Robut 33-1 (119)	P4(107)
NC Acc 2564 (119)	Robut 33-1 (119)	P7 (107)
72-R(114)	Robut 33-1 (119)	P1 (107)

Figures in parentheses represent days to maturity.

The F_2 material was advanced as bulks; the

Table 1. Mean performance of groundnut cultivars over postrainy and rainy seasons.

	Yield (kg/ha)		
Cultivars	Postrainy season 1977-78	Rainy season 1978	Mean
NC Acc 10	2571 (5)[a]	437 (9)	1504
NC Acc 11	2247(13)	354(12)	1300
NC Acc 12	2619 (3)	269(18)	1444
NC Acc 310	2442 (9)	524 (6)	1483
NC Acc 528	2169(17)	410(11)	1289
NC Acc 529	2153(18)	303(15)	1228
NC Acc 690	2550 (6)	429 (10)	1489
NC Acc 770	2196(15)	562 (3)	1379
NC Acc 1107	2013(19)	282(18)	1148
NC Acc 1278	2474 (8)	549 (4)	1512
NC Acc 2187	2353 (10)	221 (19)	1287
NC Acc 2 190	2226 (14)	213(21)	1220
NC Acc 2475	2529 (7)	348(13)	1429
NC Acc 2569	1982(20)	138 (22)	1060
NC Acc 2719	2584 (4)	886 (1)	1735
NC Acc 2841	2253 (12)	219 (20)	1236
NC Acc 2843	1847 (21)	323 (14)	1085
NC Acc 2884	2661 (2)	517 (8)	1589
NC Acc 2938	2353(11)	282(17)	1318
NC Acc 1714	2765 (1)	522 (7)	1634
M-13	1773 (22)	628 (2)	1190
M I	2178(16)	527 (5)	1343
Mean	2314	404	

a. Figures in parentheses represent ranking.
LSD at 5% level: season 48, cultivar 152, season within cultivar 225, season between cultivar 221.

bulking of the plants was done on the basis of plant type, pod shape, seed size, color, and yield potential. Most of the selections from TMV-7 x Chico, JH-171 x Chico, JH-89 x Chico, MGS-9 x Chico, TMV-7 x Robut 33-1, and Shulamith x Chico were very promising for yield. Two F_4 selections from Ah-65 x Robut 33-1 took 108 days to mature, whereas both the parents matured in 128 days. Chico, though the earliest-maturing cultivar, has not been considered a good parent, but our experience shows that it makes a very good parent in several combinations.

Breeding for High Yield and Quality

The material for this project came from crosses among high-yielding and adapted Indian and American cultivars and desirable lines from

Indian and exotic germplasm. Emphasis was placed on crosses between parents from the different subspecies of *Arachis hypogaea.*

Based on our results we have observed that the following parents give better segregants than other parents: TMV-7, X9-2-B-25-B, MGS-7, FSB 7-2, Goldin-1, 55-437, Dh 3-20, Manfredi, X14-4-B-19-B, M-13, Argentine, NC Acc 2944, JH-89, NC Acc 400, SM-5, TG-3, MGS-9, RS-138, 72-R, Spancross, Faizpur 1-5, JH-62, and Tifspan.

Breeding for Resistance to Rust

High-yielding and adapted Indian and American cultivars and promising germplasm lines were crossed with four sources of rust resistance that were used as male parents (PI 259747, PI 298115, EC 76446 [292], and NC Acc 17090). In the 1978 rainy season, 210 F_1s and 92 F_2s were grown. They were planted with one infector row to every ten test rows, and observations on flowering and other plant characters were recorded. Before harvest the material was scored for reaction to rust. The material was divided into four categories (resistant, moderately resistant, susceptible, and doubtful), the last category being those plants that could not be scored because of heavy defoliation or virus infection. A total of 4356 resistant plants were kept for progeny rowing in the next generation. In three crosses (NC-17 x PI 259747, NC Acc 2731 x PI 299747, and Shantung KU No. 203 x PI 259747) segregation for leaf color and nodulation was observed (see "Groundnut Microbiology" section of this report).

The material was grown in the 1978-79 postrainy season with infector rows, but observations on reaction to rust could not be recorded. The whole generation was therefore advanced further in the form of four single-plant selections for yield, 175 bulks of single pods from each plant and 138 bulks from good-yielding plants. The plant selections for high yield were from G-37 x NC Acc 17090, JH-335 x NC Acc 17090, NC-17 x NC Acc 17090, and NC Acc 2785 x PI 259747. In two crosses, NC Acc 2564 x PI 259747, and NC Acc 2564 x NC Acc 17090, transgressive segregation for pod and leaf size was observed.

In the 1978 rainy season, F_6 plant progenies (464) and bulk selections (392) from the FESR (ex USDA Puerto Rico) material were planted with infector rows. As in last year's testing of the F,s, all the plant progenies and bulk selections were found to be segregating for reaction to rust. Records were made on plant growth, reaction to rust, and reaction to insect damage. It was possible to select highly resistant plants from both the plant progenies and the F_6 bulk selections in all 14 FESR lines. Insect-resistant selections were made in 13 FESR lines. All these selections were planted again in the postrainy season but had to be advanced as bulks since observations on rust reaction could not be recorded.

Cytogenetics

Disease Resistance Screening

Fertile hexaploids, selected from progenies of interspecific hybrids originating from the *Arachis* Breeding Program at Reading University, were grown in the field in the 1978 rainy season, with an infector row of cultivars susceptible to *Cercospora* leaf spot and rust next to each test row. Date of first flowering, habit, vigor (plant size), and number of flowers were recorded on the hexaploids. Plants were assessed on a 0 (immune) to 5 (susceptible) scale for *Cercospora* resistance and for rust resistance, the score being derived from the mean area infected on 15 leaves per plant. Defoliation was assessed as the percentage of leafless nodes on three branches. Disease resistance and defoliation were recorded after the onset of pod formation. Date of harvesting, pod number, and pod type were also recorded.

The mean disease rating for *Cercosporidium personatum* was 1.2 for selected hexaploids derived from *Arachis hypogaea x A. chacoense,* 1.6 for those from *A. hypogaea x A. cardenasii,* and 1.4 for those involving *Arachis* sp "HLK 410." Ratings for the unselected plants, grown in 1976, were 2.8, 1.5, and 2.8, respectively. The original amphiploids from *A. cardenasii* did not include any immune or susceptible plants, but the progeny consisted of plants representing all disease reactions, including immunity. Frequencies of immune and resistant plants increased in the other two amphiploids (Fig. 1). Scores for rust reaction were 2.0. 1.9, and 2.3 for the three types of hexaploids. Immune and resistant plants were selected from each for backcrossing.

Defoliation was less in the hexaploids than in the infector rows (Fig. 2). Some hexaploids retained the majority of leaves. There was a significant correlation between *Cercosporidium personation* infection and defoliation in hexaploids derived from *A. chacoense* and *Arachis* sp "HLK 410," but not for those from *A. cardenasii.* Infection is a major cause of defoliation in hexaploids of the first two species; the third, *A. cardenasii,* is immune to *C. personation.* However, there are other factors contributing to defoliation. This indicates that the inheritance of leaf spot resistance and defoliation is more complex than was originally thought.

Many hexaploids had an extended flowering season similar to the wild species, with pods maturing over a long period, and a mixture of sprouts and mature and immature pods at harvest.

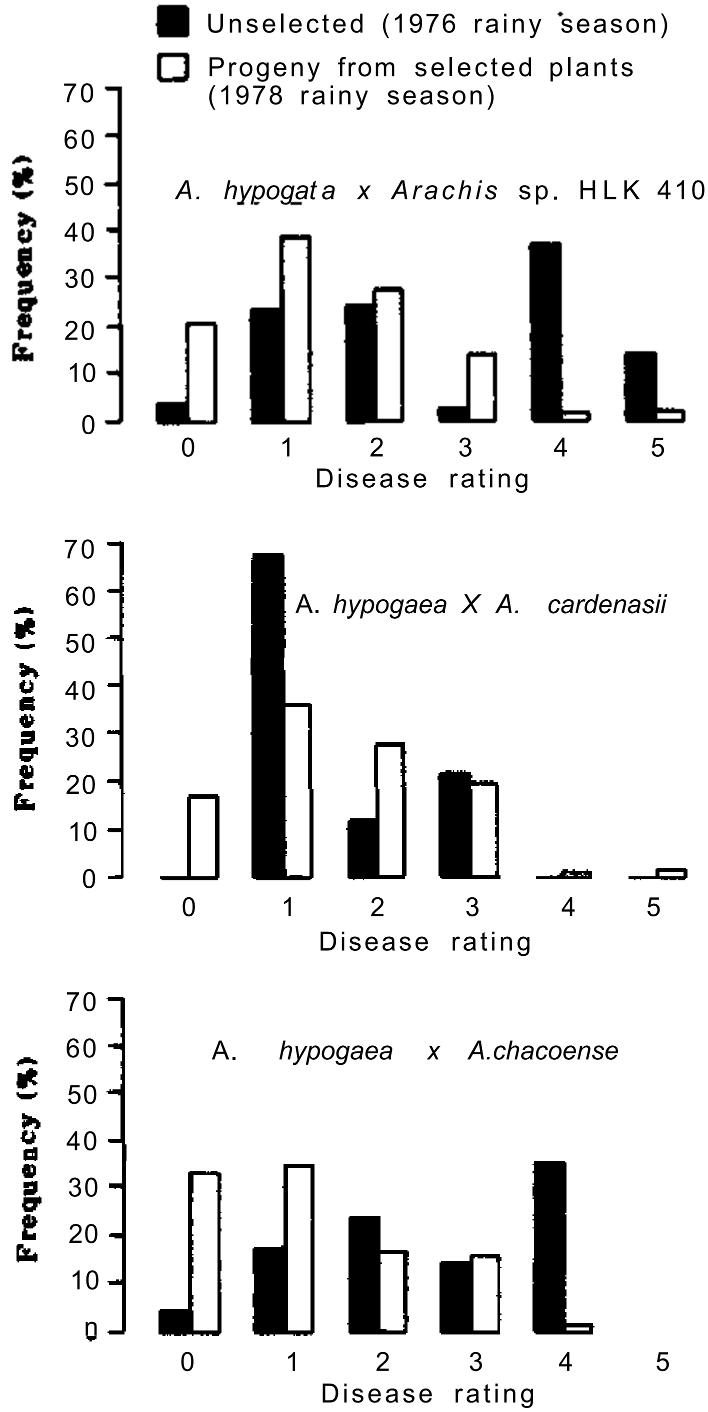


***Figure 1. Frequency of leaf spot ratings of successive generations of* Arachis *hexaploids exposed to* Cercosporidium personatum.**

Backcrossing

Hexaploids selected for disease resistance, earliness, and productivity have been backcrossed to *A. hypogaea,* to reduce the chromosome number to the tetraploid level.

Interspecific Hybridization

A hybridization program between wild species was commenced to combine desirable characteristics at the diploid level and to increase our knowledge of the relationships among them and with *A. hypogaea* (Fig. 3). Seven species were used in the crossing program, and pods were produced in 20 cross combinations; 18 reciprocals of these were also successful. *A. batizocoi* was the pollen parent in both unsuccessful

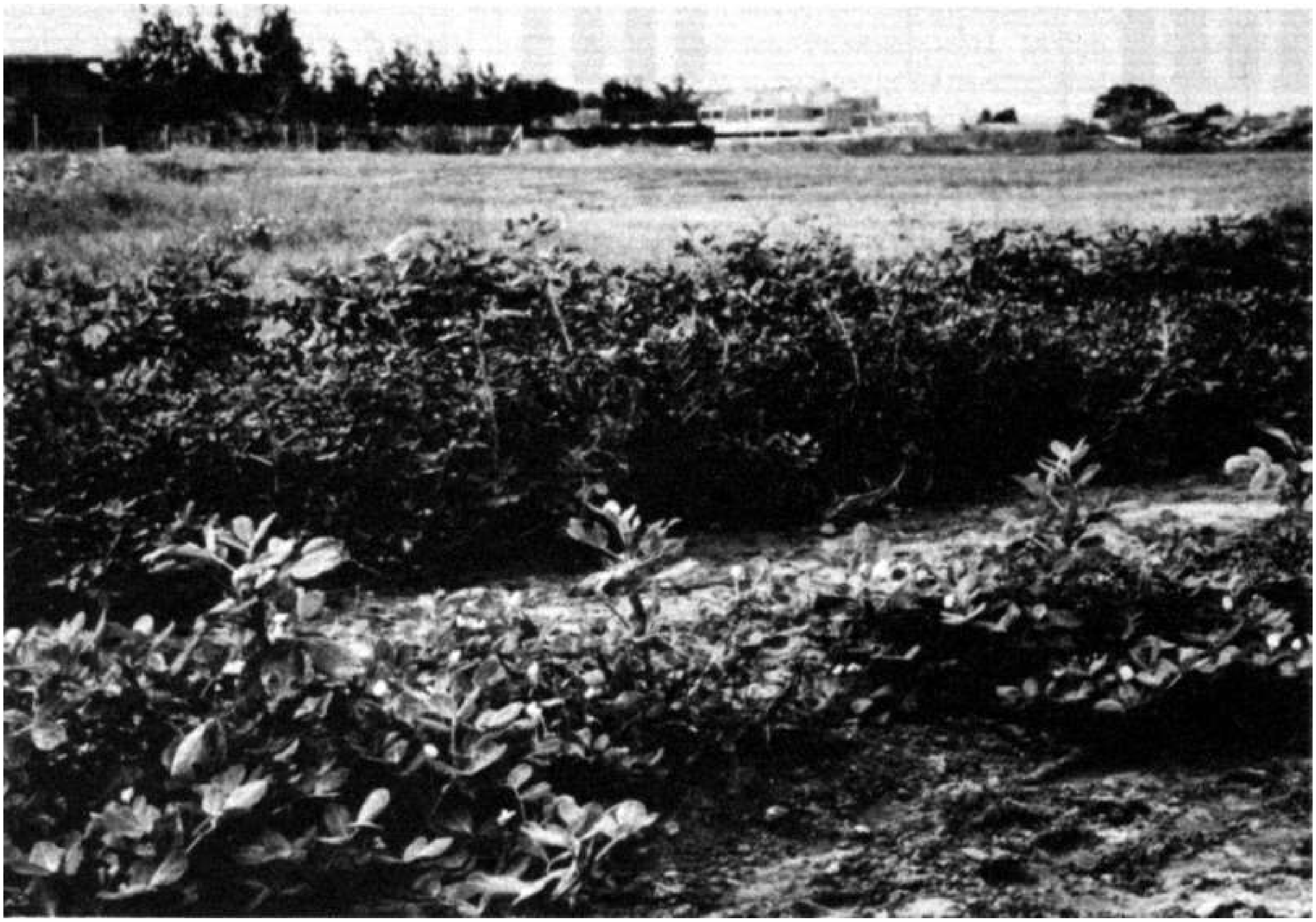


Figure 2. Resistant hexaploids (foreground) and susceptible injector plants (background); the latter with leaves heavily infected with **Cercosporidium personatum** ***and the lower nodes defoliated.***

crosses, though it crossed successfully in five cross combinations.

Two more species *(A. duranensis* and *A. correntina)* and an F_1 hybrid between *A. chacoense* and *A. cardenasii* were incorporated in the breeding program and were crossed with *A. hypogaea* to produce three more sterile triploids, which will be treated with colchicine to produce hexaploids (Fig. 3).

Cytogenetic Analysis

Hybrids. The triploid hybrids between *A. hypogaea* and five wild *Arachis* section diploids and one F_1 hybrid were similar at meiosis, with 5 to 12 bivalents and 3 to 16 univalents, while occasional trivalents and rare quadrivalents were also recorded. Pollen stainability ranged from 5.3 to 12.5%. This and the karyotype-analysis indicate one genome common to these wild species and *A. hypogaea.* Although the triploids are almost completely sterile, some seed and seedlings are produced.

Wild species. Karyotypic and meiotic studies of wild diploid species belonging to section *Arachis* confirmed the division of these wild species into B genome species, containing only *A. batizocoi* (distinguished by one pair of large submedian chromosomes with a prominent secondary constriction and satellite) and the A genome species (with one pair of chromosomes shorter than the rest). Further studies of arm ratios and chromosome lengths indicate that

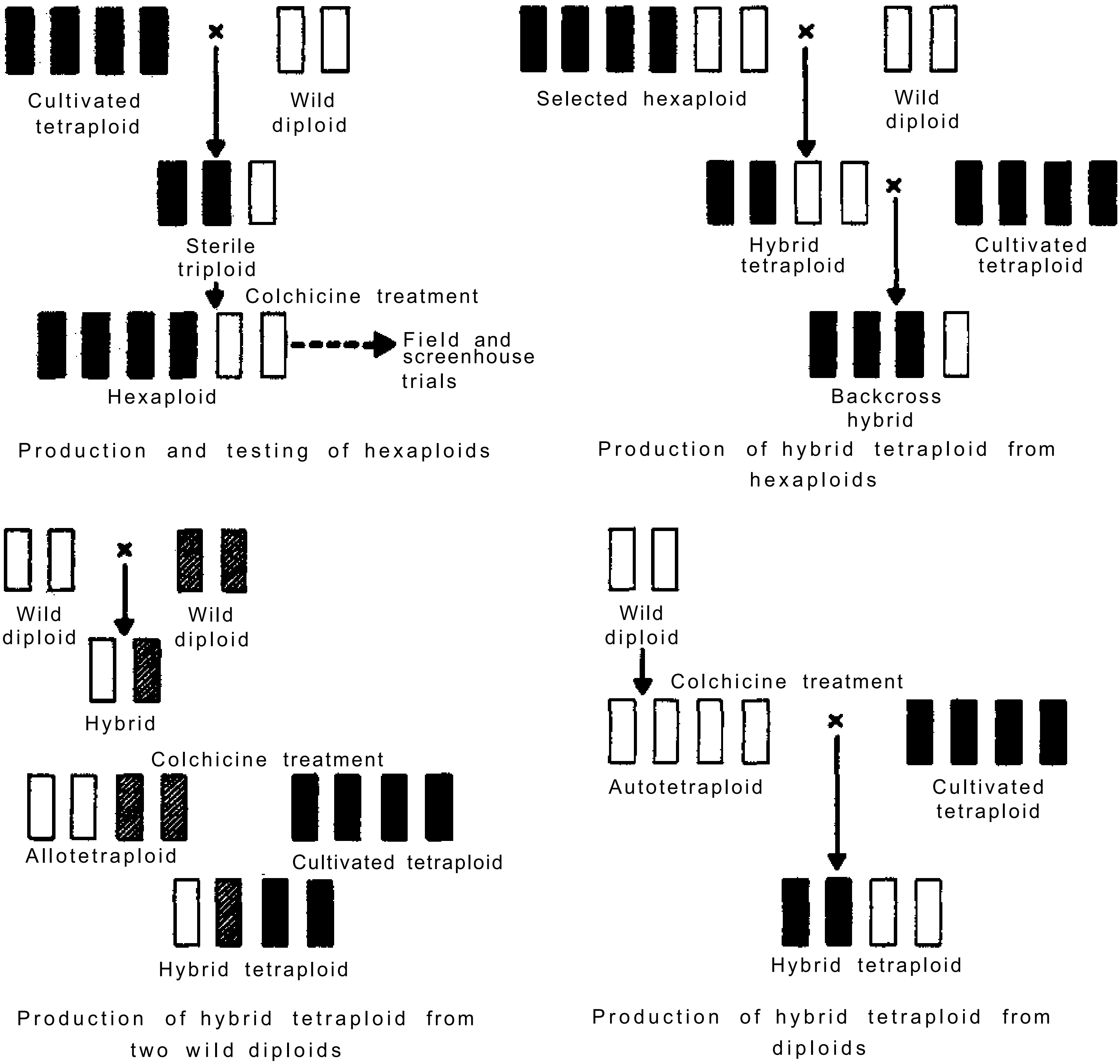


Figure 3. Methods of producing hexaploids and hybrid tetraploidsfor backcrossing to* Arachis hypogaea *to transfer genes from wild species into cultivated groundnuts.

the A genome group can be further subdivided.

Analysis of chromosome size and arm ratios in two tetraploid species in series *Eurhizomatosae* revealed six groups of four chromosomes and a maximum of nine quadrivalents at meioas, suggesting the possibility of autotetraploidy in this section of the genus.

Polyploidization. Polyploidy was induced by colchicine treatment in four species and one F_1 hybrid, to enable crossing at the tetraploid level between wild species and cultivated *A, hypogaea* (Fig. 3). Of these, only tetraploid *A. batizocoi* has produced pods.

Mutants. A number of spontaneous mutants or natural hybrids have been observed in groundnut fields at ICRISAT Center. The progeny from a dwarf mutant of M-13 segregated for normal and dwarf plants in the next generation.

Physiology

Assessment of Seed Dormancy Level

The seed dormancy levels of 44 cultivars were evaluated in the rainy season and 97 in the postrainy season. Assessment was made by a germination test of seeds cured for ten days after harvest, and by observations on sprouting of seeds in the field. In both seasons, all erect bunch cultivars (subsp *fastigiata)* were nondormant, except L.No. 95-A, which showed weak dormancy. Among spreading bunch and runner cultivars (subsp *hypogaea*) there was a wide spectrum of dormancy levels from non-dormant to dormant. In the rainy season, NC Acc 2692 and.2797, Fla-393-12-B-28, and Robut 33-1 had germination percentages from 97 to 85 5 days after sowing, and in the postrainy season, D-47, OG 43-41, K 4-11, and X-52-X-X-3B had germination percentages from 94 to 63, 5 days after sowing.

Flowering Patterns and Reproductive Efficiency

The relationship between seasonal flowering patterns and reproductive efficiency in SAT conditions was studied, using 11 cultivars in the rainy season and 16 in the postrainy season. In both seasons, earliness and seasonal patterns of flowering were characteristic among cultivars within subsp *fastigiata* and within subsp *hypogaea.* In the rainy season the flowering peaks of the subsp *fastigiata* cultivars appeared at the end of August and mid-September. In the postrainy season, the 16 cultivars were divided into three groups based on the date of initiation of flowering, and their flowering peaks appeared in mid-February, early March, and the end of March. Results of fruiting analyses showed that in the irrigated crops sown in December and harvested at the end of April, most mature pods and highest seed yields and shelling percentages were obtained in those cultivars that had produced 60% or more *of* their flowers by early March.

Production of Adventitious Roots from the Hypocotyl

Adventitious hypocotyl roots grow into the same soil zone as do pegs and pods and possibly compete for water and nutrients. Competition for calcium could be very important in relation to pod development. There may be a complex relationship among secondary root growth, longevity of adventitious roots, *Rhizobium* infection, nitrogen fixation, and soil moisture content.

The frequency of plants with hypocotyl roots ranged from 0 to 47% (mean 14.3%) in 19 cultivars of subsp *fastigiata* and 5.6 to 93.7% (mean 48.3%) in 26 cultivars of subsp *hypogaea.* The difference between cultivars in production of adventitious roots was reflected in differences in ability of cuttings to form roots.

Entomology

Survey of Insect Pests

About 50 species of insect pests have been reported to damage groundnuts in India, but only a few are regarded as pests of economic importance: *Aphis craccivora, Stomopteryx subsecivella. Lachnosterna consanguinea,* and *Caliothrips indicus.* In recent years there have been changes in the pest status of some insects. For example, *Frankliniella schultzei* and *Scirtothrips dorsalis* have become serious pests in coastal Andhra Pradesh and Karnataka. On the other hand, *Caliothrips indicus* has become less serious, but *Heliothis* sp and *Spodoptera* sp have been more serious during the last 3 to 4 years. Jassids have become serious pests in Gujarat and mites have caused substantial damage in localized areas. *Maruca testulalis,* a serious pest of cowpea flowers and pods, has been reported for the first time on groundnut in south Andhra Pradesh. Red hairy caterpillars, *Amsacta* spp which were the most important pests during the last decade in south India, caused negligible damage during the last few years. Termites caused severe pod scarification in the Alfisols of the Kadiri groundnut belt in Andhra Pradesh, but only scant attention has so far been paid to them, though economic losses occurred.

Outside India, recent losses due to termites in Africa have been estimated to be 10%. *Enneothrips flavens* has become the most important pest of groundnut in Brazil. *Aphis craccivora* and white grubs have been serious pests in China and *Stomopteryx subsecivella* is serious in Thailand.

Host-Plant Resistance

Thrips. Three of the germplasm lines that were identified previously as being promising for resistance were found to support fewer thrips than susceptible cultivars. Females also produced fewer nymphs on these cultivars (Table 2). Wild species of *Arachis* differed widely in their susceptibility to thrips. It appears that of the nine species tested *A. chacoense* has the highest level of resistance, and the thrips deposited very limited numbers of eggs on this species.

Jassids. Two cultivars from the Virginia growth habit group had good field resistance as judged from the number of nymphs present in three young terminal leaves. The cultivar NC Acc 2214 had 0 to 0.5 nymphs per plant compared to 0.9 to 3.1 nymphs in adjoining checks (M-13). Another cultivar NC Acc 2232 had 0.2 to 0.6 nymphs per plant, while the count in the adjoining checks ranged between 0.8 and 4.1

Table 2. Susceptibility of some groundnut cultivars to *Frankliniella schultzei.*

Cultivar	ICG No.	Thrips injury rating[a]			Thrips per 3 terminals[b]	Progeny per female"	Remarks
		1978	1978-79	1979			
NC Acc 2242	5044	6.0	5.0	4.0	4.5	11.0	Corduroy mutant
NC Acc 2214	5040	8.0	3.0	3.0	5.0	8.5	Leathery leaves, pubescent
NC Acc 2232	5042	5.0	6.0	6.0	6.5	5.0	Leathery leaves
NC Acc 2243	5045	6.0	4.0	4.0	8.3	4.0	Leathery leaves
TMV-2'		8.0	8.0	8.0	12.0	15.0	
Robot. 33-1'		9.0	9.0	9.0	15.1	12.0	
M-13'		8.5	8.0	8.5	10.0	NT	

a. 0-9 scale in which 0 = no injury and 9 = heavy stippling and distortion of leaves.
b. 1978 rainy season figures.
c. Standard cultivars.
d. tests conducted at 28°C and 23°C in 12 hour cycles.
NT= Not tested..

nymphs per plant. The cultivar NC Acc 2214 is pubescent and has leathery leaves and is a very poor yielder. NC Acc 2232 has leathery leaves and yields reasonably well.

Aphids. None of the 1000 germplasm lines screened in the net house proved to be resistant. Some wild species were highly resistant, particularly *A. chacoense* and *A. batizocoi,* while others showed moderate resistance.

Role of Thrips in Transmission of Viral Diseases

Bud necrosis disease. Bud necrosis disease is caused by tomato spotted wilt virus (TSWV), which is widespread in India, and damages green gram *(Vigna radiata),* black gram *{Vigna mungo*), and tomato *(Lycopersicum esculentum*) (Fig. 4), in addition to groundnut. Under field conditions, the disease was associated with *Frankliniella schultzei* but not with *Scirtothrips dorsalis.* In laboratory tests, *F. schultzei* was an efficient vector and *S. dorsalis* a poor vector.

The cultivar Robut 33-1 was found to be less susceptible to bud necrosis disease, though the leaf damage due to *Frankliniella* injury was very severe. The incidence of bud necrosis disease for the last two seasons in Robut 33-1 was much less than in TMV-2 (Fig. 5). It seems possible that just the use of this cultivar can substantially reduce the menace of bud necrosis disease. A field trial has now been designed to study the interaction of this cultivar sown on two different dates with and without insecticidal protection.

It appears that *Frankliniella* is primarily a flower feeder and has been found in about 29 weed and cultivated plants belonging to the

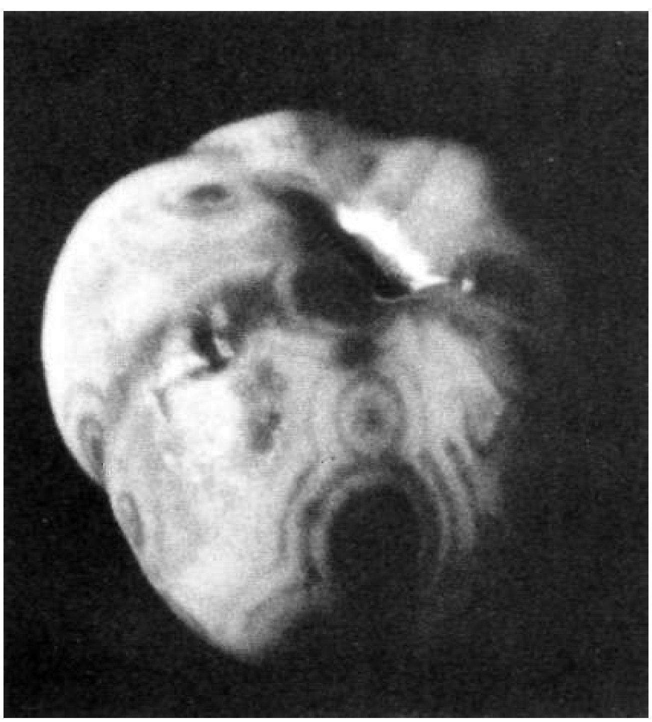


***Figure 4.** Ring spot caused by tomato spotted wilt virus on tomato. This virus also causes bud necrosis disease in groundnut.*

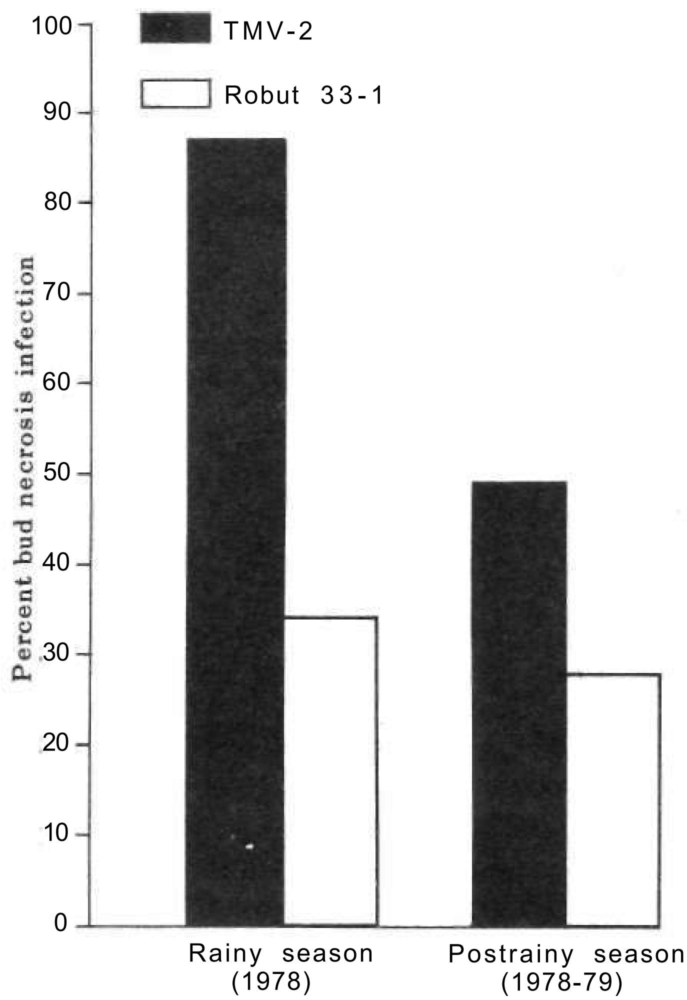


Figure 5. Bud necrosis disease incidence in two groundnut cultivars.

families Solanaceae, Compositae, Leguminosae, and Euphorbiaceae. *Ageratum conizoides* (Compositae) is the most susceptible of the weeds at ICRISAT Center. This weed germinates with the first showers of the rainy season and was found to harbor *Frankliniella* adults, and is also a host of TSWV.

Yellow spot disease. This virus disease was discovered in early 1978. It is transmitted by *Scirtothrips dorsalis* but not by *Frankliniella schultzei* or *Caliothrips indicus.* The disease is prevalent throughout the year and is associated with *Scirtothrips* populations. The minimum acquisition period tested and found positive was 15 min. The highest level of transmission reached was 74% when the acquisition period was 3 hr. The minimum latent period was 5 days and the optimum period was 8 to 10 days. The insects, once infective, transmitted the virus for about 8 to 9 days.

Role of Insects in Cross Pollination

About 20 species of bees, mostly solitary, have been collected from the pesticide-free area. Eight species have been identified so far; they belong to the genera *Megachile, Nomia, Sphecodes, Xylocopa, Andrena, Steganomus, Apis,* and *Pithitis.*

Pathology

Viruses

Bad necrosis disease. Extensive surveys have shown that bud necrosis disease (caused by tomato Spotted wilt virus—TSWV) is widespread in India, and that 27 plant species including nine common weeds of groundnut crops are hosts of TSWV. The virus also causes serious damage to mung bean, urd bean, and tomato in many localities. *Vigna unguiculata* cv C-152 and *Petunia hybrida* are good diagnostic hosts. There is no evidence of TSWV being seed-borne.

Three cultivars (NC Acc 2575, NC Acc 2372, and NC Acc 1107) had shown some tolerance to bud necrosis disease in preliminary trials. Cumulative disease incidence curves for these and TMV-2 are shown in Figures 5 and 6. The final percentage of diseased plants in NC Acc 2575 and NC Acc 1107 was considerably less than in NC Acc 2372 and TMV-2. These results need further confirmation.

Trials with TMV-2 showed that wide spacing (low plant populations) resulted in a higher percentage of diseased plants than close spacing but actual numbers of diseased plants on a unit area basis were highest in close-spaced crops. However, close spacing still gave the highest yield.

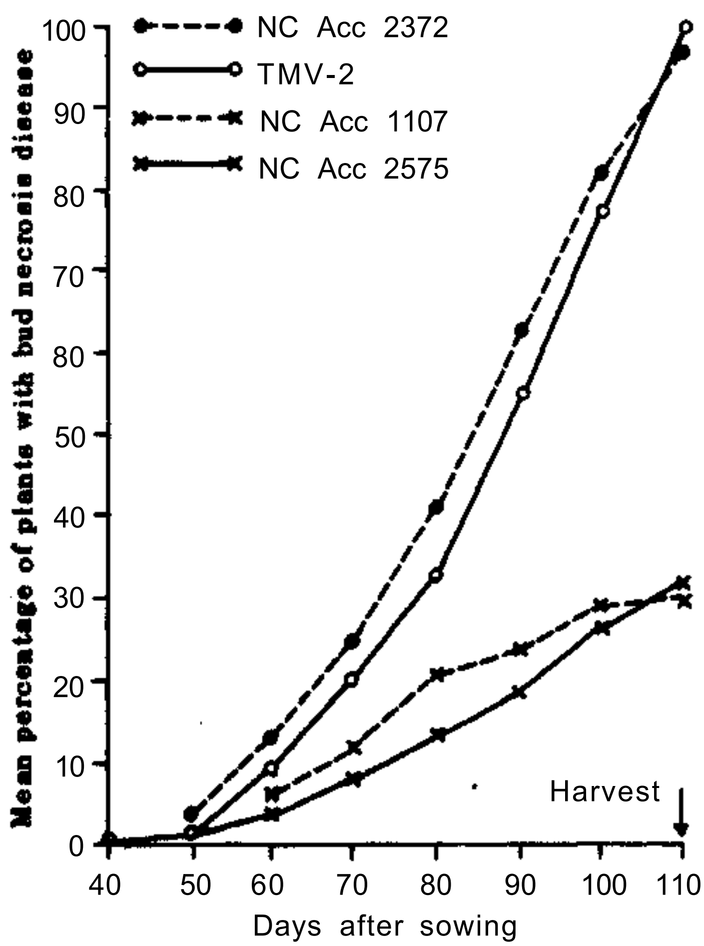
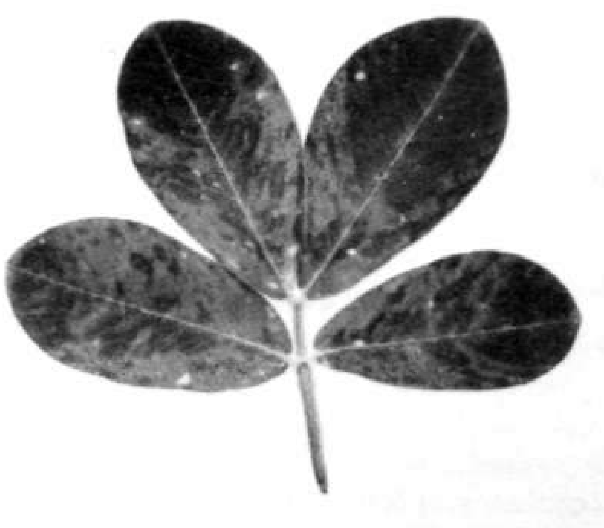


Figure 6. Bud necrosis disease on four groundnut cultivars (1978-1979 postrainy season crop).

Yellow spot disease. A disease characterized by appearance of large yellow spots on the leaves was observed in several areas of India in 1978-79. Incidence reached 80% in some crops. Coalescence of the lesions sometimes led to death of leaflets, and defoliation also occurred. The disease was transmitted by mechanical sap inoculation, and on some hosts it resulted in symptoms similar to those produced by TSWV. Biological properties were all identical with those of TSWV. The virus was transmitted by *Scirtothrips dorsalis.* On the basis of the above findings it is possible that yellow spot disease is caused by a strain of TSWV.

Peanut clump virus (PCV). Electron microscopy has now shown that the virus particles are straight rods, about 20-nm wide and 200 to 600 nm long. The disease is soilborne and can readily be transmitted by growing seedlings in soil taken from 12 to 24-cm depth from around infected plants. When mechanically inoculated onto groundnut plants, purified virus produces typical peanut clump symptoms. The fungus *Olpidium brassicae,* known to transmit some viruses, and some nematode species that may act as virus vectors, have been found associated with roots of clump affected plants.

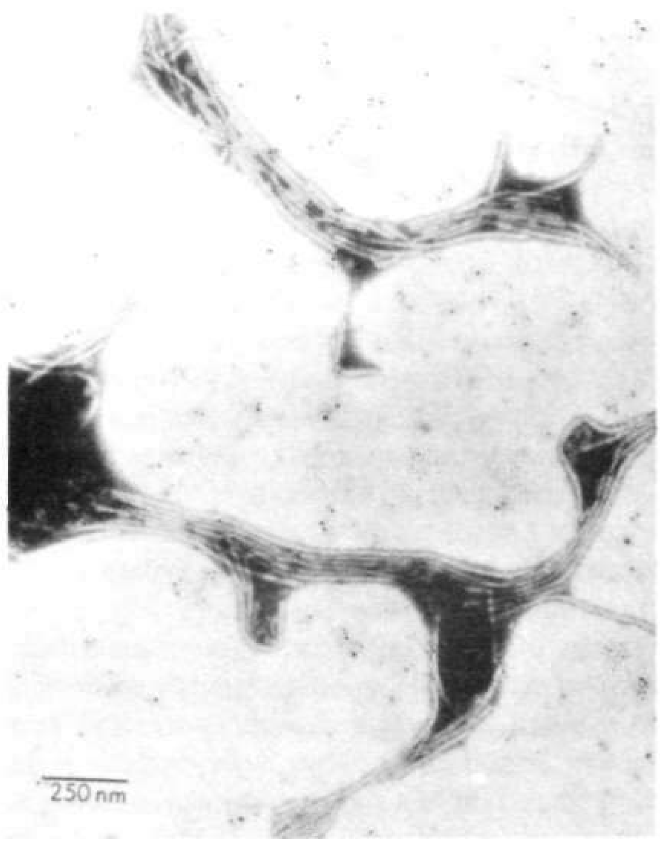
***Figure 7. Peanut mottle virus symptoms on* Arachis hypogaea.**



Peanut mottle virus (PMV). Insect vectors of PMV so far identified are *Aphis craccivora, A. gossypii,* and *Myzus persicae.* This virus is readily sap transmitted and a field-inoculation method has been devised in which extracts from infected leaves prepared in phosphate buffer containing celite and mercaptoethanol are sprayed onto test plants under high pressure from a fine nozzle. This results in infection of around 80% of the plants. Over 200 lines from the germplasm collection were susceptible and their yields were reduced. However, a few lines showed lower than normal rates of seed transmission. Neither *Arachis correntina* nor *A. glabrata* could be infected by sap inoculation or grafting. Symptoms on groundnut and details *of* virus particles are shown in Figures 7 and 8.

Cowpea mild mottle virus (CMMV). This virus was isolated from groundnut plants collected in Punjab and Andhra Pradesh states. Affected

Figure 8. Peanut mottle virus particles.



plants were severely stunted, with inward rolling of leaves and veinal necrosis. *Chenopodium amaranticolor* and *Beta vulgaris* were found to be good diagnostic hosts. So far, no success has been achieved in attempts to transmit this virus using *Aphis craccivora.* Plants grown from seed of CMMV-infected groundnuts and soybean have not developed the disease. The CMMV was characterized on the basis of electron microscopy of partially purified virus and by serology (gel diffusion and hemagglutination tests), host range, and physical properties

Groundnut Rust (*Puccinia arachidis*)

Biology. Many specimens of rust-infected groundnuts from different parts of India and from the ICRISAT germplasm collection have been carefully examined but only uredospores were found present. Attempts have been made to induce teliospore production by holding rust-infected plants under a range of daylength and temperature regimes, but without success. It appears extremely unlikely that teliospores play any part in the perpetuation of the disease in India.

Investigation of pods and seeds from a severely infected crop confirmed that uredospores on stored seed became nonviable after storage of 50 days (*ICRISAT Annual Report 1977-78*). Rust did not occur on seedlings grown from seed that had been surface-sterilized and then coated with freshly collected uredospores. These experiments indicate that rust is not carried from season to season on pods or seeds, and there is little danger of rust being spread on seed samples, especially if the seed is stored at normal temperature for 2 months.

Nature of rust resistance. The adaxial surfaces of detached leaves of ten species of *Arachis* were inoculated with rust uredospores and then incubated at high humidity. Leaf segments were cleared and stained and development of the rust fungus was observed. In section *Rhizomatosae* there were few successful leaflet penetrations, whereas in section *Arachis* there was often extensive hyphal development within the leaf tissues. Differences in mycelial growth after penetration indicated that there could be several resistance mechanisms within section *Arachis.* Section *Rhizomatosae* could be an important source of further types of resistance to rust.

Leaf Spot (*Cercosporidium personatum*)

Screening for resistance. From initial screening of over 7000 cultivars, 50 were selected for further examination in the 1978 rainy season. These were grown in a replicated trial in the field with infector rows of the highly susceptible cultivar TMV-2. Using a nine-point field disease scoring scale the cultivars were checked at various stages during crop development. Maximum disease scores were in the range of 3 to 5. In the selected cultivars little defoliation occurred and leaf spots were few in number. The lesions were small and with sparse sporulation as compared to the susceptible check. Some of the cultivars also showed good resistance to rust. The most promising entries for leaf spot resistance were PI 259747, PI 350680 (Fig. 9), NC Acc 17090, NC Acc 17133 (RF), and EC 76446 (292).

Forty genotypes were also tested in the laboratory for resistance to *C. personatum* by use of the detached leaf technique. Differences in lesion diameter, incubation period, sporulation, and time to 50% leaflet loss were observed. Variation in the "halo" symptom was also observed.

Fungicide Application for Foliar Diseases

Six fungicide spray regimes were tested in a replicated field trial with natural leaf spot and rust inoculum at ICRISAT Center in the 1978 rainy season (Fig. 10). The very susceptible cultivar

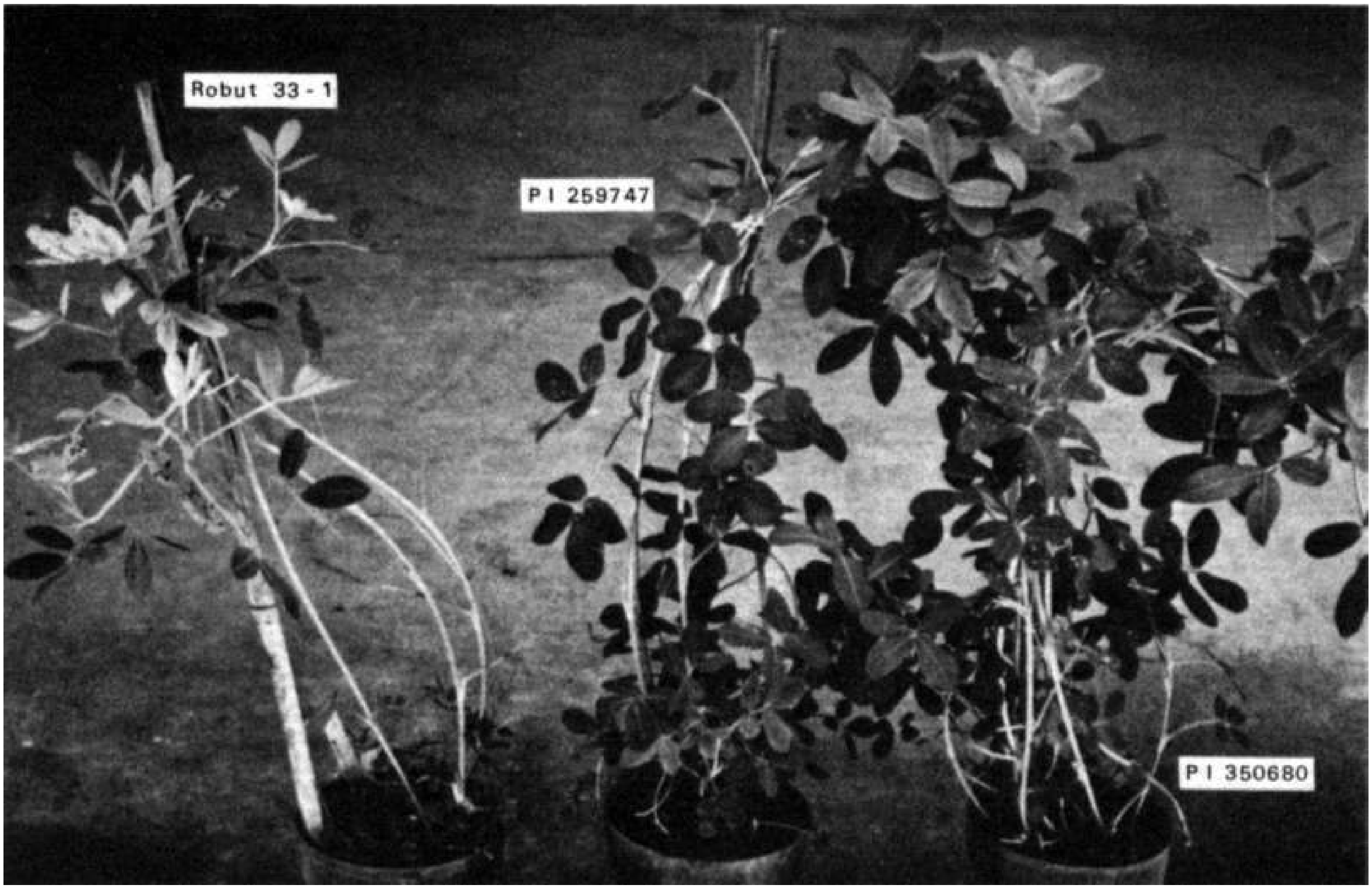


***Figure 9. Suseeptible and resistant reactions of groundnut to* Cercosporidium personatum.**

TMV-2 was used and fungicides were applied 30 days after sowing when both diseases had appeared. Results are given in Table 3. Disease attack was considerable for all treatments at harvest, by which time the sulphur-treated and check plots were decidedly senescent, with many rotted pods. The highest pod yield came from the Daconil treatment, which controls both leaf spots and rust in contrast to fungicides such as Bavistin which only control leaf spots.

Seed and Seedling Diseases

Many soil fungi cause seed and seedling diseases, the most important being *Aspergillus niger, A flavus, Fusarium oxysporum, F. solani, Rhizoctonia bataticola,* and *R. solani.* Some infections arise from seed-borne fungi and others from attack by soil fungi.

Crown rot and collar rot were found to cause significant damage to seedlings in the 1978-79 postrainy-season crop at ICRISAT Center. Collar rot was caused mainly by *Aspergillus niger* and damaged 4- to 8-week-old seedlings. The inoculum probably came from the soil. *A. niger* also caused some crown rot of younger seedlings; in this case it was likely that the inoculum was in the seed at sowing. The major cause of crown rot was *Aspergillus flavus,* the most common form of the disease being that designated elsewhere as "aflaroot" disease, causing poorly developed roots and chlorotic foliage. Isolations of the pathogen tested for aflatoxin-producing properties proved positive, supporting the theory that symptoms are due to production of aflatoxin.

Figure 10. Daconil-treated (left) and untreated plots of groundnut, showing that fungicides ean be used to control leaf spots and rust.

Pod Rots

Pod rots caused by soil fungi do considerable damage to groundnuts, being more severe in irrigated crops but with considerable variation from field to field. The plants with heavy rust, leaf spot, or virus diseases tend to have more preharvest pod rots than plants with healthy foliage. There was much variation within cultivars but a few had consistently low percentages of rotted pods. The dominant fungi were species of *Fusarium* (with *F. solani* and *F. oxysporum* being the most common); *Rhizoctonia solani* and *R. bataticola* also occurred. *Pythium* spp, regarded as important members of pod rot complexes in other areas, have not so far been found in significant levels at ICRISAT Center.

Microbiology

Nitrogen Fixation

Effect of soil moisture. During the postrainy season we studied the effect of soil moisture on nitrogen fixation. The acetylene reduction activity of the cultivar Ah-8189 reached a peak on the third day after irrigation. This suggests that excess or insufficient moisture decreases the nitrogen-fixing activity of the nodule.

Seasonal differences in acetylene reduction and nodulation. We have reported earlier the differences in acetylene reduction between two cultivars, MH-2 (a dwarf mutant) and Kadiri

Table 3. Effects of fungicide treatments on foliar diseases and pod yields of the cnltivar TMV-2.

Fungicide treatment	Leaf area (%) infected at 10 days before harvest by Rust	Leaf spot C.a	Leaf spot C.p	Yield of dried pods (kg/ha)	Pods rotted or discolored (%)
Daconil	9.7	5.5	1.8	1663	2
Dithane M 45 4- Bavistin	29.6	0.2	0	1456	5
Duter	22.4	17.4	2.5	1246	2
Dithane M 45	11.3	41.3	1.7	1226	3
Bavistin	47.3	0.7	0	972	7
Sulphur	Total defoliation			607	82
No spray	-do-			523	85

C.a = *Cercospora arachidicola.*
C.p = *Cercosporidium personal urn.*

71-1 (a late-maturing runner type). During the postrainy cropping period the seasonal variation in nodulation and acetylene reduction of these two cultivars was studied (Figs. 11,12, and 13). There were marked differences in the weight of nodules and their acetylene reduction activity. Except for a short period, however, the acetylene reduction expressed per gram of shoot weight was very similar for the two cultivars. This may indicate that in dwarf cultivars, such as MH-2, nitrogen fixation is limited by photosynthate supply.

Intercropping. Observations in 1977 suggested that when groundnuts were intercropped with pearl millet (in a ratio of one row of millet to three rows of groundnuts) they nodulated poorly compared with sole crops of groundnuts. During the rainy season of 1978, samples were taken for acetylene reduction assays in an intercropped and sole crop situation. The groundnut cultivar was Robut 33-1, which matures in 110 days. The results (Fig. 14) show that there were marked differences in nitrogen fixation in the two systems. Further work is being planned to study whether the differences in nitrogen fixation relate to the position of the three individual

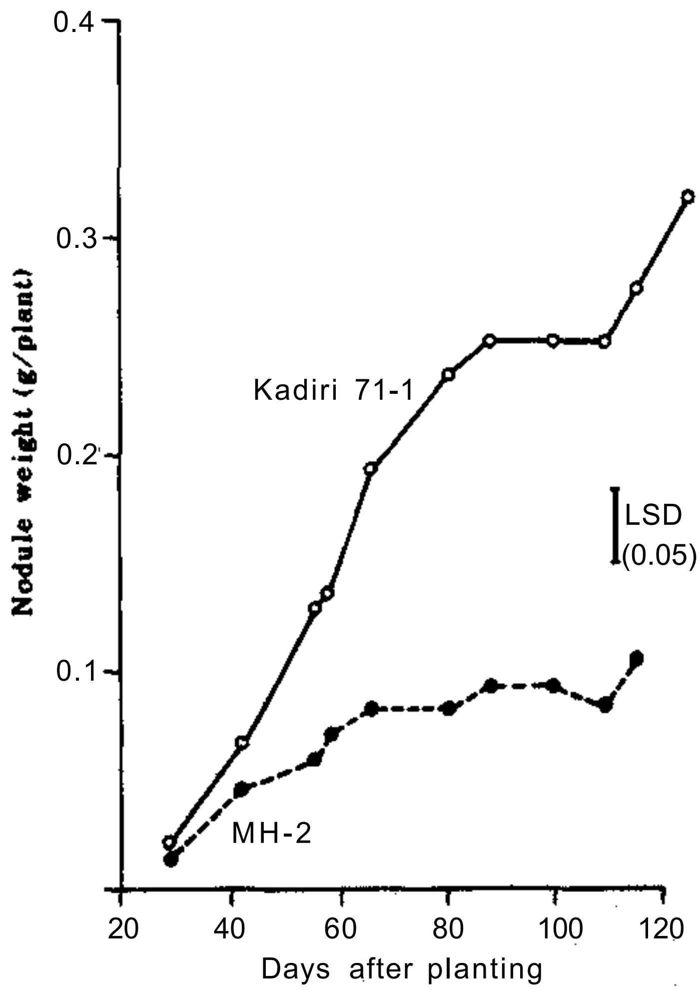


Figure 11. Nodulation of Kadiri 71-1 and MH-2 during 1978-79 postrainy season.

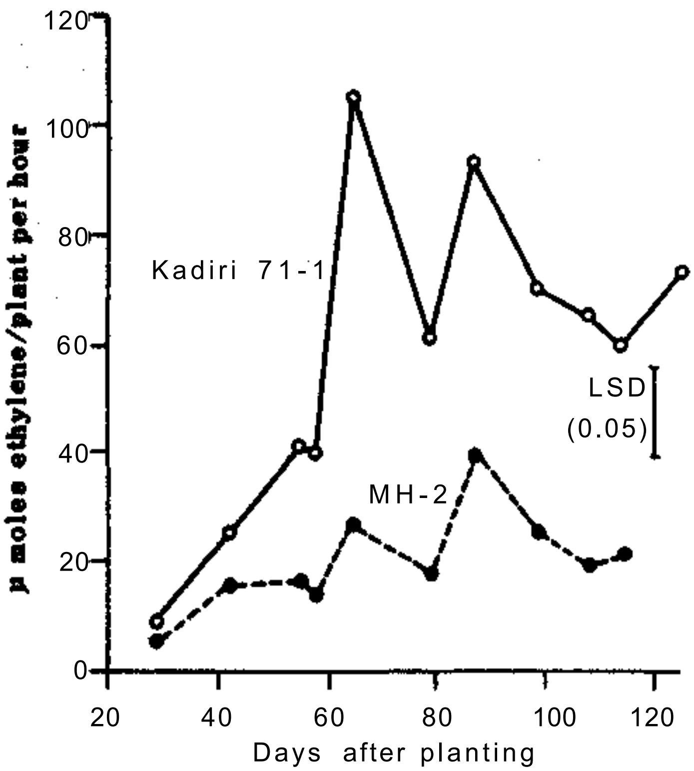


Figure 12. Acetylene reduction by Kadiri 71-1 and MH-2 during 1978-79 postrainy season.

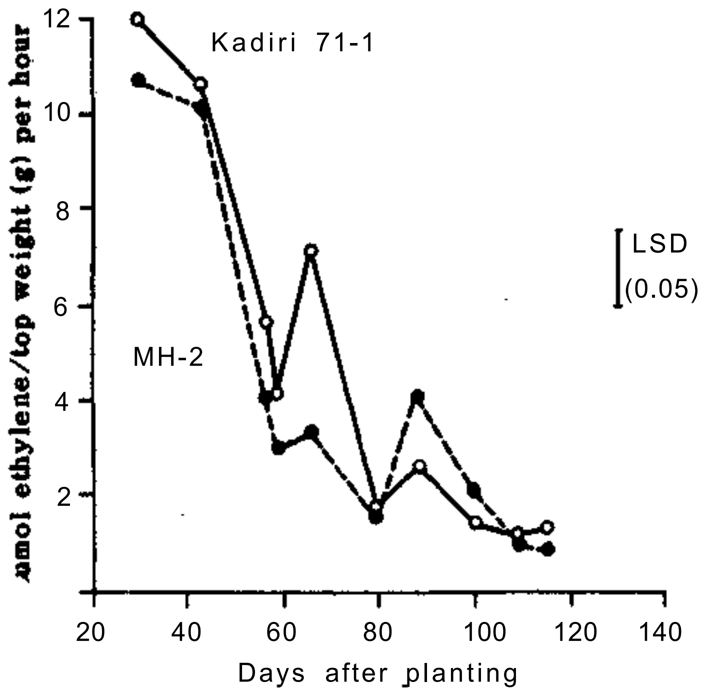


Figure 13. Acetylene reduction activity expressed per gram shoot weight to account for the difference in the growth habit of Kadiri 71-1 and MH-2.

groundnut rows with respect to the single row of millet, which received fertilizer nitrogen at the rate of 80 kg/ha nitrogen.

Host-*Rhizobium* interactions. Nonnodulating plants, easily recognized by their yellow foliage, were found in an F_2 rust screening nursery. Progenies of the three crosses in which these plants were found all had the rust-resistant Valencia groundnut PI 259747 as one of the parents. The other parents were Virginia cultivars. All the parents, including PI 259747, nodulated normally. Individual F_2 nonnodulating plants (Fig. 15) were harvested and will be progeny-rowed during the next growing season to study the genetic control of nonnodulation.

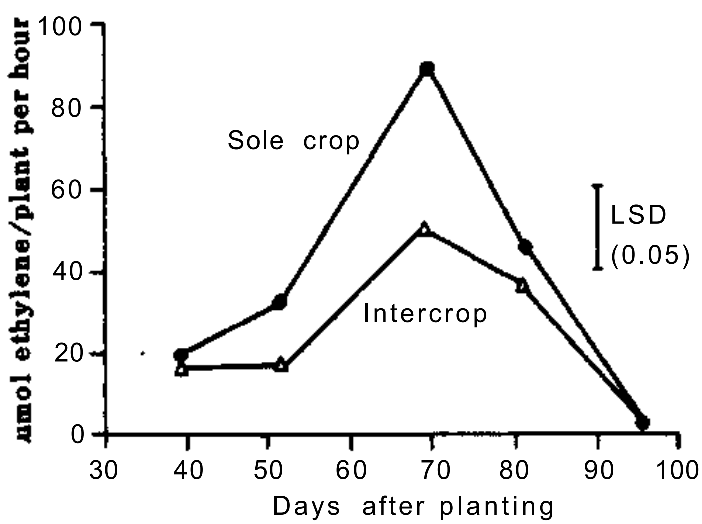


Figure 14. Effect of intercropping on nitrogen fixation by groundnut.

Response to inoculation. The effect of inoculation on pod yield was nonsignificant in the rainy season on two Alfisol sites at ICRISAT Center in a trial involving three cuitivars and three *Rhizobium* cultures. During the postrainy season when the experiment was repeated, a significant increase in yield was obtained with the cultivar Robut 33-1 and the North Carolina strain NC 92 (Table 4).

Figure 15. Nonnodulating groundnut (center) with normal nodulating plants (left and right).

Table 4. Groundnut response to *Rhizobium* inoculation in an Alfisol (1978-79 postrainy season).

	Pod weight (kg/ha)			
Cultivars	Uninoculated	1C 6009	NC 92	Mixture (1C 6009 + NC 92)
MH-2	2222	1888	1944	2027
Robut 33-1	3500	3333	4500**	2805
AH-8189	2833	2861	2694	2805

LSD (at 1%)850.
CV(%)=15.5.
** Significant at 1% level.

Looking Ahead

Breeding. The emphasis on breeding for stable disease resistance, high yield, and earliness will continue. Promising material emerging from the program will be supplied to breeders in other countries. Early-generation material will be supplied for selection in situ, and more stable later-generation material will be distributed for immediate testing of stability of yield and disease resistance. The possibility of breeding for multiple disease resistance and the selection of material to fit into specific cropping systems will be intensified.

Cytogenetics. Material with resistance to leaf spots and rust at the chromosome level of the cultivated groundnut will become available for use in the conventional breeding program. By using tissue culture and other techniques we will endeavor to overcome the existing barriers that prevent us from using certain useful wild *Arachis* species in our program.

Physiology. The physiology subprogram is in the process of development and should become fully operational in the very near future. Priority research areas will include the development of drought-screening techniques and, subsequently, the identification of drought-resistant cultivars.

Entomology. This program will be expanded to cover the major pests of groundnut on a worldwide scale. Cooperative programs and identification of sites to investigate pests that do not occur at the ICRISAT site will be developed. The biology of the major pests will be studied to develop suitable integrated methods of control. The entomologists will continue to work closely with the virologists on the important vectors of virus diseases and with agronomists on the effects of intercropping on the levels of pest development.

Pathology. The search for additional sources of stable resistance to the major pathogens, both fungal and viral, will continue to be a major thrust of this program. Refining present techniques and developing new ones will receive high priority. Investigations on whether races of the rust and leaf spot pathogens occur will be carried out. The aflatoxin laboratory will be expanded to screen large quantities of breeding material for resistance to *Aspergillus flavus.* More detailed studies will be initiated to identify resistance to the pod rot fungal complexes. Work will be initiated on the intensity of fungal diseases in the intercrop situation compared to the single crop situation.

Microbiology. Priority will be given to the development of suitable competitive inoculants of *Rhizobium* for areas where native rhizobia are lacking or are inefficient. The development of inoculant application techniques and machinery will be an important task for the near future. We also look forward to the development of cultivars with increased capabilities of fixing nitrogen. We need to do further research to quantify the amount of nitrogen fixed and the residual amounts of nitrogen that are available to the subsequent crops in the rotation.

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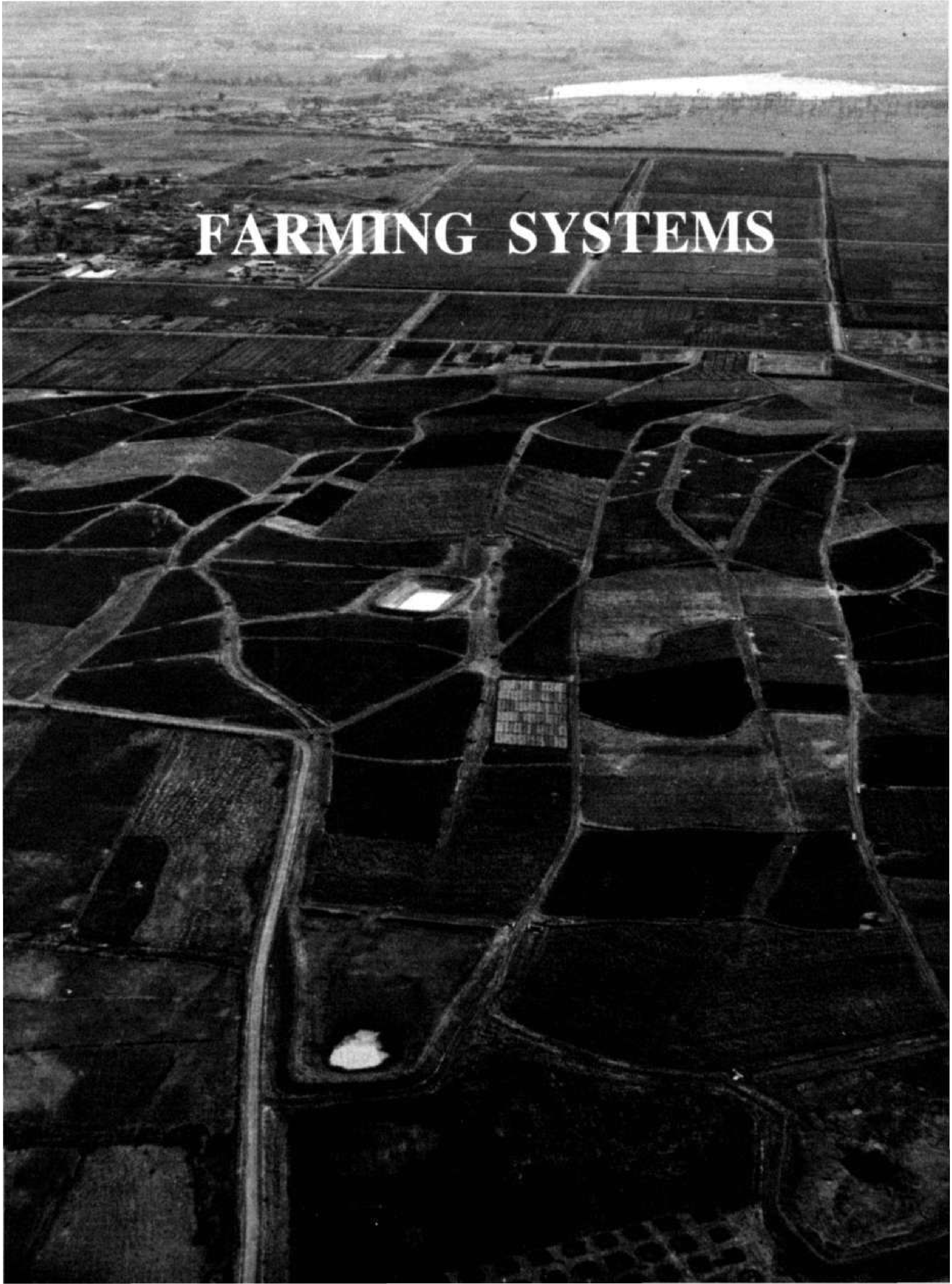
FARMING SYSTEMS



Contents

FARMING SYSTEMS

In the rainfed areas of the semi-arid tropics (SAT), the soil is often low in fertility and difficult to cultivate, the rainfall is low, erratic and highly seasonal, and the socioeconomic resources are limited. Agricultural productivity in this harsh environment has been low, and it is difficult to meet the needs of the rapidly increasing populations in many developing countries. This has led to the need for improved farming systems to provide higher and stable production.

The Farming Systems Research Program (FSRP) at ICRISAT aims to:

- describe and classify the agronomically relevant features of the soil and climatic resources of the SAT.
- identify the physical and biological processes that largely determine crop performance in the various agroclimates of the SAT, and to establish the basic principles that describe these processes.
- develop production practices and systems of farming that result in improved, stable food production by optimum utilization of natural resources.

This research is conducted at ICRISAT Center near Hyderabad, at other research locations, and in farmers' fields in India and other SAT countries. Specific factors influencing crop yields are studied within the relevant subprograms of FSRP, but interactions among several of these factors or processes require interdisciplinary investigations. These investigations often involve several subprograms in ICRISAT and scientists from outside organizations. Alternative practices and systems of production developed from this research are initially tested in operational research at ICRISAT; those that appear promising are then evaluated on research stations and farmers' fields in the collaborative Village-level Studies.

Research undertaken in 1978-79 is reported here under the following major categories: (1) research in subprograms, (2) watershed-based resource development and utilization, and (3) collaborative research with national programs.

RESEARCH IN SUBPROGRAMS

Agroclimatology

ICRISAT agroclimatologists seek to quantify the several climatic factors that are of major importance for plant growth, describe their spatial and temporal distributions and variabilities, and classify them into agronomically meaningful agroclimatic types. The work consists of collection and analysis of weather data for the SAT, studies of field measurements of flows of energy and matter in the crop canopy, and collaborative studies with other disciplines in developing and testing dynamic weather-driven crop production models.

Weather at ICRISAT

This year although the monsoon arrived late at Hyderabad, it also withdrew late, so the length of the wet period in the rainy season was approximately average. The rainy season was unique in several respects. The seasonal rainfall was 1077 mm from June to October, or 56% above average, the highest since ICRISAT was established in 1972. The rainfall in August was the highest on record for this month in the last 78 years; the heaviest rainfall for any single day was on 14 August. On this day, 174 mm occurred in a storm between 0500 and 1900 hrs (Table

1, Fig. 1), and the total rainfall for the period from 13 to 15 August was 273 mm. During the past 7 years, August rainfall has been above average in 5 years and below average in 2 years, while the opposite has been the case for September rainfall. Data on the high-intensity, high-

Table 1. Monthly mean rainfall and monthly rainfall in 1978 recorded at ICRISAT Center.

Month	Mean rainfall	Rainfall in 1978	Deviation from mean
Jan	5.5	17.2	+ 11.7
Feb	11.0	20.5	+ 9.5
Mar	12.5	3.8	- 8.7
Apr	24.0	56.4	+ 32.4
May	26.5	15.0	- 11.5
June	115.5	181.4	+ 65.9
July	171.5	228.2	+ 56.7
Aug	156.0	515.8	+ 359.8
Sept	181.0	81.5	- 99.5
Oct	67.0	70.5	+ 3.5
Nov	23.5	10.4	- 13.1
Dec	6.0	0.9	- 5.1
Total	800.0	1201.6	401.6

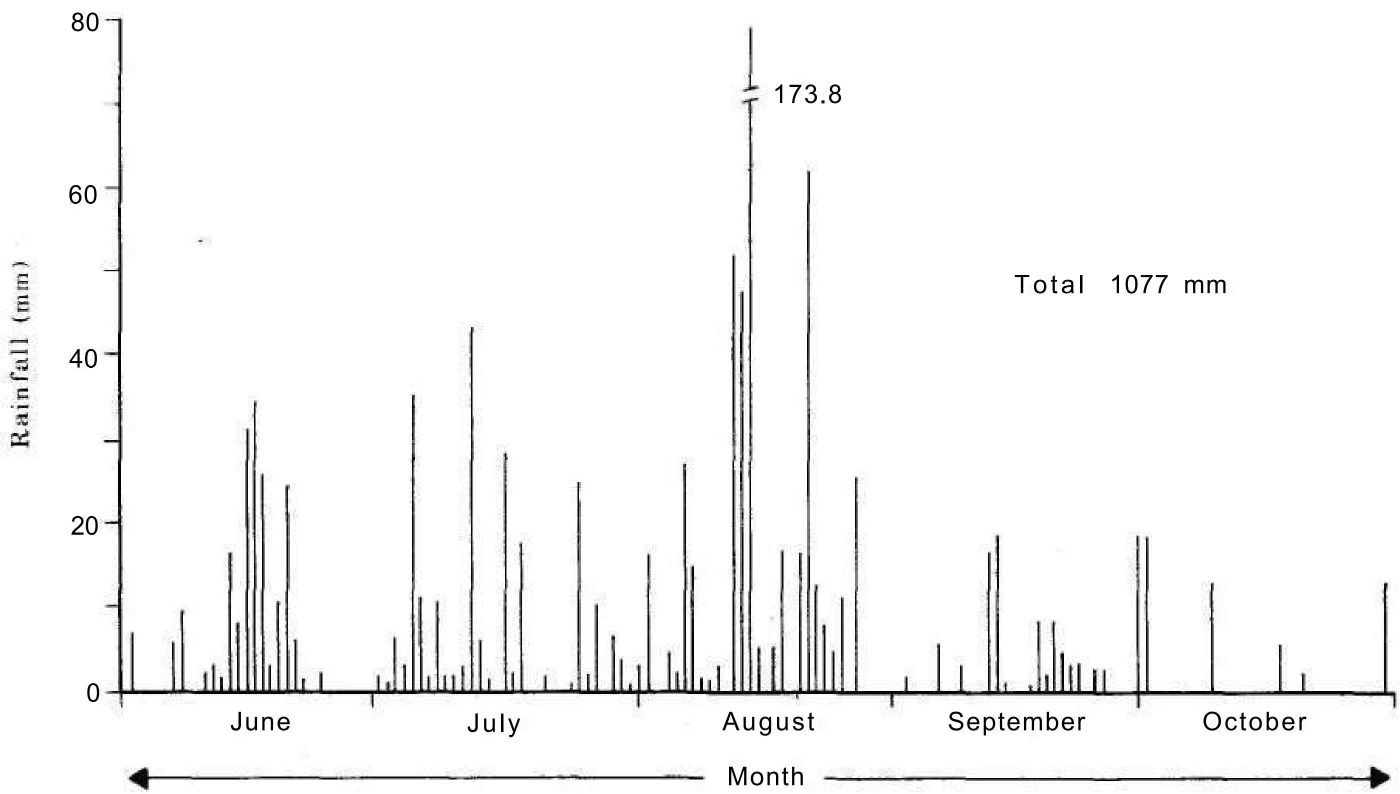


Figure 1. Daily rainfall distribution during the rainy season at ICRISAT Center, 1978.

volume storms are given in Table 2; rainfall exceeded 10 mm on 32 days in 1978, compared with 21 days in 1977 and 19 days in 1976.

Open-pan evaporation rates, air and soil temperatures, relative humidity, wind speed, sunshine hours, and daily radiation data are given in Figures 2 to 6 and Table 3. These show clearly the marked changes that are associated with the arrival of the south-west monsoon.

The heavy rainfalls on 30 September and 1 October (40 mm total) created problems in harvesting rainy-season crops, especially sorghum on Vertisols, although this rain recharged the soil profile and thus contributed to good postrainy-season crops on the Vertisols.

Using a water-balance equation, seasonal trends of available soil moisture in Vertisols and Alfisols were computed from the 1978

Table 2. Duration and amount of high intensity rains recorded during 1978 at ICRISAT Center.

Date	Duration (min)	Rainfall[a] (mm)	Date	Duration (min)	Rainfall[a] (mm)
16 June	15	10.5	8 Aug	15	11.5
	15	6.5	13 Aug	25	41.0
17 June	15	22.0	15 Aug	15	15.0'
5 July	15	12.5	18 Aug	10	4.5
16 July	30	23.5	23 Aug	15	12.0
18 July	15	7.0	14 Sep	15	5.0
25 July	5	7.0	1 Oct	15	8.0
30 July	5	3.0	2 Oct	15	10.8
2 Aug	10	3.5	10 Oct	15	90
7 Aug	10	18.0	30 Oct	15	9.5

a. High intensity recording > 5 mm per 15 min.
b. Highest intensity on that day: total amount of rainfall recorded was 174 mm.

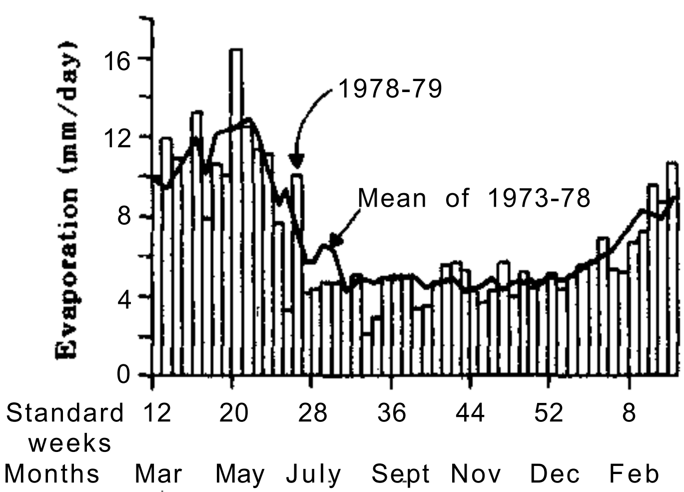


Figure 2. Mean daily evaporation for 1973-1978 and 1978-79 at ICRISAT Center.

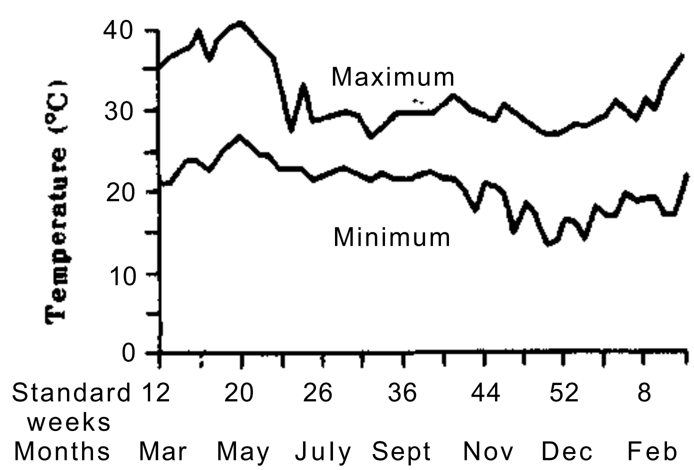


Figure 3. Mean weekly air temperatures at ICRISAT Center, 1978-79.

meteorological data; runoff data are measured values from the maize/chickpea sequential cropping systems in deep Vertisol watershed BW3 and from groundnuts in Alfisol watershed RW1. The available moisture in the root zone was above 50% of available water capacity from about mid-July to the end of November in Vertisols and from late June to mid-October in Alfisols (Fig.7).

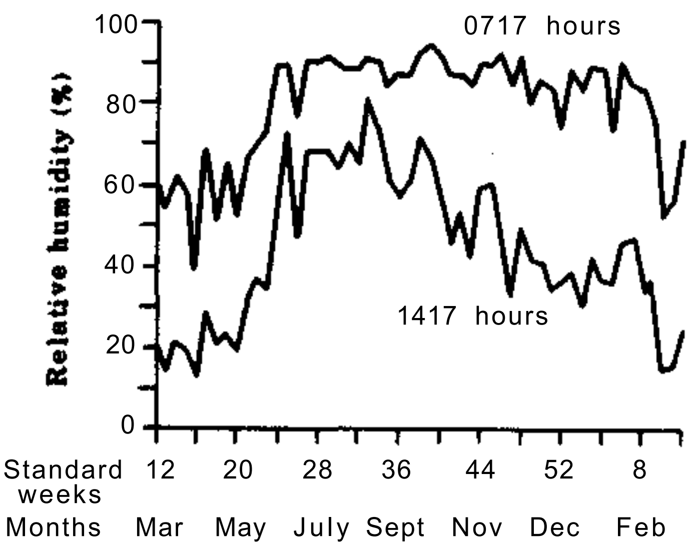


Figure 4. Mean weekly relative humidity at ICRISAT Center, 1978-79.

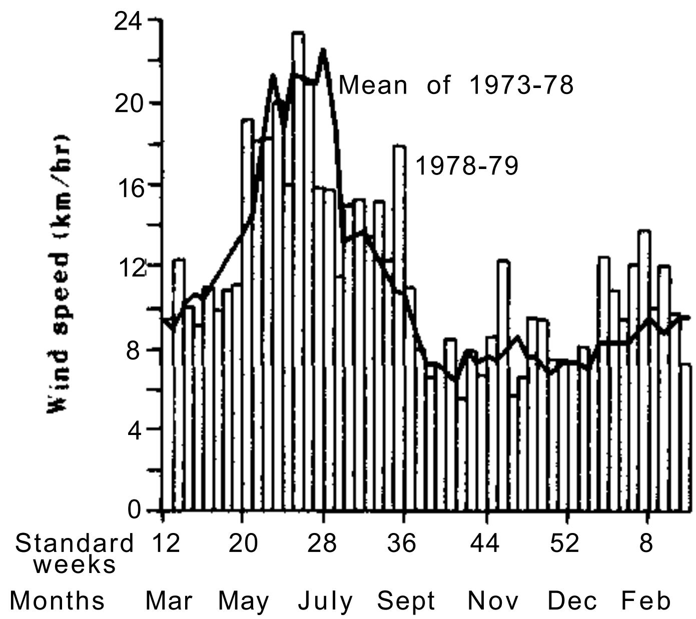


Figure 5. Average weekly wind velocity for 1973 1978 and 1978- 79 at ICRISAT Center.

Table 3. Soil temperatures at various depths recorded in a Vertisol at the Agrometeorological Observatory at ICRISAT Center in 1978.

			Soil temperature (°C)			
Season	Period	Time	Surface	5-cm depth	30-cm depth	150-cm depth
Hot-dry	16-22 Apr	0717	29	29	30	28
		1417	44	44	32	28
	14-20 May	0717	31	32	32	29
		1417	42	42	33	29
Rainy	6-12 Aug	0717	22	23	26	27
		1417	29	30	27	27
	1-7 Oct	0717	22	23	27	27
		1417	34	35	27	27
Postrainy	10-16 Dec	0717	18	18	25	28
		1417	31	34	25	28

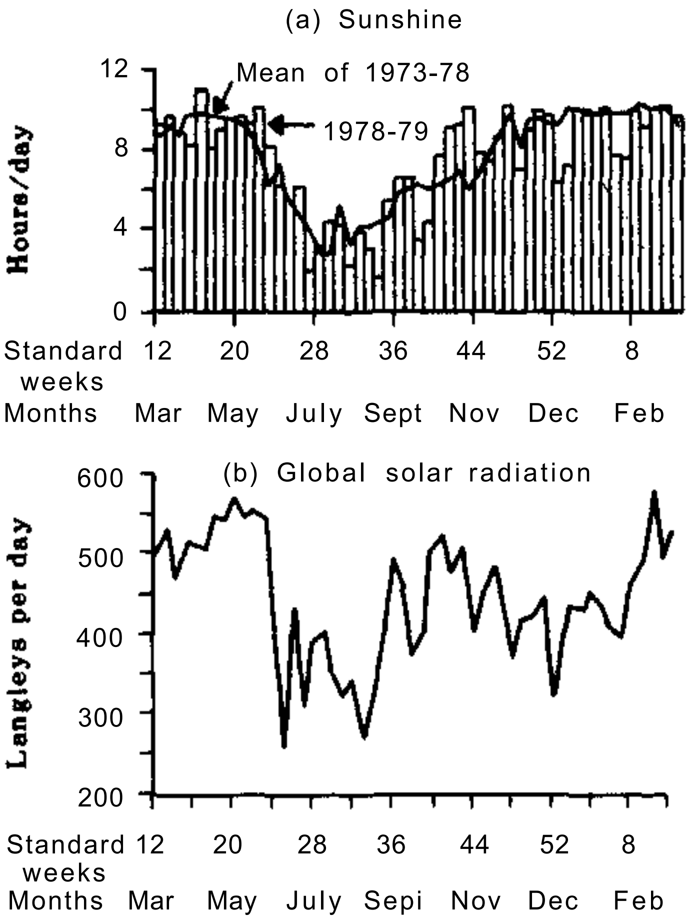


Figure 6. Hours of bright sunshine for 1973-1978 and J 978-79 and global solar radiation for 1978-79 at ICRISAT Center.

Microclimatological Studies

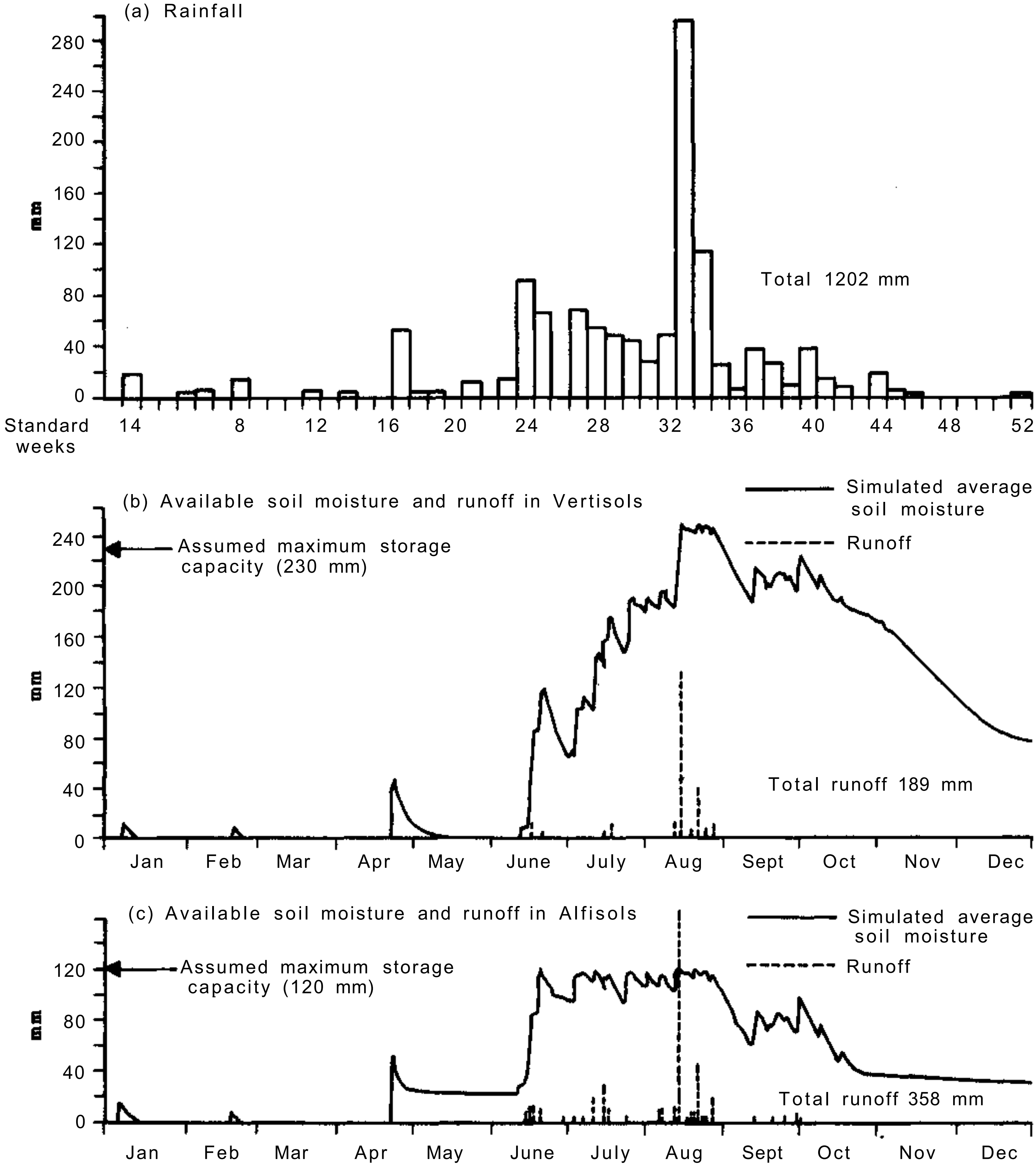
The interception and disposition of solar energy by the crop canopy and the soil, and the movement of water across the interfaces between the atmosphere and the leaf and soil surfaces, are among the most important physical processes affecting crop production. The amount and spatial array of leaf area and the water status of the leaf tissue largely determine the dynamic interaction between the crop and its aerial environment. Studies are, therefore, being conducted on the microclimate of the crop canopy to quantify these processes.

Interception of solar energy by the crop canopy. Temporal and spatial changes in the amount of photosynthetically active radiation (PAR) captured by the crop canopy were measured and related to leaf area index (LAI) and dry-matter production. The phytosynthetic efficiencies of rainy-season maize, sorghum, and a maize/pigeonpea intercrop were 0.82,0.62, and 0.93 g/einstein of intercepted PAR, respectively. These were much higher than the 0.23 g/einstein of sole pigeonpea in both rainy and postrainy seasons. The photosynthetic efficiency of irrigated sorghum in the postrainy season was 0.40 g/einstein, or only two-thirds of its rainy-season value, probably because the incoming solar radiation during July and August was unusually low. The relationship between LAI and the logarithm of the fraction of incoming PAR intercepted is given by the extinction coefficient. For maize and sorghum in 75-cm rows and LAI values ranging from 1.8 to 3.7, the extinction coefficients ranged from 0.42 to 0.69. In a maize/pigeonpea intercrop with an LAI of 3.4, it was 0.36, and sole pigeonpea had an extinction coefficient of 0.63, with LAI in the 2.8 to 3.7 range (Fig. 8).

Moisture stress effects. When transpiration is reduced, a smaller fraction of the solar energy absorbed by the leaf is used to vaporize water; consequently, more energy is available to increase the temperature of the leaf. This in turn increases the rate of longwave radiation and sensible heat losses by the leaf to the surrounding air. Leaf temperature, therefore, is a useful indicator of the onset and intensity of moisture stress in the plant.

On 4 January, a clear day, the daily incoming solar radiation was 432 langleys (Fig. 9). Integrated over the day, the net radiation of severely stressed sorghum was 213 langleys, compared with 230 langleys from a more adequately watered plot nearby. Net radiation over the nonstressed crop was higher throughout the day than over the stressed crop, indicating higher transpiration rates.

Leaf temperatures of sorghum at 40 days after sowing (DAS) were the same across an 18-m area 3 days after receiving a continuously decreasing quantity of irrigation ranging from



(d) Pan evaporation (mm)

1978	149	171	322	321	381	255	140	112	126	161	129	146
mean	158	188	291	318	375	276	174	130	138	149	132	146

Figure 7. Weekly rainfall, available soil moisture, runoff, and pan evaporation at ICRISAT Center, 1978.

30 to 0 mm (Fig. 10). Leaf temperatures increased linearly across the area 2 and 4 weeks later, which indicated more severe stress where less water had been applied. Leaf conductances measured in the same differentially irrigated area decreased linearly with the water application rate (Fig. 11) on all three occasions. At each position, conductances decreased progressively after the differential irrigation at 37 DAS.

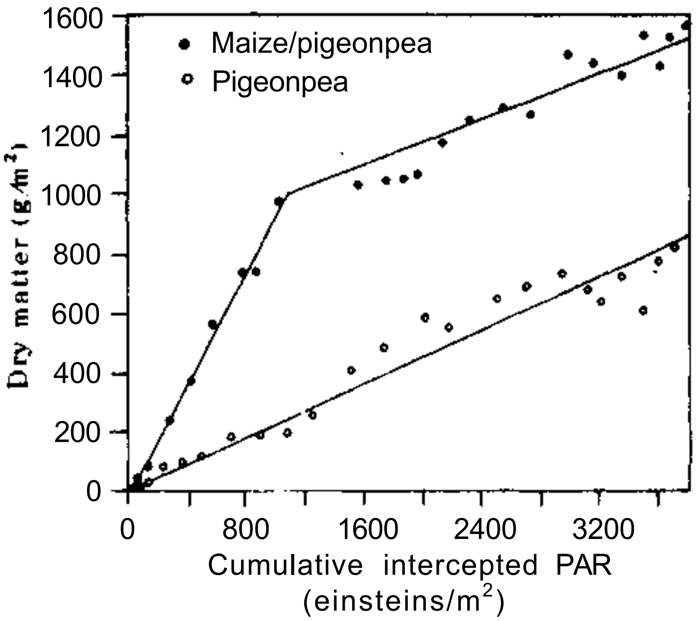


Figure 8. Relationship between cumulative intercepted PAR and dry matter produced for maizelpigeonpea and pigeonpea.

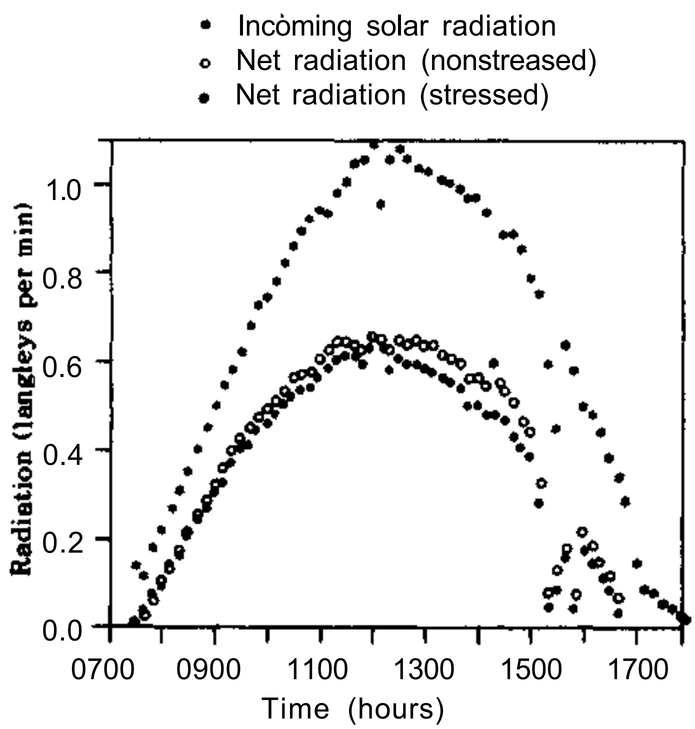


Figure 9. Diurnal variation in the incoming solar radiation and net radiation for non-stressed and stressed sorghum on 4 Jan 1979.

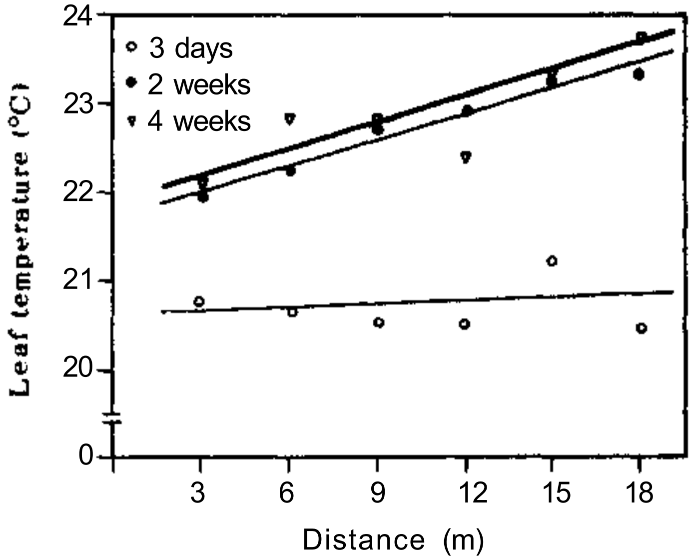


Figure 10. Leaf temperature of sorghum as related to distance from sprinkler line measured 3 days, 2 weeks, and 4 weeks after the differential irrigation.

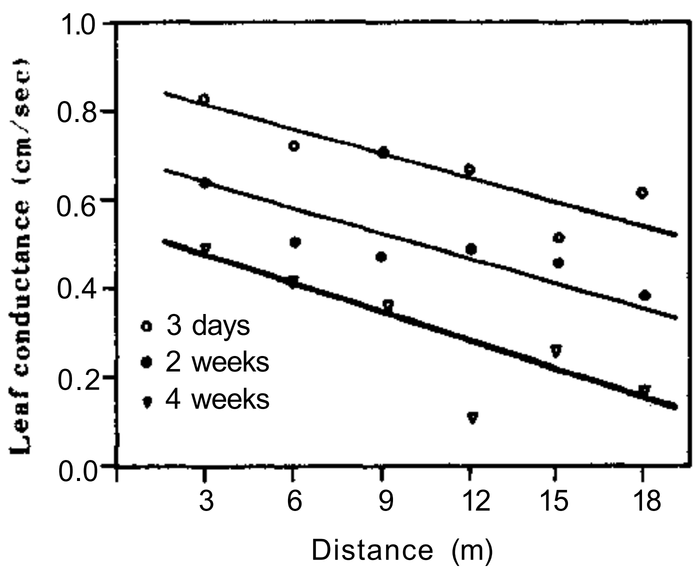


Figure 11. Leaf conductance of sorghum as related to distance from sprinkler line measured 3 days, 2 weeks, and 4 weeks after the differential irrigation.

When plants experience moisture stress, plant leaves become hotter than the surrounding air; the canopy becomes a source rather than a sink of sensible heat. The effects of different levels of moisture stress on the leaf-to-air-temperature differentia] of chickpeas are shown in Figure \

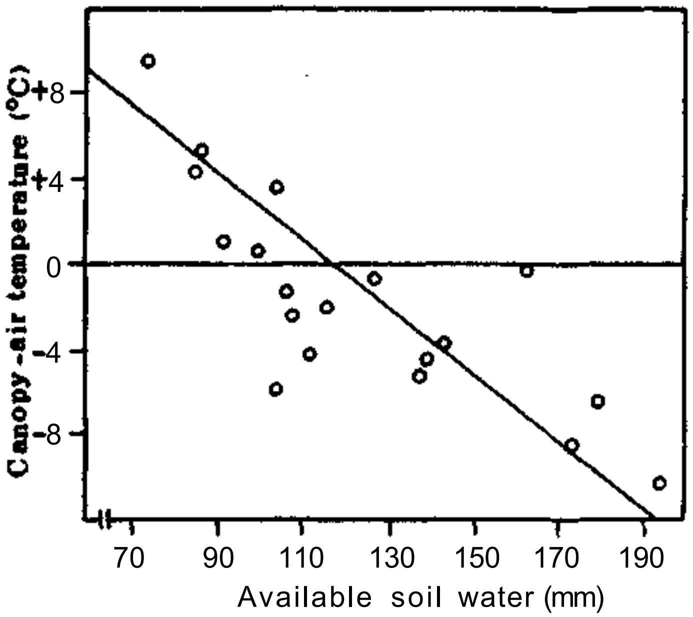


Figure 12. Relationship between canopy-air temperature differential of chickpea and available soil water throughout the growing season.

Rainfall Characteristics of Niger

The republic of Niger, with an area of 1 267 000 km^2, lies between 11°37'N and 23°33'N. About 95% of its people live by farming in the south and by nomadic and semi-nomadic herding in the Sahel. The amount and seasonality of rainfall imposes major restrictions on the economy, and agriculture is concentrated in the more humid southwestern border areas.

Daily rainfall data for 78 locations supplied by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) Paris, show a characteristic decrease in the amount of rain and the duration of the rainy season with increasing latitude (Fig. 13). Only in the Gaya and Dosso regions are the average 4-week rainfalls above 100 mm for a 4- or 5-month cropping season.

From a probability analysis of the 38 stations having rainfall records of 15 years or more, maps showing the spatial and temporal distribution of the probabilities of receiving 5, 10, and 20 mm of rain in each week were prepared (Fig. 14). These show that the probabilities are distributed across the country and throughout the rainy season at a given location in patterns similar to the average annual rainfall.

From another analysis, maps were prepared that show the amounts of rain that would be received at 25 and 50% probability levels for each 4-week period (Fig. 15). These maps also show the characteristic decrease in rain from south to north and its seasonality, indicated by the annual rainfall isohyets.

When used with data on the water storage characteristics of the soil and the rooting behavior and developmental phenology of the crop, the probability analyses provide a basis for evaluating in stochastic terms the agronomic feasibility of alternative systems of cropping. A complete report of this study is available (ICRISAT Information Bulletin No. 5).

Environmental Physics

The emphasis in the Environmental Physics subprogram continues to be on the dynamics of water as it moves through the soil-plant-atmosphere continuum. This involves close collaboration with agroclimatologists, crop physiologists, soil and water engineers, and agronomists. The major areas of research are (a) physical characterization of soils, (b) quantification of the effects of the physical properties of the soil-crop system on the components of the water-balance equation, (c) measurement of the effects of changing time and depth patterns of soil water in the root zone on transpiration and crop-growth, (d) developments of a process-based, weather-driven crop production model that will be useful in explaining and generalizing

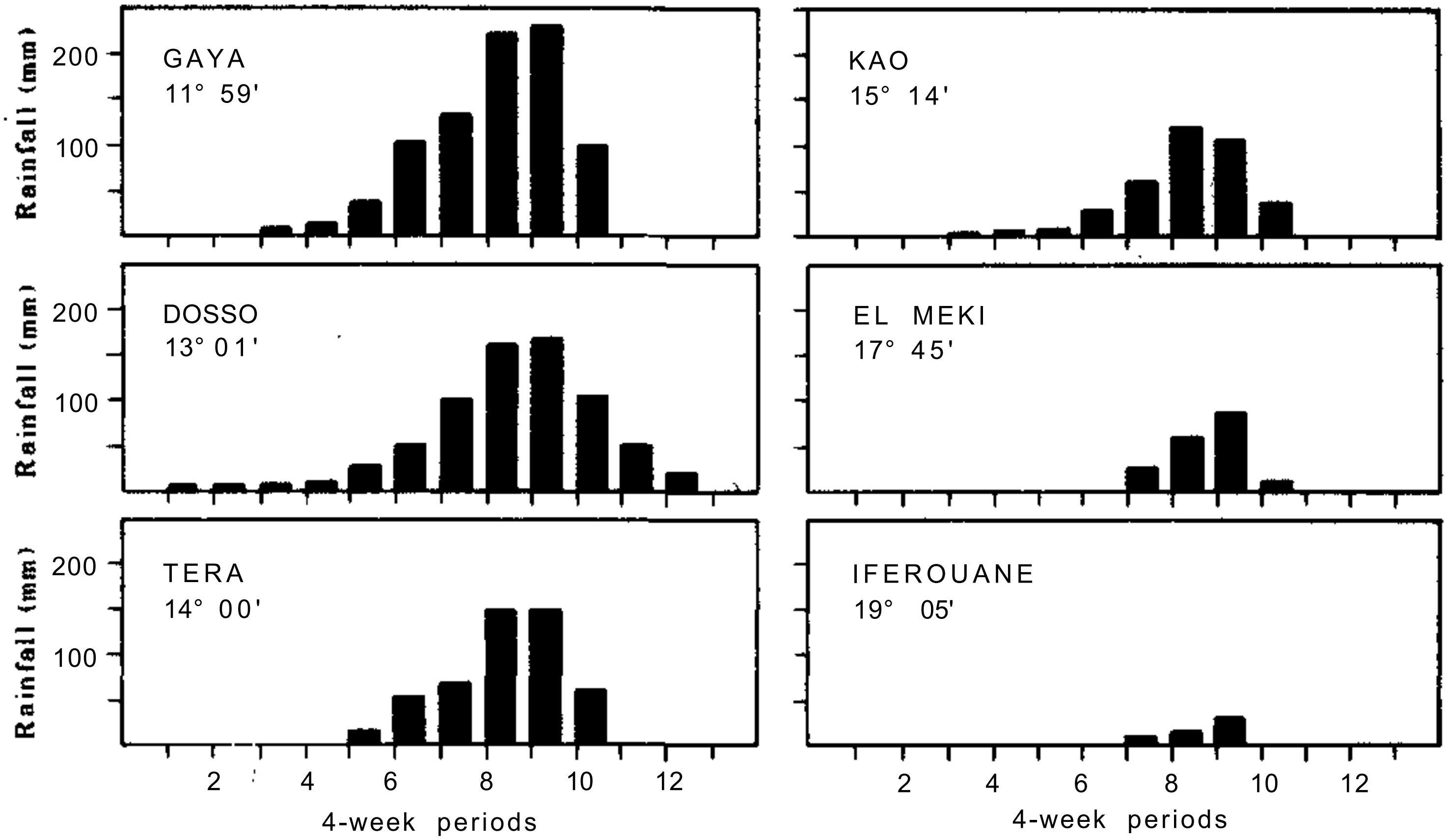


Figure 13. Latitudinal distribution of 4-week periods of rainfall in Niger.

the results of site- and season-specific field experiments and that will help in classifying climate in agronomically relevant terms.

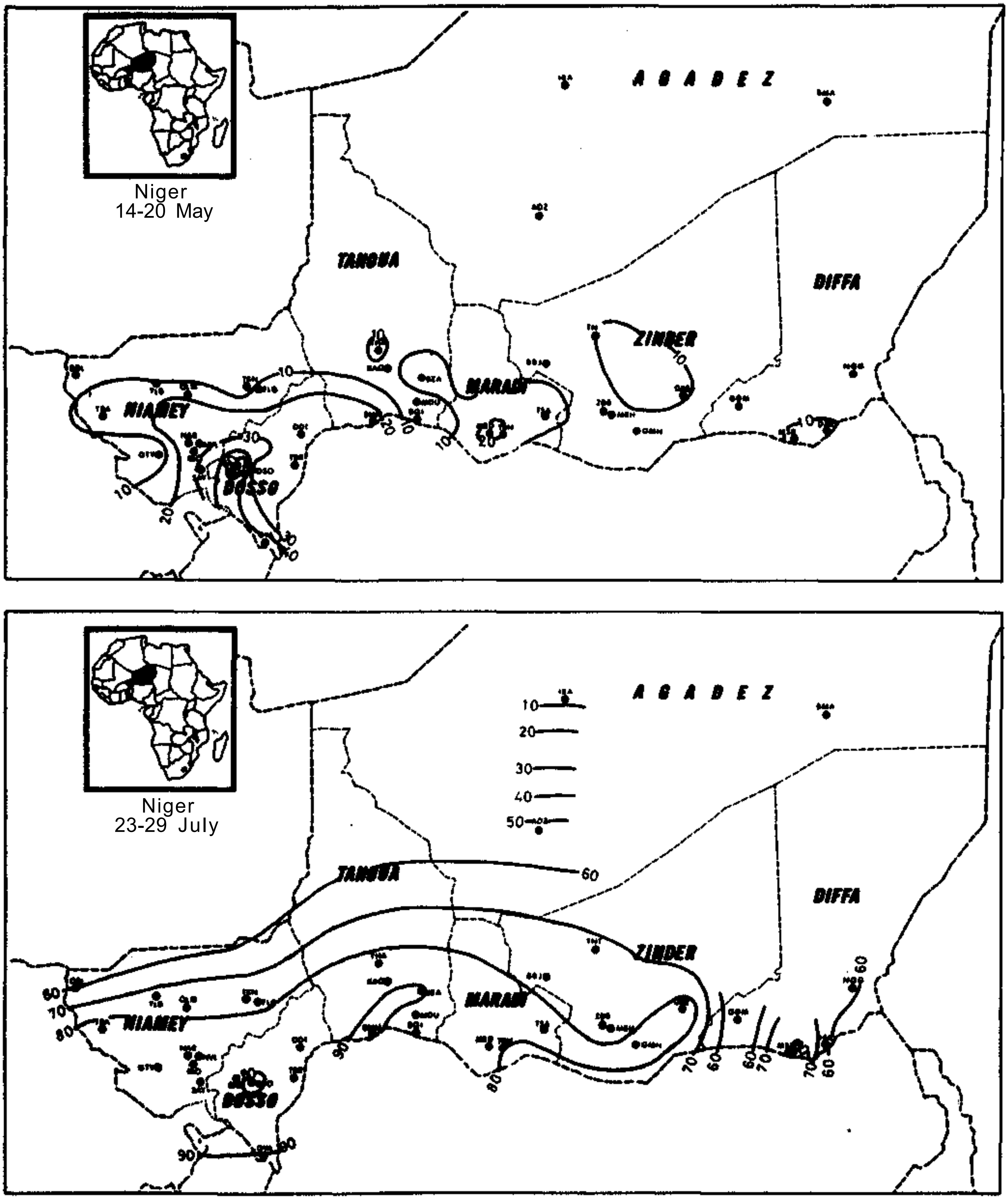
Physical Properties of Alfisol Profiles

Alfisols are highly variable in depth, texture, bulk density, and stoniness from place to place. Their water retention and transmission properties are therefore very site-specific and must be evaluated in the areas where quantitative studies of soil-plant-water relations are being made. Such a detailed evaluation of a deep Alfisol was made for the ST2 and RA10 areas at ICRISAT Center.

The stone content of samples taken at 15-cm intervals to a depth of 180 cm was measured at 12 locations in a 0.2-ha experimental area in field ST2 and nine locations in a 0.5-ha area in field RA10. Results are given in Table 4. The high standard deviations reflect the fact that the depth at which the stone content was appreciable (i.e., > 10%) varied from 45 cm in one profile to 135 cm in six others. As in ST2, the standard deviations in the RA10 area were also high because the depth below which stone content was greater than 10% varied from 75 cm in one profile to 135 cm in five others.

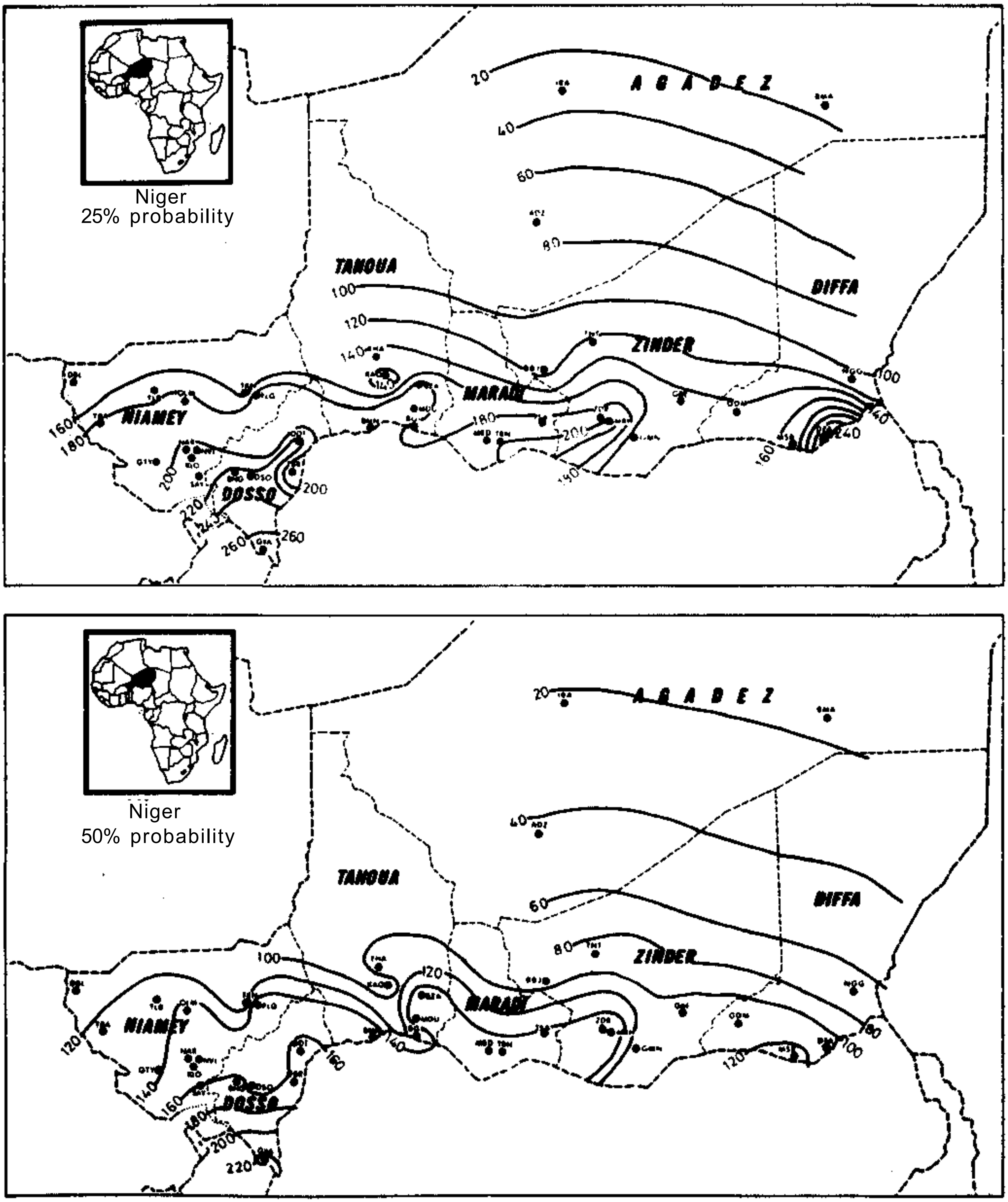
Bulk densities measured with 6.8 or 4.1-cm diameter core samples increased more or less linearly in both ST2 and RA10 (Table 4). In only two cases did the standard deviations exceed 10% of the mean values. Most of the variation in bulk density values was associated with high stone content. When the observed bulk densities were corrected for the amount of material greater than 2.0 mm, the bulk densities in ST2 ranged from 1.50 to 1.66 g/cc and were independent of depth. In RA10 the stone-free values ranged from 1.48 to 1.73 g/cc, with the values above 1.65 g/cc occurring between 45 and 135 cm.

Moisture retention is also given in Table 4; the one-third bar values were determined only



Source: ICRISAT Information Bulletin 5.

Figure 14. Probability fin percent) of receiving 10 mm or more rainfall during two selected 1-week periods: 14 to 20 May and 23 to 29 July in Niger.



Source: ICRISAT Information Bulletin 5.

Figure 15. Precipitation (in mm) that could be received during 13 August to 9 September at two levels of probability (25% and 50%) in Niger.

Table 4. Physical properties of two Alfisol profiles.

Depth (cm)	Stone content % [a]		Bulk density (g/cc)		Moisture content at[b] 15 bar		0.3 bar
	ST2	RA10	ST2	RA10	ST2	RA10	ST2
0- 15	2.4 ± 0.8	10.9 ± 9.1	1.55 ±0.22	1.57 ±0.20	6.0	8.6	8.3
15- 30	1.5 ± 0.8	7.7 ± 6.0	164 + 0.15	1.72 ±0.19	10.2	10.3	13.5
30- 45	0.6 ± 0.8	2.9 ± 1.7	1.59 ±0.07	1.67 ±0.10	14.8	10.4	18.7
45- 60	2.2 ± 4.8	1.4 ± 0.5	1.59 ±0.12	1.63 ±0.11	16.1	14.2	20.3
60- 75	4.3 ± 10.4	2.3+ 1.3	1.64 ±0.04	1.71 ±0.10	17.1	15.7	21.1
75- 90	5.0 ±13.0	11.1 ±19.7	1.60 ±0.04	1.79 ±0.12	17.2	15.8	21.8
90-105	6.6 ±10.1	16.2 ± 20.2	1.68 ±0.10	1.83 ±0.15	17.7	16.0	21.7
105-120	11.2 ±13.6	30.3 ± 27.8	1.65 ±0.09	1.85 + 0.14	17.6	16.9	21.5
120-135	12.4 ±14.5	21.7 ±18.4	1.75 ±0.10	1.81 ±0.16	16.8	16.6	20.6
135-150	18.1 ± 17.8	28.3 ± 8.1	1.70 ±0.09	1.86 ±0.16	16.4	16.4	20.6
150-165	28.0 ± 14.7	33.1 ± 14.1	1.80 ± 0.11	1.86 ±0.05	15.7	16.8	20.1
165-180	30.7 ± 10.0	31.0 ±15.9	1.74 ±0.08	1.83 ±0.13	14.9	16.4	19.6
180-195	16.6 ±14.2	35.1 ±21.6	1.80 ±0.14	1.89 ±0.20	15.0	ND	19.6

a. Weight percentage of material > 2 mm.
b. On a weight basis in stone-free samples.

on the ST2 samples. The de facto available water capacity of the ST2 deep Alfisol profile to a depth of 187 cm is 116 mm, where de facto available water capacity refers to the soil water available to the plant as determined in the field by moisture extraction patterns.

Soil Water Dynamics in an Uncropped Deep Alfisol

Twelve sets of tensiometers extending from 15 to 180-cm depths were used to monitor soil water pressures in a 0.2-ha area of a deep Alfisol during the 1978 rainy season. The volumetric water contents of the 187-cm profile were determined by neutron moderation and gravimetric sampling at 72 positions in the area on six dates during the rainy season.

The 5-day average tensiometer data (Fig. 16) showed that from mid-July to the end of September the soil was unsaturated at depths of 30, 60, and 90 cm, except for a fortnight following the very heavy mid-August rains. Soil water pressures at the 180-cm depth were positive throughout the period, indicating that the water table was above that depth continuously. Soil water pressures increased with depth throughout the period. The decrease in pressures at all depths during a 15-day rainfree period in early September showed that the profile was slowly draining; about 10 mm of water drained from depths below 30 cm during this period. By mid-September soil moisture suctions ranged from 52 mb at 30 cm to 22 mb at 90 cm. The data indicate that 0.1 bar would be more appropriate than 1/3 bar as an estimate of the suction at field capacity for this soil.

Hydraulic heads decreased with depth throughout the rainy season. The downward-directed hydraulic gradients were quite uni-

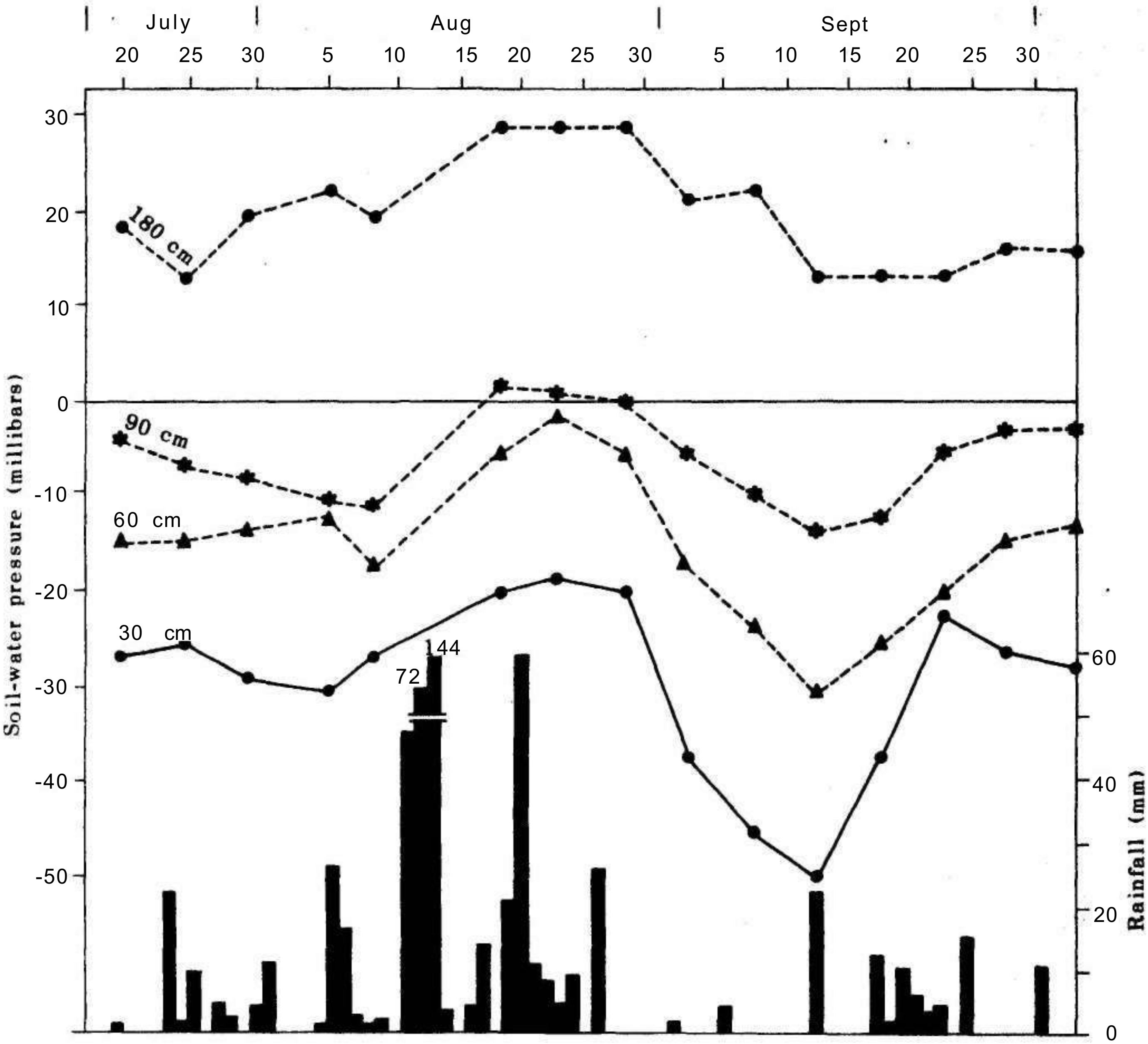


Figure 16. Soil water pressure at four depths in an uncropped deep Alfisol during the rainy season.

form throughout the profile, ranging between 0.8 and 0.6 cm/cm. The size of the gradients decreased as the drainage process proceeded.

Soil moisture profiles taken at 5 or more days after rain were very similar and indicated water-holding capacities of 45, 65, 71, and 106 mm for the 0 to 22, 22 to 52, 52 to 82, and 82 to 127-cm layers, respectively. The de facto available water capacities of those four layers are 29, 39, 25, and 20 mm, respectively.

Recharge and Drainage of an Uncropped Deep Vertisol

June rains (180 mm) fully recharged the uncropped Vertisol profile and caused 15 mm of runoff. During the month an estimated 100 mm of water was lost by evaporation. In July and August the soil surface was wetted nearly every day; 250 mm of evaporation losses occurred and the remaining two-thirds of the 745 mm of rain produced 260 mm of runoff and 240 mm of drainage below 187 cm. Some of the drainage occurred during the dry period in the first half of September. Rain in mid-September (35 mm) and a similar amount at the beginning of October recharged the upper parts of the profile and contributed slightly to drainage. Subsequent rains were retained in the partially depleted surface layers and did not cause drainage.

Three sets of 11 tensiometers at depths from 15 to 240 cm were used to monitor the pressure in the soil water from July 1978 to April 1979. From July to mid-October, hydraulic heads decreased with depth through the entire profile, from 30 to 240 cm, indicating downward-acting hydraulic gradients. During this period, pressures in the water were positive at all depths below 120 cm. Above that depth, suctions ranging from 0 to 100 mb and downward-acting hydraulic gradients around 0.3 cm/cm or less were recorded.

From October to March, hydraulic heads decreased progressively at all depths as water moved out of the profile by evaporation and drainage (Fig. 17). The "zero plane," i.e., the depth at which the sign of the hydraulic gradient changed, moved slowly downward from 45 cm on 7 October to 120 cm on 3 March, indicating that evaporation gradually replaced drainage as the cause of the slow depletion of moisture throughout the profile. This transition occurred when the soil moisture suction was at or near 0.1 bar. Below the "zero plane," changes in volumetric water content were too small to be detected by neutron moderation. Therefore evaporation was responsible for the 30 mm of water lost from the profile between 20 October and 13 January. The amount of drainage that occurred as unsaturated flow appears to have been negligibly small in the upper 2 m of this deep Vertisol.

Seasonal Water Balances in a Cropped Deep Vertisol

Profile water content to a depth of 187 cm of a Vertisol watershed (BW1 cropped with a maize/pigeonpea intercrop) was measured by neutron moderation on 13 dates from June to mid-January. Daily rainfall, open-pan evaporation, and runoff were measured and evaporation, transpiration, and drainage were computed for 12 periods totalling 226 days (Table 5).

Rainfall during the months was sufficiently high that the profile was fully recharged by mid-July, and remained so almost continuously until early October. As a result, the rainy-season maize crop experienced no moisture stress and runoff totalling 273 mm occurred on 17 dates from 16 June to the end of August. Two-thirds of the runoff was from the 273-mm storm recorded from 13 to 15 August. Runoff occurred only from storms greater than 20 mm, except when smaller rains followed a large rainfall.

Drainage, calculated as a decay function of the daily profile excess above 830 mm, occurred

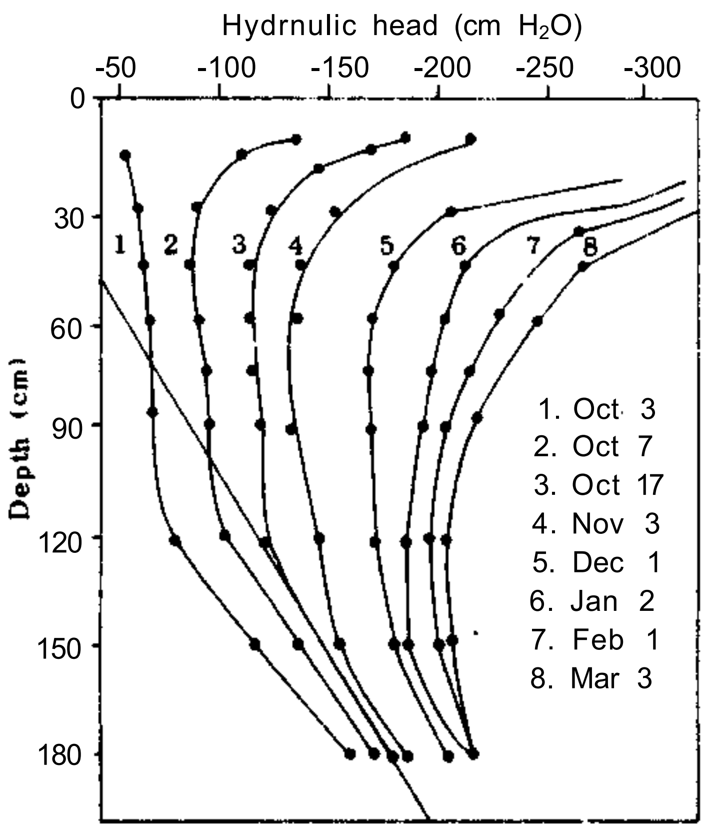


Figure 17. Hydraulic heads during drainage of a deep Vertisol.

Table 5. Water balance components for a cropped deep Vertisol* during tha rainy and postrainy seasons.

Period	Days	P	E_0	ΔM	E	T	R	D
		-(mm)-						
1 to 28 June	27	181	220	+ 81	90	0	10	0
28 June to 21 July	23	180	126	+ 74	60	23	12	0
21 July to 9 Aug	19	118	82	+ 2	20	72	0	24
9 Aug to 8 Sept	30	452	114	+ 21	25	90	250	65
8 Sept to 28 Sept	20	75	75	-36	15	61	0	35
28 Sept to 14 Oct	16	50	81	-33	20	30	0	30
14 Oct to 30 Oct	16	8	81	-31	10	30	0	0
30 Oct to 14 Nov	15	22	56	-18	10	30	0	0
14 Nov to 29 Nov	15	0	72	-34	4	30	0	0
29 Nov to 15 Dec	16	0	77	-21	0	21	0	0
15 Dec to 2 Jan	18	0	83	+ 1	0	0	0	0
2 San to 13 Jan	11	0	54	+ 2	0	0	0	0
Total	226	1086	1131		254	387	273	154

P = precipitation, E_o= open-pan evaporation, Δ M = change in profile content, E = soil evaporation, T = transpiration, R = runoff, D = drainage.

a. Location: field BW1, ICRISAT Center.

in each of the four periods from 21 July to 14 October. Because the soil surface was wet during most of the rainy season, evaporation from 1 June to 8 September was 195 mm, compared with 185 mm of transpiration. Thus evapotranspiration during the 99-day period was 70% of the open-pan evaporation value.

From 8 September to 13 January the available water content of the 187-cm profile decreased progressively from a maximum of 225 mm to a final value of 84 mm. During this period the upper 50 cm of the profile was partially recharged by a series of rains in September and October totalling 155 mm.

Pigeonpea transpired 200 mm of water and 60 mm of evaporation occurred in the 107 days beginning on 8 September. Thus the evapotranspiration during this period was 45% of the open-pan evaporation. The 187-cm profile contained virtually the same amount (650 mm) of water on 13 January as it did on the preceding 1 June.

Postrainy-Season Water Use by Pigeonpea

From 4 September to 21 December, water use by intercropped pigeonpea on a deep Vertisol (BW3) was 327 mm, representing 53% of the open-pan evaporation for that period. This consisted of 67 mm of evaporation and 260 mm of transpiration, which were supplied by 146 mm of rain and 181 mm of net profile depletion. During the rainy period prior to 10 October, water use was confined to the upper 52 cm of the profile where the available water fraction (AWF) remained above 0.5 (Fig. 18). After that date, profile depletion proceeded downward progressively. The AWF was less than 0.5 continuously from mid-October in the 0 to 52-cm layer and from mid-November in the 52 to 97-cm layer. The AWF for the 187-cm profile was 0.30 at harvest on 21 December. However, if the AWF of the individual layers was weighted by use of the relative extraction rates during the

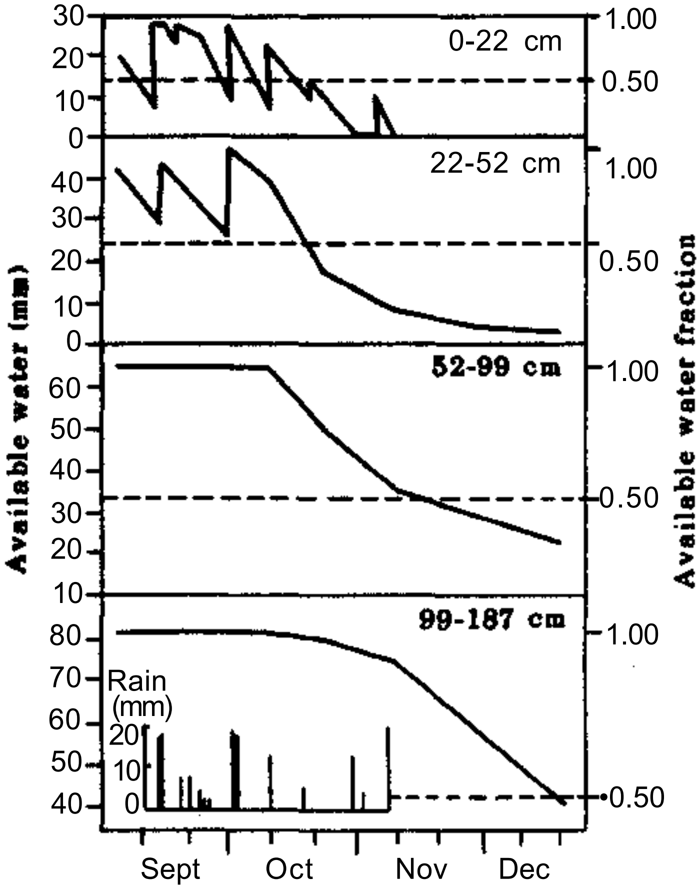


Figure 18. Available water at four depths under pigeonpea on deep Vertisol during the postrainy season.

10 to 23 October period as estimates of the relative root density, the weighted residual water fraction at harvest was only 0.14. During the profile depletion period, beginning about 10 October, the ratio of transpiration to open-pan evaporation decreased linearly with the weighted available water fraction. This suggests that the crop experienced increasing water stress during the 2 months before harvest. The yield was 1520 kg/ha.

Interdisciplinary Studies of Soil-Plant-Water Relations

Scientists from Agroclimatology, Cereal Physiology, Environmental Physics, Land and Water Management, and Pulse Physiology subprograms collaborated in a series of field experiments to examine the effects of differential depletion of profile moisture on the growth and yield of sorghum and chickpeas. These investigations were designed to produce congruent data sets of the physical and physiological performance of the soil-crop-atmosphere system for use in the development and/or testing of dynamic process-based crop production models.

The time and depth changes in available moisture in the profile were determined by periodic neutron moderation and gravimetric sampling and these related to the seasonal patterns of leaf area index. (LAI), dry-matter production, and transpiration estimated by water-balance calculations. Diurnal changes in leaf-water potential, canopy conductance and leaf temperature, and seasonal changes in light interception and leaf temperature were measured.

Effects of Profile Water Depletion on a Medium Alfisol

When sorghum was irrigated at 10-day intervals, its growth rate from 40 to 100 DAS was essentially constant at 18 g/m^2 of land area per day and its transpiration rate was also essentially constant at 3.6 mm/day, or about 80% of the average open-pan evaporation rate. The photosynthetic efficiency during that 60-day period was 0.60 g/einstein of intercepted photosynthetically active radiation (PAR) and the increase in rate of dry matter production was 6 g/day per square meter of green leaf area (Fig 19).

In a second treatment, the crop was not irrigated 35 DAS and growth rates decreased to 10, 6, and 3 g/m^2 per day for the periods from 40 to 60, 60 to 80, and 80 to 100 DAS, respectively. The corresponding values for transpiration were 2.0, 1.1, and 0.8 mm/day. Thus the dry matter produced per millimeter of water transpired remained close to the 5 g/m^2 that was its value for the unstressed sorghum (Fig. 19).

In a third treatment, no water was applied from 35 to 65 DAS but irrigation at 10-day intervals was resumed thereafter. From 40 to 60

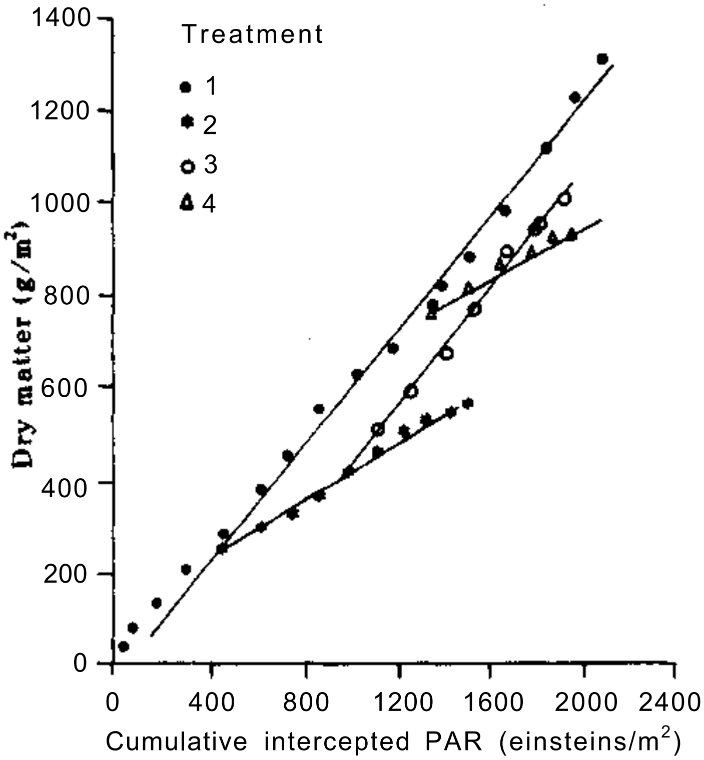


Figure 19. Effect of soil moisture on the photosynthetic efficiency of sorghum.

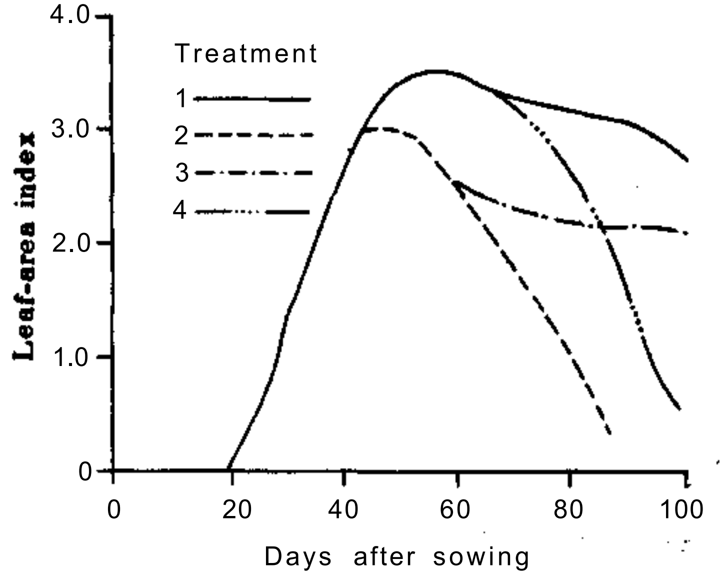


Figure 20. Effect of soil moisture on the amount and duration of green leaf area of sorghum.

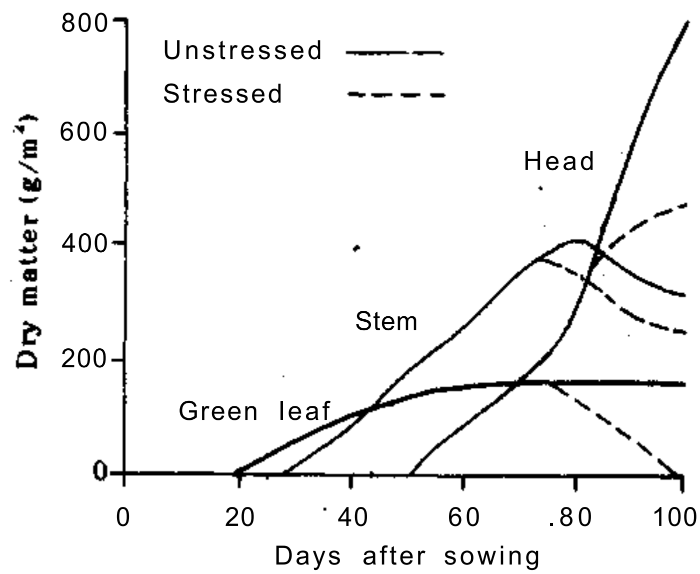


Figure 21. Effect of moisture stress on the growth of leaves, stems, and heads of sorghum.

DAS, growth and transpiration rates were the same as in the second treatment, but after the profile was recharged both returned to their unstressed values (Fig. 19).

For the fourth treatment, the crop was irrigated at 10-day intervals until 65 DAS, after which no water was applied. Crop performance was the same as in the first treatment until the 80 to 100 DAS-period when the dry-matter production and transpiration rates fell to 5.5 g/m^2 per day and 1.2 mm/day—again not far from the production rate of 5 g/m^2 of green leaf for each millimeter of transpiration of the unstressed crop. The photosynthetic efficiency during a 20-day stress period of 0.28 g/einstein was the same as in the second treatment, which was stressed from 35 DAS to harvest (Fig. 19). In both cases the value was roughly half that of the unstressed sorghum.

The four treatments had marked effects on the size and duration of the crop canopy (Fig 20). The leaf area durations were 227, 122, 188, and 183 LAI days, respectively, for the four treatments. The corresponding total dry matter of 300, 650, 1040, and 1010 g/m^2 was divided by the leaf area durations to give values close to 5.6 g/day for each square meter of leaf area.

The growth of the leaves, stems, and heads of the unstressed sorghum and for the late-stressed crop (Fig. 21) indicate that stress during the grain-filling stage increased the mobilization of dry matter from the stem, which may have contributed to filling of the grain. Late-season stress also produced a considerable reduction in the dry weight of green leaves, although total leaf dry weight was largely unaffected. The effects of stress on dry-matter translocation to the head are summarized in Table 6.

Profile moisture was monitored at 10-day intervals throughout the experiment and was analyzed in terms of the available water in the 0 to 10-, 10 to 22-, 22 to 52-, and 52 to 127-cm layers. The capacities of these layers were 10, 15, 30, and 45 mm of available water, respectively. When the treatments were irrigated at 10-day intervals the available water content of four layers ranged between 10 and 2, 15 and 5, 30 and 20, and 48 and 35 mm, respectively, indicating clearly that ample water was present at all depths throughout the 100-day growing season.

With the termination of irrigation 35 DAS, available water declined steadily in all layers and reached zero by 42, 52, 62, and 98 DAS for the four layers, respectively. If stress days for a layer are defined as the period of time when the available water content of a layer is less than half of its capacity (about 1 bar of suction), then the stress days for the four layers were 62, 60, 55, and 40, respectively—giving a stress day total of 217 for the second treatment. The corresponding values for the first, third, and fourth treatments were 30, 70, and 105.

Root densities measured at 10-cm depth intervals 65 DAS revealed no significant differences in the quantity or distribution of roots between the unstressed sorghum and the crop that received no irrigation during the preceding month. The fractional root length in the 0 to 10-, 10 to 22-, 22 to 52-, and 52 to 127-cm layers at 65 DAS were 0.23, 0.24, 0.34, and 0.19, respectively.

The grain yield, harvest indices, and water-use efficiencies were 7200, 1500, 3000, and 3300 kg/ha; 0.37, 0.24, 0.35, and 0.31; and 20, 7.5, 9.5, and 11.8 kg/ha of grain per millimeter of water transpired for treatments 1, 2, 3, and 4. respectively.

Response of sorghum to stress on a deep Alfisol. On 10 October, CSH-8 sorghum was planted on a deep Alfisol having a fully charged profile. Uniform irrigations at 17 and 36 DAS recharged the profile and good germination and vigorous early growth occurred. On 27 November (48 DAS) treatments I-11 and I-10 received 30 mm of irrigation which again recharged the profile. Three weeks later (70 DAS) treatment I-11 and I-01 were recharged with an irrigation of 75 mm. The fourth treatment, 1-00, received only sufficient water to ensure establishment of the crop.

Withholding of irrigation resulted in more complete depletion of the available water in the profile and a more rapid reduction in green-leaf area (Fig. 22). The rates of dry-matter

Table 6. Effects of moisture stress on dry-matter production and translocation in sorghum during 20 days prior to harvest.

Treatment	Prior to harvest			At harvest
	Heads	Stems	Current photosynthate	Heads
	(g/m^2)			
Unstressed	+ 550	- 80	470	830
Stressed from 65 DAS	+ 230	-100	130	510
Stressed from 35 DAS	+ 140	-110	30	285

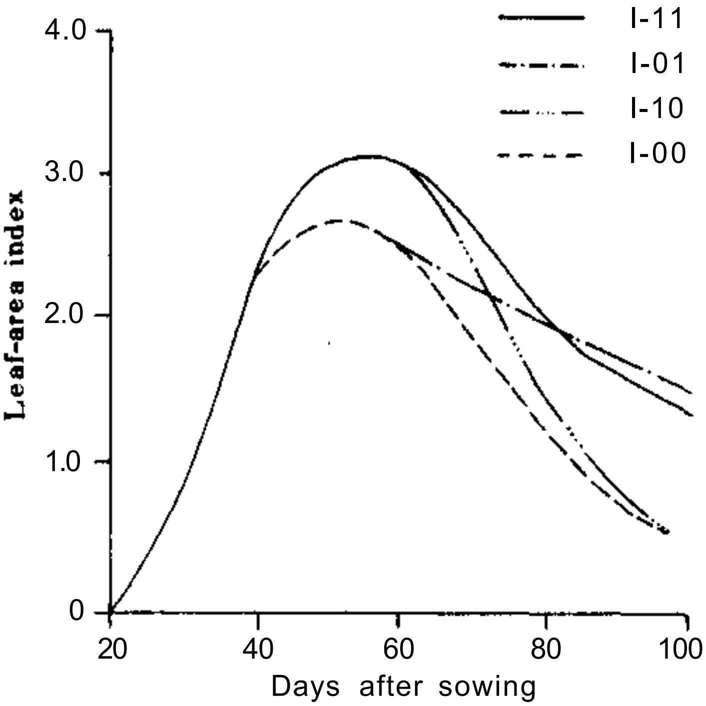


Figure 22. Effect of soil moisture on leaf area index (LAI) of sorghum.

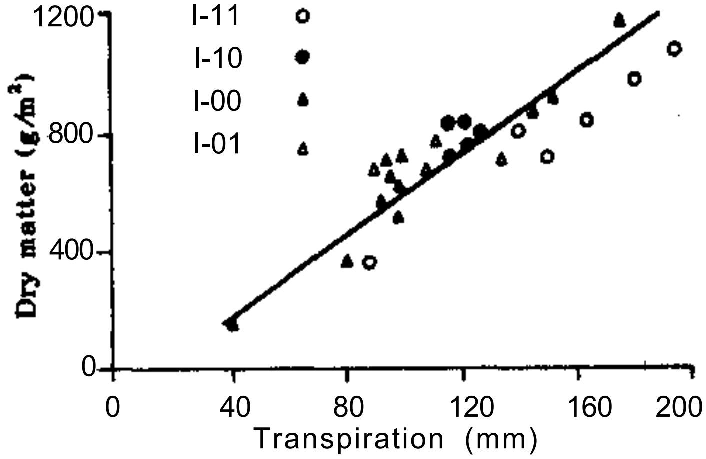


Figure 23. Relationship between transpiration and dry-matter production of sorghum.

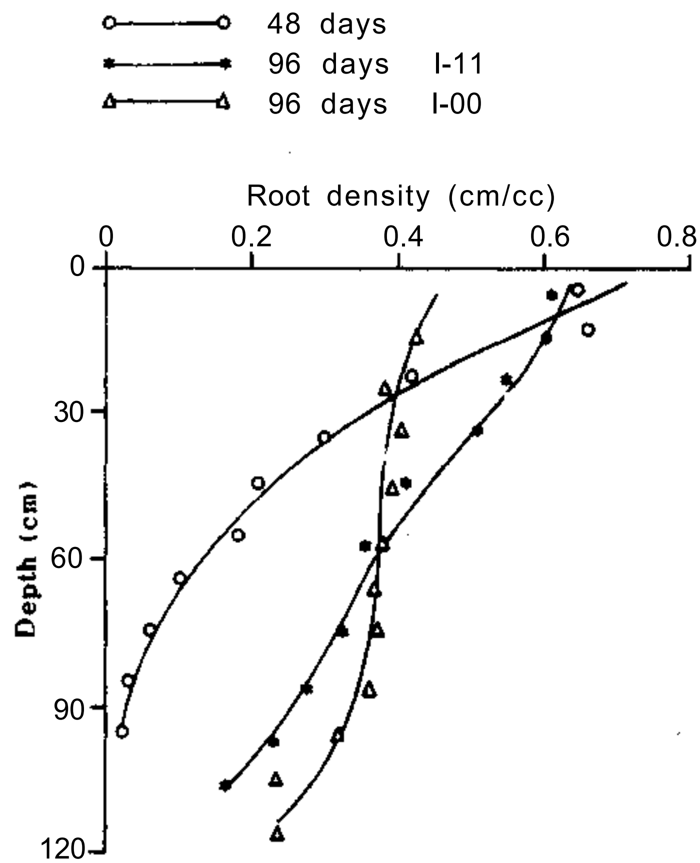


Figure 24. Effects of age and soil moisture on sorghum root profiles.

accumulation and of transpiration also decreased as profile depletion became more severe, but the ratio between them remained quite uniform at 6.8 g/m^2 per millimeter of water transpired (Fig. 23).

The amounts of dry matter at 100 DAS for I-11, I-10, 1-01, and 1-00 were 990, 780, 1010, and 730 g/m^2, respectively. The corresponding values of the average daily dry-matter production by each square meter of green-leaf area were relatively constant: 5.9. 5.1, 6.8, and 5.6 g, respectively. The photosynthetic efficiencies during the unstressed periods ranged from 0.58 to 0.65 g/einstein intercepted PAR. These values dropped steadily to as low as 0.21 g/einstein as the intensity and duration of profile water deficit increased.

Root density decreased with depth on each of the three dates of sampling (Fig. 24). At 48 DAS only 5% of the roots had penetrated beyond 75-cm. Twenty days later this had increased to 18% in MI and 25% in 1-00. The amounts and distribution of roots at 98 DAS were the same as at 70 DAS. Relatively high root densities of 0.2 to 0.3 cm/cm^3 at a depth of 120 cm, particularly in the treatments that had experienced more intense depletion, strongly suggest that significant root development had occurred below 120cm and that water was utilized from the deeper subsoil. This would explain the cluster of points for 1-00 and I-10 above the regression line in Figure 23. The four I-11 points lying below the line may indicate that the evaporation loss was underestimated for this treatment and/or that some drainage beyond 127 cm may have occurred following the last irrigation.

Rates of water extraction at different depths were determined from the soil moisture profile data and were used to prepare profiles of relative rates of water uptake. These were similar to the root density profiles at the dates and depths at which the available water fraction (AWF) was above 0.6 but were much reduced when the soil was more depleted. When the extraction rates of different soil layers were plotted against AWF, no simple relation emerged. However, the extraction rates for the entire 127-cm profile were approximately proportional to the available water fraction of the profile over the range from 0.85 to 0.20 AWF (Fig. 25).

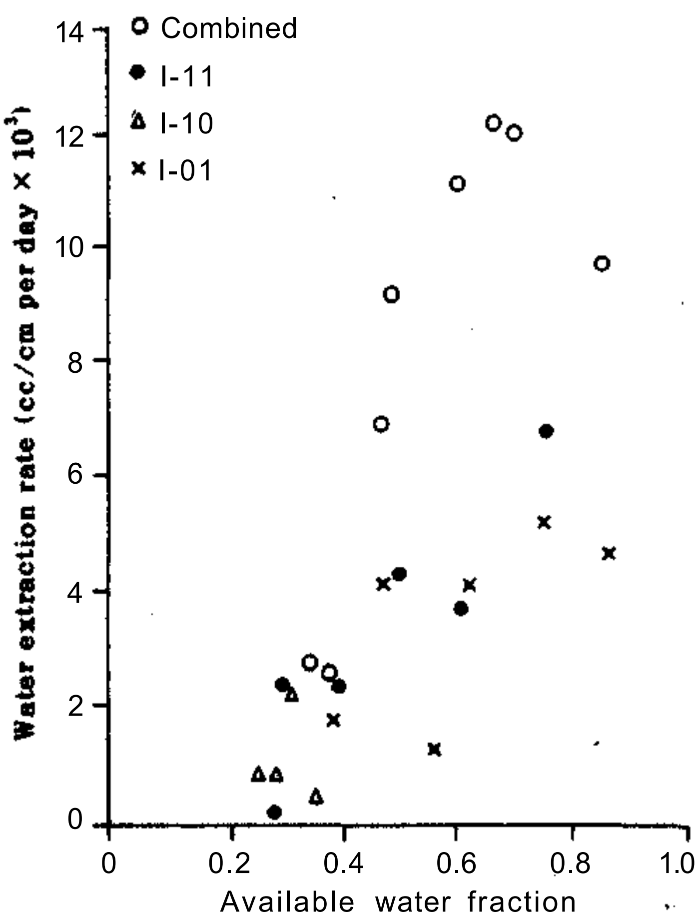


Figure 25. Effect of available water content on the rate of water extracted by sorghum roots.

The grain yield, harvest indices, and water-use efficiencies, respectively, for I-11, I-10, I-01, and 1-00 were 5400, 3100, 4800, and 2700 kg/ha; 0.46, 0.36, 0.43, and 0.38; and 64, 67, 67, and 79 kg/ha of dry matter per millimeter of transpiration. The higher water-use efficiency for the highly stressed sorghum I-00 gives further support to the possibility that significant amounts of water had been used from below 127 cm but were not included in our calculations.

Profile Water Use by Chickpeas on a Deep Vertisol

Annigeri chickpeas were planted in mid-October on a fully recharged deep Vertisol. A light sprinkler irrigation after sowing resulted in quick germination and good establishment. Treatment 1-0 received no further irrigations. For treatment I-1 the profile was recharged twice by irrigations at 26 and 38 DAS. In treatment I-2 the profile was recharged four times by irrigations at 26, 38, 60, and 97 DAS. Except for 13 mm on 31 October, no significant rain was received during the growing season.

In the nonirrigated plots the available water was exhausted to a depth of 22 cm by 30 DAS and to 52 cm by 75 DAS. Eighty percent of the available water of the 52- to 97-cm and 30% of the 97- to 157-cm layers were used in 105 days by the nonirrigated crop (Fig. 26). The number of days in which the AWF was below 0.5 in each of the three layers were 95, 65, and 48; 83, 55, and 43; and 67, 30, and 10 for treatments I-0, I-1, and. I-2, respectively. At 62 DAS the total root length in the 157-cm profile was 24 cm/cm^2, with no differences among the three treatments. The fractional root lengths in the four layers were 0.25, 0.26, 0.37, and 0.12. These were used as weighting factors for the number of days when AWF of each soil layer was below 0.5 to give seasonal stress indices of 59, 51, and 29 for f-0, I-1, and 1-2, respectively.

The size and duration of the chickpea canopy and final yield were affected strongly by soil moisture stress (Fig. 27). The leaf-area durations and yields were 40, 64, and 96 LAI days and 1300, 2100, and 3000 kg/ha for I-0, I-1, and

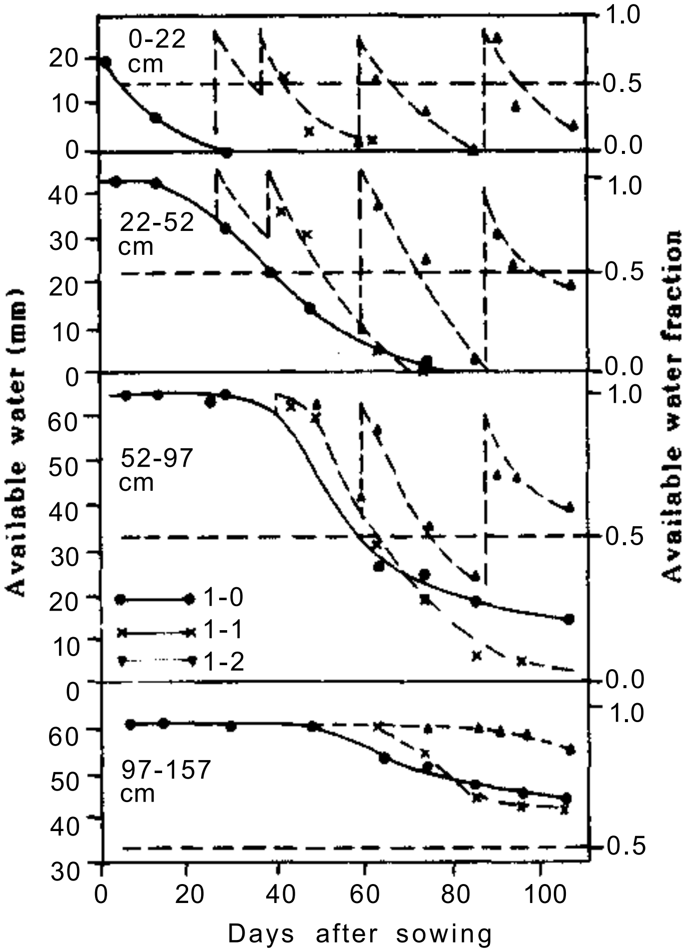


Figure 26. Seasonal changes in available water at four depths in a deep Vertisol under chickpea.

1-2, respectively. Thus the yield per LAI day was essentially constant.

The temperature difference between the chickpea canopy and the surrounding air was negative throughout the day in unstressed plots, but was positive in the stressed plots and it became positive progressively earlier in the day as moisture stress increased. The temperature differential at 1300 hr was inversely related to the available water fraction of the 157-cm-deep Vertisol (Fig. 28).

Soil Fertility and Chemistry

Most soils of the SAT are unable to supply

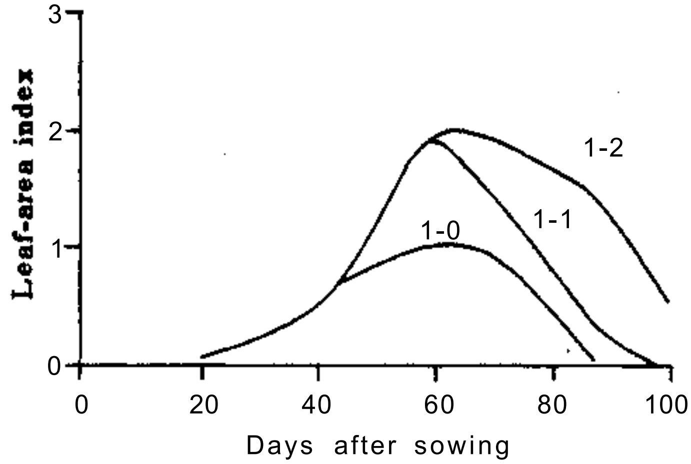


Figure 27. Effects of soil moisture on leaf area of chickpeas.

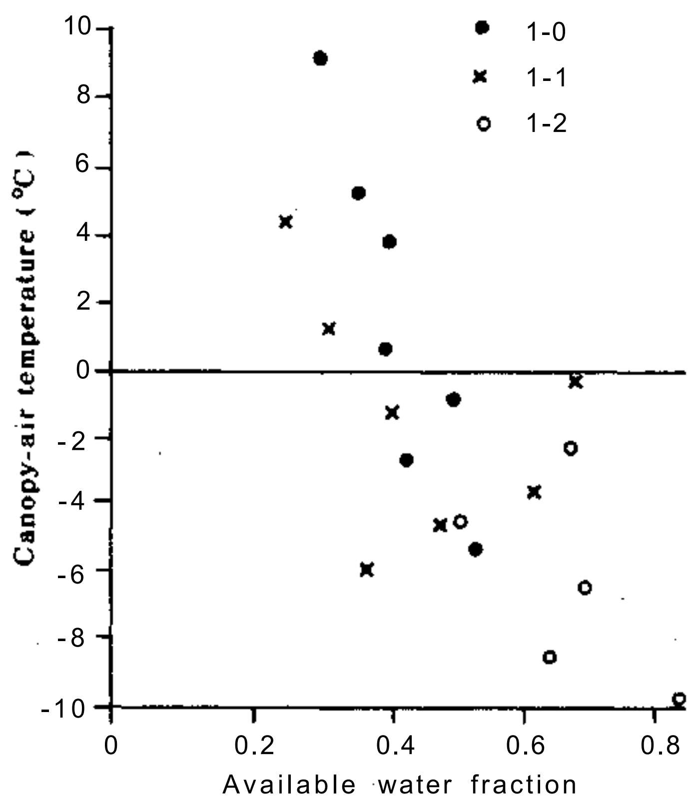


Figure 28. Effect of available water supply on leaf temperature of chickpea.

sufficient nitrogen and phosphorus for the optimum growth of crops. Deficiencies of these nutrients are likely to become more pronounced because increased cropping intensities and introduction of new varieties with higher yield potentials and higher nutrient requirements will place increased stress on soil nutrient supplies. Recent research in the Soil Fertility and Chemistry subprogram has therefore given increased attention to the nutrient requirements of new agronomic developments such as improved cropping systems.

Nitrogen Fertilization of Intercropped Cereals

Intercropping of cereals and legumes gives a considerable yield advantage over sole crops with a similar ratio of areas of land under monoculture. Although cereals require a substantial application of nitrogen fertilizer for maximum yield, little is known of the effect of intercropping with a legume on the response of the cereal to nitrogen fertilizer. Results obtained in the 1977-78 season on a Vertisol indicated that there was no significant difference in the nitrogen requirements of sorghum between sole cropping and intercropping, although there was a trend toward more efficient use of nitrogen fertilizer under sole cropping. Results obtained in the 1978-79 season again indicated that the response of sorghum grain yield to application of fertilizer nitrogen was greater under sole sorghum than under sorghum intercropped with pigeonpea (Figure 29); the effect of the intercrop was smaller this year than in the previous year, but it was statistically significant. In contrast to the results obtained previously, pigeonpea yields were significantly decreased (from 840 to 630 kg/ha) when nitrogen fertilizer was increased (from zero to 120 kg N/ha) on the companion sorghum, presumably due to the competitive effect of more vigorous sorghum growth.

Millet/groundnut intercropping is common on light-textured soils in the SAT, but this intercropping system is much different from that of sorghum/pigeonpea. Whereas pigeonpea continues to grow long after sorghum has been harvested, millet and groundnut mature at about the same time; the marked differences in the growth habits of the two species and stimulation of millet by nitrogen fertilizer

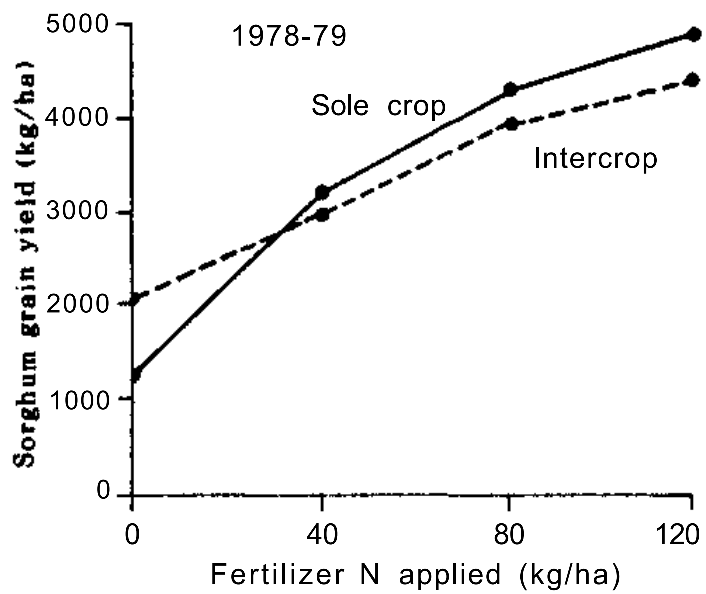


Figure 29. Response of sole and intercropped sorghum to fertilizer nitrogen.

could be expected to result in increased shading of groundnut as well as competition for available soil water. In a preliminary response-to-nitrogen experiment on an Alfisol, millet responded less to fertilizer nitrogen when intercropped and there was a significant reduction in groundnut yield (Table 7).

The significant reduction in legume growth that occurs following nitrogen fertilization is of considerable interest because of the contrast in growth habits and competition between the components in the two intercropping combinations.

Phosphorus Fertilizers

Because India has few indigenous sources of sulphur, it is desirable to investigate whether its deposits of rock phosphate can be used as a substitute for superphosphate, which is more expensive though it contains phosphorus in a much more readily available form. A long-term experiment, now in its third year, clearly demonstrates the superiority of superphosphate over rock phosphate (Table 8), on an Alfisol that is only slightly acid (pH 5.5 to 7.0). Sorghum grain responded substantially to superphos-

Table 7. Effect of fertilizer nitrogen applied to intercropped millet on yield of millet grain and groundnut pods (kg/ha).

Fertilizer nitrogen applied (kg/ha)	Cropping system					
			Intercropped		Mean	
	Sole millet	Sole groundnut	Millet/ groundnut 1:2	Millet/ groundnut 1:3	Millet	Groundnut
0	468	903	217/400	201/433	295	417
40	1477		653/339	478/426	859	382
80	1985		1055/281	660/355	1234	318
120	1901		1139/271	918/315	1319	293
Mean	1458		766/323	564/382	927	353

		Nitrogen	Planting patterns	Nitrogen x Planting patterns
LSD (0.05)	Millet	180	156	311
	Groundnut	42	29	NS

Table 8. Response of sole sorghum and intercropped pearl millet/pigeonpea to phosphorus applied as single superphosphate or rock phosphate.

Phosphorus applied (kg/ha)	Grain yield (kg/ha)		
	Sorghum	Pearl millet	Pigeonpea
0	2500	580	730
	Rock phosphate		
20 annually	2690	820	680
40 „	2550	830	760
80 in 1977	2880	850	580
160 in 1977	3360	980	730
	Single superphosphate		
5 annually	3010	1150	930
10	3360	1250	950
20	3950	1370	780
LSD (0.05)	360	60	180

phate applications of up to 20 kg P/ha per year. Millet responded relatively little to applications greater than 5 kg P/ha; pigeonpea, which was intercropped with the millet, gave only a small and nonsignificant response. Responses to rock phosphate were significant, in contrast to the previous year, with a large application in 1977 giving greater responses than smaller annual applications. This experiment is continuing.

Land and Water Management

Improved land and water management systems are being developed to increase and stabilize crop production in the semi-arid tropics (SAT). The objective is to improve the efficiency of use of land and water resources and to transfer the improved technology to national action agencies. The five major areas of activity are: (1) land and water management research under field conditions, (2) hydrologic data collection and modelling, (3) systems research on an operational scale, (4) collaborative land management research with national organizations, and (5) on-farm watershed development and management projects.

On Vertisols

Studies were conducted in the field on deep and medium-deep Vertisols to measure the effect of three land management techniques on runoff, soil loss, and crop production during the rainy and postrainy seasons. On deep Vertisol plots, maize was planted as the rainy-season crop, followed by chickpea in the post-rainy season. The treatments compared were (1) 150-cm broadbeds, (2) 75-cm narrow ridges, and (3) flat cultivation. In all three, crop rows were maintained at a 0.6% grade, and plot sizes ranged from 0.5 to 1.0 ha. The broadbeds and the narrow ridges had a more friable surface layer than the flat treatment. Both maize and chickpea populations were highest on the broadbeds; thus, as in earlier years, this method of cultivation appeared to provide more favorable conditions for crop establishment. No breaching of the broadbeds occurred. Runoff exceeded 20% of precipitation, with no significant differences among the treatments (Table 9). Soil loss from the broadbeds was 30% less than that from the other treatments. Yields of maize were highest with the broadbed-and-furrows land management practice (Table 9). The higher returns for the maize and chickpeas on the broadbeds observed during the last 3 years (Table 10) indicate the superiority of this treat-

Table 9. Runoff, soil loss, and crop yields for three land management systems on a deep Vertisol at ICRISAT Center.

	Runoff (% of rain)[a]	Soil loss	Yields: Maize	Yields: Chickpea
		kg/ha x 1000		
Flat	24	2.1	1.78	0.98
Narrow ridges	22	2.0	2.05	0.73
Broadbeds	25	1.4	2.10	1.01

a. Seasonal rainfall: 1010 mm.

Table 10. Monetary return in rupees/hectare of three land management treatments on two Vertisols.

	Maize and chickpea on deep Vertisol		Maize/pigeonpea on a medium-deep Vertisol	
Treatment	1978	1976-78 (Av)	1978	(1976-78(Av)
Flat	3860	3770	1960	2910
Narrow ridges	3570	3930	3050	2980
Broadbeds	4400	4470	2500	3130

Maize @ Rs 0.95 kg; chickpea @ Rs 2.2 kg; pigeonpea @ Rs 2.6/kg.

ment on deep Vertisols during years of below-average rainfall (1977) as well as above-average rainfall (1978).

On the medium-deep Vertisol, weed growth was intense in the maize/pigeonpea intercrop due to frequent wet periods and inadequate crop cover. Runoff was generally higher on broadbeds than in the other two treatments. On a seasonal basis, runoff on these soils was only about half of that observed on deep Vertisols. The results of the past 3 years are not conclusive. Although studies of broadbeds indicate somewhat higher yield levels over time, further experimentation is required to obtain conclusive results.

On Alfisols

A sorghum/pigeonpea intercrop was grown to compare two land management treatments, fiat cultivation and broadbeds, on Alfisols (RW 3). Weed growth was less on broadbeds, but crop yields were not different on the flat-planted and broadbed treatments. In another experiment on Alfisols flat cultivation, broadbeds, and narrow ridges were compared. Measurements of the soil-water contents showed that during wet periods the moisture content of the top layers in flat plots was higher than in broadbed plots, whereas during dry periods moisture in the surface layers of flat plots was less than in broadbed plots. Thus, in both situations, the flat cultivation was inferior. Further studies on land-surface configuration are required to evaluate the effects of land management on runoff, erosion, and crop yields on Alfisols.

Hydrologic Modeling and Simulation

A parametric simulation model was developed at Utah State University, USA, by an ICRISAT scientist (J.H. Krishna, PhD dissertation, 1979) to predict runoff from small agricultural watersheds. The input data for it are the daily rainfall amount, storm duration or rainfall intensity, pan evaporation, and soil moisture.

By means of a univariate optimization procedure, measured runoff data are used to determine the proportion of rainfall that infiltrates and the part that runs off. Once these parameters are determined for a particular soil and land management treatment, they can be applied directly to other watersheds of similar cover, topography, and moisture storage and transmission properties for predicting runoff and other water balance components.

The model embodies upper zone and lower zone soil moisture reservoirs that are depleted by evapotranspiration and recharged by infiltration sequentially from the top. When both reach their capacities, further infiltration causes deep percolation. Daily evapotranspiration is computed from open-pan evaporation, vegetative cover, and the amount of water in the root zone.

At ICRISAT Center, hydrologic data from three Vertisol watersheds of similar size, shape, and topography but having different land management treatments were used for deriving and testing the model. Two years of data were used for calibration and the model was tested with data from the third year (Table 11). In all cases, there was excellent agreement between computed and observed runoff events (Fig. 30). There were 12 runoff-producing storms and the objective function (R^2) was 0.974, while the mass balance (MB) was 0.029. When measured soil-moisture data were compared with those computed by the model they were found to match very closely (Fig. 31). The model was further verified with data for a small Vertisol watershed in Texas, USA. The two parameters obtained from a single year of data were similar to those obtained for the ICRISAT watersheds having similar land management treatments, but the computed runoff was 27% less than the measured amount. These results demonstrate that as a first approximation, parameter values can be used for similar soils and treatments under a range of rainfall conditions.

The computed rainy-season water balances for the "traditional" watershed BW4C, and the "improved" watersheds—BW1 without field bunds and BW2 with field bunds— indicated that evaporation from uncropped BW4C was virtually the same as the evapotranspiration

Table 11. Results of storm runoff simulation model.

Watershed	Area (ha)	Location	Year	Land treatment	Computed runoff (mm)	Measured runoff (mm)
BW1	3.4	ICRISAT	1974	Ridges and furrows	112.3	114.1
BW2	4.0	ICRISAT	1975	Within-field bunds	134.3	124.2
BW4C	3.5	ICRISAT	1974	Flat, monsoon fallow	204.1	210.3
TW13	4.5	TEXAS	1971	Ridges and furrows	20.8	28.3

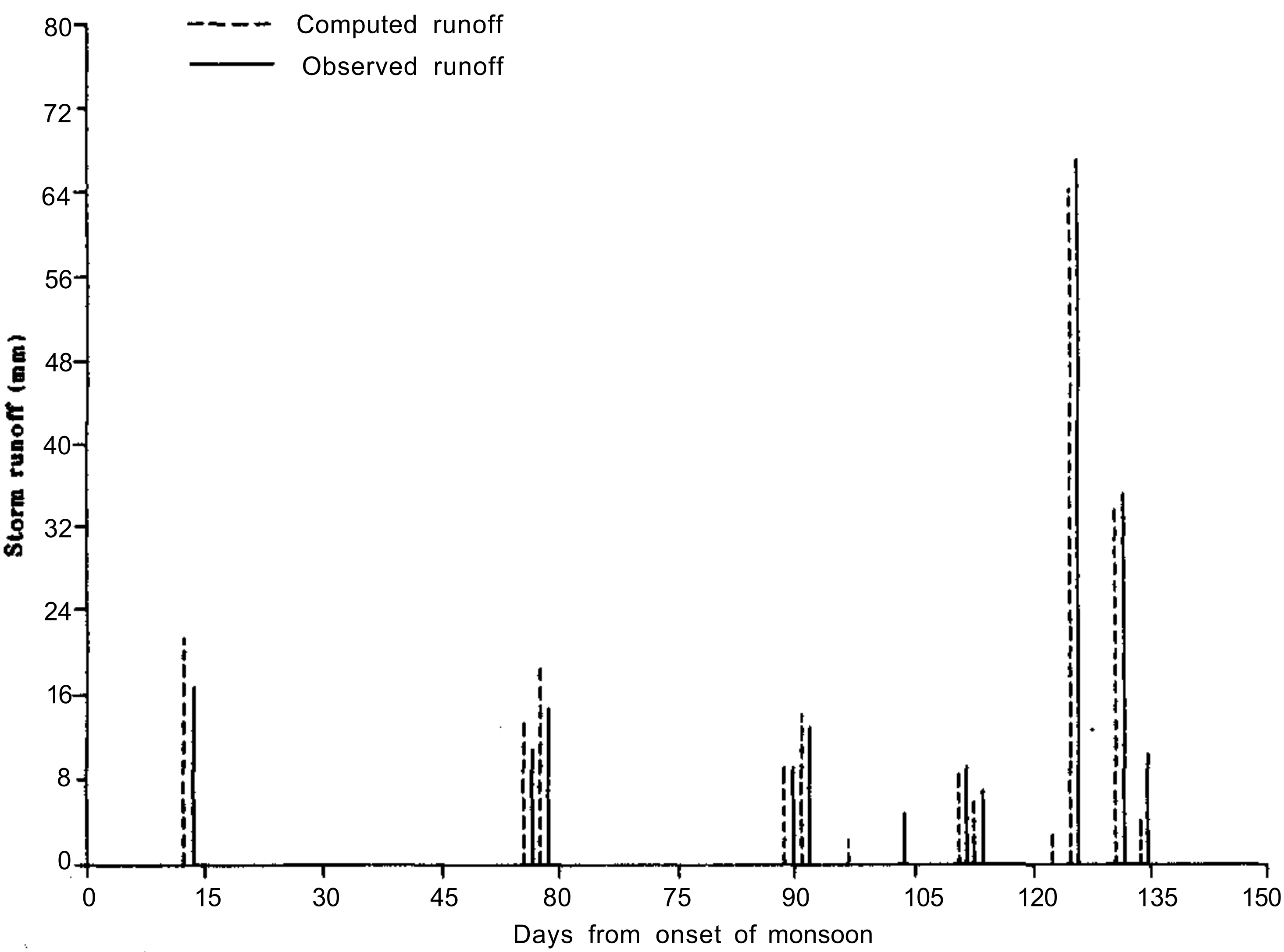


Figure 30. Comparison of computed and observed runoff events for BW-4Cin 1974.

from the BW1 and BW2, which were cropped. Seasonal profile accretion was similar in the three watersheds. The presence of the crop reduced runoff by about 50% (BW1 vs BW4C), and field bunds reduced runoff in the cropped watersheds about 30% (BW2 vs BW1). Since rainfall, profile accretion, and evapotranspiration losses were not different among the three watersheds, the reductions in runoff were balanced by corresponding increases in deep percolation.

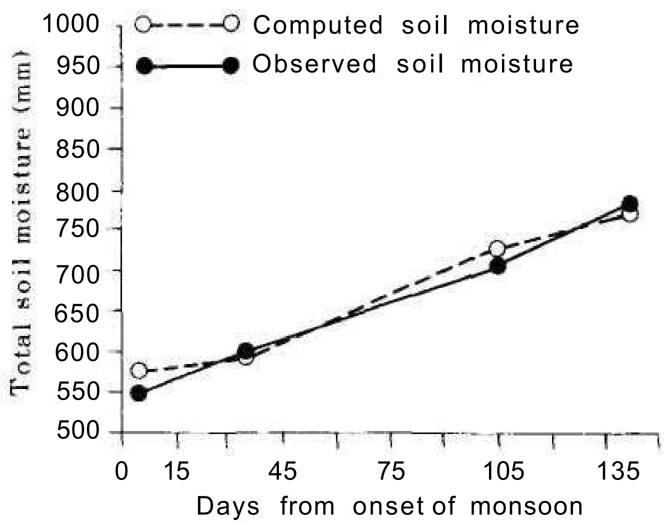


Figure 31. Comparison of computed and observed soil moisture variation for BWI in 1974.

Farm Power and Equipment

The Farm Power and Equipment subprogram aims to improve the understanding of processes and systems utilizing agricultural machinery. In keeping with ICRISAT's mandate to assist, in particular, small farmers of limited means, special attention is being given to the use of animal power, which is prevalent in many parts of the SAT. Major areas of research in this subprogram are (1) machinery management, (2) soil management, (3) harvest and postharvest technology, and (4) design and fabrication.

Machinery Management

Collection of data on machinery operations was continued to determine more precisely the factors affecting operating efficiencies. Service recorders were used to measure the '"time efficiencies" of the Tropicultor, a bullock-drawn wheeled tool carrier, during several tillage operations on the Vertisol watersheds (Table 12). Time efficiency is defined as the percentage of time a machine is operating out of the total time it is committed to the operation, and includes all operations (such as turning time and transport to and from the farmstead to the field).

Table 12. Average time efficiency of the Tropicultor in the Vertisol watersheds at ICRISAT Center.

Operation	No. of observation days	Time efficiency (%)	Total time[a] (hr/day)
Ridging	32	74 ± 6.7	8.2
Plowing	60	66.9+ 9.9	8.1
Cultivation	62	71.2 ± 11.7	8.0
Bed shaping	17	86.6 ± 9.1	9.4
Planting	30	75.1 ± 15.0	9.6
Interrow cultivation	50	78.1 ± 10.5	9.6

a. Includes a lunch break of approximately 1 hour.

as opposed to field efficiency, which includes only the actual operating time in the field.

The relatively low time efficiency for plowing, which involves the highest draft, indicates that the animals required more rest time. Other factors that contribute to differences among operations and to the rather high standard deviations of the mean values are the level of supervision, the experience of the bullock drivers, and the soil conditions. Bed shaping, planting, and interrow cultivation are often done in double shifts using two pairs of bullocks per day. The amount of rest time is thereby reduced and time efficiency increased.

The effects of field layout on machinery capacity during bed forming and interrow cultivation were measured on two Vertisol watersheds, each having a similar area under the bed-and-furrow system of land management. One (BW1) contains 222 beds averaging 98 m in length but has no bunds. The adjacent BW2 has the original field bunds, which increase the number of beds to 426 with a mean length of 55 m. Despite this large difference in bed length and turning time there were no significant differences in the field capacities of the Tropicultor field, when operating in the two watersheds (Table 13). This suggests that the bed-and-furrow system can be used on some bunded fields without significant loss of the Tropicultor's field capacity.

Table 13. Field capacities for various operations in watersheds BW1[a] and BW2[b] at ICRISAT Center using the Tropicultor and its implements.

	Actual field capacity (ha/hr)	
Operation	BW1	BW2
Bed shaping	0.42	0.35
Interrow cultivation (I)	0.35	0.36
Interrow cultivation (II)	0.43	0.40

[a]BW1 a 3.25-ha watershed containing no bunds.
[b]BW2—a 3.55-ha watershed containing field bunds.

Soil Management

The effects of primary and secondary tillage practices on the growth and yield of pearl millet and on weed growth were studied on an Alfisol during the rainy season. Three primary tillage methods shallow sweeps, chiseling to a depth of 15 cm at 45-cm spacing, and strip plowing with left- and right-hand moldboard plows at 90-cm spacing—were used on 150-em beds. Their draft requirements under normal working conditions were 90, 250, and 220 kg, respectively. Pearl millet was sown in 45-cm rows with a planter having three kinds of press wheel designs. Four levels of interrow cultivation (0, 1, 2, and 3 cultivations) and a weed-free treatment were imposed on each of the primary tillage treatments.

The press wheels (Fig. 32) gave soil compactions over the seed of 0, 0.3, and 0.4 kg/cm^2 and millet stands of 265, 318 and 354 thousand plants/ha. By 42 days after planting these dense stands had fallen to about half of their initial values, and final yields were unaffected.

Except for the weed-free treatment all yields were low and weed growth was high (Table 14). Primary tillage did not influence millet yields

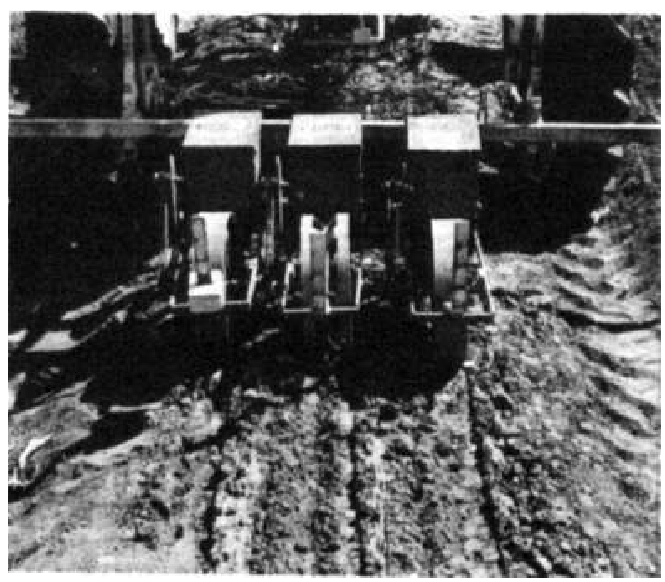


Figure 32. Planter press wheels giving compaction levels of (left to right) 0.4,0.0, and 0.3 kg/cm^2.

Table 14. Effects of primary tillage and interrow cultivation on millet yields and early season weediness.

	Pearl millet PHB-14		Weediness
	Grain	Dry matter	Dry matter @ 42 DAS
	-(kg/ha)-		
Primary tillage			
Strip plow	800	2060	1370
Chisel	740	1880	1390
Sweeps	710	1720	1180
Secondary tillage			
None	420	950	1960
1 Cultivation	370	1230	1740
2 Cultivation	490	1140	1400
3 Cultivation	690	1730	1380
Weed-free	1830	4540	0
LSD (0.05)	390	1050	420

DAS = Days after sowing.

or weediness. Interrow cultivation reduced weediness and increased yields slightly. But, because the season was exceptionally wet, weed growth was vigorous—particularly within the crop row—and was the major determinant of millet yield.

In all primary tillage treatments the center row on each bed was taller and gave higher yields than the adjacent side rows (Fig. 33). This effect was most pronounced in the strip-plowed treatment and may have been caused by differences in the amount of surface-soil nitrogen mineralized during the 2-week period after primary tillage and before the reshaping of the beds prior to sowing.

Harvest and Postharvest Technology

Preliminary evidence has indicated that some hybrid sorghums are difficult to thresh; therefore tests were conducted on 21 cultivars using the IRRI portable axial flow thresher. Three 2-kg samples of subdried heads of each cultivar with 12 to 14% moisture and similar maturities were threshed. The weights of unthreshed grain (i.e., seeds with glumes still attached), broken grain, and the percentage of clear grain that passed through the concaves were determined (Table 15). The wide range (0.5 to 27%) in amount of unthreshed grain confirms the fact that sorghum cultivars differ widely in ease of threshing. Even for the cultivars that threshed easily, the cleaning percentages were low because the axial-flow thresher used has no provision for winnowing or screening the material passing through the concaves.

In cooperation with the Economics Program, a marketing study was conducted with 22 samples of CSH-6 sorghum having differing amounts of broken and unthreshed grains. Up to 4% of broken grain did not affect the price (Fig. 34). Above that level the price decreased 1% for each percentage point increase in the content of broken grain up to 10%, which was the maximum level checked. Unthreshed grain content affected the price to a greater extent: As the

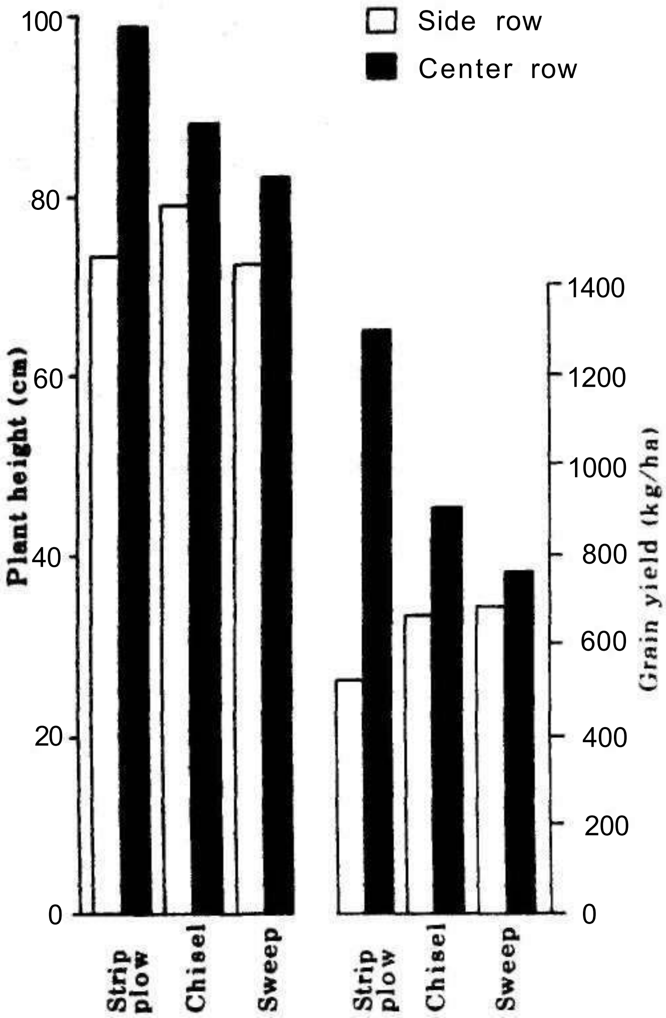


Figure 33. Effect of primary tillage on plant height 39 days after planting and final yield for side and center rows of pearl millet (ICRISAT Center, 1978).

Table 15. Sorghum threshing results (%), ICRISAT Center (postrainy season 1978-79).

	Percentage of grain		
Variety	Unthreshed	Broken	Clean
CSH-8	26.6	2.8	58
CSH-6	21.0	2.1	62
CSV-5	20.8	0.4	78
TX-63	12.7	0.4	86
SPV-86	11.5	1.3	63
CSH-1	11.4	1.5	82
M-3	10.4	0.4	79
FLR-53	7.0	0.7	81
M-4	4.4	12	86
V-302	3.9	1.8	85
CS-3541	3.2	0.5	81
CSH-5	2.6	2.1	83
M-35-1	2.3	1.4	87
RSH-1	2.1	1.7	86
Local	2.1	1.6	90
FLR-101	2.0	0.6	81
RSI x VGC	1.9	12	83
M2	1.4	0.4	85
MI	12	1.4	84
TX-62	0.8	12	88
IS-1037	0.5	2.4	84

amount of unthreshed grain increased from 0 to 10% the price decreased by 10%. It declined by an additional 5% when the amount of unthreshed grain increased from 1 to 20%.

Because of adverse weather conditions and storage problems, a need exists for mechanical threshing of crops such as sorghum and pearl millet, which mature at the end of the rainy season. Threshing tests with sorghum and millet conducted with five threshers of comparable capacity, but differing in cost and mechanical complexity, revealed wide differences in threshing percentages, separation losses, cleaning efficiencies, and capacities. The IRRI portable

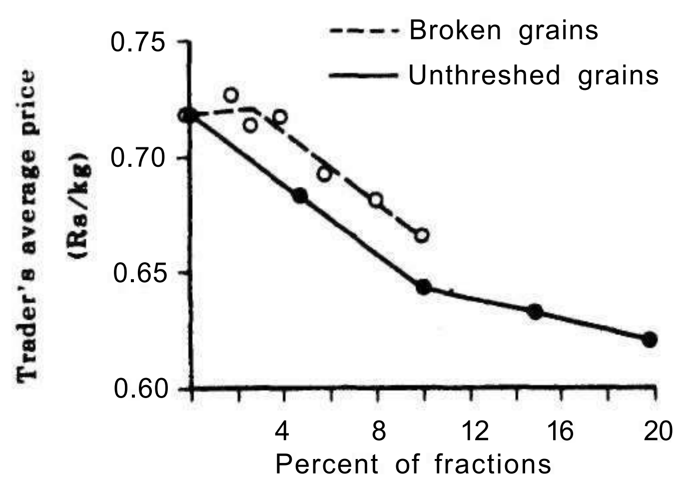


Figure 34. Effect of unthreshed and broken grain on the market value of sorghum.

axial flow thresher, which is the simplest to manufacture and to operate, was selected for modification. Replacement of alternate rows of cylinder spikes by flaps of canvas belting improved the threshing percentage from 68 to 83, and the capacity from 150 to 182 kg/hr. Modification of the concave and the angle of the feeding spiral gave further increases to 85% threshing and 210 kg/hr capacity, and reduced separation losses to 5%.

Machinery Design and Fabrication

During the past several years considerable emphasis has been placed on the adaptation and use of the Tropicultor. This animal-drawn wheeled tool carrier provides the basic unit of a complete set of implements needed in an improved crop production system; but it is too expensive (at Rs 8000, US $1000) for most of the small farmers in the SAT.

Discussions were started with several manufacturers in India to begin production of a wheeled tool carrier and associated implements. As a result three manufacturers are producing the basic unit and one of them is also making the necessary tillage implements. We are working with the manufacturers to incorporate the modifications needed to comply with the Indian Standards Institution specifications, to maintain quality control, and to redesign to incorporate local materials and components.

Efforts are being made to develop other designs of cheaper and simpler wheeled tool carriers. The most advanced prototype, a modified, small, low-cost bullock cart used in parts of central India strictly as a personnel carrier, has been modified to incorporate a toolbar with a mechanical lifting and lowering mechanism and a 150-cm wheel track (Fig. 35). The implements mounted on the toolbar are generally simpler, smaller, and lower in cost than those used with the Tropicultor. The prototype is less versatile than the Tropicultor because of its fixed track and low axle, and it has

Figure 35. Low-cost bullock cart modified for use as a wheeled tool carrier.

less structural strength. The prototype's wooden wheels with bush bearings increase friction and rolling resistance, which increases its draft in comparison with the more sophisticated and expensive Tropicultor.

Collaboration has started with the Overseas Division, National Institute of Agricultural Engineering, U.K., to develop a lower cost animal-drawn wheeled tool carrier incorporating only adjustments that are considered essential, and using fabrication methods that can be easily utilized by relatively small manufacturers. The first prototype has been made and appropriate modifications are being made, based on the results of initial testing.

A suitable fertilizer distributor is needed as part of a complete system of machinery for small farmers. A conventional seed-fertilizer drill with fluted metering has been used for applying fertilizer as a separate operation before planting, both at ICRISAT Center and in Village-Level Studies. Frequent choking of the metering mechanism and difficult maintenance are the drill's major drawbacks. Because it is desirable to combine the fertilizer application and planting into one operation, development of a unit fertilizer distributor to match the unit planters was undertaken. Investigations have shown that use of an auger for positive metering is acceptable. Figure 36 is a sectional view of the unit fertilizer distributor, consisting of a hopper with a capacity of 6 kg of fertilizer and an easily removable Acme threaded auger supported on nylon bushes. Application rates can be varied by changing the speed of the auger.

Cropping Systems

Intercropping receives major emphasis at ICRISAT because *of its* importance in farming practice and because it offers the possibility of achieving substantial yield advantages cheaply and easily. Since last season, major expansion has occurred in crop physiological work, which seeks an understanding of how yield advantages are achieved, and in studies on identifying and selecting more appropriate genotypes.

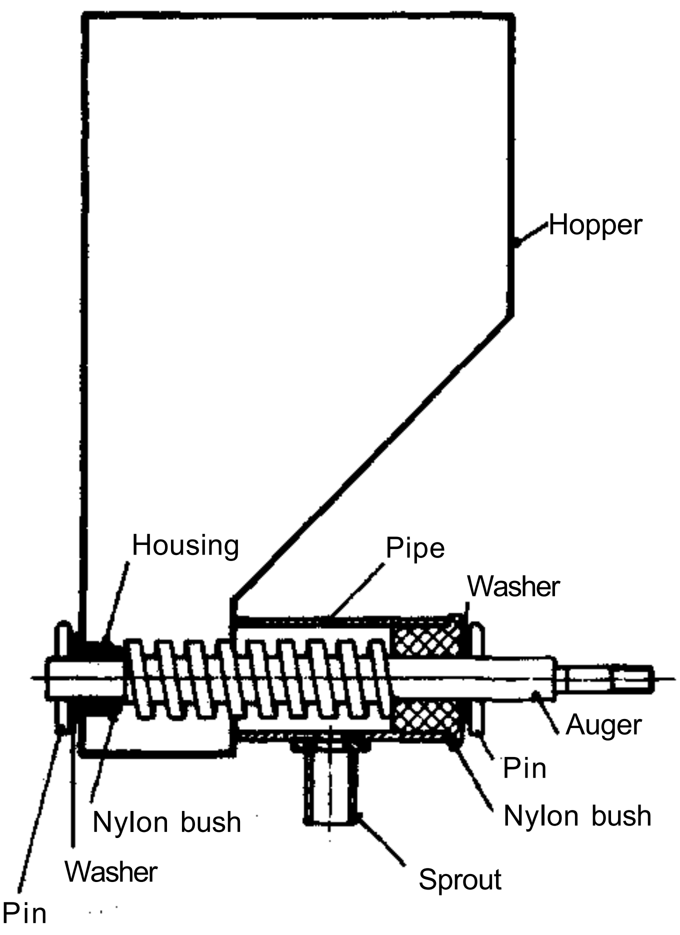


Figure 36. Sectional view of fertilizer distributor.

Research has also been initiated in two important new fields—yield stability, and the effects of intercropped legumes on associated and subsequent crops.

Investigations on double cropping in Vertisols continued, and a study has been started on the possibilities of increasing the cropping intensity of Alfisols.

Physiological Studies in Intercropping

In 1977, a detailed growth study of sorghum/pigeonpea intercropping on a Vertisol indicated that, with a row arrangement of 2 sorghum: 1 pigeonpea, a full yield of sorghum could be maintained but the pigeonpea yield was limited by very poor light interception just after sorghum harvest.

In this season a similar study, also on a Vertisol, examined how far light interception and yield of pigeonpea could be improved by using a 1.1 row arrangement to increase the number of pigeonpea rows, and by increasing the pigeonpea population. The sorghum growth was in general very good, and the sole crop yield was 4909 kg/ha. In contrast to last year's results, however, the sorghum yield decreased in intercropping, averaging only 85% of the sole crop; it was also rather less at the 1:1 row arrangement (83%) compared with the 2:1 (88%), but it was not affected by pigeonpea population.

The general growth of pigeonpea was exceptionally good, though final seed yield of the sole crop was only a little higher (1299 kg/ha) than last year. Growth in intercropping was better than last year and it was less affected by competition from the sorghum. At sorghum harvest, the dry-matter yield of intercropped pigeonpea averaged 33% of the sole crop, compared with less than 15% last year, and the mean seed yield at final harvest was very high at 91% of the sole crop.

Light interception after sorghum harvest was much greater in the 1:1 row arrangement than in the 2:1 (Fig. 37). This was reflected in

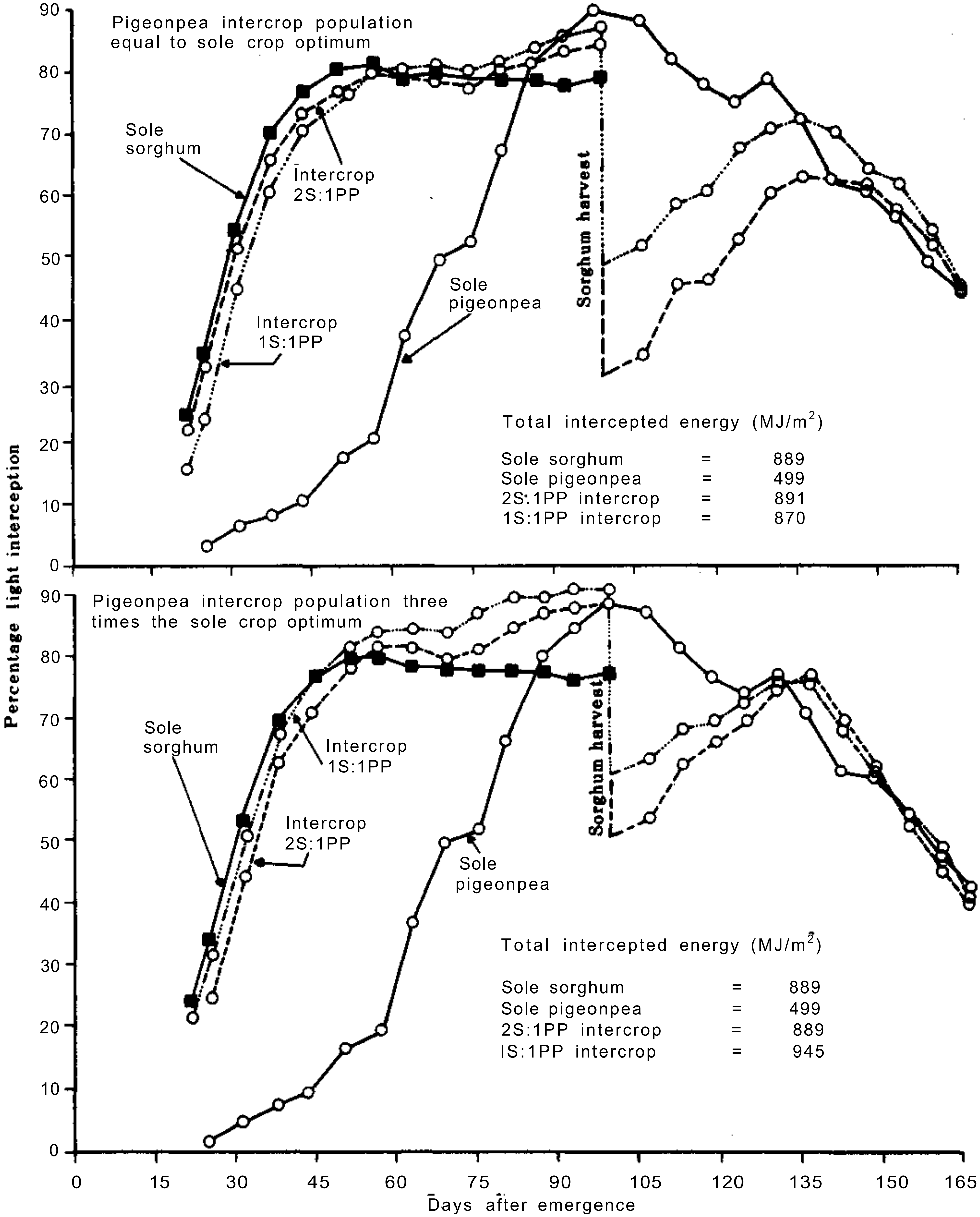


Figure 37. Light interception by sole crops of sorghum and pigeonpea and by intercrops at two row arrangements and two pigeonpea populations on a Vertisol (2S: 1 PP — two rows sorghum: 1 row pigeonpea, IS: 2 PP = one row sorghum: two rows pigeonpea).

higher dry-matter yields but there was no effect on final seed yield. Light interception was also greater at a higher pigeonpea population (Fig. 37), where there was still some further response to row arrangement; again these light interception patterns reflected changes in dry-matter yields but not in seed yields. It is suggested that this lack of response in seed yields was because pigeonpea growth was in general very good, even the poorest being almost 90% of the sole crop, and thus there was very little scope for further improvement. This very good pigeonpea growth was due probably to the favorable moisture conditions just before and after sorghum harvest.

The efficiency of conversion of light energy into dry matter in comparison with that in 1977 is given in Figure 38. The much higher efficiency of sole sorghum than that of pigeonpea in both seasons presumably reflected the respective C_4 and C_3 photosynthetic pathways. The higher efficiencies in 1978, especially for sorghum, were probably because of the lower light intensities. In 1977, the efficiency of the intercrop was higher than that of sole sorghum because the intercropped sorghum yield was not reduced and the pigeonpea yield was additional. This effect was not repeated in the comparable treatment this year, mainly because of the reduction in sorghum yield. There was no effect of row arrangement, but efficiency was improved at the high pigeonpea population where there was a substantial additional pigeonpea yield. In both years, the efficiency of the intercropped pigeonpea after sorghum harvest was very similar to the sole pigeonpea. Combining the 85% sorghum mean yield with the 91% pigeonpea mean yield as a Land Equivalent Ratio (LER) gives a value of 1.76, i.e., an advantage of 76% over sole cropping. This was achieved at some sacrifice of sorghum yield, and in farming practice "full" yield of this component is generally required. However, the mean absolute yield of sorghum in intercropping was still very high at 4192 kg/ha.

Another detailed growth study conducted on an Alfisol compared an intercropping treatment of 1 row millet:3 rows groundnut with the

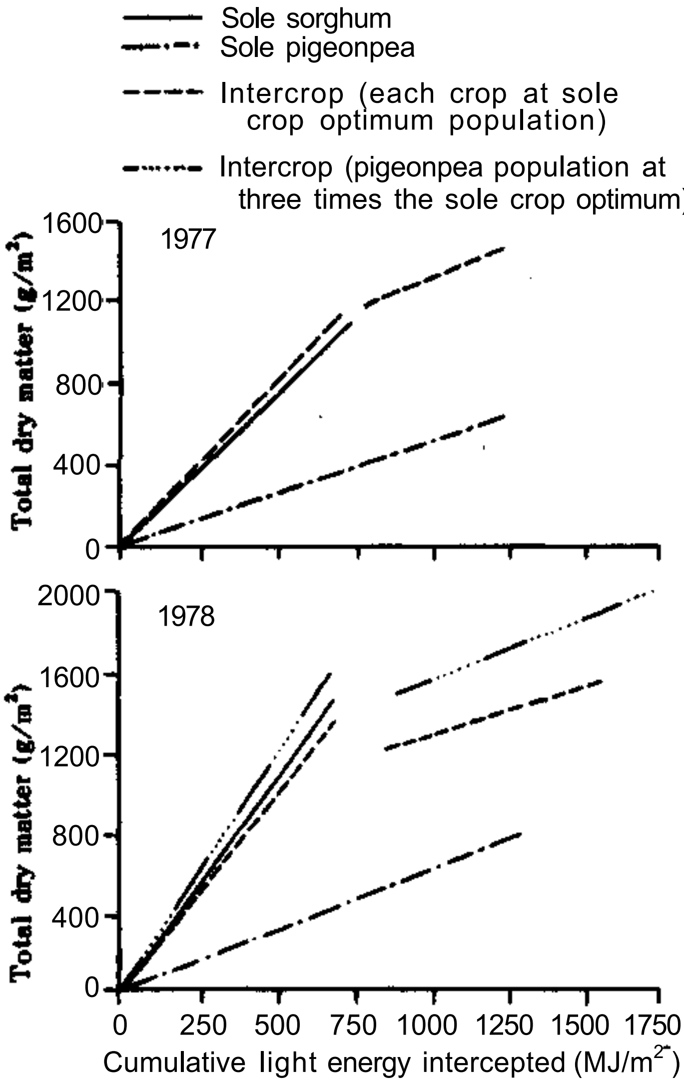


Figure 38. Dry-matter accumulation in sole crops and intercrops of sorghum and pigeonpea as a function of the cumulative light energy intercepted.

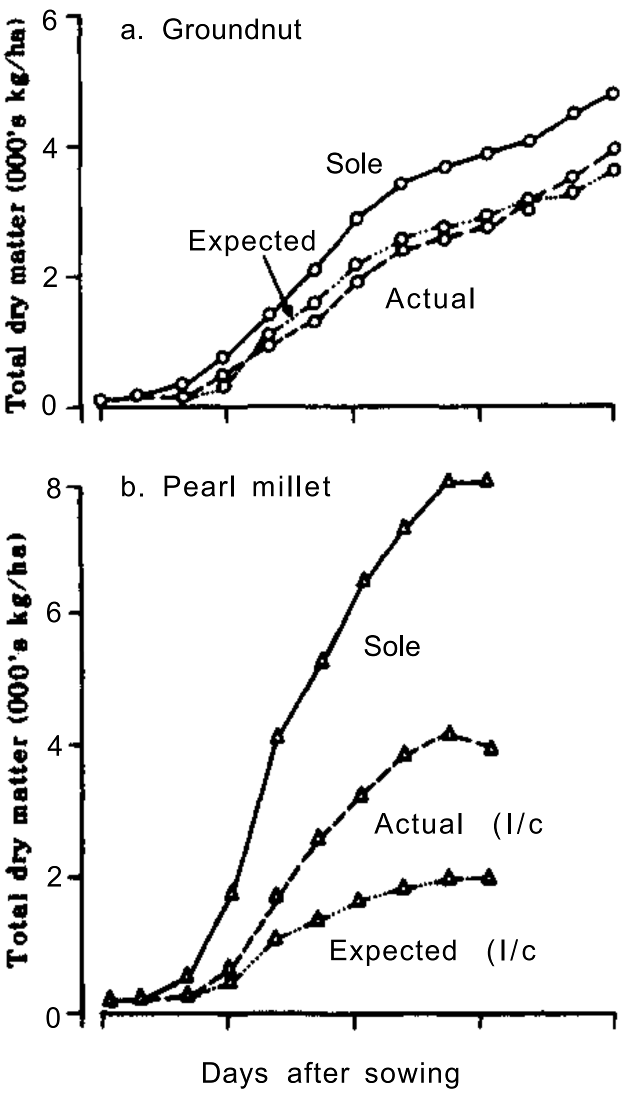
respective sole crops. A basal dressing of 50 kg/ha of P_2O_5 was applied to all treatments, and all millet rows were topdressed at the rate of 80 kg/ha of nitrogen.

Yield per plant of groundnut was similar in both systems, so on an area basis both the cumulative dry-matter yield (Fig. 39a) and the final pod yield approximated the 75% sole crop yield "expected" from the sown proportion of this crop. Yield per plant of the millet in intercropping was approximately twice that in sole cropping, mainly because of greater tillering and larger heads. On an area basis, the cumulative dry-matter yield (Fig. 39b) and the final grain yield of millet were more than half the sole crop yield and approximately twice that of the "expected" 25% sole crop yield. The LERs for combined cumulative dry matter were well above 1 in the later growth stages (Fig. 39c), and for final pod and grain yields the LER was 1.26. i.e., an advantage of 26% over sole cropping.

Measurements of light interception showed that intercropping did not intercept more light energy than sole cropping; but this energy was more efficiently converted into dry matter (Table 16). There was no evidence that water was used more efficiently in intercropping or that it limited yield, though the latter finding was not surprising in view of the particularly wet season. Similarly, there was no evidence that nutrients limited yield in intercropping, though there was a greater uptake commensurate with the higher yields. Future studies will examine the relative importance of the different resources when water and nutrients are more limiting.

Plant Population Studies in Intercropping

Plant population responses in sorghum/pigeonpea were examined on a Vertisol at a constant 2 sorghum :1 pigeonpea row arrangement, and with four populations of sorghum arranged as main plots and seven pigeonpea populations



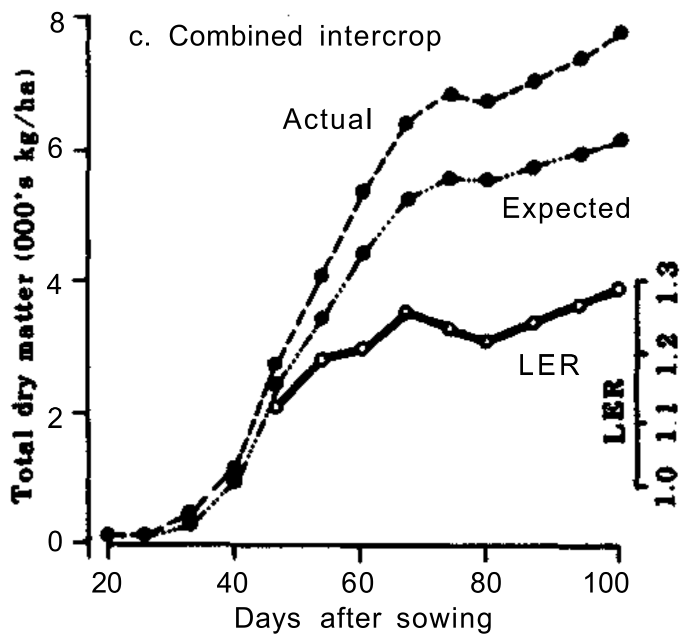


Figure 39. Dry-matter accumulation of pearl millet and groundnut in sole cropping and intercropping. Expected yield for individual crops in intercroppirig (a & b) is that expected from their sown proportions (i.e., 75% of sole crop for the intercrop groundnut and 25%of sole crop for the intercrop millet). Expect' ed yield for the combined intercrop is when the land equivalent ratio — 1.

Table 16. Weekly mean values of efficiency of dry matter production per unit of light intercepted for sole crops and an intercrop of pearl millet and groundnut (g/MJ).[a]

Days after sowing	Sole groundnut	Sole millet	Expected[b] intercrop efficiency	Actual intercrop efficiency
26-33	0.48	1.20	0.70	1.82
33-40	1.44	1.90	1.66	1.95
40-47	1.49	2.90	2.32	2.68
47-54	1.33	1.71	1.55	2.37
54-61	1.09	1.55	1.30	1.65
61-68	0.60	0.95	0.75	1.22
68-75	0.28	0.81	0.50	0.51
75-82	0.11	0.04	0.05	0.44
82-89	0.20	_	0.20	0.38
89-%	0.49	-	0.49	0.57
96-103	0.44	-	0.44	0.76
26-103	0.60	1.32	0.83	1.08

a. Light was measured with a soiarimeter sensitive to all wavelengths for which the standard unit of energy is the Joule: MJ = megajoule.

b. Efficiency "expected" if each crop had the same efficiency in intercropping as in sole cropping.

systematically arranged as subplots. The sorghum population response in intercropping was similar to that in sole cropping, a fitted response function suggesting an optimum of about 180 000 plants/ha which is the generally recommended sole crop optimum for sorghum. However, the yield level was somewhat lower in intercropping, the maximum being equivalent to only 81% of the maximum sole crop yield of 4972 kg/ha.

Even at the lowest population of 20 000 plants/ha (i.e., about half the generally recommended sole pigeonpea crop optimum), the pigeonpea yield was very high at 83% of the maximum sole crop yield of 1025 kg/ha; there was a very small response up to about 70 000 to 80 000 plants/ha (about twice the sole optimum), at which point yield was equivalent to 87% of the sole crop. Total LER was very high at 1.67, i.e., an advantage of 67% over sole cropping; this differed little among the different population treatments.

Another cereal/pigeonpea experiment examined the population response at three different row arrangements on 1.5-m broadbeds. In the Farming Systems operational research the standard row arrangement on these broadbeds has been one pigeonpea row in the center of the bed with a cereal row on either side (CPC). To try to improve the poor light interception of the intercropped pigeonpea after cereal harvest, the number of pigeonpea rows was doubled in both sorghum/pigeonpea and maize/pigeonpea; in one arrangement, two rows of pigeonpea were sown in the middle of the bed (CPPC), and in another arrangement one row was sown on each side with two cereal rows in the middle (PCCP). These arrangements differ because the gap between beds (60 cm) is greater than the between-row spacing on a bed (45 cm). CPPC gave an intercrop pigeonpea yield equivalent to 76% of the 1822 kg/ha sole crop; this was similar to the original 2:1 arrangement (CPC = 78% of sole crop). PCCP produced an increase in pigeonpea yield (84% of sole crop), but this was offset by a slightly reduced cereal yield.

In general, maize performed rather better in intercropping (96% of the sole crop yield) than did sorghum (90% of sole crop yield). Also the pigeonpea at low populations suffered less competition from the maize than from the sorghum, presumably because the maize was harvested 2 weeks earlier. But with both cereals, the mean population response of the pigeonpea was up to about twice the sole crop optimum population and gave the same maximum yield (83% of sole crop). Total LER values were again very high, averaging 1.68 for sorghum/ pigeonpea and 1.77 for maize/pigeonpea.

In millet/groundnut on the Alfisols our previous experiments highlighted the need for a high groundnut population to maintain a reasonable contribution from this component, but little information has been obtained on the required millet population or the optimum row arrangement. This season, at constant within-row groundnut population, four millet populations were examined in the millet: groundnut row arrangements of 1:2, 1:3, 1:4, 2:2, 2:3, and 2:4. The double millet row in the last three arrangements was included because this is often seen in farming practice in India, but it is uncertain whether this is done for practical convenience (e.g., because the sowing equipment handles two rows more easily than one) or because there is a beneficial yield effect.

When intercropped with two rows of groundnut, the yield per row of millet was appreciably higher than the yield per row in sole cropping, but there was no difference between single or double rows (Fig. 40a). With three and four rows of groundnut, the yield per row increased further for the single millet row but not for the double row; thus a given intercrop millet row suffered more competition when it was adjacent to another millet row than when it was between two groundnut rows.

With a single row of millet, mean yield of all groundnut rows in intercropping was a little less than the yield per row in sole cropping, and it was much the same whether there were two, three, or four rows *of* groundnut (Fig. 40a). With a double row of millet, yield per row of groundnut decreased at all row arrangements, presumably because the double millet row produced a more dense lateral shade. Arrangements with double millet rows were therefore poorer-yielding than the single row arrangements because they reduced yield of both the millet (with the exception of the 2:2 arrangement) and the groundnut.

The intercropped millet showed a much more definite response to population than the sole

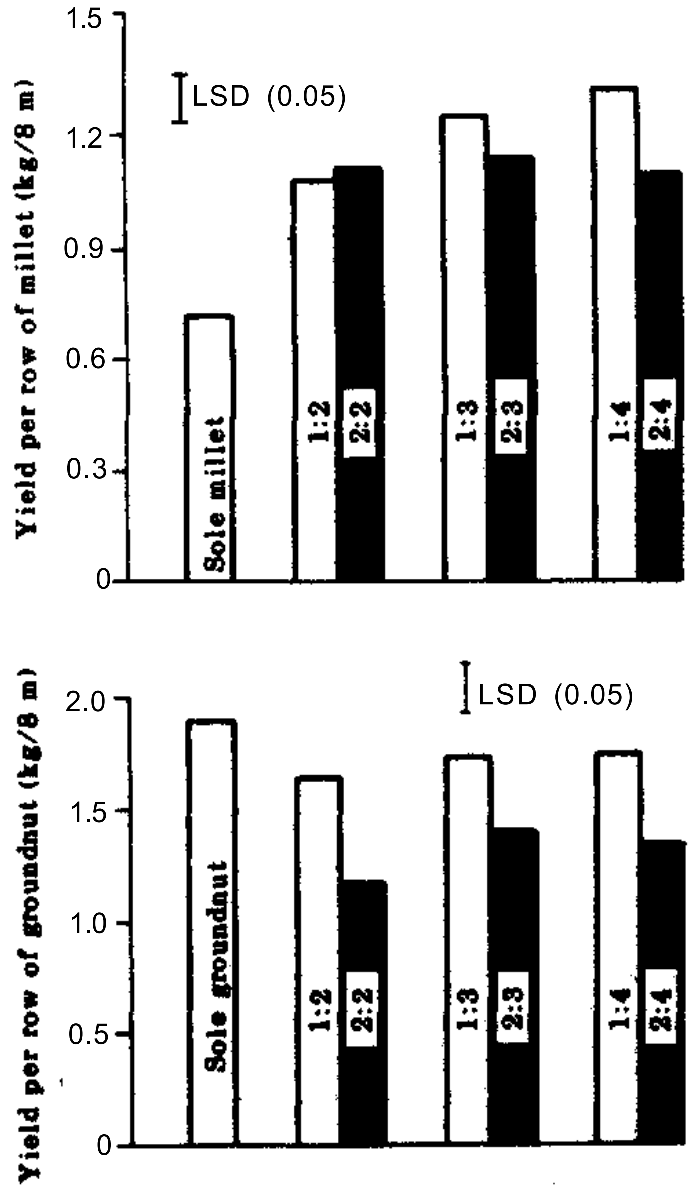


Figure 40 a. Effect of number of millet rows to groundnut rows on yield per row in intercropping.

crop, indicating an optimum within-row population of about eight plants/m (Fig. 40b). However, increasing the millet population also decreased the groundnut yield, so total LERs were little different throughout the experiment. It is emphasized, however, that even when population or row arrangement does not affect the overall efficiency of intercropping in terms of LER, these factors are still an important means of manipulating the contributions of the two crops; e.g., increasing the millet population gave more millet but less groundnut, and increasing the proportion of rows of either crop gave a higher yield from the increased crop at the expense of the other.

Continuation of the sorghum/chickpea studies on the Vertisol in the postrainy season indicated that the sorghum population should only be 50 000 to 60 000 plants/ha, which is even lower than indicated last year. Again, a 1:1 row arrangement with a mean LER of 1.17 proved better than a 1 sorghum:2 chickpea arrangement with a mean LER of 1.07.

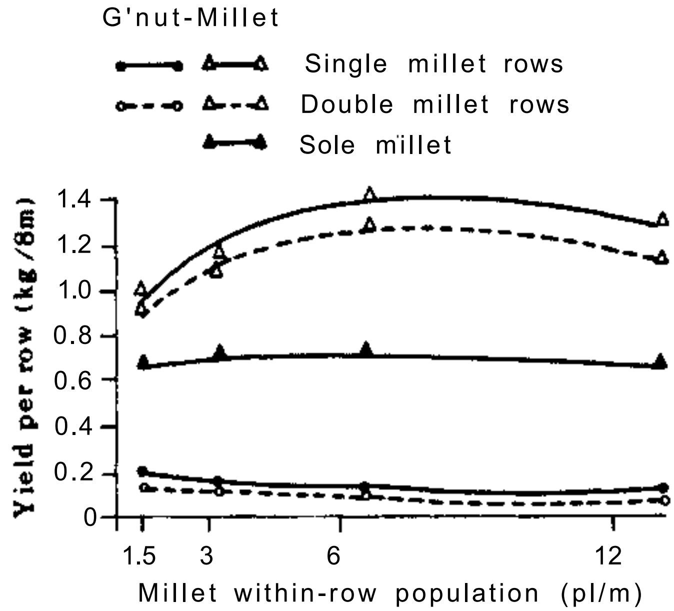


Figure 40 b. Effect of millet within-row population on yield per row of millet and groundnut in intercropping.

Genotype Studies in Intercropping

The agronomic evaluation of pigeonpea genotypes started in 1977 in conjunction with the Pigeonpea Program's breeding subunit continued, and 20 medium-maturity genotypes were grown on a Vertisol with and without an intercrop of CSH-6 sorghum; the row arrangement in intercropping was 2 sorghum: 1 pigeonpea. The intercropped pigeonpea yield ranged between 73 to 96% of sole crop yields, which was much higher than the previous year, and absolute intercrop yields were more closely correlated with sole crop yields ($r^2 = 0.74$ compared with 0.40 in 1977). The best plant type for intercropping again appeared to be one that was fairly compact in the early stages (and thus better able to withstand the sorghum competition) but having a more spreading habit later. However, the different results across the two seasons suggest that plant characters which ensure a high intercrop performance may be less important in very favorable seasons, such as this 1978 one; proportional intercrop yields were all so high that genotype yield differences in intercropping were largely a reflection of the yield differences in sole cropping.

Four pigeonpea genotypes of different maturities were also examined on an Alfisol in combination with four sorghum genotypes of different maturities and two pearl millet genotypes (Fig. 41). Intercrop cereal yields averaged 94% of sole crop yields and were not differentially affected by pigeonpea genotype. Intercropped pigeonpea yields decreased with increase in cereal maturity: they averaged 66% for the earliest sorghum (M-35652) and 67% for the two pearl millets, but decreased to 30% for the latest sorghum (E35-1). Increase in the pigeonpea maturity increased the intercropped pigeonpea yield, which ranged from 49% with the earliest genotype (HY-2) to 68%.with the latest one(PS-41).

These data emphasize that, in relative terms, the largest intercropping advantage occurs where there is the greatest difference between the maturity periods of the two crops. In absolute terms, this means having a cereal as early maturing as possible without sacrificing yield, and, at least on the rainfed Alfisol, a pigeonpea genotype as late as can be reasonably sustained on the residual soil moisture. Of the genotypes examined here, this objective was best achieved with the relatively early but high-yielding CSH-6 sorghum and the relatively late and high-yielding PS-41 pigeonpea.

To examine the scope for identifying genotypes suitable for millet/groundnut intercropping, three millet genotypes were grown in all combinations with four groundnut genotypes in a 1 millet: 3 groundnut row arrangement. Total LERs for individual genotype combinations ranged from 1.14 to 1.32 (Fig. 42), supporting the previous year's evidence of worthwhile yield advantages in this combination. Intercropped millet yields were substantially higher than the 25% of sole crop yields "expected" from the sown proportion, being 36%, 41%, and 48% of sole crops for Ex-Bornu.

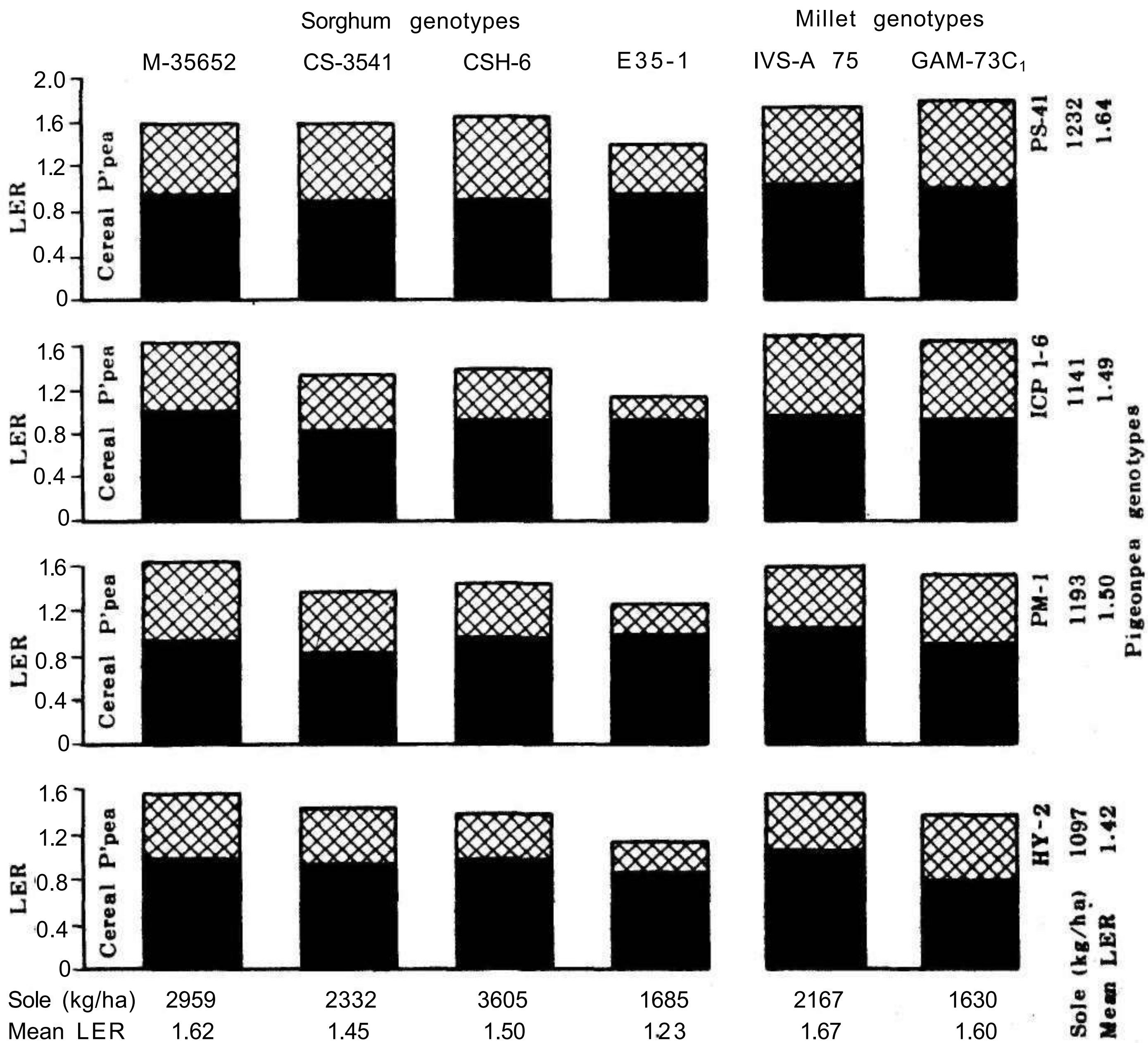


Figure 41. Effect of different heights and maturities of sorghum and millet genotypes in intercropping with different pigeonpea genotypes.

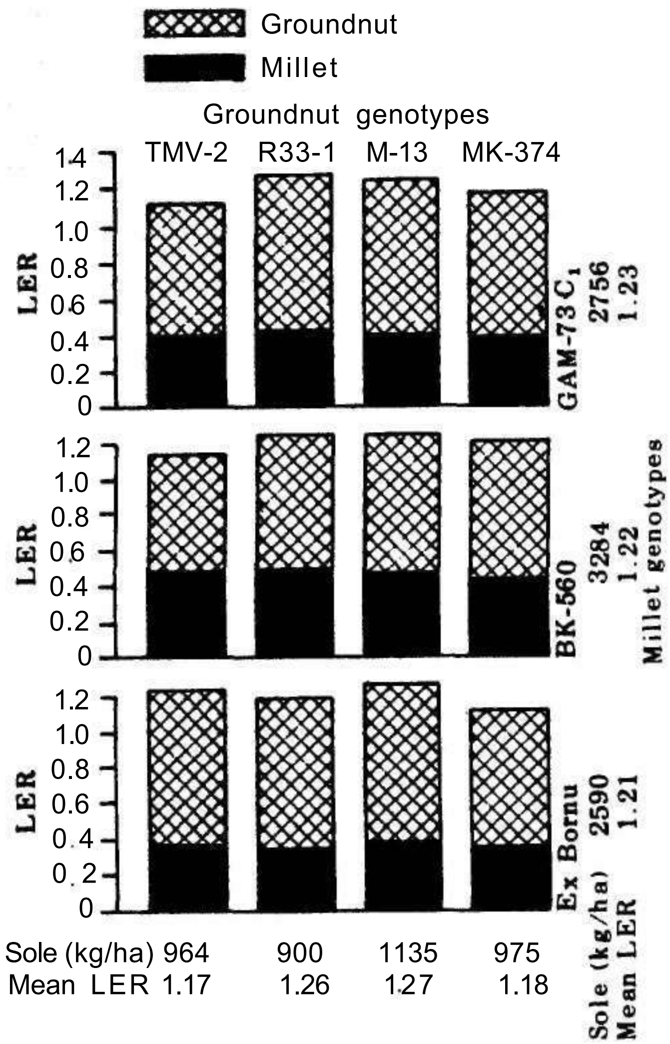


Figure 42. Effect of different genotypes in millet I groundnut intercropping.

GAM-73C1, and BK-560, respectively. Higher yields were mainly related to a greater ability to tiller and produce extra heads in the wide-spaced millet rows of the intercrop situation. Intercrop groundnut yields differed with groundnut genotype and were highest for Robut 33-1 and M-13 (83% and 85% of sole crops, respectively). These data indicate that there is scope for identifying both millet and groundnut genotypes suitable for intercropping.

A further feature of the experiment is that there was little evidence of interactions between genotypes, i.e., the genotypes of each crop gave the same order of yield irrespective of which genotype of the other crop they were growing with. This has very important implications for the screening of large numbers of genotypes since it suggests that, at least in the early stages of selection, pearl millet genotypes could be selected against a standard groundnut genotype, and groundnut genotypes could be selected against a standard millet genotype. This procedure would greatly reduce the number of combinations that would need to be examined.

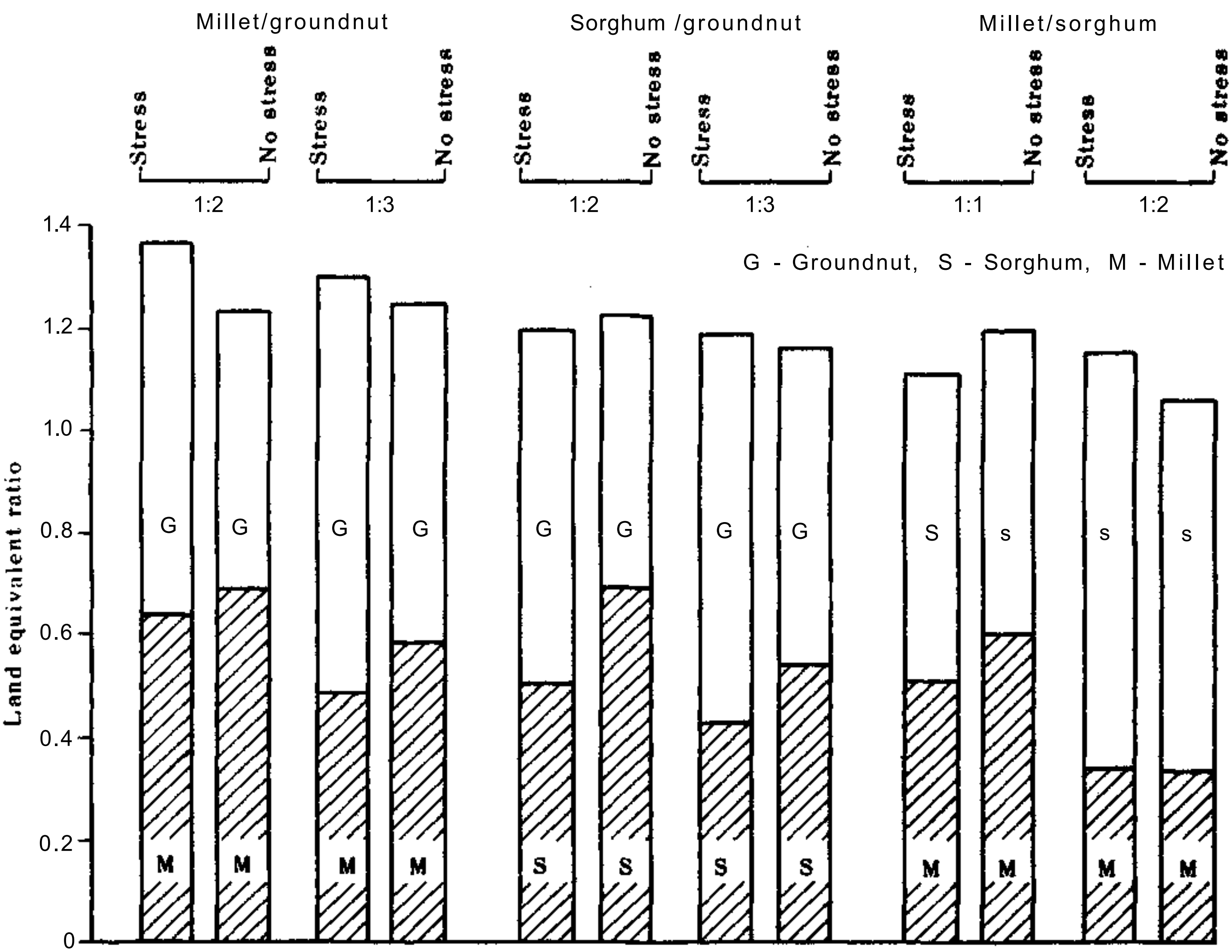
A genotype study in sorghum/millet, comprising four millet genotypes combined with four sorghum genotypes, was conducted on an Alfisol, mainly to verify earlier indications that this combination could give quite substantial yield advantages despite the very similar nature of the two crops. Results substantiated earlier evidence in that, of 16 combinations, 10 gave yield advantages greater than 10%, with two of these exceeding 30%. We plan to examine the reasons for these advantages in more detail.

Effect of Moisture Regimes on Intercropping Yield Advantages

A postrainy-season experiment in 1977 with four different intercropping combinations gave yield advantages under moisture stress but not under no-stress conditions. This could have been because intercropping was able to make more efficient use of moisture than sole cropping, a benefit that became apparent only under stress. However, under the no-stress conditions, the more competitive crops became particularly dominant and the lack of intercropping advantages could have been because of an unfavorable balance of competition.

This investigation was continued on an Alfisol in the 1978 postrainy season with crop combinations of millet/groundnut, sorghum/groundnut, and sorghum/millet. The 1:2 row arrangement for the cereal/groundnut and the 1:1 for the sorghum/millet were continued, and a second arrangement was added to include an additional row of the less competitive crop, i.e., 1:3 for the cereal/groundnut and 2:1 for the sorghum/millet. This second arrangement was to try to reduce the dominance of the more competitive crop in the no-stress situation. The no-stress treatment was irrigated every 10 days, but the stress treatment only every 20 days.

For the sole millet and sole sorghum crops, the difference in yield responses between stress and no-stress treatments were quite substantial at 35% and 41%, respectively (Fig. 43). Rather surprisingly, final groundnut yield was not reduced by moisture stress, despite obvious signs of stress during the season prior to irrigation. This may have been because the indeterminate nature of this crop enabled it to recover from the stress that occurred only for short periods. In the millet/groundnut at both row arrangements, the millet was more dominant under the no-stress treatment and this was associated with rather smaller yield advantages (Fig. 43). However, although this reflected the trend of the previous year, the effects were much less



Sole crop seed yields (kg/ha)

	Millet	Sorghum	Groundnut
Stress	1986	4470	2579
No stress	2681	6317	2481

Figure 43. Effect of moisture regime and row proportions on LERs in three intercrop combinations.

pronounced. When averaged over both row arrangements, the advantage was 33% under stress and 24% under no stress.

In sorghum/groundnut, the relative competitive ability of the cereal was again greater under the no-stress treatment, but there was little effect of either moisture regime or row arrangement on the yield advantage, which averaged 19% over all treatments. In sorghum/millet, moisture regime had no consistent effect either on the competitive balance of the two crops or on the overall yield advantage; averaged overall treatments, the yield advantage was only 13%.

These results are rather different from those of last year, and they suggest that, although moisture regime may affect the competitive balance of these component crops, it may have less effect on the magnitude of the yield advantage than previously indicated. In general, however, the effect of different growing conditions on the yield advantages of intercropping is a very complex field that needs much further study.

Yield Stability in Intercropping

Yield stability in sorghum/pigeonpea intercropping has been examined using data from ICRISAT experiments (including some multilocational ones established in 1976 especially for this purpose) and others reported in the literature. In all, 94 experiments ranging over different soil types and locations in India were examined. As an indication of the environments covered, sole crop yields of sorghum and pigeonpea ranged from 310 to 6200 kg/ha and 274 to 2840 kg/ha, respectively; and annual rainfall from 408 mm to 1156 mm.

Several approaches have been tried, including comparisons of coefficients of variation, regressions of yields of monetary returns against an environmental index (modified from the approach often used to assess genotype stability in sole crops), and estimation of the probability of crop "failure" as measured by monetary returns falling below given "disaster" levels of income. On this last basis, intercropping "fails" less often than a sole crop, or "shared-sole" system where a farmer grows some of each sole crop (Fig. 44). Taking as an example a disaster level of Rs. 1000/ha, sole pigeonpea fails 1 year in 5, sole sorghum 1 year in 8, shared-sole 1 year in 13, but intercropping only 1 year in 36.

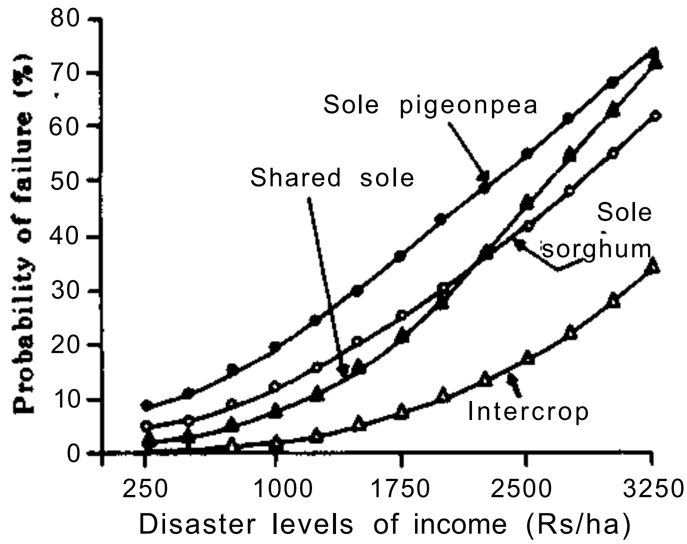


Figure 44. Probability of failure for sorghum and pigeonpea in different cropping systems at given disaster levels of income.

Effects of Legumes in Intercropping

A maize/groundnut intercropping experiment was laid out on an Alfisol to determine whether there was any beneficial transfer of fixed nitrogen from the legume to the cereal. Treatments consisted of maize at 0, 50, 100, and 150 kg/ha of applied nitrogen, and with and without a groundnut intercrop. With no applied nitrogen, maize growth was very poor and obviously nitrogen-deficient. There was no visual evidence of growth being any better if the groundnut intercrop was present. This observation was supported by maize yields that were unaffected by the groundnut at any level of nitrogen.

The relative yield advantage of intercropping over sole cropping was 44% at zero nitrogen level, but this decreased with increase in applied nitrogen and was zero at the highest nitrogen level. Since there was no evidence that these differences in yield advantage could be due to differences in nitrogen transfer, it is possible that they occurred because intercropping was more efficient in using soil nitrogen and this effect was more evident at lower levels of applied nitrogen. This finding has important implications, because it suggests that intercropping may be more advantageous in low fertility situations. However, this needs further study before any firm conclusions can be drawn.

Residual effects of the intercrop and sole crop groundnut are being examined in this experiment with a following sorghum crop, and results will be reported later.

Double Cropping on Vertisols

Investigation of the effects of a rainy season crop of maize or sorghum on a range of post-rainy-season crops continued. The soil profile was full at the start of the postrainy season (see "Environmental Physics" section of this report) and, as in previous years, the yield of sorghum, chickpea, pigeonpea, and safflower were just as good after maize as after the traditional fallow (Table 17). After sorghum, there was no real evidence of the very marked phytotoxic effect observed in 1977, but yields were a little lower than those after maize (16% lower for sorghum, chickpea, and safflower, and 10% lower for pigeonpea). The difference between these two seasons could have been because moisture stress at the beginning of the 1977 post-rainy season aggravated possible phytotoxic effects. The yields of postrainy season sorghum and pigeonpea were slightly increased if these

Table 17. Yields (kg/ha) of relay or sequential postrainy-season crops after rainy-season fallow maize or sorghum.

Rainy-season crops	Maize 3307	Sorghum 2529		
	Postrainy-season crops			
	Sorghum	Chickpea	Pigeonpea	Safflower
After maize				
Relay	2694	1100	723	569
Sequential	2650	1382	663	794
After sorghum				
Relay	2344	935	656	501
Sequential	2123	1145	598	637
After fallow				
Relay	2753	1139	812	691
Sequential	2569	1361	740	796
Mean	2522	1177	699	665

LSD (0.05) = 64.3 to compare relay with sequential sowing of a given postrainy-season crop after a given rainy-season crop.
LSD (0.05) = 104.3 to compare effects of rainy-season crops on a given postrainy-season crop sown either relay or sequential.

crops were relay-sown 14 days before harvest of the first /crop; chickpea and safflower yielded better if sown after the first crop harvest.

Extended Cropping on Alfisols

In SAT areas, a full double cropping system is not normally possible on Alfisols, but there are a number of techniques, such as relay cropping, transplanting, and ratooning, that may allow some increase in the cropping intensity, especially with the use of early-maturing genotypes. An experiment was conducted this season to gain some preliminary information on these possibilities. The gross monetary returns from the different systems are given in Figure 45. The longer-season crops of castor, *Eleusine,* millet, sorghum, and groundnut gave good returns, even without an additional second crop. In most cases, these were better than those of the double crop systems that had green gram, pearl millet, or *Setaria* as first crops. Castor matures too late to allow a second crop, and second crops after *Eleusine* and groundnut were very poor. Ratooning the sorghum gave only a moderate second crop, but in total this system gave good returns.

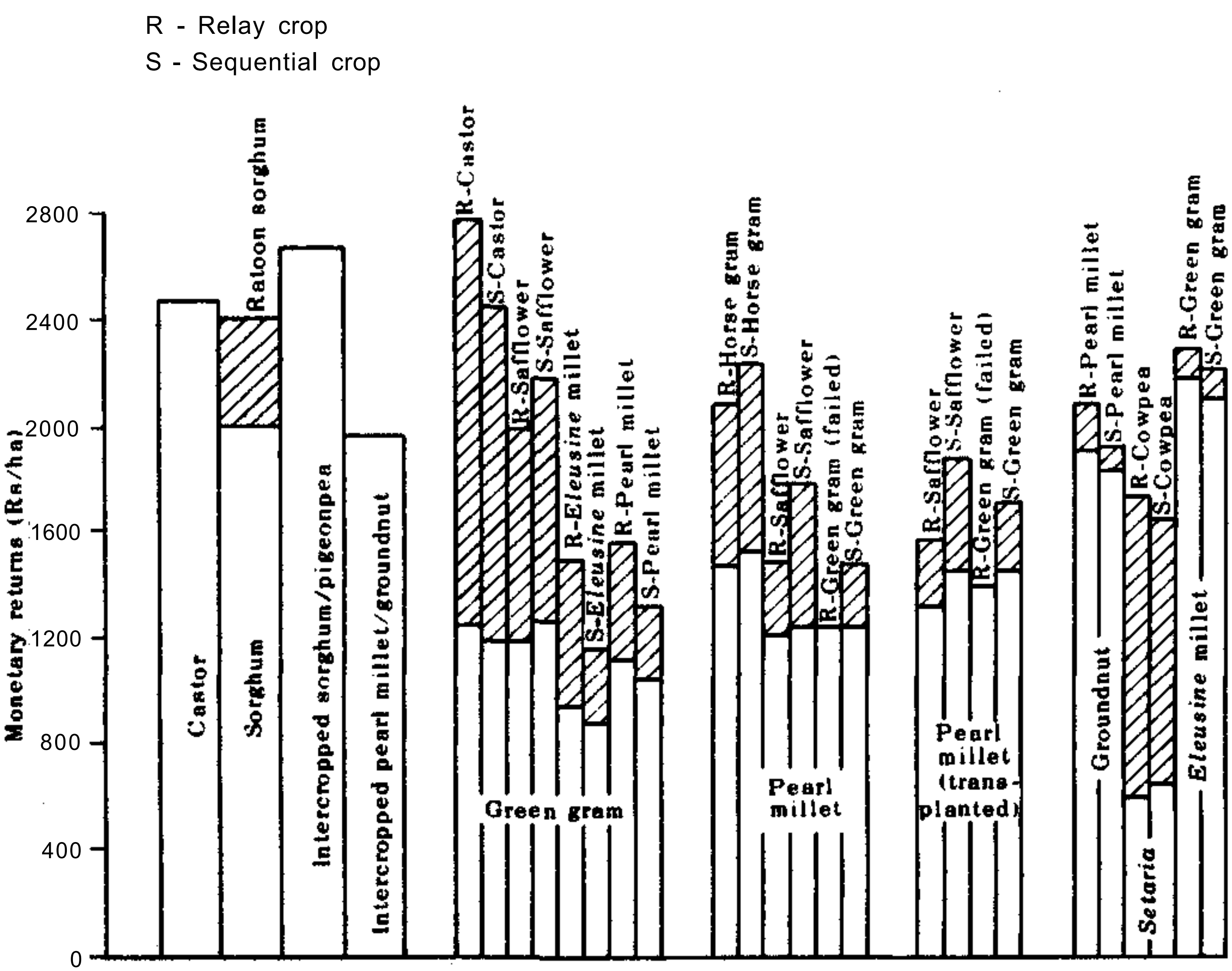


Figure 45. ***Extended cropping on Alfisols (1978-79).***

The sorghum/pigeonpea intercrop proved to be one of the best systems. This emphasizes that a pigeonpea intercrop is one of the more assured ways of growing a "second" crop since it avoids the difficulties of having to establish a second crop late in the season when upper soil layers may be very dry (though that was not a problem for most second crops this season). It also avoids the costs of establishing a second crop, so in practice the relative benefits would be even greater than indicated here by the gross returns. To some extent, pearl millet combined with a late-maturing groundnut is a similar rype of intercropping, and this system also performed well.

In the other double crop systems, the returns from the second crops were not sufficient to offset the relatively low returns from the short-season first crops; the major exception to this was castor after green gram. In general, castor, horse gram, and cowpea were promising second crops, but not pearl millet or green gram. Based on this first year's experience, promising combinations will be formulated and examined further in future seasons.

Cropping Entomology

Pest-Parasitoids and Insect Trap Studies

Several arthropod and mermithid endoparasitoids were bred from insect pests collected from cultivated crops and a few other plant species at 1CR1SAT Center and from farmers' fields in Andhra Pradesh. Use of light traps continued for monitoring changes in the distribution of several important pests and beneficial insects in the region. About 70 insect species (mainly Lepidoptera) have been recorded. Data are being compared with those obtained by pest incidence counts on the crops and by pheromone and chemical trapping of some species. Co-operative trap studies have been initiated at Coimbatore (Tamil Nadu), Hissar (Haryana), and Kanpur (Uttar Pradesh) India.

Light trap records of *Heliothis armigera* during 1978-79 showed that of the 4839 moths trapped at our Crop Improvement Building, 58% were females. Of the total catch, 40% were obtained in December when the weather condition perhaps favored an influx of moths from other areas. Of the December total, 46% were virgin, supporting this hypothesis. Most moths in early December were trapped between 0200 to 0500 hours. The fertility index declined from 0.58 at 2000 hours to 0.10 at 0400 to 0600 hours and was positively correlated with the night temperatures (Fig. 46). Although the December

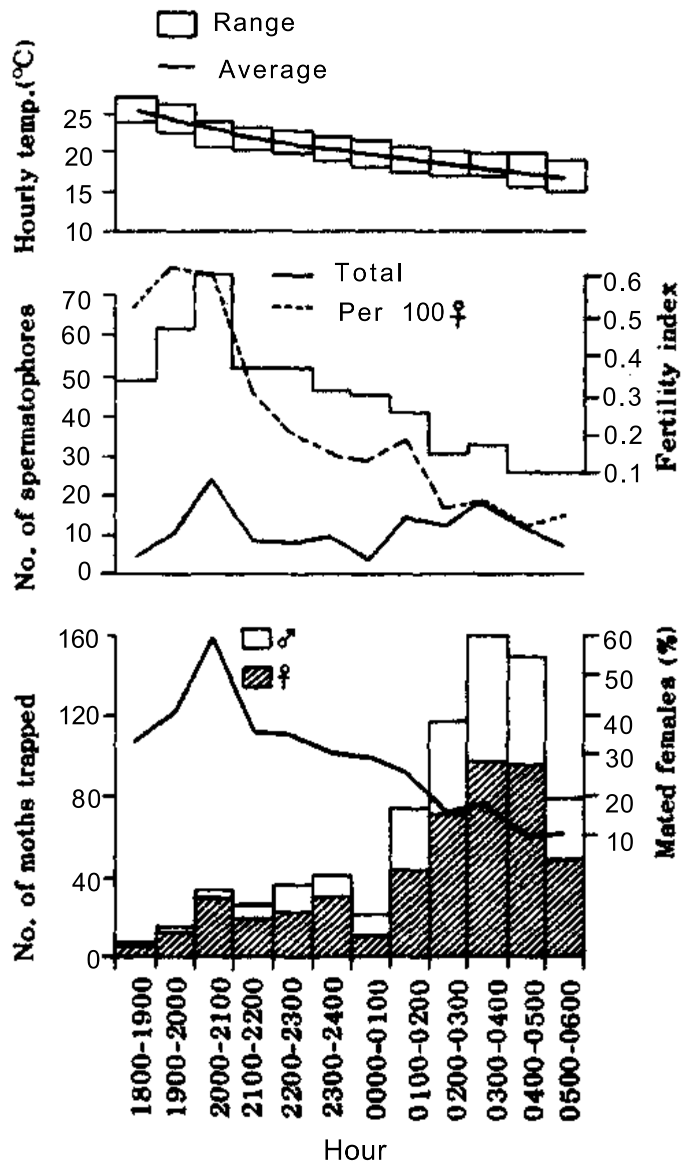


Figure 46. Hourly light-trap catch of adult* Heliothis armigera *and physiological status of trapped females at Crop Improvement Building, ICRISAT Center, 6 to 12 Dec 1978.

catches were 14 times more in 1977, the peak appeared in the same week in 1977 and 1978.

Sexlure traps with virgin females attracted more males of *H. armigera* at 2.1 meters above ground than when placed higher or lower (Table 18). The catch numbers were, however, larger in the light trap. In cooperation with the Tropical Products Institute, UK, synthetic pheromones of *H. armigera* were tested but catches were significantly lower than with virgin female traps. Observations carried out on moth behavior by using similar traps revealed that irrigation of groundnut caused a considerable increase in the numbers of adults trapped. On safflower, the proportion of *H. armigera* adults recovered from the 1494 Heliothidinae larvae obtained from 27 fields was 32% in monocrop and 57% in intercrop fields. In sorghum interplanted with pigeonpea, more (92) adult male *H. armigera* were trapped in sex traps with virgin females than in sole crop sorghum (62). These observations indicate that this noctuid is attracted by mixed crops and prefers a habitat for ovi position more than one essential host in close proximity.

An understanding of natural population regulation of *H. armigera* in this region was obtained. Twenty-six parasitoid species have been identified (Table 19). The parasite complex caused a high mortality at the egg and larval stages. However, regulation varied widely from generation to generation, from place to place, and from one host plant species to the other. In fields of maize, sorghum, and cowpea, *Trichogramma* sp, an egg parasite, caused heavy mortality of *H. armigera.*

Of over 47 500 eggs collected from the flora at ICRISAT Center, 25% were parasitized on cereals, followed by 12 to 14% on oilseed and vegetable crops, 2.7% on legumes, and 0.7% on weeds. Parasitism levels were highest on sorghum reaching 75% in one field. Pigeonpea and chickpea were least attractive to the egg parasites. This is an important contributory factor in the high larval buildup and heavy yield loss on intercropped chickpea and pigeonpea in this region.

Hymenopteran parasitoids were absent from larvae collected from intercropped pigeonpea in farmers' fields in Karnataka during December/January. Parasitism levels were low in Gulbarga and Bellary districts, where application of two to four sprays of insecticide against //. *armigera* are common. In certain cotton-

Table 18. Captures of *Heliothis armigera* males in sexlure and light traps in Vertisol watersheds at ICRISAT Center. 1978 79.

Trap	Height above ground (m)	Average males captured/trap (no.) November 7-13 (7 days)	November 14-20 (7 days)	March 8-17 (10 days)
Sexlure[a]	7.6	0.0	0.5	0.5
	5.5	1.0	1.5	0.5
	3.8	1.5	1.0 '	5.0
	2.1	19.5	31.0	8.0
	0.4	0.5	0.0	1.5
Light*	1.0	140.0	31.0	55.0

a. With 0.093 m^2 capture (sticky) area/trap (three replications).
b. Using 125 Watt m.v. bulb in a Robinson trap.

Table 19. Parasitoid species recovered on *Heliothis armigera* in surveys at ICRISAT Center (1974 79).

Parasitoids	Species (no.)				
	Egg	Egg & larvae	Larvae	Larvae & pupae	Total
DIPTERA					
Tachinidae			1	5	6
HYMENOPTERA					
Trichogrammatidae	3				3
Braconidae			3		3
Ichneumonidae		1	9	3	13
NEMATODA					
Mermithidae			1		1
Total	3	1	14	8	26

growing areas of Maharashtra, the parasitism levels were high in intercropped pigeonpea suggesting a transfer of parasitoids from cotton to pigeonpea. The dermaptenan species *Nala lividipes* (Dufour) was an important predator on *Heliothis* larvae in sorghum, particularly in fields intercropped with cotton in certain parts of Karnataka. Surprisingly no pupal diapause was observed in 1979, unlike the low but consistent proportion of diapausing pupae that occurred during 1974-78.

Field Trial on Intercropped Sorghum/Pigeonpea

Insect numbers, levels of parasitism, and insect-induced crop damage were measured in a replicated unsprayed trial (total area 14.0 ha) on large (> 0.35 ha) plots on low fertility areas at three locations each: on Alfisols and Vertisols at ICRISAT Center and on Vertisols in adjoining villages. At ICRISAT Center, the treatments were sole sorghum (CSH-6), sole pigeonpea (ICP-1), and full and half stand sorghum/pigeonpea intercrops. In the village sites, sole pigeonpea was replaced by local sorghum intercropped with local pigeonpea.

Sorghum. A month after germination, the levels of shoot fly *(Atherigona soccata)* and aphid (*Rhopalosiphum maidis*) attacks, and numbers of the common aphid predator *Menochilus sexmaculatus* were significantly lower on local than on hybrid sorghum. Neither the levels of the pests attacking sorghum in the seedling or earhead stages nor their parasitoid/predatory complexes were significantly different on sole or intercropped sorghum. In the intercropped blocks, there was a tendency of increased pest incidence with decreased sorghum population, but the differences were not statistically significant.

In late July/early August, there were significant differences among the nine locations in levels of shoot fly *(A. soccata)* attacks within a radius of 20 km, with 42 to 46% incidence at ICRISAT Center and 17% in the adjoining villages. There were 61 and 42% plants with deadhearts on Alfisols and Vertisols, respectively.

Studies of pest-parasitoid ratios on *H. armigera* revealed significant differences in egg and larval numbers of *H.armigera* and in their parasitoids on intercropped sorghum at and around ICRISAT Center. Ichneumonids were the predominant larval parasitoid on intercropped sorghum, parasitizing up to 89% of the early instar larval population in some fields. Insect counts indicated up to 59 cocoons of this parasitoid per 100 earheads in Vertisols at ICRISAT Center compared with only 3 to 10 at non-Vertisol sites around the Center. However, in early September, 24% of eggs were parasitized in the fields in adjoining villages compared with only 8% at ICRISAT Center. In a village site, intercropped sorghum near vegetables, paddy, and sugarcane fields had up to 59% egg parasitism compared to 4% in an isolated sorghum field. As in 1977, dipterans were recovered only from plots on Vertisols at ICRISAT Center.

Damage by earhead bugs, *Calocoris angustatus,* was high on intercropped sorghum with up to 78% earheads affected in Alfisols at ICRISAT Center. Losses were 4 to 8% on Vertisols at village sites and ICRISAT Center compared to 33% in Alfisols at ICRISAT Center. This was related to a slight delay in flowering and maturation.

Unlike the previous year, intercropped sorghum in 1978 carried fewer larvae of a lepidopteran cutworm, *Mythimna separata* at all the locations sampled. The number of adult moths obtained in the light trap was also lower. Mermithids were the most common endoparasitoids on this noctuid larva, parasitizing up to 55% of the larvae sampled in one of the village sites. All nine fields in the villages yielded mermithids, whereas they were found in only half of the 18 sites sampled at ICRISAT Center. Collections of grubs, pupae, and adults of coccinelid predator *M. sexmaculatus* on incubation revealed that mermithid and hymenopteran (*Perilitus coccinellae*) parasitoids attacked up to 30% population of this predator

Pigeonpea. At ICRISAT Center, the number of eggs laid and the number of larvae of *H. armigera* were far higher on pigeonpeas grown on Vertisols than on Alfisols and a similar trend appeared in the moth numbers trapped at lights. Intercropped pigeonpea in the adjoining village sites carried insects in comparatively low numbers. As in 1977, at all the locations, the first peak of oviposition occurred 5 to 7 days after a moonless night in the second week of November. No yield was obtained from this flower flush produced in deep Vertisols, since larvae appeared in large number and consumed buds, flowers, and developing seeds. Loss of this first flush resulted in a second and even third flush of flowers in the intercropped pigeonpea. A second oviposition peak was observed 5 to 7 days after a moonless night in mid-late December, but unlike in 1977 there was no third peak.

In contrast to the situation on sorghum, the egg parasitism levels on pigeonpea were very low with only two parasites recovered from over 4500 eggs. The parasitism on the 7500 *H. armigera* larvae collected from flowering pigeonpea was 10% compared with 26% in 1977. As in 3 previous years, dipterans were more common (9%) than hymenopterans (1%). The parasitism level was higher at ICRISAT Center than in the village sites (11.6% compared to 1.5%), with a peak of 32% occurring at the end of January. These dipterans, however, are of little importance in affecting pigeonpea yield since they kill larvae in the prepupal or pupal phase, after the larvae have caused pod damage.

The data on parasitism levels confirm our findings of the last two seasons that sorghum in an inter- or mixed crop system is an important source of buildup of egg parasitoids and ichneumonid larval parasitoids of *H. armigera.* However, this is of no appreciable advantage to the pigeonpea as the parasite complex that develops and builds up in *Heliothis* on intercrop sorghum does not transfer in appreciable numbers to pigeonpea (Fig. 47). The presumed entry of migrant moths in winter months creates a further disequilibrium with the local parasite fauna, leading to a rapid increase in larval populations on pigeonpea and results in heavy yield losses in intercropped pigeonpea at ICRISAT Center and in Andhra Pradesh generally. Of the 27 parasitoid species recovered and identified on ten other pests of sorghum (excluding *H. armigera)* only one parasitoid, *Phanerotoma hendecasisella* parasitizing *Eub-*

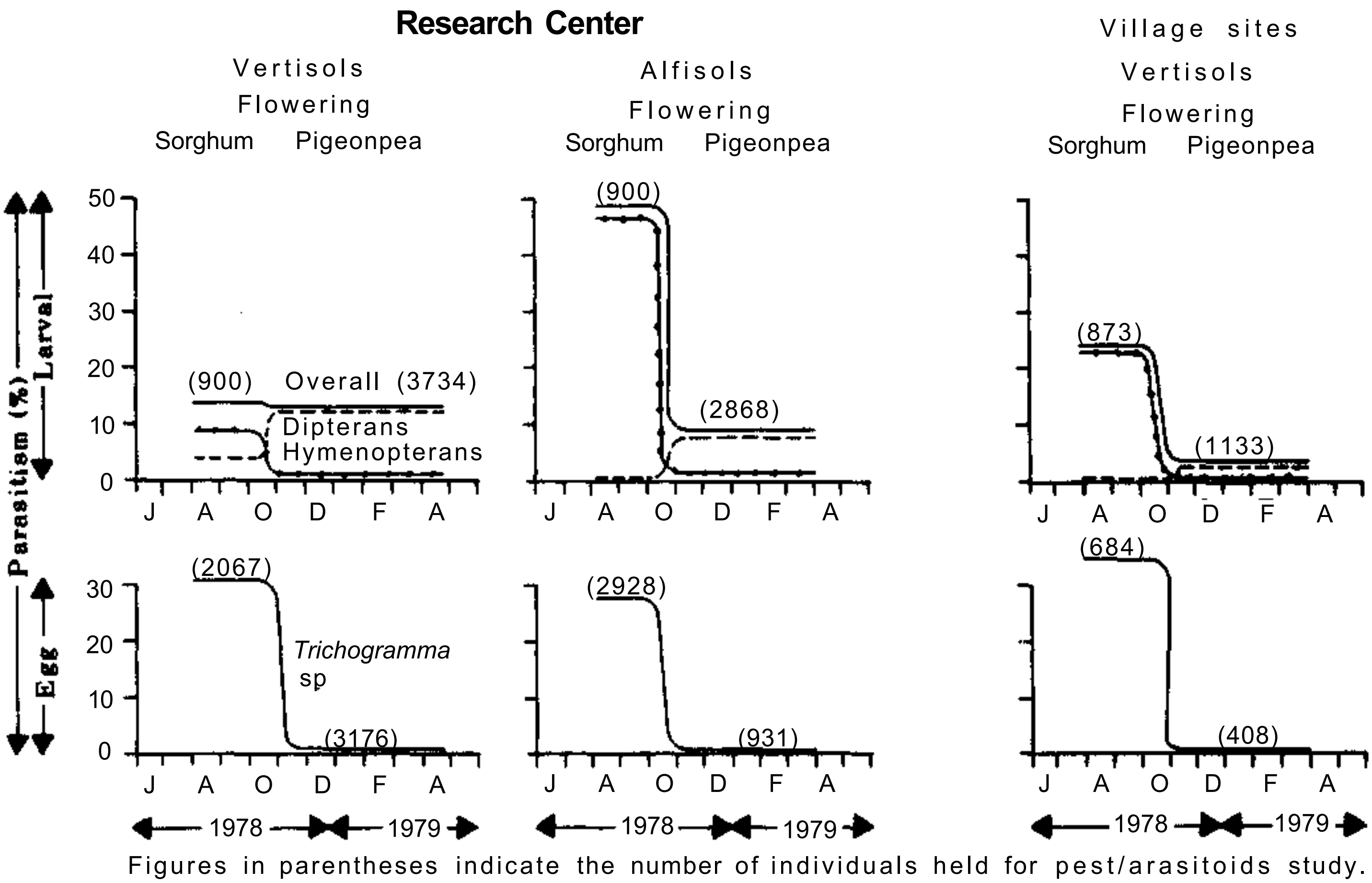


Figure 47. Transfer of egg and larval parasitoids of **Heliothis armigera** *in a sorghum/pigeonpea intercrop in district Medak, Andhra Pradesh, India (1978-79).*

lemma siliculana has been known to transfer to *Etiella zinckenella* and *Eucosma critica,* 2 of the 16 pest species studied on pigeonpea. Results obtained to date have helped to understand the status of *Heliothis* in this region in a widely grown cereal/legume crop system of the Indian subcontinent and to pinpoint the basic reasons for the serious damage it causes on intercropped pigeonpea.

Data obtained on insect-caused loss in seed weight on intercropped pigeonpea at two plant population levels revealed that for the first flower flush, the loss was 80% on intercrops at high plant populations, compared to 70% at the low plant stands in typical low fertility and pesticide-free situations. However, the final yield losses (56 and 50%) were not significantly different.

Agronomy and Weed Science

Steps in Improved Technology

Improved technology involves a large number of combinations of many crop production practice's. The factors involved in various crop production practices are grouped into four "steps": crop variety, fertilization, soil and crop management, and supplemental irrigation.

In 1978 a sorghum/pigeonpea intercrop on Alfisol and a maize/pigeonpea intercrop on Vertisol were studied using ten different combinations of four improved technologies. On Alfisol the crops were sown at the onset of the rainy season, but on Vertisol they were "dry sown" just before the onset of rains. Germination and seedling growth were excellent in all treatments. Although the crops suffered somewhat from excessive rain and cloudy weather during July and August, growth and grain formation in improved varieties were satisfactory. But in the local sorghum, grain formation was poor. The results are summarized in Table 20.

On the Alfisol the gross returns for the sorghum/pigeonpea intercrop with improved varieties increased by Rs 750/ha for fertilizer application and Rs 1170/ha for improved management applied singly. When these were combined, the increased return was Rs 2420/ha, giving a synergistic effect of Rs 500/ha. When traditional varieties were used, there was a decrease of Rs 360/ha for fertilization, an increase of Rs 650/ha for management, and an increase of Rs 770/ha for the combination, with a synergistic increase of Rs 500/ha. Use of improved varieties alone increased returns by Rs 440/ha, but when combined with fertilizer application and better soil and crop management the increase was Rs. 2860/ha. There was no response to irrigation on either the Alfisols or Vertisols because of high rainfall in 1978.

The values of the maize/pigeonpea intercrops on the Vertisols increased from Rs 2290 to Rs 4620/ha when traditional varieties and practices were replaced by a full set of improved technologies. The effect of introducing improved varieties with improved fertilization and management was an increase of Rs 280/ha. Under traditional fertilizer and management practices, use of improved varieties resulted in a decrease of Rs 310/ha. Fertilizer application alone increased returns of traditional varieties by Rs 730/ha and improved varieties by Rs 1560/ha. Improved management alone increased returns by Rs 630 and Rs 880/ha from traditional and improved varieties, respectively. The synergistic effects of fertilizer use and improved management combined resulted in increases of Rs 2050 and Rs 2640/ha from traditional and improved varieties, respectively.

Table 20. Yields and monetary returns for two intercrop systems under different combinations of improved production practices at ICRISAT Center.

Treatments	Maize/Pigeonpea (kg/ha)				Sorghum/pigeonpea (kg/ha)			
	Maize		Pigeonpea	Return* Rs/ha	Sorghum		Pigeonpea	Return* (Rs/ha)
V F M I	Grain	Fodder	Grain		Grain	Fodder	Grain	
- - - -	970	580	550	2290	300	4170	700	1960
- - + -	1210	600	710	2920	440	3550	920	2610
- + - -	1780	1950	530	3020	780	5580	420	1600
- + + -	2460	1540	800	4340	1000	6870	810	2730
+- - - -	580	430	570	1980	1150	2360	640	2400
+ - + -	960	480	780	2860	1560	2220	990	3570
+ + - -	1830	540	720	3540	2970	4250	430	3150
+ + + -	2710	1380	820	4620	3420	3830	1010	4820
- + + +	1990	1650	830	3970	970	7130	910	2950
+ + + +	2600	1260	990	4950	3290	3860	1040	4900

V, variety; F, fertilization; M, soil and crop management; I, irrigation.
— Traditional practice; 4- Improved practice.
*Sorghum Rs 70/100 kg; Maize Rs 95/100 kg; Pigeonpea Rs 250/100 kg; Fodder, no value.

These results illustrate the interdependence among the various factors of production and emphasize the complementarity and synergism of the joint use of a set of improved technologies.

Forage Evaluation

Several grasses and legumes are being evaluated in nurseries established in 1977. They received 20 kg/ha of nitrogen as urea. In only 4 of the 25 collections of *Cenchrus setigerus,* establishment and regrowth was satisfactory with dry-matter yields of 6000 kg/ha or more. About one-third of the 61 collections of *Panicum antidotale* gave green fodder yields above 6000 kg/ha. *Chloris gayana, Chrysopagon fulous, Setaria sphedata, Pennisetum squamulatum, P. aleopecures,* P. *massaicum,* Pusa Giant Napier, and Napier bajra performed well on Vertisols, with green fodder yields of 12 000 kg/ha or more. On Alfisols, *Siratro* sp, *Clitoria ternatea, Glycine wightii,* and *Centrosoma pubescens* performed well.

Grass-legume mixture trials including three grasses and two legumes were planted in 1977 on Alfisol and in April 1978 on Vertisol. Two harvest cuts were made in 1978-79. The trials on the Alfisol were also grazed by bullocks. On the Alfisol, mixtures of *Cenchrus ciliaris* and *Siratro, Urochloa mosambicensis* and *Siratro,* and *Chloris gayana* and *Siratro* each produced more than 1000 kg/ha of the dry fodder on a "two cut" basis with or without grazing. The corresponding mixtures with *Clitoria ternatea* in place of *Siratro* had yields ranging from 7300 to 9900 kg/ha. Yields from the six combinations on the Vertisols ranged from 4000 to 8400 kg/ha of dry fodder.

Weed Science

Weed research was intensified by further studies on the weed suppression effects of additional "smother crops" and by manipulating crop density, fertility level, row arrangement, and time of weed removal. Evaluation of various weed control measures, including herbicides, for double cropping on deep Vertisols received greater attention. In addition to these agronomic field studies, investigations were initiated to quantify the response of a few major weeds to different levels of shading. On-farm studies of farmers' present weeding practices and of the performance of improved weed control measures under existing farming systems and socioeconomic situations were continued.

Cowpea and mungbean planted as "smother crops" between the rows of sorghum and sorghum/pigeonpea intercrop again showed promise as a means of minimizing weed infestation and reducing the number of hand weedings without significantly affecting the main crop yields. In general, the net returns from smother cropping of cowpea and mungbean with one hand weeding each were higher than from sorghum or pigeonpea alone with two weedings (Fig. 48). The advantage was more pronounced on Alfisols. Net returns from the pigeonpea with a cowpea interplanting were also substantially superior to sole pigeonpea on both soils. However, in the sorghum/pigeonpea system, on Vertisols, the two hand weedings practice was superior to the three-crop system with one or no hand weeding. In general, the three-crop system with one or no hand weedings resulted in equal or higher net returns than sole crop of sorghum or pigeonpea with two hand weedings.

As light intensity plays a major role in the weed suppressing ability of the additional inter-row crop canopy, a study was initiated to examine the growth response of four weed species to different degrees of shading. Bamboo shade screens having different-sized perforations allowing approximately 10, 20, or 40% light transmission were used on 12-day-old seedlings. All four species—*Cyperus rotundas, Digitaria ciliaris, Acanthospermum hispidum,* and *Celosia argentta*—were sensitive to shading (Fig. 49). In *Cyperus,* which was highly shade-sensitive, there was a marked reduction in both shoot and tuber dry weights and in the number of new shoots and tubers when light intensity was reduced. Clearly, shading showed considerable potential as a means of reducing the spread of this weed. This re-emphasizes the possible importance of a fast-growing smother crop that provides additional canopy and shading early in the season, thus suppressing weed growth during the early vegetative stage of the crop.

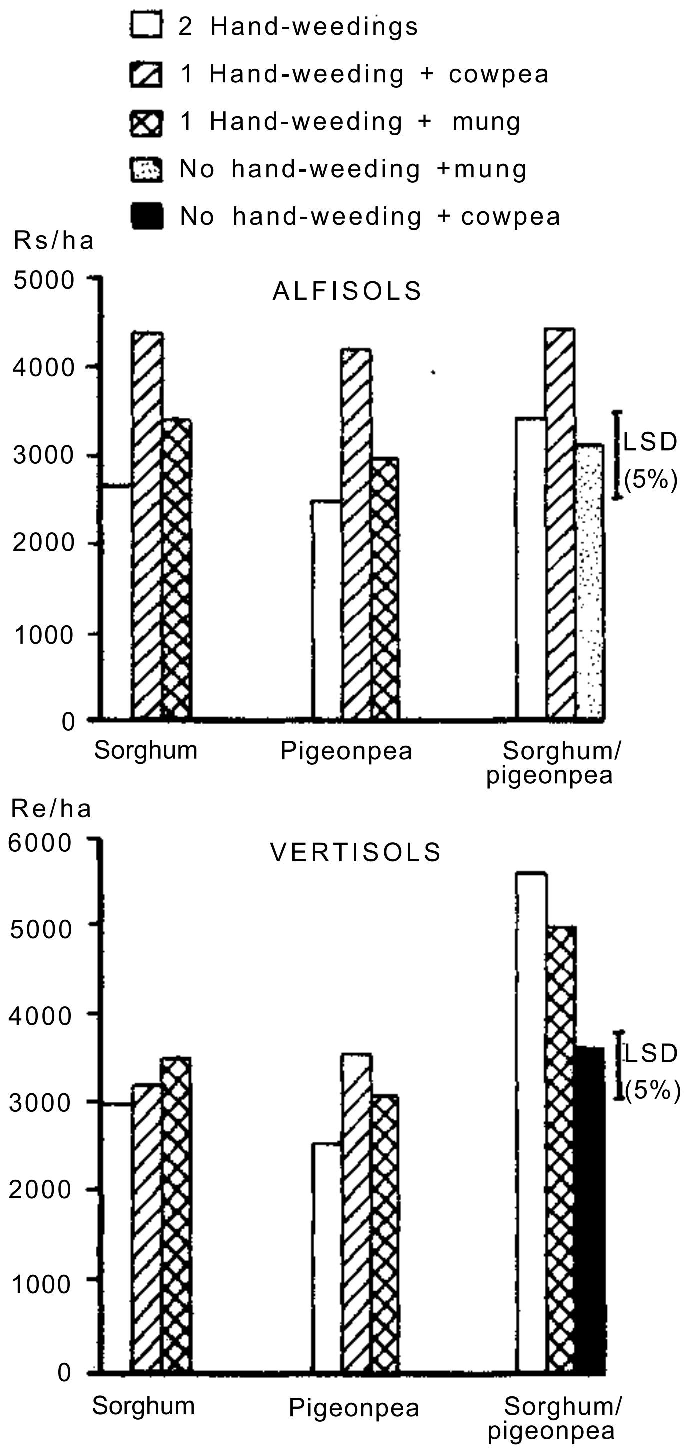


Figure 48. Net monetary value of various cropping systems under different weed management systems (1978-79).

In a trial conducted to examine the weed competitive ability of the pearl millet/groundnut intercrop in different row proportions, the row arrangements of one pearl millet with three groundnut gave the highest yield advantage (Fig. 50). Weed growth increased steadily as the proportion of groundnut increased, presumably because of the slow development of the groundnut canopy. The severity of weeds in groundnuts was evident both in the amount of growth and in the composition of the flora. In sole pearl millet, the flora comprised a mixture of several weeds, while in the groundnut system there was a predominance of the more competitive tall-growing weeds, especially *Digit-*

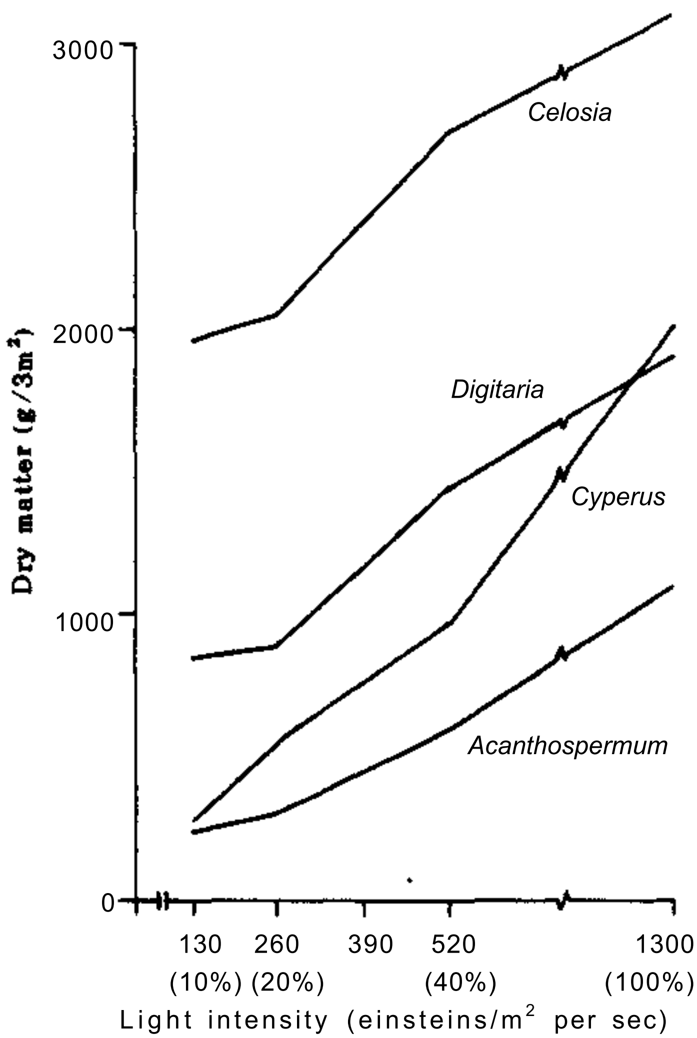


Figure 49. Effect of different levels of light intensity on the growth of four major Alfisol weeds (1978-79).

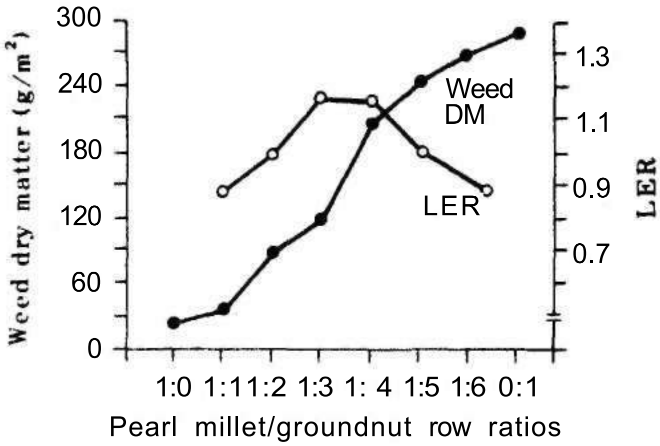


Figure 50. Effect of row arrangement in pearl millet/groundnut intercrop on weed growth and land equivalent ratio (1978-79).

aria and *Celosia,* which grow above the groundnut canopy (Fig. 51). *Cyperus* also occurred in the groundnut systems, though as the number of groundnut rows increased it became relatively less important than *Digitaria* and *Celosia.*

Herbicide research was mainly oriented towards reducing herbicide application rates and cost. The effects on crop yields of band application of preemergence herbicides followed by one hand weeding were evaluated on a sorghum/pigeonpea intercrop and on sole maize on deep Vertisols during the rainy season. In the intercrop, terbutryn applied at 0.3 kg/ha in a 15-cm band over the crop rows performed on par with the weed-free treatment. However, it was not as cost-effective as one hand weeding. Band applications on maize were not very

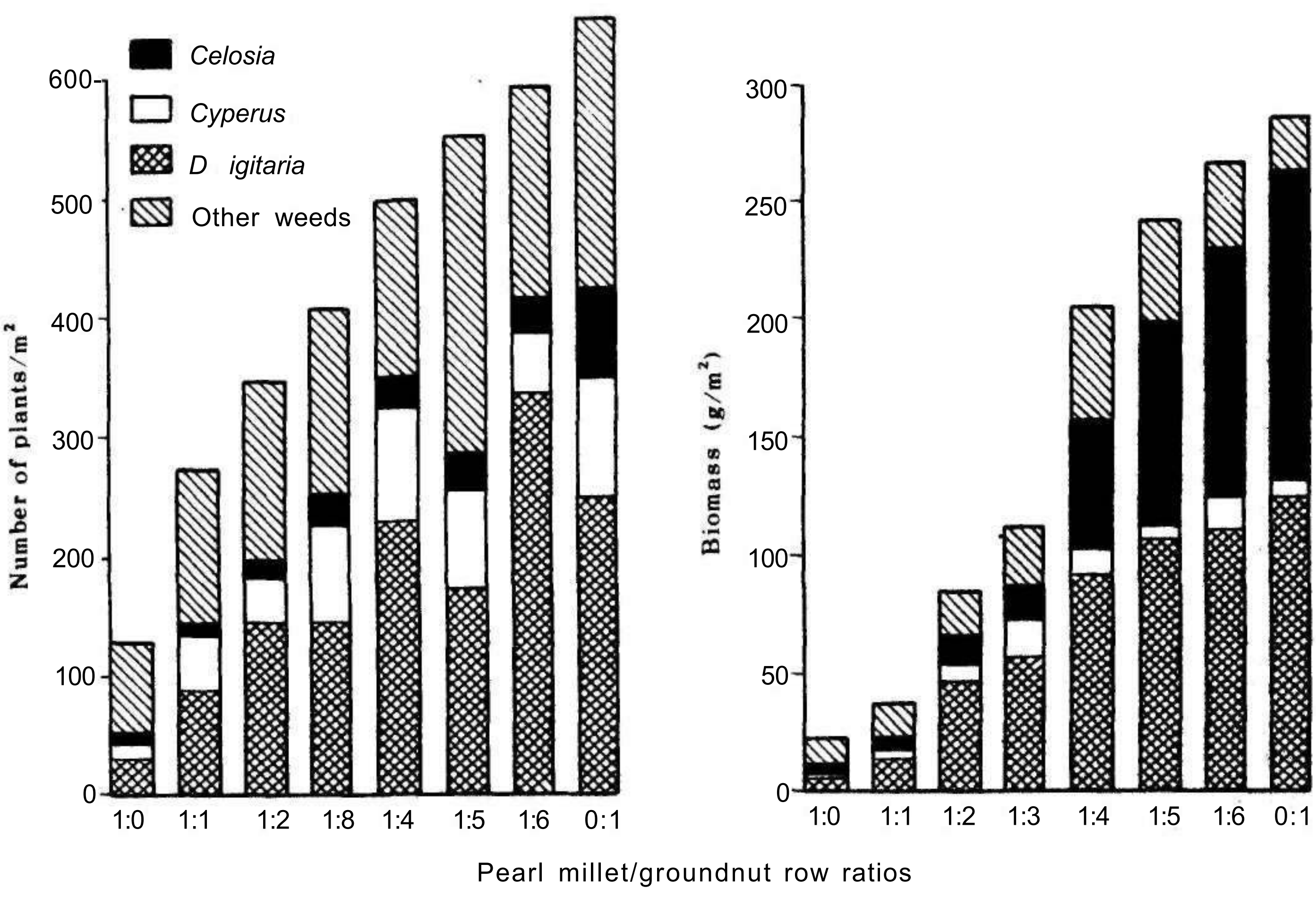


Figure 51. Contribution of three dominating weeds—*Cyperus, Digitaria, *and* Celosia*—to cumulative density and biomass of the weeds at pearl millet harvest (1978-79).

successful as they failed to check the weed growth between the crop rows. The highest maize yields were obtained with three hand weedings. The next best system was a 'blanket' application of preemergence herbicide, followed by one hand weeding. A blanket application of atrazine + alachlor gave yields similar to those obtained with two hand weedings.

Trials were conducted on both Alfisols and Vertisols at two different fertility levels to determine the effects of different row widths and within-row crop densities of sorghum on crop yields and weed growth. In the Vertisols at both high and low fertility and at constant plant population, within-row weed growth decreased as the within-row crop density was increased by increasing row width from 45 to 90 and 135 cm (Figs. 52 and 53). However, crop yield also decreased, presumably because growth resources were not so fully utilized in the wider rows.

The Alfisol experimental field was heavily infested with weeds, and all sorghum yields were lower than those on the Vertisols. Unlike on Vertisols, sorghum yields increased when planted in wider rows (Fig. 53). Yield increases were observed under lower fertility when the row spacing was increased to 90 cm, whereas under higher fertility higher yields were observed even with 135-cm spacing. Further, when the within-row densities were increased, there were marked decreases in weed growth. The losses

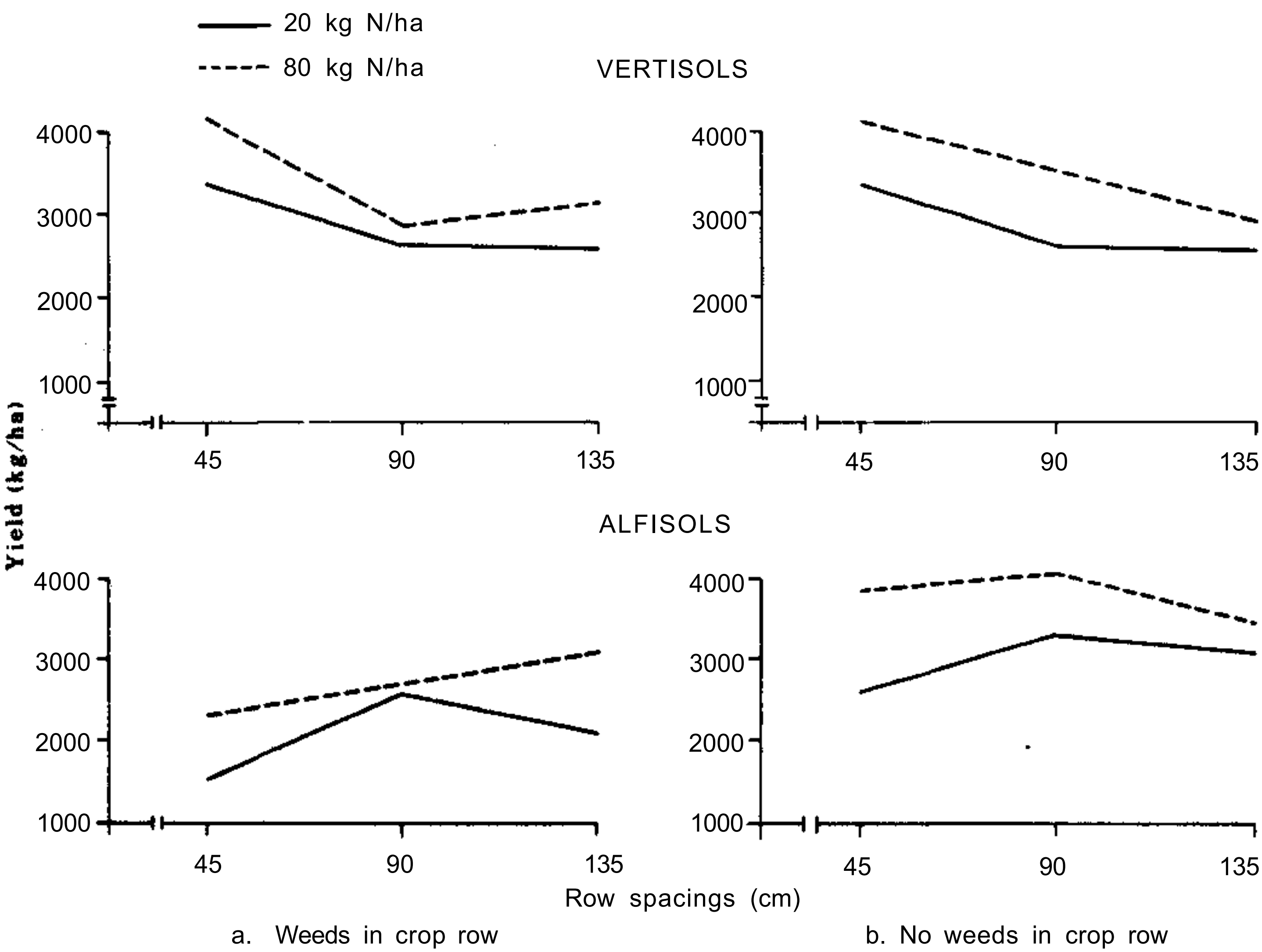


Figure 52. Effect of row spacings and nitrogen fertilization on sorghum yields (1978-79).

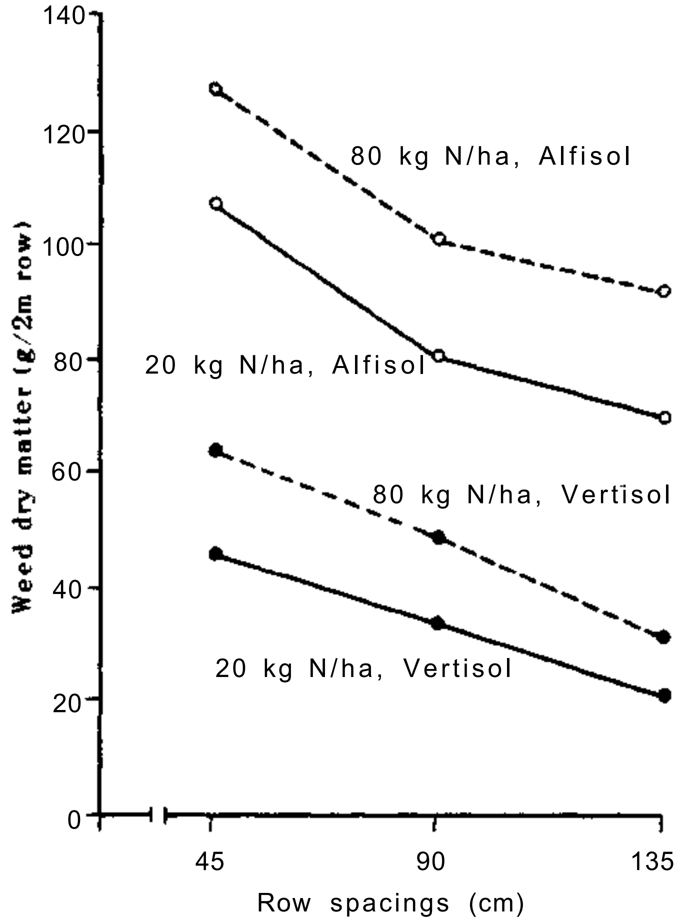


Figure 53. Effect of row spacings and nitrogen fertilization on within-row weed growth (1978-79).

caused by weeds in the 45-cm crop row in Alfisols ranged from 9 to 44%.

A few on-farm experiments were conducted at different locations to determine the success of farmers' own methods of weed control and to observe whether improved methods involving the use of herbicides were feasible under existing farming systems. Farmers in Dokur, Kanzara, Pocharam, and Aurepalle villages generally achieve satisfactory weed control under their existing farming systems. The use of herbicides on sorghum and groundnut superimposed on farmers' traditional methods reduced weed growth and increased yield slightly, though net returns did not increase. However, weed control methods involving costly inputs like herbicides could improve net returns where yield levels are higher.

RESOURCE UTILIZATION RESEARCH ON WATERSHEDS

The field-scale operational research conducted on the Alfisol and Vertisol watersheds serves to test and integrate principles and methodologies developed in several subprograms. Various combinations of land and water management and crop-production practices are being compared on small experimental watersheds at Bangalore, Sholapur, Hayatnagar, and at ICRISAT Center as part of the ICAR/ICRISAT Collaborative Research Program (for results at centers other than ICRISAT, see "Collaborative Studies"). Data on runoff, soil loss, water balances, crop yields, rainfall productivities (RP), and economics are collected and jointly analyzed.

Runoff

At ICRISAT in 1978 there were several high-intensity rains of long duration. This created a relatively wet soil profile throughout the season, resulting in substantial runoff from all watersheds. The rainfall and runoff summaries for Alfisols and Vertisols are given in Tables 21 and 22.

On clayey Alfisol watersheds with broadbeds, runoff was much greater than from those that were bunded but flat-cultivated. This was not the case with the more sandy Alfisols in RW3. The area under natural vegetation produced only a small amount of runoff. On Vertisols 37% of the rainfall ran off from the fallow watershed. Watersheds having broadbeds with or without bunds produced large amounts of runoff; however, on flat-cultivated fields runoff was substantially greater. The highest peak runoff rates recorded on Vertisols and Alfisols were similar to values observed in earlier years.

Table 21. Rainfall runoff and soil loss on Altisol watersheds, ICRISAT 1978.

Watershed	Area (ha)	Treatment	All storms Rainfall (mm)	All storms Runoff (mm)	Excluding storms of Aug 14, 15,22 Rainfall (mm)	Excluding storms of Aug 14, 15,22 Runoff (mm)	Peak runoff rate m^3/sec per ha	Soil loss (kg/ha x 1000)
RW1C	0.86	Flat, graded bunds	1038	208	763	77	0.13	2.8
RW1D	1.15	Broadbeds, 0.6%	1071	356	786	151	0.12	5.0
RW1E	1.58	Flat, contour bunds	1071	207	786	53	0.10	1.4
RW2A	28.93	Grazed	1046	202	765	66	0.08	
RW2B	2.60	Broadbeds, 0.6%	1035	339	755	131	0.10	4.2
RW3A	3.15	Flat, field bunds	929	212	692	40	0.05	2.7
RW3C	4.25	Broadbeds, 0.8%	938	143"	701	54	0.05	
RW3D	3.80	Broadbeds, 0.8%	938	214	701	88	0.05	4.9
RW3E	2.90	Natural vegetation	946	49	702	1	0.04	0.3

a. Not accurate because of overflow of boundary bunds during some of the August storms.

Soil Erosion

In a year such as 1978 with many intense storms, soil losses would be expected to be relatively high; however, except for the rainy-season fallow watershed BW4C, soil losses did not exceed 5000 kg/ha on the Vertisols or Alfisols. The lowest amount of soil loss from the cropped areas was 1400 kg/ha from a flat-planted, contour-bunded watershed. On the Alfisols, soil losses were somewhat higher from watersheds having broadbeds.

Crop Yields and Rainfall Productivity

The central objective of our watershed-based operational research is to develop management systems that increase and stabilize yields and increase the efficiency of rainfall use. At ICRISAT Center nine systems were compared in 1978 on the four RW3 Alfisol watersheds established in 1977. A sorghum/pigeonpea intercrop was compared with a millet or sorghum crop on each of the four watersheds. A postrainy-season crop of CSH-8 sorghum was also grown on 0.5 ha of watershed R.W3D. It was given four 50-mm irrigations from the on-site runoff storage tank. This represented about 15% of the runoff that occurred during the rainy season from the 3.8 ha watershed. Rainfall was well above normal in 1978. Consequently none of the stored runoff was used during the rainy season.

The use of improved varieties and recommended fertilizers greatly increased yields, gross returns, and rainfall productivities (Table 23).

Table 22. Rainfall and runoff on Vertisol watersheds, ICRISAT 1978.

Watershed	Area (ha)	Treatment	All storms		Excluding storms of Aug 14, 15,22		Peak runoff rate m^3/sec per ha	Soil loss (kg/ha x 1000)
			Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)		
BW1	3.41	Broadbeds, 0.6",,	1125	273	844	53	0.11	3.4
BW2	3.96	Broadbeds, 0.6% field bunds	1125	186	844	21	0.08	1.7
BW3A	4.81	Broadbeds, 0.4%	1107	195	825	32	0.07	3.6
BW4A	3.07	Flat, field bunds	1125	280	835	59	0.03	2.0
BW4C	3.46	Fallow, flat	1117	410	828	161	0.15	9.7
BW5BS	0.67	Fallow, broadbeds 0.4%	1108	239	822	74	0.08	4.4
BW6	4.48	(C + D) $Flat_2$, contour bunds	1079	286	803	76	0.05	3.8
BW7A	3.31	Broadbeds, 0.6%	1075	276	792	62	0.06	2.6
BW11	2.25	Natural vegetation	1017	135	750	1	0.08	

With improved practices, gross returns and rainfall productivities of the sorghum/pigeonpea intercrops were twice those of the single crop alone or in combination with a small area of irrigated sorghum in the postrainy season. If all of the runoff from RW3D had been available for use on the postrainy-season sorghum, the entire 3.8 ha could have been irrigated and the gross value (Rs. 3620/ha) and the rainfall productivity (Rs. 38/cm per ha) of the sequential cropping system would have been similar to those of the intercrop systems. The inclusion of a high value crop such as pigeonpea as an intercrop was a major determinant of gross value and rainfall productivity. All of the rainfall productivity values were relatively low because runoff, drainage, and evaporation losses were high in 1978 due to the unusually high rainfall.

It is expected that these and other combinations of practices will perform differently at other locations and under other seasonal rainfall patterns. Additional new practices of weed control, intercropping, draft-power use, and equipment/tillage practices, etc., generated by the Farming Systems subprograms will be incorporated into systems and will be operationally tested on the experimental watersheds. Performance data from such studies will be used to guide the more extensive evaluation in village-level studies.

COLLABORATIVE STUDIES

Several cooperative research projects on improved land and water management, agricultural hydrology and on-farm studies were formulated during workshops involving cooperating scientists, the All India Coordinated Research Project for Dryland Agriculture

(AICRPDA), state agricultural universities, and the ICRISAT Farming Systems Research Program, together with other ICRISAT programs as pertinent. The draft proposals for investigations were approved by the ICAR-ICRISAT Policy Committee on Collaborative Research, and work was initiated at a few locations in 1977. Several additional research centers participated in 1978; on-farm studies were also initiated in that year.

Resource Development and Conservation

This research project was started at 12 cooperating centers. Its objectives are (1) to evaluate existing soil and water conservation practices and to establish, in a quantitative manner, under which conditions contour bunding has significant effects on agricultural production, and (2) to develop improved technology for the use and conservation of land and water resources under rainfed conditions.

Initial experimentation has yielded promising results at some centers and mixed results at others; a detailed report was presented by Drs. W. Nicholaichuk, D.S. Rajput, and I.V. Subba Rao at the Seventh Annual Workshop of the AICRPDA held at Hyderabad in May 1979. The focus of the project to date has been on the evaluation of modifications of the graded broadbed-and-furrow system. It was found at all research centers that appropriate farm equipment is essential for successful implementation of the studies; hence much more emphasis should be given to strengthening the soil and water and equipment phases of these cooperative studies.

Preliminary results indicate that the present 150-cm broadbed-and-furrow system is most effective in increasing crop yields on the heavier

Table 23. Yields, gross monetary returns, and rainfall productivities of alternative fanning systems on Alfisol watersheds.

Treatment	Practices [a] 1	2	3	4	5	Cropping system	Yields (kg/ha) Sorghum	Pigeonpea	Millet	Value Rs/ha[b]	RPΔ Rs/cm per/ha[b]
A	0	0	F	0	0	Intercrop	140	140	-	700	7
						Single	100			135	1
B	+	+	C	0	0	Intercrop	2450	660	_	4030	43
						Single	-	-	2300	I960	20
C	+	4 -	0	+	0	Intercrop	2770	810	-	4780	51
						Single	-	-	2700	2300	24
D	+	+	0	+	+	Intercrop	3370	780	-	5090	54
						Single	...	-	2550	2160	23
						Sequential[c]	2070	-	2550	2380	25

a. 1 Variety: 0 traditional; + improved.
2 Fertilization: 0 FYM only; + recommended chemical fertilizers.
3 Bunds: F field bunds; C contour bunds; 0 none.
4 Graded furrows and 150 cm beds: 0 none; + present.
5 On site runoff storage for irrigation: 0 none; + present.
b. For whole watershed.
c. Millet in rainy season and 0.5 ha irrigated sorghum in postrainy season.
RP A: rainfall productivity—value per centimeter of rain from 1 June to 31 October.

soils and under medium to high rainfall conditions. Compared with flat cultivation, the use of graded broadbeds increased the yields of pigeonpea at Indore, pearl millet at Jodhpur, and maize and finger millet at Ranchi (Table 24). There was some evidence that on lighter soils, such as Alfisols, sowing flat on a grade with subsequent furrowing was the most effective technique for some crops.

The initial experience with these cooperative experiments clearly illustrates the need for greater integration of disciplines. Little further progress in the development of new techniques or their implementation will be made by additional research focusing on single components of the farming systems. The reasons for differences in performance of alternative systems cannot be inferred from yield data alone. A much more detailed interdisciplinary and interregional effort is required to clearly determine the interactions among climate, soil, crop, nutrient, and managerial inputs.

On-Farm Watershed Development

A cooperative on-farm research project was initiated in 1978 with AICRPDA, three state agricultural universities, and the ICRISAT Farming Systems and Economics Programs. Small watersheds in three villages were selected and land development was completed before the rainy season.

The objectives are: (1) to adapt, test, and measure the performance of prospective land and water management technology on fanners' fields, (2) to find ways for farmers to participate in the technology development process, and (3) to examine the need and feasibility of group action for adoption of watershed-based systems

Table 24. Crop yields with alternative land treatments.

Location and crop	Treatment	Crop yields (kg/ha)
Indore/Maize	Graded broadbeds	2180
	Graded flat cultivation	1920
Indore/Pigeonpea	Graded broadbeds	650
	Graded flat cultivation	540
Jodhpur/Pearl millet	Graded broadbeds	1760
	Interrow water harvesting*	1350
	Graded flat cultivation	1360
Ranchi/Maize	Graded broadbeds	1310
	Flat sown/later ridging	690
	Graded flat cultivation	890
Ranchi/Finger millet	Graded broadbeds	1750
	Graded flat cultivation	1450
Bangalore/Maize[b]	Graded broadbeds	2550
	Flat sown/later ridging	2760

a. Crop planted in 40-cm-wide furrows having 10-cm-wide runoff producing strips on either side.
b. The same experiment at Bangalore in 1977 resulted in yields of 2790, 3220, and 3770 kg/ha on graded broadbeds, narrow ridges, and flat sowing with subsequent ridging, respectively.

New technology is discussed with farmer and son in ICRISAT's on-farm research project.

of resource development and management.

An 11.7-ha Alfisol watershed at Aurepalle was developed during the dry season when draft animals were customarily idle and labor underemployed. The farmers were continuously involved in planning the work, and they participated in the development activities, which consisted of the removal of stones and brush, a thorough cultivation, land smoothing, drainageway construction, and the layout and establishment of the semipermanent, graded broadbeds. An existing shallow well was recribbed and is being used to supply supplemental irrigation on a limited adjacent area. The development costs totalled about Rs 450/ha. The cost of drainageways was Rs 125/ha (2500 m of waterways, Rs 894; five small drop structures, Rs 574). Land smoothing was relatively expensive at Rs 67/ha; the initial cultivation cost was Rs 62/ha and the ridge-marking operation Rs 58/ha. Less than 10% of the total costs were for capital expenditures; the rest were for locally hired labor and bullocks. Reconstruction of the well cost about Rs 135/ha, 60% of which was for the purchase of granite stones and cement. Almost half of the development costs were borne directly by the farmers. The watershed was planted to sorghum, castor, and a millet/pigeonpea intercrop early in the 1979 rainy season. Similar projects have been initiated with six farmers on a 10.8-ha medium-Vertisol watershed near Kanzara and eight farmers on a 13.9-ha deep-Vertisol watershed near Shirapur.

LOOKING AHEAD

Agroclimatology

Research efforts will be focused on:

1. Developing an understanding of rainfall variability across diverse locations for quantifying associated risks in crop production.
2. Characterizing crop response to the prevailing moisture environment in order to assist in crop planning for increased and stabilized agricultural production.
3. Developing a climate-driven production model based on crop-weather interaction studies in order to predict crop performance under different locations.
4. Developing agronomically relevant classification of the climate for identifying isoclimes to assist in the transfer of technology.

Environmental Physics

Studies to characterize the response of crops to different moisture environments will continue. Future research will concentrate on the dynamics of water in the soil-plant-atmosphere system, with particular attention to the quantities of water involved, the rates at which transfers occur, and the effects of the whole system on the rates of transfer.

We will continue to participate in interdisciplinary field research to assess the importance of physical properties of the soil on plant productivity.

Soil Fertility and Chemistry

Research on the behavior of nutrients in the soil-plant-water system will be expanded considerably. This is needed to improve the efficiency of use of fertilizer nitrogen by crops, in order to reduce their dependency on chemical fertilizer. Particular attention will be given to assessment of the losses of fertilizer nitrogen and maximising nitrogen inputs by biological fixation and recycling of residues.

Land and Water Management

Cooperative research with national programs must now be strengthened to rapidly gain information about the performance of improved natural resource development and management practices under a range of conditions. Such cooperative projects have started in India and will soon be initiated in other regions, particularly in West Africa. Cooperation is also sought with research centers in similar agroclimates in the developed world that have more expertise in modeling and simulation of the hydrologic and associated processes. These techniques are expected to greatly facilitate answers to questions regarding transferability of improved technology across similar regions in the SAT.

Farm Power and Equipment

Increased emphasis will be placed on the development of a simple, reliable, and accurate fertilizer applicator and a seeder. Efforts to design simpler and cheaper wheeled tool carriers will continue. Field performance of different machinery systems will be evaluated on an operational scale to collect information on draft and power requirements and field capacities for various operations. Studies will also continue on the effect of tillage and planting techniques on seedling emergence and weed management. Some efforts will be made to develop a multicrop thresher.

Cropping Systems

The exceptionally good pigeonpea growth this season and the consistently high intercrop yields with much smaller treatment differences than in last season suggest that the factors examined (plant population, spatial arrangement, and genotypes) may have greater influence on yield in situations where the intercropped pigeonpea yield is a much smaller proportion of its sole crop yield. We plan to examine these factors under situations of greater stress and to evaluate their effects over different seasons.

The greater efficiency of light use in millet/groundnut intercropping is potentially an extremely important finding that needs further verification. This season's experimental conditions provided good nutrient and moisture supply; we hope to examine the relative importance of light use efficiency when these belowground factors are more limiting.

There seem good possibilities for improving intercropping performance by the use of more appropriate genotypes, and future work will put more emphasis on identifying the required plant characters so these can provide a basis for selection in breeding programs. Such identification depends to a great extent on breeders' ability to provide a sufficiently wide range of material for examination. A further need in genotype work is to establish procedures for screening relatively large numbers of both crop components of a given intercrop combination.

Compared with last season, there was less evidence of greater intercropping advantages with increased moisture stress, and this needs much further study. The related field of yield stability in intercropping also deserves more attention; first results with sorghura/pigeonpea are extremely promising, but we need to determine if greater stability also occurs with other types of intercropping combinations and if the stability of traditional systems is affected by 'improved' practices.

Off-research-station entomological work on cereal/legume intercropping will be intensified and the influence of plant population and use of insecticides on pest/parasitoid levels and on crop losses will continue to be studied. A detailed survey is planned to elucidate factors involved in maximizing the role of natural control agents of *Heliothis armigera* in mixed crops and intercrops and to improve our understanding of the behavior of this noctuid moth. Efforts to establish a collaborative light trap grid on the Indian subcontinent will continue. Collaboration with the Center for Overseas Pest Research (COPR) and the Commonwealth Institute of Biological Control (CIBC) on surveys of natural control agents and biological control in mixed farming is being discussed. Research on parasite preference/avoidance of certain legumes is obviously an important area for more penetrating and intensive study. Synthetic pheromones of *H. armigera* supplied by the Tropical Products Institute (TPI) will be further tested for early season detection of *Heliothis* moths. Training opportunities for young entomologists from developing SAT regions will be increased.

Agronomy and Weed Science

As weed management often involves many aspects of farming systems including tillage, soil and water management, cropping pattern, crop variety and density, soil fertility, and economics, improved weed management systems will be evaluated on an operational scale in relation to these factors on a year-round basis.

The primary emphasis will be on the evaluation of widely applicable principles of weed management. We hope to intensify studies on the agronomic manipulation of the crop-weed balance to quantify the effects on it of physical and biological factors. Ecophysiological studies to understand the mechanisms involved in weed competition with crops will also be intensified. Weed-monitoring studies to determine how weed populations respond to crops, management techniques, and systems of cropping will be continued. In collaboration with the plant breeders and physiologists we plan to evaluate the performance of different cultivars of ICRISAT crops under alternative weed management systems.

Resource Utilization Research and Collaborative Programs

The extensive data on watershed-based research on the deep and medium-deep Vertisols have provided clear evidence of the advantages of the broadbed-and-furrow system of cultivation and land management. Cooperative studies under different climatic conditions but on similar soils are being conducted to extrapolate these results. Investigations on the medium and shallow Vertisols and the Alfisols show that further work is needed to develop more productive natural resource development and management methods; this will be a major focus of work in the next few years. Other aspects of operational-scale studies such as new cropping systems, weed management methods, and equipment are becoming increasingly incorporated in our research on the development of improved resource utilization systems.

The initial duration of the cooperative research projects with the All India Coordinated Research Project for Dryland Agriculture on soil and water management and on watershed-based resource management was envisaged as 5 years; our present experience indicates that this time frame may have to be extended. Although work at ICRISAT was initiated in 1973 and our projects now serve as "models" for the work at cooperating centers, simulation techniques need to be further developed and tested across different regions. The cooperative projects will therefore continue, with greater emphasis on the development of locally appropriate techniques and on training. It is expected that the number of cooperating centers and the diversity of the work will increase when staffing and facilities are further improved.

In the on-farm studies, increased attention will be given to facilitating more active participation of all cooperating organizations and subprograms. Additional work is required to adapt technology to the specific agroclimatic and socioeconomic conditions encountered. Our studies suggest that it is necessary to develop two levels of experimentation: precise, small-scale, special-focus research, and larger-scale investigations aimed at integration of technology and operational questions. We also realize that these studies must now be expanded to other areas, especially to the deep Vertisols under high rainfall conditions.

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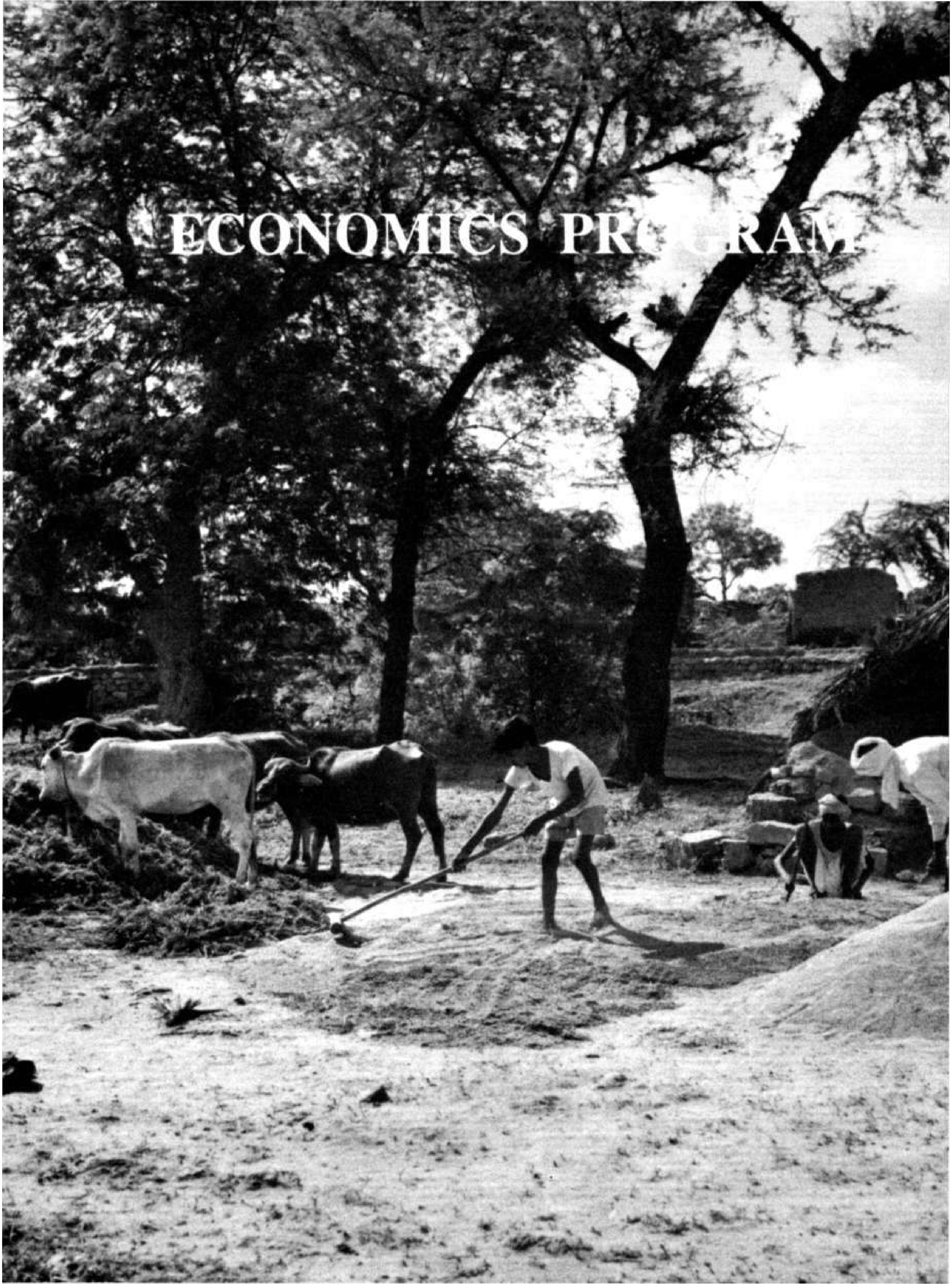
ECONOMICS PROGRAM



Contents

ECONOMICS PROGRAM

The Economics Program conducted in 1978-79 a variety of studies designed to increase understanding, and to help solve problems in production and marketing economics and in the social organization of SAT agricultural production. The results of these studies are presented below.

Agricultural Development in the Indian SAT

To summarize major aspects of agricultural development in the Indian SAT, we carried out a detailed comparative study of the region. A total of 190 Indian districts fall in the areas having an annual rainfall range between 500 and 1500 mm. These districts comprise over three-quarters of the area sown to ICRISAT mandate crops in India. Irrigation in the Indian SAT is relatively uncommon. Up to now, in areas where irrigation has increased, cropping patterns have changed in favor of rice, wheat, and sugarcane.

In India, farmers have been slow to adopt high-yielding varieties (HYVs) of pearl millet and sorghum compared with the progress made by HYVs of wheat and rice (Table 1). HYVs of pearl millet spread rapidly for a few years after their initial introduction, until struck by downy

Table 1. Percentage area in selected states and throughout India under high-yielding varieties for different crops in 1974 75.

State	Sorghum	Pearl millet	Wheat	Rice	Maize
Andhra Pradesh	7	33	NA	68	30
Gujarat	2	65	81	26	15
Haryana	NA	33	89	50	12
Kamataka	20	18	29	31	100
Madhya Pradesh	10	13	26	20	8
Maharashtra	8	33	43	27	23
Punjab	NA	25	83	84	17
Rajasthan	1	4	51	21	2
Tamil Nadu	8	39	NA	83	NA
Uttar Pradesh	NA	4	69	32	1
All ten States	8	23	61	43	12
India	8	22	62	29	18

Source: *Fertilizer Statistics,* 1976-77, Fertilizer Association of India, New Delhi.

NA = Not applicable.

mildew disease in many areas. Statistics indicate that they have continued to be successful where the crop is grown with good soil moisture or irrigation or where the varieties in question are relatively well adapted to local conditions. HYVs of sorghum seem to have been less successful due to several factors including harsh crop environments, susceptibility to diseases and pests, and difficulties in meeting consumer requirements for grain quality and fodder. These hypotheses regarding adoption of HYVs of both pearl millet and sorghum in India need to be tested with detailed and extensive farm-level data.

Most of the fertilizer used by SAT Indian farmers is for irrigated crops such as wheat, paddy, and sugarcane, or for high value non-irrigated crops such as cotton and groundnut. High-yielding varieties of pearl millet and sorghum are fertilized at fairly high rates under irrigated conditions, but the area so treated is small. There is some evidence to show that farmers have started applying fertilizers to some pulse crops. In this context, we note that grain legumes have witnessed sharp price rises in recent years.

It seems that SAT Indian farmers are aware of the potential of fertilizers and that their actual use offertilizers is influenced by size and certainty of returns. There would be good scope for improvement in production of the ICRISAT mandate crops in India if more, better-adapted HYVs were available, if market demand increased leading to higher profits to farmers from growing these crops, and if measures to reduce risk were devised, including conservation of moisture and improvements in its use.

Market Channels of ICRISAT Crops in India

Our estimates of market arrivals in 29 selected markets sampled in SAT India showed that in the mid-1970s only 22% of sorghum was marketed and 78% was retained on farms or in the village. About 26% of pearl millet was marketed. Higher percentages of the grain legumes were marketed: 35% of pigeonpea, 45% of chickpea, and 80% of groundnut. Interregional trade in sorghum and pearl millet is concentrated within the SAT areas of India where these crops are used as staple food. The major producing areas for sorghum (Maharashtra State) and pearl millet (Gujarat State) are also the major importing regions for these crops. The pulses flow into other non-SAT areas (Figs. 1 and 2).

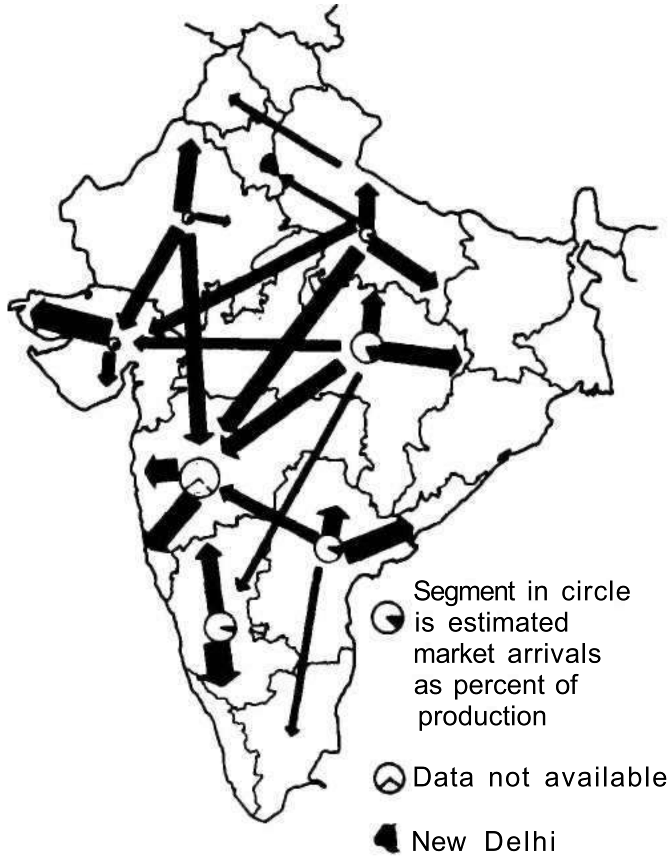
In all the markets studied, large farmers participated more than small farmers. Generally, small farmers seemed to produce for home consumption. When they did sell part of their produce, small farmers usually used only nearby markets, possibly because of small quantities of produce for sale and transportation problems. Relative access to product markets and participation in these is an important area for further research. Means to increase small farmer participation in markets need particular attention.

Estimates based on marketing costs and margins in three representative markets indicated that these markets were operationally efficient for all five ICRISAT crops. The margins obtained by delears in the different channels were consistent with overhead costs and services rendered. The farmer's share in the final retail price paid by the consumer varied between 74% for groundnut and 85% for sorghum, net of marketing costs but not of production costs.

Economic Assessment of Technologies for SAT India

From 1975 through 1978 experiments were conducted at ICRISAT to test improved methods of soil, water, and crop management for increased food production in the SAT. We carried out an economic analysis of the data from these experiments, with the following conclusions:

- A complete improved technology package generated maximum profits per hectare in small plot experiments at ICRISAT Center.



Name of state	Production" (1000 metric ton)	Estimated market arrivals as % of production
Andhra Pradesh	1571	8
Madhya Pradesh	1869	18
Maharashtra	3622	NA
Rajasthan	306	31
Gujarat	320	16
Karnataka	1815	5
Uttar Pradesh	397	12

NA = Not available

Arrows across state borders represent flows to markets in other states.

Medium length arrows represent flows to markets in other districts within the state.

Short arrows represent flows to other markets within the district. .

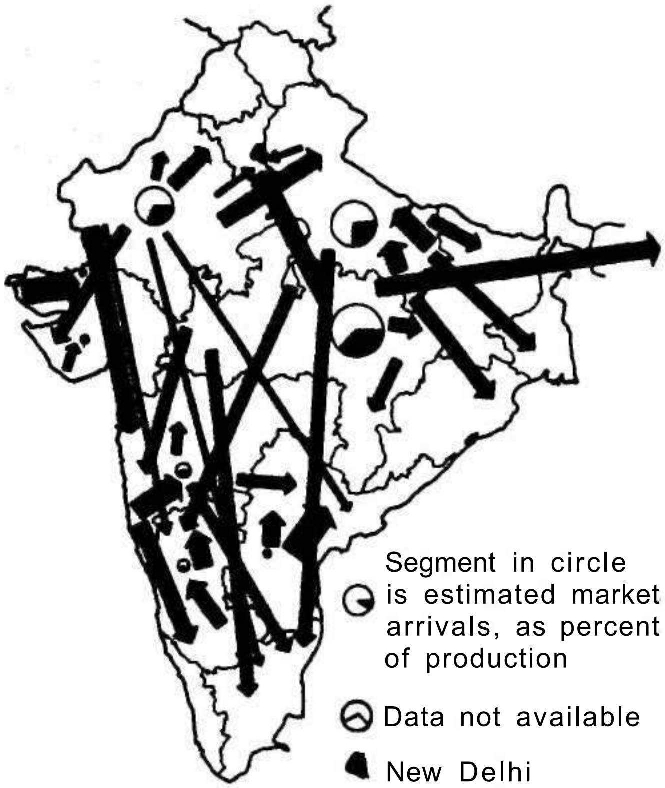
Width of arrow represents relative proportion of flow.

Figure 1. Sorghum marketing in India: market** arrivals as percent of production and total flows as* ***percent of market arrivals, 1974-75.

The package, tested on both Vertisols and Alfisols, utilized improved seed varieties, fertilization, plant protection and soil management and employed an improved, bullock-drawn wheeled tool carrier for all operations.

- Maximum profits were achieved with risks that seemed well within tolerances revealed by the Indian SAT farmers.
- On deep Vertisols at ICRISAT Center the broad bed -and -furrow system of soil and water management plus improved crop management was highly profitable in the large-scale experiments.
- On Alfisols at ICRISAT Center profits from improved soil and crop management were also attractive in the small plot experiments although 60% less than on the Vertisols.
- A profit could not be shown for improved soil and crop management on medium-deep Vertisols in the larger-scale trials at ICRISAT Center.
- Traditional cultivation and crop management was more profitable than broadbed-and-furrow cultivation in the large-scale Alfisols experiments.

On ICRISAT Center Vertisol watersheds, a maize/pigeonpea intercrop system generated substantially higher profits, with less variability, than did a maize-plus-chickpea sequential system, especially on medium-deep Vertisols. The likelihood that water harvesting and supplementary irrigation will prove viable is much higher on ICRISAT Center Alfisols than Vertisols, due to the greater runoff-generating potential and scope for profitable crop responses to irrigation on Alfisols. It is unlikely that this technology will be viable on deep Vertisols in a climate similar to that of Sholapur District



Name of state	Production (1000 metric ton)	Estimated market arrivals as % of production
Andhra Pradesh	28	NA
Madhya Pradesh	1147	37
Maharashtra	146	46
Rajasthan	794	31
Gujarat	15	NA
Karnataka	66	NA
Uttar Pradesh	1048	26

NA = Not available

Arrows across state borders represent flows to markets in other states.

Medium length arrows represent flows to markets in other districts within the state.

Short arrows represent flows to other markets within the district.

Width of arrow represents relative proportion of flow.

***Figure 2.** Chickpea marketing in India: market arrivals as percent of production and total flows as percent of market arrivals, 1974-75.*

in India, where the early monsoon is very sparse and undependable and overall rainfall levels are low. Optimum small watershed sizes seemed to be between 8 and 16 ha for the situations tested.

Model to Predict and Evaluate Runoff

We used data from ICRISAT Center and from Sholapur District of India to develop a model to predict and evaluate runoff from rainfall. The data from Sholapur, a particularly drought-prone area, were made available through the cooperation of the local station of the All India Coordinated Research Project for Dryland Agriculture. The range of variables tried in the various regression equations was as follows: daily runoff, daily rainfall, antecedent rainfall, peak rainfall intensity, average rainfall intensity, vegetative cover, soil type, type of cultivation, type of bunding, area of runoff plots or watersheds, soil depth, years after initial land shaping on watershed, and mulching.

Results suggest that the empirical models derived for determining runoff on Vertisols and Alfisols in these two areas of India will enable predictions for these areas to be made with quite a high degree of accuracy. This accuracy will increase the more one moves away from daily predictions and sums predictions into weekly, monthly, and annual totals. In some cases, annual runoff totals can be predicted on average with less than 10% error.

Economics of Improved Bullock-drawn Tool Carriers

A study at ICRISAT Center by scientists of the Economics Program and the Farming Systems Research Program shows that on Alfisols and Vertisols significant increases in returns from

SAT crops can be realized by the use of a wheeled, bullock-drawn tool carrier with attachments to carry out improved soil management practices along with improved levels of plant protection. We find that these returns are attributable inter alia to the relatively high efficiency and precision with which certain traditional and improved practices can be carried out with the aid of such frame and set of implements (Fig. 3).

A simple way to examine the economics of the wheeled tool carrier is to compute a contract hire rate that an entrepreneur would have to charge to make a profit from investment on the tool carrier, implements, and a sturdy pair of bullocks. This calculation can be made under various assumptions about machine costs, profit rates, and utilization rates of the bullocks and the tool carrier. These rates can then be compared with existing bullock hire rates in the central peninsular SAT Indian villages studied by ICRISAT.

One finding from these calculations and comparisons is that the equivalent rental rate for traditional implements of Rs 37 per day cannot be achieved even under the most favorable assumptions of a low-cost machine and a 10% profit rate, although the difference in this case is only Rs 2. The calculations also show that increases in utilization rates allow for large reductions in rental rates; the machine thus must be made to work for nonagricultural purposes such as hauling as well as for field use. The costs of bullocks and the wages of the driver form the larger portion of the cost of the package under nearly all assumptions. Because of this, reduction in machine costs by about 50% only reduces the rental rate of the entire package by approximately 27%.

In future, research attention should be focused on how to increase bullock utilization rates. Efficiency increases for the machine itself are also of prime importance since these would allow operation with smaller and cheaper bullocks. Reductions in machine costs will be helpful only if they do not require design changes that reduce the efficiency of the machine, thus increasing the bullock cost component.

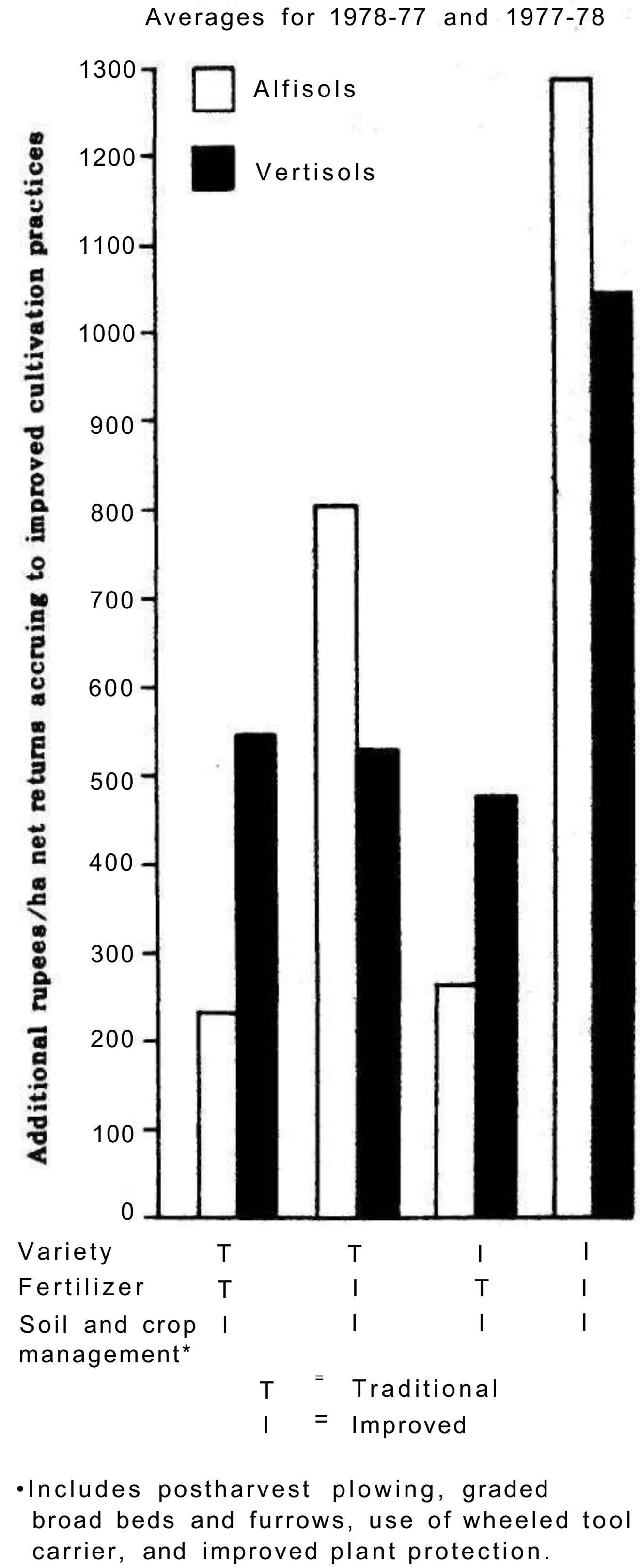


Figure 3. Increased net returns per hectare attributable to improved soil and crop management practices with wheeled tool carrier at ICRISAT Center.

Field Studies of Watershed Development and Group Action

Experiments were initiated during 1978-79 to test in farmers' fields systems of watershed development evolved at ICRISAT Center. The experiments are being conducted in cooperation with farmers from three villages, with member institutions of the Indian Council of Agricultural Research, and with the Farming Systems Research Program of ICRISAT.

The watershed areas being studied involve groups of from 5 to 15 farmers and are located in each of the three central peninsular Indian agroclimatic and soil subregions under study since 1975 in ICRISAT's Village-Level Studies (VLS). Farmers are protected against failure of the experiment for its 3-year duration, and they provide substantial amounts of the labor and bullock power used.

During the 1978-79 crop season small plot experiments covering approximately 4 ha in each village were laid out on individual fields to test different possible cropping patterns. A 3-day workshop involving all the farmers from each of the three watersheds proposed for development and study was held in August 1978. During this workshop, farmers were able to examine a range of agricultural innovations and to test for themselves the improved, bullock-drawn wheeled tool carrier used in ICRISAT's watershed development experiments. During the dry, premonsoon season of 1979, integrated, watershed-based development involving improved drainage structures and the formation of graded beds for planting was begun on several farmers' fields on each watershed.

The fanners' reactions to the technologies and to the types of group action involved are being monitored at present; they will also be observed when the present management assistance and financial aid end with the completion of the 1980-81 crop season. Concurrent, supplementary studies on the social organization and the economics of watershed-based agricultural development are being undertaken.

Labor Availability and Allocation

Attempts are under way at ICRISAT to develop technologies that will be viable for all SAT farmers, including the small landholder, and have potential for augmenting rural employment. Recent experiences with modern varieties of wheat and rice in Asia suggest that new seed/fertilizer/irrigation technology does have scope for creating emplpyment and for benefiting small farmers. However, there is evidence that some of the mechanization that occurred with introduction of the new varieties may have led to labor displacement with little gain in productivity. In view of this, a study was initiated to obtain insights into the likely effects that prospective improved land-, water-, and crop-management technologies being studied at ICRISAT would have on existing village labor-use patterns in peninsular India, one of the major SAT regions of concern. It was also thought that with a thorough understanding of existing labour patterns it would be possible to design technologies that would capitalize on periods when opportunity costs of labour are relatively low.

The data for analysis were drawn mainly from the six VLS villages in SAT peninsular India. Details from sample households on utilization of the labor of each family member and of hired personnel were obtained and related to both on- and off-farm activities as well as to household work. Labor-use data from the watershed-based research being conducted at ICRISAT Center by the ICRISAT Farming Systems Research Program were used for a comparison with the village situation.

Major results from this research project to date are as follows:

- There is a tremendous employment-creating potential in existing tank and well irrigation systems in the Alfisols of peninsular India, and new technologies for the rainfed portions will have to compete with these systems for labor at strategic times.
- Factors including rainfall patterns, crop-

ping patterns, the extent of mixed cropping, and the extent and quality of irrigation all play important roles in determining the intensity of labor use.

- Employment potential for women seems greatest in the highly irrigated and cotton-growing villages (Dokur and the Akola villages).
- There is a substantial contribution of female labor in the crop agriculture of SAT peninsular India.
- Males contribute substantially more of the total family labor, while females contribute substantially more of the total hired labor.
- Females from the poorest socioeconomic group are at the greatest disadvantage in terms of employment opportunities, since they must seek work throughout the year, and not just at peak periods.
- Average opportunity costs of male labor (Rs 2.26 per day) were about 90% greater than those of female labor (Rs 1.20) in these villages.
- Coefficients of variation of opportunity cost were quite large throughout the season (12 to 47%). Hence, there seems to be good scope for design of technology that strategically uses low opportunity costs periods; this would also generate additional income for disadvantaged groups at times when job opportunities and/or wages are low.
- The prospective technologies being evaluated at ICRISAT offer scope for increased employment compared with existing technologies, ranging from at least 48% more employment in Alfisols to more than 150% in deep Vertisols. If traditional threshing methods are utilized, the potential employment increases could be much higher (Figs. 4 and 5).

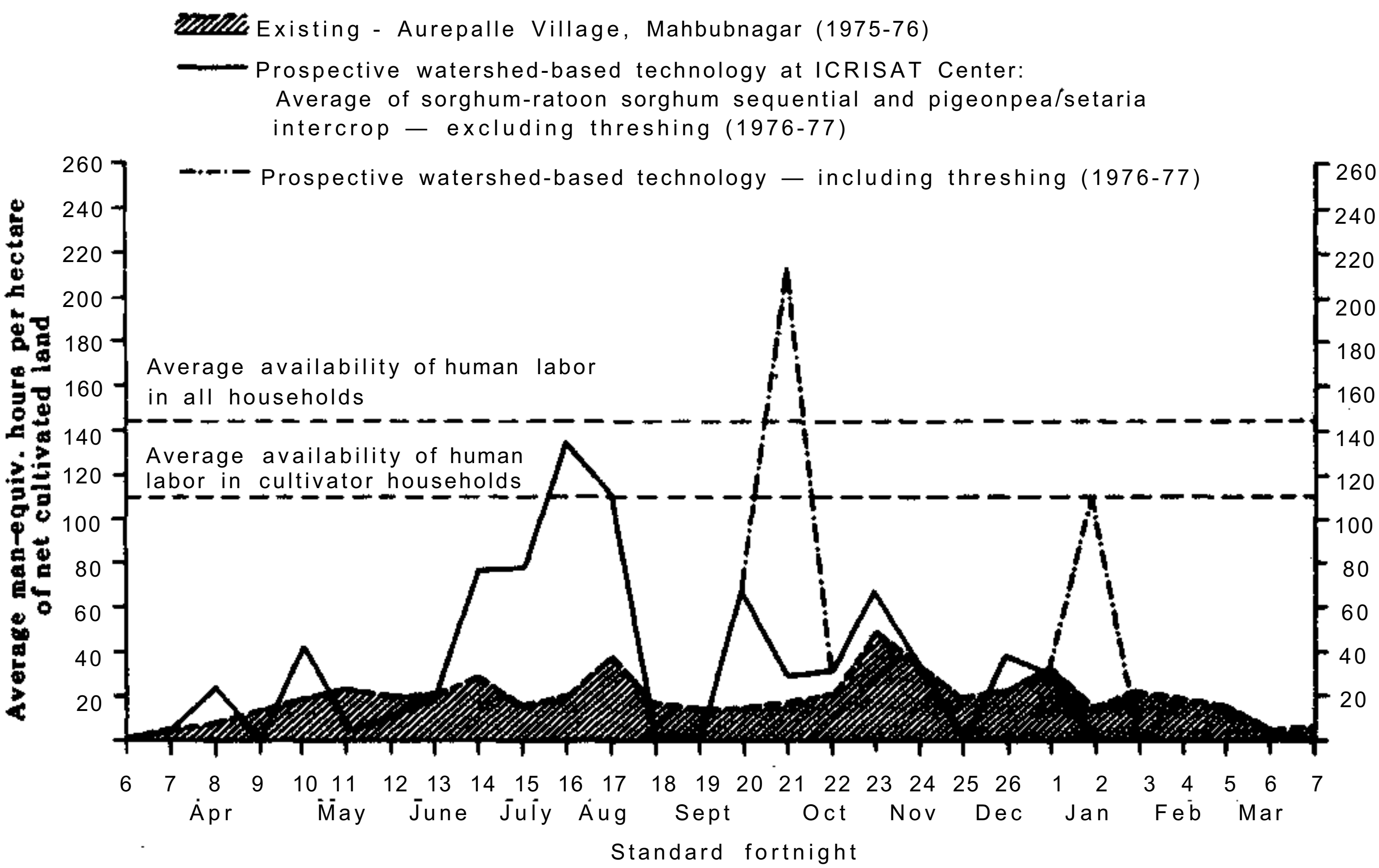


Figure 4. Average seasonal human labor availability and use with existing and prospective water-based technology on Alfisols.

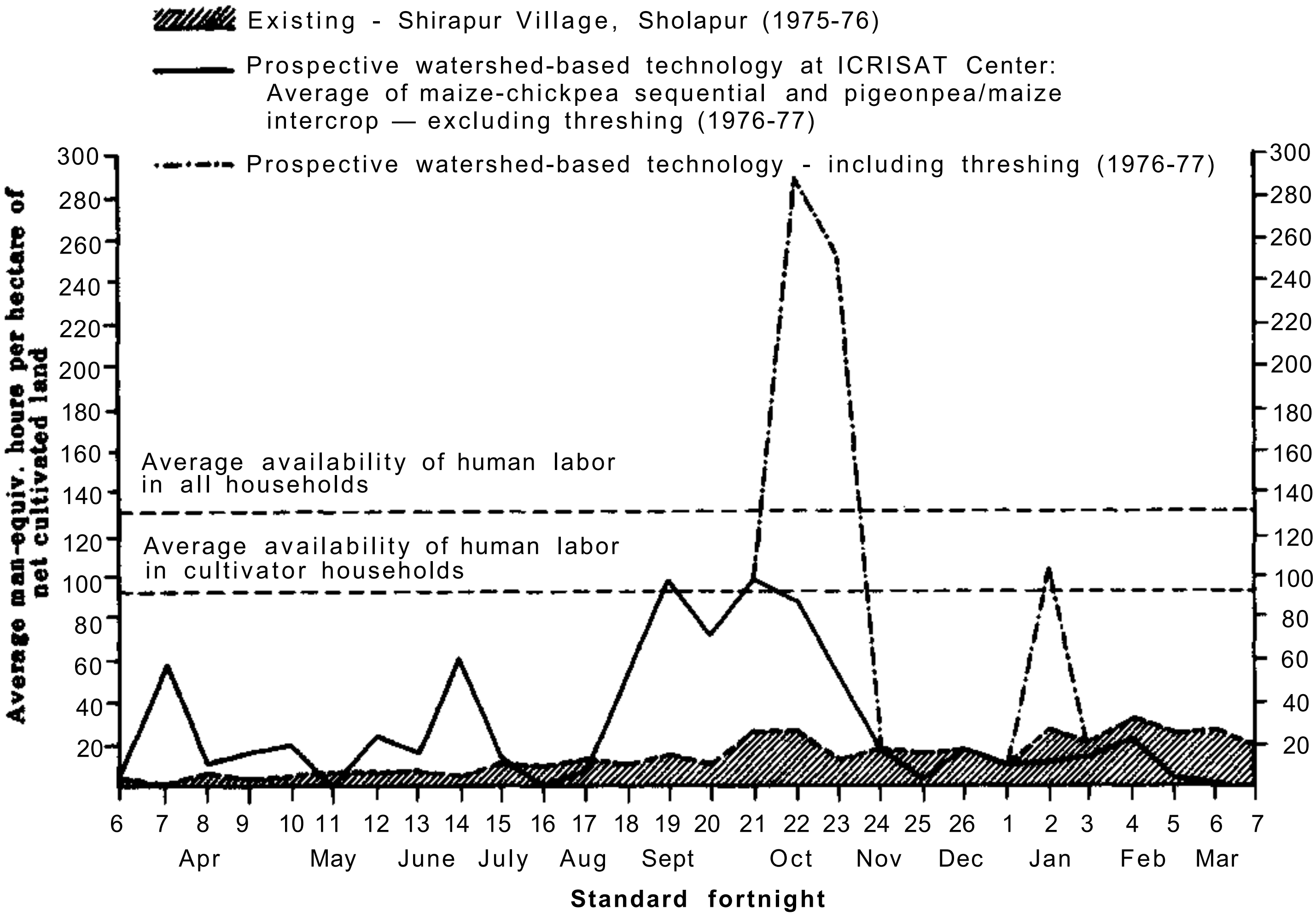


Figure 5. Average seasonal human labor availability and use with existing and prospective watershed-based technology on deep Vertisols.

- Given the existing availabilities of labor in these villages the watershed-based technologies would be expected to encounter major farm labor bottlenecks in July, August, and October on Alfisols, and in September, October, November, and January on deep Vertisols. Medium-deep Vertisols would experience major bottlenecks in two periods: in June and from September to January. Such bottlenecks would be expected to create demands for selective mechanization of operations such as threshing at some periods.

Factor Proportions and Technology Development

Farm data from village-level studies conducted in the Indian states of Andhra Pradesh, Maharashtra, and Himachal Pradesh were analyzed to determine the extent to which small and large farms differed with respect to their resource endowment ratios.

From the evidence examined it seems that for such regions there is no basic reason why the type of technology relevant for small farms should be substantially different from that for large farms with respect to its resource-saving or resource-using characteristics. The differences in the average resources endowment ratios between the small and large farm groups seem to be too minor for separate large-farm and small-farm developmental pathways to exist, at least under present conditions. The difference in factor ratios between the extremities of the farm data analyzed was minor compared with that between the U.S. and Japan, countries which are often cited as the prime examples of induction of different technological growth paths. The heterogeneity in resource endowment ratios within the farm-size groups studied also makes it impossible to identify a unique target such as "small farms" for technology design.

The relevant technology for both small and large farms in these regions of India is one that is land-saving and/or labor-using. This will be of benefit to large and small farmers alike.

Intercropping

Our data from the central Indian SAT suggest that intercropping in this area is highly complex and diverse because farmers attempt to achieve multiple objectives simultaneously through intercropping. Research cannot and need not generate equally complex new intercropping systems. Instead, research could concentrate on generating simple systems that satisfy key objectives like profitability and stability, without completely ignoring the other objectives that underlie traditional intercropping systems. Such a research strategy could realize relatively quickly the great potential of intercropping for higher and more dependable gross returns per hectare and per unit of peak period labor use.

Socioeconomics Workshop

A successful international workshop was held on the socioeconomics of agricultural development in the SAT. This is reported in more detail in the section "Conferences, Workshops, and Seminars."

Looking Ahead

Scientists of the Economics Program posted in West Africa will establish initial research priorities in production and marketing topics. Steps will also be taken leading to the early initiation of field research at the farm level in major SAT areas of West Africa. The sites for this research will be chosen so as to be useful to ICRISAT's biological and physical scientists for field observations and experiments, as has been the case with the present VLS. These West African studies will provide important data for comparison with those from the continuing central Indian VLS, and from the expansion of the Indian VLS into major chickpea, pearl millet, and groundnut growing areas of northern India.

Building on the results of our studies of risk in our central Indian VLS sample of farmers and laborers, further experiments and analysis will be undertaken. It is proposed to analyze the relationship of experimentally-measured risk aversion with actual agricultural decisions taken by the respondents. Furthermore, the impact of credit market imperfections on risky decisions will receive increasing attention.

Field experiments to test watershed development technology developed at ICRISAT will continue in cooperation with VLS farmers, Indian Council of Agricultural Research scientists, and ICRISAT scientists of the Farming Systems Research Program.

In order to assess further the feasibility and likely consequences of new land- and water-management technologies, activities analysis models are being developed that will try to incorporate all the possible alternatives available in improved as well as traditional technologies and most of the constraints present in semi-arid tropical regions. In order to evaluate the economics of the use of runoff from small watersheds for life-saving irrigation in the rainy season, the derived equations used to predict runoff will be employed in simulation exercises.

As part of a strategy to test hypotheses regarding supplementary irrigation and its social organizational requirements, studies of the ownership and management of existing irrigation sources including wells and tanks will be carried out.

We plan to utilize central Indian VLS data and intensive special interviews with respondents to describe the socioeconomic conditions that structure this area's daily and long-term agricultural labor markets.

We will attempt to quantify the effects of market infrastructure and market regulation policies on aggregate agricultural productivity in major SAT states in India. Grain quality indices based on general consumer preferences are being developed to aid in efficient selection of breeding material for good consumer acceptance.

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GENETIC RESOURCES UNIT

Contents

GENETIC RESOURCES UNIT

In 1978, the International Broad for Plant Genetic Resources (IBPGR) requested that ICRISAT assume the responsibility of serving as a major repository for the germplasm of the five mandate crops and the minor millets. The Governing Board of ICRISAT accepted this responsibility.

The Genetic Resources Unit (GRU) was established on 1 January 1979 by incorporating the various crops germplasm activities and facilities of the Institute into one coordinated unit. The unit was created to enhance ICRISAT's services as a world center for the improvement of the genetic potential of the mandate crops.

The major objectives of the unit are the collection, evaluation, maintenance, documentation, conservation, and distribution of germplasm of the mandate crops—sorghum, pearl millet, pigeonpea, chickpea, groundnut—and the six minor millets: finger (*Eleusine coracana*), foxtail (*Setaria italica*), proso (*Panicum miliaceum*), little (*Panicum miliare*), kodo (*Paspalum scrobiculatum*), and barnyard (*Echinochloa crusgalli*).

An operational flow plan (Fig. 1) describes

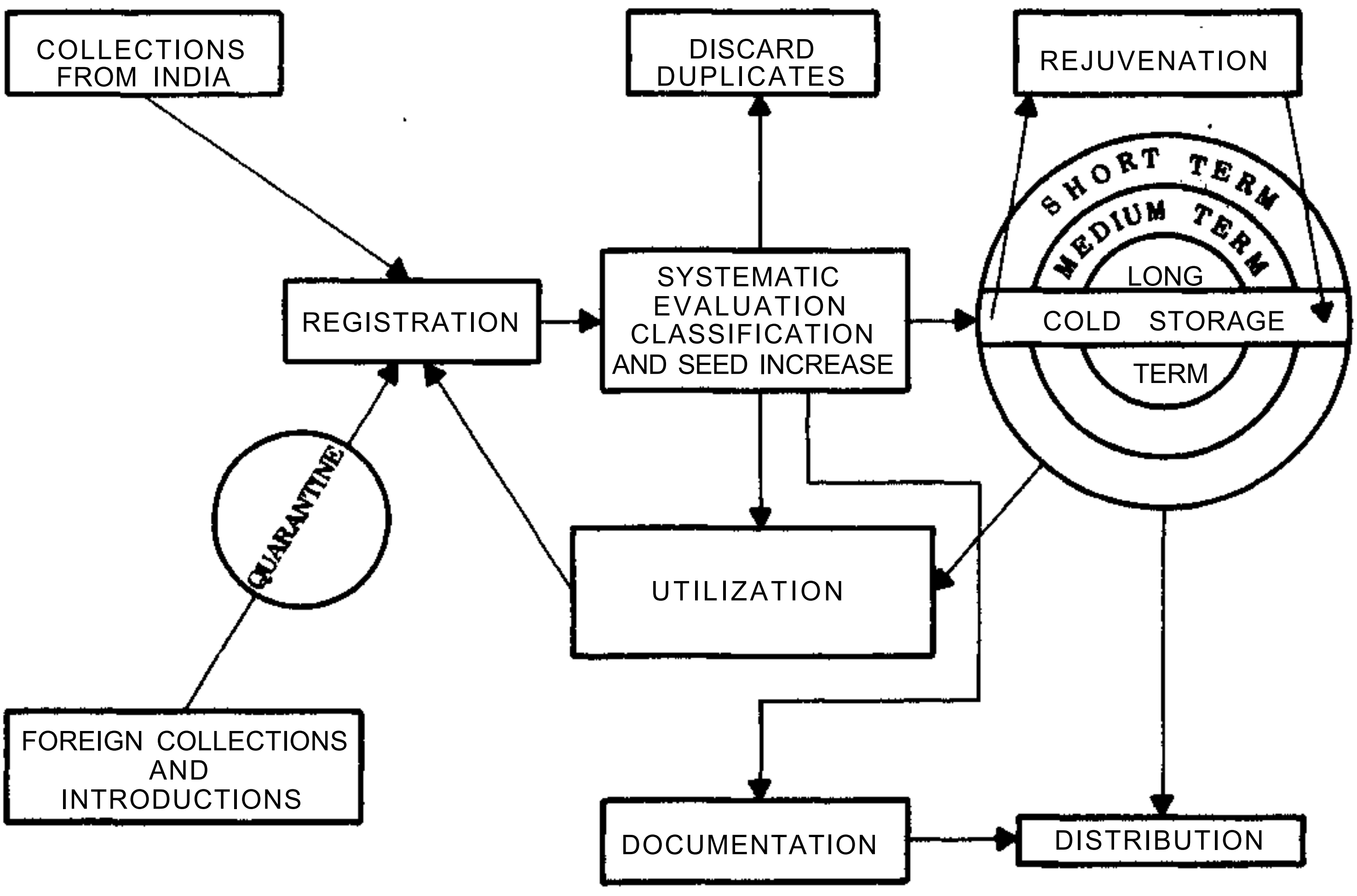

Figure 1. Genetic Resources Unit, ICRISAT—Operational flow chart.

the organization and activities of the unit.

To date, a total of 58 067 germplasm accessions of all the mandate crops and their wild relatives have been assembled at ICRISAT Center's gene bank. The germplasm accessions of each crop presently maintained at ICRISAT and their source countries are shown in Table 1.

The types of germplasm collections maintained at the ICRISAT gene bank are:

1. Accession collection—The available world collection and new accessions.
2. Spontaneous collections—The wild and weedy races.
3. Named cultivar collection—Cultivars released by private and public institutions from different countries.
4. Genetic stock collection—Selfed lines with known and useful genetic traits for special qualities and/or resistance to stresses of disease, insects, drought, *Striga,* etc.
5. Conversion collection—Depending on the crop, a collection of converted lines from either tall or short, photosensitive or insensitive, late or early, etc.
6. Other types of collections, such as basic, bulks and population, will be developed.

The past and future worldwide germplasm collection areas in the semi-arid tropics are shown in Figure 2. Most of the world's centers of genetic diversity of these crops are located in the semi-arid areas of developing countries, where productivity levels are relatively low and where farmers are willing to exchange their time-tested, genetically broad-based landraces for newly bred, more uniform, high-yielding cultivars. This situation threatens to cause genetic erosion of the primitive types that have become fit for their environment in their struggle for survival through centuries of spontaneous hybridization and evolution. The GRU is giving a high priority to salvaging the primitive cultivars and their wild relatives in

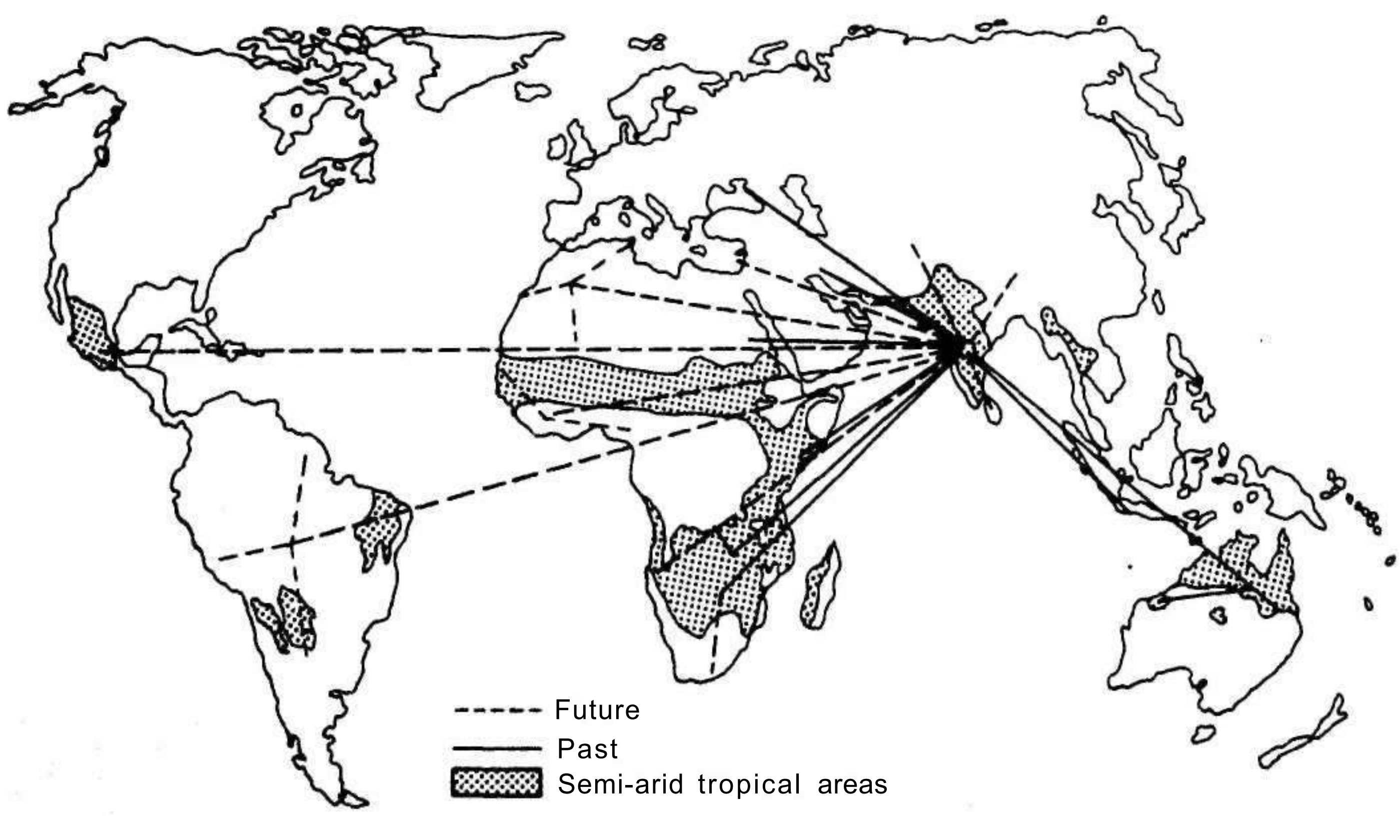

Figure 2. Past and future germplasm expeditions.

Table 1. Germplasm collection status at ICRISAT.

Country	Number of accessions as of June 1979				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
AFRICA					
Algeria	0	0	0	18	0
Angola	23	0	0	0	2
Botswana	56	0	0	0	0
Cameroun	1 753	169	0	0	0
Central African Rep.	37	58	0	0	0
Chad	125	62	0	0	0
Egypt	21	0	0	50	3
Ethiopia	2 863	0	0	159	0
Ghana	63	1	1	0	3
Kenya	317	47	64	0	96
Liberia	0	0	0	0	11
Malawi	58	2	0	0	21
Mali	95	527	0	0	0
Morocco	3	0	0	53	3
Niger	403	1 032	0	0	0
Nigeria	1 029	399	27	3	132
Rhodesia	133	1	0	0	334
Senegal	222	304	10	0	123
Somalia	5	0	0	0	0
South Africa	485	10	0	0	22
Sudan	1 548	2	0	4	625
Swaziland	18	0	0	0	0
Tanzania	31	0	5	1	82
Tunisia	0	0	0	30	0
Uganda	493	48	0	0	50
Upper Volta	206	28	0	0	6
Zaire	24	0	0	0	0
Zambia	3	0	0	0	0
ASIA					
Afghanistan	5	0	0	675	0
Bangladesh	9	0	25	0	0
Burma	2	0	59	6	2
China	42	0	0	0	101
Cyprus	0	0	0	0	5

Continued

Table 1 *Continued*

Country	Number of accessions as of June 1979				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
India	3 677	8 649	8197	4 983	1419
Indonesia	6	0	5	0	13
Iran	7	0	0	4 091	4
Iraq	2	0	0	18	0
Israel	22	0	0	48	24
Japan	106	0	0	0	37
Jordan	0	0	0	24	0
Lebanon	179	0	0	18	0
Malaysia	0	0	0	0	5
Nepal	7	0	110	0	0
Pakistan	19	5	16	151	0
Philippines	4	0	13	0	3
Sri Lanka	2	0	59	3	10
Syria	0	0	0	12	0
Taiwan	13	0	3	0	9
Thailand	5	0	2	0	0
Turkey	3	0	0	432	4
Yemen (N)	23	0	0	0	0
EUROPE					
Bulgaria	0	0	0	5	0
Cyprus	1	0	0	21	1
France	5	0	20	1	0
Greece	1	0	0	24	4
Hungary	21	0	0	4	0
Italy	8	0	0	18	0
Netherlands	0	0	0	0	5
Spain	0	0	0	77	1
USSR	27	12	2	89	27
UK	1	0	0	0	8
AMERICA					
Argentina	2	0	0	0	144
Bolivia	0	0	0	0	40
Brazil	0	0	7	0	202

Continued

Table 1 *Continued*

Country	Number of accessions as of June 1979				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
Chile	0	0	0	9	8
Colombia	0	0	5	1	0
Costa Rica	0	0	0	0	5
Cuba	1	0	0	0	5
Dominican Republic	0	0	6	0	0
Jamaica	0	0	18	0	1
Mexico	207	0	2	264	8
Nicaragua	0	0	0	0	7
Paraguay	0	0	0	0	87
Peru	0	0	5	2	37
Puerto Rico	0	0	45	0	20
Trinidad	0	0	22	0	0
Uruguay	0	0	0	0	21
USA	1 785	48	3	108	959
Venezuela	0	0	15	0	8
AUSTRALASIA					
Australia	6	4	17	0	29
OTHERS	5	1	12	14	17
Unknown	370	58	0	67	2886
Total	16 587	11 467	8775	11 483	7679

Minor millets collections at ICRISAT

Species	No. of accessions
Eleusine coracana (finger millet)	631
Setaria italica (foxtaine millet)	660
Panicum miliaceum (proso millet)	118
Panicum miliare (little millet)	148
Echinochloa crusgalli (barnyard millet)	298
Paspalum scrobiculatum (kodo millet)	221
Total	2076

the priority areas before they are completely extinct.

The 1978-79 cereals germplasm collection in eastern Africa was jointly planned and executed by IBPGR, ICRISAT, and national organizations. The countries covered in this program are Malawi, Somalia, Sudan, and Tanzania. Planning also was completed for collection in Zambia and Botswana, to be carried out in 1980. Several regions in India were visited for collections by ICRISAT scientists in close collaboration with All India Coordinated programs, agricultural universities, and departments of agriculture in various states.

Pulses and groundnut germplasm have been collected largely from several regions of India, Nepal, Australia, and Greece. Several accessions of groundnut were transferred to ICRISAT from USA, USSR, Africa, and Asia.

Sorghum Germplasm

In all, 1283 new accessions were received this year. Over 3501 samples are in transit and are expected to be released by the Indian plant quarantine. They include the Kenya collection (602), Malawi collection (417), Tanzania collection (181), a portion of the original world collection transferred from USA and Puerto Rico (2301).

For the purpose of distribution, 5688 accessions were rejuvenated and increased. Several thousand new accessions were evaluated and screened for resistance to insect, disease, *Striga,* and drought stresses. Internationally accepted descriptors for evaluating sorghum germplasm. have been prepared and reviewed by an IBPGR/ ICRISAT committee composed of Dr J. R. Harlan (Chairman), Dr L.R. House, Mr K.E. Prasada Rao, Dr K..F. Schertz, and Dr A. Sotomayor.

The introgression and conversion sorghum projects were continued, using our genetic resources to introgress new germplasm into the adapted breeding material and to convert the tall, photosensitive, tropical germplasm into day-neutral material of good agronomic background. The F_4 and BC_1F_4 populations of the introgression material looked very uniform, with high-yield potential on good agronomic background. The material was displayed in field conditions for ICRISAT and Indian breeders to make selections to utilize in their programs.

The wild relatives of *Sorghum* presently maintained at ICRISAT are the following. (Several others are being cleared by the Central Plant Protection Training Institute, Rajendranagar, Hyderabad.)

Section *Parasorghum :*

- *S. versicolor* Anderss.
- *S. purpureosericeum* (A. Rich.) Aschers. & Schweinf.

Section *Sorghum:*

- *S. halepense* (L.) Pers. (races: halepense—Johnson grass, and almum—Columbus grass)
- *S. bicolor* (L.) Moench, subsp *arundinaceum* (Desv.) de Wet and Harlan (races: arundinaceum, virgatum, verticilliflorum, and aethiopicum) and subsp *drummondii* (Steud.) de Wet comb. nov. (weedy sorghums).

Pearl Millet Germplasm

A total of 5505 accessions from India and West Africa were added this year to the pearl millet gene bank. All West African accessions were FAO/ORSTOM collections. Indian plant breeders contributed 2845 accessions. Some 918 additional accessions were collected by ICRISAT scientists in collaboration with millet breeders of Indian agricultural universities and the All India Coordinated Program.

So far, 5332 accessions have been rejuvenated after their seed quantity had reached a critical level or they had started losing viability. This year, 2136 accessions were rejuvenated and evaluated for various agrobotanical characters in terms of the standard list of descriptors proposed by ICRISAT/IBPGR, and 209 photosensitive accessions were identified. Medium-

ICRISAT scientists observe with ORSTOM representative, second from right, West African germplasm collections that have been collected by ORSTOM and transferred to the ICRISATgene bank.

duration and photosensitive types were found to be the most productive fodder types. Pathologists screened the germplasm and identified nine low-ergot-susceptible lines and five low-smut-susceptible lines. In addition, 224 different lines having specific morphological traits were identified and are being purified. After preliminary evaluation of the available collection, accessions were carefully identified and stratified by geographical distribution and general variability. So far, 552 accessions have been selected that represent the general variability of the world collection. They consist of accessions from Cameroun (46). Central African Empire (23), Ghana (1), India (75), Mali (84), Niger (184), Nigeria (24), Senegal (61), Uganda (1). Upper Volta (5), USSR (3), and unknown sources (45).

As per recommendations of the 1BPGR Advisory Committee on Sorghum and Millets, continuations of the already assigned IP numbers were assigned to all the new authentic landrace accessions. The new numbers are from 3019 to 6851.

The following wild species of *Pennisetum* are maintained. (Several more wild species collected from East and West Africa are presently in transit.)

Pcnnisetum purpureum, P. squamulatum, P. hohenackeri, P. orientale, P. mczianum, P. setaceum, P. polystachion, P. pedicellatum, P. violaceum, P. villosum, P. clandestinum, *P. mecrorum, P. cenchroides, P. mollissimum,* and other unidentified species.

The following interspecific hybrids are also maintained:

Pusa giant napier, Napier bajra-21, *P. orientale* x *P. typhoides,* Pusa giant napier x *P. squamulatum,* Shibra x Pusa giant napier, *P. americanum* x *P. violaceum* (Shibra).

Pigeonpea Germplasm

Within India, collections were made from the Western Ghats, South India, Bundelkhand, and Andhra Pradesh. A total of 114 accessions of pigeonpea were obtained. In Nepal, 100 samples were collected from the central to eastern Terai and foothills. In Bangladesh, 32 samples were collected. Wild pigeonpeas (*Atylosia* spp) were the target in Australia. From Queensland and the Northern Territory, seven species in 28 samples were added, some of them for the first time. Some faced problems in maintenance at ICRISAT Center.

The pigeonpea germplasm bank contained 8775 accessions at the end of May 1979. The reference vouchers of the collected wild relatives are deposited in the ICRISAT Reference Herbarium, where vouchers of weeds and companion species are also kept. The Herbarium provides identification of plants for all disciplines within ICRISAT, and visiting scientists can also consult this facility, maintained by the GRU. Duplicates were sent to Wageningen (Netherlands), Kew (UK), and Calcutta (India).

A total of 2327 lines were grown, of which 1482 were for evaluation and 845 for rejuvenation and preliminary yield test. Postrainy-season rejuvenation was carried out on 1633 lines. Entire plants, which remained small due to short days and consequent early flowering, were bagged to obtain selfed seeds.

For classification into the four photoperiod-response groups, 1500 lines were tested at three sowing dates: 14 November 1978, 14 December 1978, and 15 February 1979. Of those tested, 206 lines were not affected by daylength, while 1287 lines flowered when sown on 14 November and 14 December and six lines flowered only when sown on 14 November. One entry did not flower in any of the dates of sowing.

Introgression of Wild Germplasm

We now have several accessions of 14 species of *Atylosia* and 8 species of *Rhynchosia,* both close relatives of pigeonpea, besides several other related genera. Blight resistance was observed in *A. sericea* and *A. platycarpa.* Our entomologists report antibiosis in *A, sericea* and *A, scarabaeoides* and some in C. *cajan* x *A. scarabaeoides* hybrids. Our biochemists recorded high protein content in *A. sericea* and *A. albicans.* So far crossability of seven *Atylosia species,* namely, *albicans, cajanifolia, lineata, platycarpa, scarabaeoides, sericea,* and *trinervia* with *Cajanus cajan* has been achieved. This effort is continuing.

Chromosome numbers n = 11 and 2n = 22 were established for *Atylosia albicans, A. cajanifolia, A. lineata, A. platycarpa, A. scarabaeoides, A. sericea, A. trinervia, A. volubilis,* and *Rhynchosia rothii.* Also the species not earlier reported show remarkable homology in chromosome morphology, whether crossable with pigeonpea or not.

The several wild genera and species related to Cajaninae that are maintained at ICRISAT are the following:

Atylosia—A. albicans, A. cajanifolia, A. goensis, A. grandifolia, A. lineata, A. marmorata, A. mollis, A. platycarpa, A. rugosa A. scarabaeoides, A. sericea, A. trinervia.

Rhynchosia—R. aurea, R. cana, R. cyanosperma, R. densiflora, R. filipes, R. heynei, R. minima, R. rothii, R. suaveolens.

Dunbaria—D. ferruginea, D. heynei.

Paracalyx—P. scariosa, Flemingia sp.

The revision and biosystematical study of *Atylosia* and *Cajanus* proceeded, and manuscripts were partially finalized. Localities of occurrence were studied in detail in preparation for further explorations. Crosses among *Aty-*

losia spp were successful in some cases and served to obtain information on specific affinities.

The previous season's yield data were stored on our computer. Corrections were made by hand and through a computer search to render the catalog operational without duplications or errors. Scanning of parts of data or entire sets of data is now possible.

Chickpea Germplasm

The important drought-prone Bundelkhand area of Madhya Pradesh and Uttar Pradesh, India, was explored for chickpeas, in expectance of local diversity and drought resistance, and 53 samples were secured. Himachal Pradesh, though not a major area, was also explored, resulting in 103 samples. The Terai of Nepal yielded 37 samples, and in Bangladesh 32 samples were obtained. Except for its southwest and mountainous pockets, Nepal now has a fair representation in our collections. *Cicer graecum* was collected near Trikala, Greece, but seeds had hardly ripened. F_2s and backcrossed plants of *C. arietinum* x *C. reticulation* grew well, and many showed promise for *Ascochyta* blight resistance.

The following wild annual and perennial species of *Cicer* are maintained.

Annuals —*Cicer bijugum, C. chorassanicum, C. cuneatum, C. echinospermum, C. judaicum, C. pinnatifidum, C. reticulatum, C. yamashitae.*

Perennials—*C. anatolicum, C. floribundum, C. graecum, C. microphyllum, C. montbretii, C. rechingeri.*

A total of 5225 lines were evaluated at Patancheru and Hissar with the use of 27 descriptors. The evaluation data are being computerized in a retrieval system for documentation and further use.

Further germination tests showed that after 27 months of low temperature storage in plastic bottles seed viability was almost as good as for fresh seeds, but seeds stored in paper bags showed some loss of viability in some accessions. Viability was completely lost in all accessions stored for over 18 months at room temperature in paper or cloth bags. Seeds stored in plastic bottles at room temperature retained about 70% viability.

Chickpea cv JG-62, G-130, and P-5462 were again crossed with *Cicer reticulatum.* The generations obtained earlier were used for screening against blight. Several BC_1 plants were free after severe inoculation and thus form an important new source of resistance. Seeds obtained from F_1s between some wild species failed to germinate.

Data on 11 295 properly evaluated lines have been entered on computer. The data are available to those requiring information on the performance of chickpeas at our two locations, Hyderabad and Hissar, India. Lines not achieving good stand will be tested in the next season (s).

Groundnut Germplasm

A total of 1277 groundnut accessions have been added to the existing collection. The bulk of this addition comes from North Carolina State University, USA. The exotic material includes cultivars from China, Japan, Malawi, Nigeria, Rhodesia, South Africa, and USSR. The local collections include materials collected in Karnataka and Andhra Pradesh. New accessions of wild species were added and a list of *Arachis* spp available at ICRISAT is given below:

A.duranensis	*A. cardenasii*	*Arachis* sp 410
Arachis sp 10038, 2 forms SL, LL.	*A. pusilla*	*Arachis* sp 10002
Arachis sp 565-6	*A. villosa*	*A. paraguariensis*
A. monticola	*Arachis* sp 10582	*A.pmtoi*
	Arachis sp 14444	*A. glabrata*
A.batizocoi	*Arachis* sp 559	11 accessions of section Rhizomatosac
A. correntina	*Arachis* sp 9993	
A. chacoense	*Arachis* sp 9990	

A total of 5400 accessions has been rejuvenated and evaluated for various morphological and agronomic characters. The germplasm has been screened by pathologists, virologists, and entomologists for new sources of resistant genes for various pests and diseases. Based on the past 3 years' experience, it has been decided that the postrainy season should be the main season for multiplication and rejuvenation and the rainy season for evaluation of groundnut germplasm.

Sources of tolerance to jassids and rust identified in the germplasm are being maintained. Apart from this, new sources of resistance to rust and leaf spot, and early and high-yielding lines that have been obtained are being maintained and utilized in breeding programs.

Efforts are being made to develop a descriptive language for groundnuts. A tentative set of 36 descriptors is currently being used for evaluating the available germplasm. Assignment of ICG numbers has been completed up to 7679 accessions.

Minor Millets Germplasm

Recently, we have received 832 new accessions from Syria (through ICARDA), 256 from Kenya, 190 from Malawi, and 13 from Tanzania. After the release of the new arrivals from quarantine inspection, the total number of minor millet accessions will reach 3367.

Preliminary evaluation of these millets was made for the important descriptors, such as plant height, maturity, pigmentation, lodging, peduncle exsertion, panicle type, grain color, glume length in *Eleusine,* brittling in *Setaria,* and general plant aspects. In the course of the evaluation, it was clearly observed that all the minor millets except *Setaria* required supplemental irrigation to survive the unusual early drought of the 1979 rainy season at Hyderabad. A total of 7346 samples were distributed to scientists in India and Africa.

Germplasm Distribution

More than 110 400 samples of germplasm of all ICRISAT crops have been distributed so far to scientists around the world. Requests for germplasm from the semi-arid tropics are increasing every year. The GRU supplies the available germplasm free of charge to all scientists who wish to utilize them in their national programs. This is a unique service handled by ICRISAT and its value will have an impact in the future as the natural genetic diversity gradually diminishes throughout the world.

Looking Ahead

As a newly established unit, the Genetic Resources Unit has a huge task ahead of it. Its paramount objectives are the collection and conservation of the germplasm of the Institute's crops and to serve as a repository and resource center of the mandate crops for the utilization of the germplasm. The salvaging of the vanishing land races that are the irreplaceable raw material for crop improvement programs is our most important responsibility. To achieve these objectives, we look forward to developing:

a. an effective organizational setup,
b. the required physical facilities for laboratories and short-, medium-, and long-term cold storage (scheduled for construction in 1980-81),
c. collaborative linkage with national and international organizations of genetic re-resources, and
d. well planned germplasm collection missions at the areas of priority, throughout the world.

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INTERNATIONAL COOPERATION

Contents

INTERNATIONAL COOPERATION

This year was one of consolidation of the research programs at the sites selected for ICRISATs work in the semi-arid countries outside of Asia. Major emphasis continued on sorghum and millet improvement in the West African region, and considerable progress was also made in the Sudan, Tanzania, and Mexico. In particular, the chickpea breeding program in Syria underwent considerable development.

ICRISAT scientists posted to SAT countries are closely associated with their national programs ; this year they increased their international and regional role in effecting rapid transfer of germplasm and breeding material, including pest- and stress-resistant material for accelerating local research in breeding. Efforts were intensified to collect landraces of ICRISAT's mandate crops as a safeguard against the erosion of genetic stocks resulting from introduction of new cultivars in several countries.

West African Cooperative Program

We completed the first phase of the UNDP/ICRISAT contract GLO/74/005 and began the second. Under this agreement, ICRISAT scientists are posted to Senegal, Mali, Upper Volta, Niger, Nigeria, and the Sudan, and assistance is also provided to Gambia, Mauritania, Ghana, Togo, Benin, Cameroon, and Chad. Scientists in the West African program maintain close linkages with the research programs at headquarters in India and also with ICRISAT scientists in specially funded projects in other countries. All our West African work takes place at national research centers of the countries concerned. In some instances, ICRISAT has assisted with the development of facilities, both buildings and land, at these centers. Significant expansion of the Upper Volta Government station at Kamboinse was initiated this year. The station serves as a base for the largest ICRISAT multidisciplinary team in Africa and as a center for improvement of crops for the South Sahelian zone. By the end of the period under review the ICRISAT team in West Africa comprised:

1. A project manager, posted at Dakar, Senegal, partially funded by IRAT under an agreement with the French Government and partially by UNDP.
2. Three sorghum breeders, one in Upper Volta, one in the Sudan, and one in Mali who is also responsible for millet breeding.
3. Five millet breeders, one each in Senegal (Bambey), Upper Volta (Kamboinse), Niger (Maradi), Nigeria (Samaru), and the Sudan (Wad Medani).
4. Two entomologists, one in Senegal and one in Upper Volta.
5. Two pathologists, one in Nigeria and the other in Upper Volta.
6. One agronomist posted in Upper Volta.

USAID continued to support one fulltime agronomist in Mali and later in the year took over funding responsibility for the cereal breeder in Mali. The Government of the Netherlands supported an additional agronomist at Kamboinse, Upper Volta; he assisted particularly in development of the farm research fields in the planned expansion of the station.

To the extent possible and desirable, our scientists integrated their work with that of the local research centers and followed the general working arrangements at those centers. In most instances local support staff were recruited through the national system. The level of training of this local staff was increased, both locally and at ICRISAT Center during the year. There also was a significant increase in exchange of both seed material and information under this system.

The effort to recruit additional scientists with regional responsibility under OAU/SAFGRAD suffered a setback when candidates withdrew after they were identified; this necessitated further recruitment. A new post of *Striga* scientist, funded by IDRC, was filled in May 1979, and the major emphasis of *Striga* work will now shift from ICRISAT Center to West Africa; the main program for sorghum will be in Kamboinse and for pearl millet in Niger.

Sorghum Program

The aims and general strategy of the program are to produce sorghum cultivars adapted for the highly varied situations of rainfall, soils, and topography in the SAT areas of West Africa. Such cultivars will have higher yield capability than the landrace cultivars presently grown, will retain the desirable consumer preference characteristics for the different areas, and will incorporate superior traits for combating stress factors such as drought, parasitic weeds, pests, and diseases. Improvement work on new cultivars also aims to produce lines that will make maximum use of the limited amount of precipitation in the SAT. Yields on farmers' fields currently average 600 to 900 kg/ha. A doubling of even the lower level would have a very significant effect on the living standards and nutritional status of the world's poorest peoples.

Progress in Sorghum Breeding

Upper Volta. The main breeding effort in Africa is based at Kamboinse, Upper Volta. Major emphasis was given this year to breeding pure-line varieties that will mature in 150 days in deep soils, 120 days in medium-deep soils, and 105 days in shallow soils. Nine hundred entries were evaluated in a preliminary trial, and more than 80 originating from ICRISAT Center, the ALAD/Ford Foundation Program, and Texas A & M University were selected for further study. Intensive selection from among crosses made at Kamboinse was carried out, and 328 heads from 109 progenies were finally selected. In the summer season, over 500 crosses were made in the nurseries. Considerable promise was shown by some straight introductions from overseas. One cultivar, E35-1, was particularly promising in trials at research sites and will be introduced next year on selected farmers' fields. The situation with regard to plant establishment in this cultivar will be further examined. Other cultivars that showed promise in certain conditions were VS-702 and SPV-35. All three of these cultivars gave considerable yield increases over traditionally grown cultivars.

Other West African countries. Useful results were obtained from a trial of advanced breeding material distributed to Senegal, Mali, Sudan, Upper Volta, and Niger. The most adapted cultivars were CE90, VS-702,940, 9289 and E35-1. Selections made at Hyderabad for the postrainy season performed very well in the cool "off-season" in the Senegal river valley.

A full-scale program on *Striga* was started in Upper Volta and will include a breeding component.

A major objective of the-program in Mali this year was to identify short-season elite material with greatly increased yield over traditional cultivars for the 400- to 800-mm rainfall zone. Fifteen promising cultivars were selected for field test. The arrival of a fulltime cereal breeder in early 1979 gave considerable impetus to development of a crossing program and increased testing of introduced lines. E35-1 was promising in Mali and was tested in collaboration with the Malian agricultural staff and SAFGRAD. There was some question with regard to its suitability for preparation of the preferred local dish, *teau.*

In Sudan, a large crossing program and work on hybrids was initiated.

Progress in Sorghum Pathology

The two ICRISAT pathologists are posted at Samaru in northern Nigeria and at Kamboinse in Upper Volta. In the past year both worked on sorghum and pearl millet, and both had a regional responsibility in supporting ICRISAT scientists working with country programs. Research emphasis was placed on grain molds, charcoal rot, and leaf diseases of sorghum.

Upper Volta. The pathologist at Kamboinse was increasingly involved in the expanded sorghum program in Mali, where Cinzana proved to be an ideal site for sooty stripe disease testing. Resistances to three leaf diseases and two grain molds were identified. Eleven lines selected from the 1977-78 international sorghum collections were identified for use in crossing programs at Kamboinse: IS 2261, IS 2327, IS 2328, IS 8272, IS 9225, IS 14332, M 6065, M 6125, M 6461, M 35586, and M 36381. Appropriate nurseries were grown at several sites, including Farako Ba and Sotuba. A detailed study of charcoal rot was initiated in view of the observed incidence on exotic sorghums. Some less susceptible lines were identified, including CSV-1 and VS-701. Environmental conditions were shown to have an important bearing on development of symptoms.

Nigeria. The disease nurseries were grown at Samaru and sufficient disease pressure was obtained to screen for leaf blight, grey leaf spot, and anthracnose. For the second year running, CSV-2 was blight free at Samaru, indicating the probability of location-specific pathotypes (or races) since it was susceptible elsewhere. IS 2419 was another line with a low disease score. There was a severe attack of gray leaf spot, and scores were high on most lines included in the sown nursery. Indications were that resistance levels to this disease were low in almost all entries tested except IS 2232 and IS 10262. The line IS 7254 did well at Samaru and at several other sites where the anthracnose nursery was grown. Several other lines also recorded very low anthracnose scores at Samaru.

Progress in Sorghum Entomology

From our base at Bambey, Senegal, efforts were made to encourage growing of resistance nurseries in neighboring countries, including Mali, Gambia, and Upper Volta. More extensive surveys were carried out on farmers' fields within Senegal to determine the extent of damage on sorghum and the insect species involved. It was found that *Atherigona* was very important in the Fanaye area and that, generally speaking, attacks in farmers' fields were of the order of 15 to 20%. A heavy infestation of *Mythimna* was observed in several areas; up to 81% of plants were attacked by one to seven larvae in some places. Grasshoppers were of little importance except in the Casamance region. The only lepidopterous borer found on sorghum in Senegal was *Acigona ignefusalis,* and the highest infestation (11% of plants attacked) was noted in Sefa. The sorghum midge was again found to be severe at research stations, particularly Bambey, but of little importance on farmers' fields. Heavy infestations of *Heliothis, Mylabris* beetles, and earwigs were observed from time to time on compact heads. A list of pests of sorghum was prepared from the surveys.

Trials to assess pest losses were carried out at Bambey, Nioro, and Sefa using a local cultivar (Congossane) and an improved cultivar (either CE90, 51-69, or MN1056), and two dates of sowing. At Bambey, the attack by *Atherigona* sp was low on both cultivars, and attack by other pests, except *Mythimna,* was also low. However, midge attack was high on both late-sown cultivars, 36 to 38% of the heads were affected at 50% flowering. At Nioro, pest attack was generally low, again except for *Mythimna* which was particularly heavy on both Congossane and 51-69 in the second scoring. At Sefa. pests other than leaf eaters were of little importance. There was an indication that *Acigona ignefusalis* was more important in early sowings of Congossane. *Atherigona* sp and *Contarinia sorghicola* were of little importance. At all sites, late sowing generally resulted in heavier pest attack and Congossane was more susceptible.

Studies on the dynamics of insect populations in Bambey continued, but collections of shoot fly were also made at Nioro and Sefa using fish meal traps. Two parasites were recorded *Tetrastichus diplosidis and Eupelmus popa-* but the numbers were relatively low at the time of midge population buildup.

Laboratory rearing of *Acigona ignefusalis* and *Heliothis armigera,* using fresh sorghum material, produced information on length of larval and pupal stages. Some success was obtained using artificial media to rear both *H. armigera* and *Eublema gayneri.*

Progress in Sorghum Agronomy

Our main efforts in sorghum agronomy were focused on two countries. Upper Volta and Mali.

Upper Volta. Here a major objective was to identify suitable cultivars for sowing in the various ecological situations and zones and to compile suitable recommendations for growing the crop. A number of studies on adaptation to sowing dates, soil types, and intercropping were initiated in collaboration with the breeders, primarily on small plots and subsequently on large plots along a toposequence. It was observed that marked improvement in sorghum yields was obtained only where the maturity and growth characteristics of the cultivar were matched to the various rainfall regimes and soils. Indications were that partially- or nonphotosensitive material should be sown at higher plant densities than the tillering photosensitive materials.

Type and depth of land preparation had a marked effect on crop performance, especially where soils were likely to dry out rapidly in drought conditions. The main "ecological" zones of Upper Volta have been characterized with respect to desirable cultivars, with emphasis on sowing date, flowering, and harvesting time, particularly for E35-1, VS-702, and other early nonphotosensitive types.

Several more years of experimentation is required to fully assess the stability of improved cultivars in these zones, so that the best possible cultivars can be selected for farmer use. It appears that breeders may need to investigate emergence characteristics and tillering ability. There is a need to develop quick-maturing cultivars that are suitable for sowing when the rains are late.

Interesting preliminary results have been obtained using cowpea as an intercrop with the improved cereals. Cowpea has important effects both on soil fertility and as an erosion control measure. Studies on mixed cropping—sorghum/maize, sorghum/millet and millet/groundnut —were initiated.

Mali. Priority in agronomic research was given to the commonly grown traditional intercrop combinations of sorghum/cowpea and pearl millet/cowpea. Surveys were made in villages to better understand and appreciate local cultural techniques and cropping patterns. Information was obtained and experimentation carried out on dales of sowing and on plant densities of cowpea/cereal intercrop. It was clear that there are significant differences in the densities sown in the northern and southern areas of the country and that these appear to be related to moisture stress. In the south both intercrops are sown simultaneously, but in the north cowpeas are sown 4 to 6 weeks after the millet. Cowpea is sown traditionally at low plant densities. There is evidence that pigeonpea may have a place in the cropping systems of Southwest Mali. Surveys of possible sites for an experiment station for the 600- to 800-mm rainfall zone and sandy soils were made in cooperation with the Division of Agronomy of the Mali Government. The costs of developing and building the station will be borne by USAID and the Ciba Geigy Foundation.

Millet Program

The major emphasis of ICRISAT's work in West Africa is on pearl millet improvement, in view of the crop's position as the preferred cereal in the Sahelian and Northern Sudanian zones. Traditionally, farmers' cultivars have good yield stability and grain quality, moderate to large panicles, and moderate levels of resistance to stress factors. Yields, however, are low (400 to 700 kg/ha). The cultivars that are grown flower at the end of the rains and mature under conditions of moisture stress. Residual soil moisture is often not sufficient for grain filling, in spite of the fact that the crop has exceptional drought resistance and adaptability to poor environments. We believe that yields can be improved and good grain quality maintained by breeding cultivars with a maturity that more nearly matches the length of the growing season and by improving ergot resistance.

In general, past research work has produced cultivars from local germplasm that are phenotypically similar to the existing cultivars grown but with only slight yield superiority. These improved local populations are being utilized along with exotic materials from India and other millet-growing areas of Africa in ICRISAT's improvement program to breed for earliness, better plant architecture, and synchronous tillering. The Indian exotics generally have been found to be susceptible to disease, but they have otherwise favorable characteristics. More use will be made of material in the West African germplasm collection, which has been used only to a limited extent in the past.

Progress in Millet Breeding

Under the UNDP/ICRISAT West African program five millet breeders were on post in 1978—79. This represents a substantial input and reinforcement of national programs, which until very recently were meager. All breeders collaborated in evaluation of the local germplasm collections made by ORSTOM/FAO/IBPGR. (These collections are also being evaluated at ICRISAT Center.) Lines possessing desirable agronomic and/or disease-resistant characteristics have been selected for use in breeding programs. All the breeders grew a number of trials and nurseries furnished by the ICRISAT Center program, and these provided an array of breeding material for local programs. An increasing exchange of material between West African millet breeders was initiated this year to capitalize on local germplasm traits.

Upper Volta. In 1978, 1132 germplasm accessions from Senegal, Mali, Niger, Cameroon, and the Central African Republic were evaluated at Kamboinse. Of these, 269 were found to be of late maturity (more than 125 days) and will have to be evaluated further at Farako Ba. Characteristics recorded included date of flowering, plant height, head length and shape, as well as reaction to downy mildew and ergot. At harvest the accessions were classified into variety groups based on phenotypic expression. This information will be invaluable for future breeding work in West Africa. Some 863 early-maturing lines (less than 125 days) from West Africa were evaluated for ergot reaction under high natural infection; 160 were found to be free and will be tested further. In the 1978 off season, 52 crosses were made utilizing adapted lines, Ex Bornu, 3/4 Seno, and Dori local, among others. The F_2s were evaluated at Kamboinse and Gorom Gorom. It was found that Dori local is a good combiner for crosses tested at Gorom Gorom. and Ex Bornu is a useful parent for materials tested at Kamboinse. This material appears to be more promising than material emanating from the exotic x local crosses.

Senegal. The season was characterized by a normal rainfall (709 mm) at Bambey, which is the main center for ICRISAT pearl millet breeding research in Senegal. Yields were somewhat higher than in 1977. Three composite progeny trials were carried out at Bambey—new early composite (full sib), D_2 composite (half sib), and Super Serere composite (half sib). The first trial was also sown at Louga. Super Serere composite and D_2 composite showed reasonable adaptation, and several lines produced higher yields than the check cultivars, with reduced incidence of downy mildew but with some susceptibility to smut. The mean scores of the best selected entries in the D_2 composite trial were substantially greater than the checks and there was improved smut resistance. The best entries in the trial, HS 256 and HS 42, yielded 1640 and 1603 kg/ha, respectively, compared with 735 kg/ha from the check, IVSA 75. Somewhat similar results were obtained in the Super Serere composite progeny test, where the best entries gave 50 to 100% more yield than the checks. The best entries from the various composite trials will be recombined at Hyderabad and tested in multilocational tests. Experimental varieties will also be produced from the five to ten best progenies.

In trials using experimental varieties the top performers in 1977 (WC x 75, IVSA x 75, 1CS 7703, and SSC x 75) were again tested against Souna 3 and performed well in several trials. In the elite variety trial at Bambey, the best hybrid, ICH 165, gave 3059 kg/ha, ICMS 7703 gave 2462 kg/ha, and WC x 75 gave 2231 kg/ha compared with 2508 kg ha for Souna 3. Some of the experimental varieties have considerable variation in useful traits, such as height and ear characteristics, and considerably improved downy mildew resistance; they will be improved through S, progeny testing.

Work continued on testing of F_1 hybrids made with local improved and Indian material. Good yields were obtained and head lengths were very satisfactory. Attempts to incorporate dwarf genes resulted in higher downy mildew scores and poor yield. In experiments in which the best ICRISAT material was crossed to GAM material, good general combining ability was noted, and the most satisfactory material was observed with the 3/4 population. F_1 progeny were selected for agronomic appearance, seed setting, disease susceptibility, and yield. Work also continued on selection within F_2, F_3, and F_4 breeding lines, development of synthetics, and evaluation of cytoplasmic male steriles.

A range of international trials was successfully conducted. Several ICRISAT Center hybrids and synthetics outyielded Souna 3 by more than 25%, but rainfall conditions were generally favorable. The off-season was mainly devoted to multiplying lines, recombining the best crosses, and making top crosses between Indian and West African material.

Niger. Pearl millet ranks first in crop area and production in Niger, and the 1978 season was generally favorable, since rainfall was up to normal and was well distributed. Material from the 1977 off-season nursery was utilized for making crosses between local African material and exotics. Of 240 intervarietal crosses-single and top -and about 30 interpopulation crosses made from IRAT and ICRISAT Center material, some 50 were found promising. Particularly interesting were 3/4 HK x 3/4 Ex Bornu, (3/4 HK x 3/4 Ex Bornu) x GAM 73, and (ICS 7702 x IC 7703) x ICS 7705.

In all, 38 trials and nurseries were conducted at Maradi in the rainy season with entries representing Indian and West African genotypes. Some 1000 entries were selected and the seed was used to develop four gene pools—tall (local African), semi-tall (Indian D, type), dwarf (D_2 type), and bristled. Some of the synthetics such as ICS 7703, ICS 7803, and ICS 7806 and experimental varieties from the World Composite appeared promising. These will be evaluated in northeastern Niger. Several of the IC hybrids including ICH 118, ICH 211, ICH 226, ICH 154. and ICH 165, were superior to experimental and local varieties in many trials, but their utility in local farmers' situations needs to be assessed.

Nigeria. Millet breeding work at Samaru and Kano was aimed at broadening the genetic base of material used in Nigeria, improving local materials by incorporation of desirable genetic traits—including reduced plant height, early maturity and synchronous tillering—and producing widely-adapted, stable, high-yielding types with stress resistance. Currently the program is not concerned with hybrid breeding; the emphasis is on pure lines, composites, and synthetics. In general, trials at Kano performed better than those at Samaru.

A range of germplasm lines consisting of *gero* hairy lines, a working collection from the ICRISAT Nigeria program, and a collection from ICRISAT Hyderabad were evaluated. None of the entries from the *gero* collection was early and few had any apparent resistance to downy mildew in conditions of high incidence. Only five crosses were made between these entries and selections from the 1977 synthetic progeny trial, which had favorable characteristics including early maturity and synchronous tillering. Few entries from the other two collections were useful for crossing.

Hybridization and selection from crosses made with both locally derived nurseries and nurseries from Hyderabad continued. However, downy mildew and stem borer were severe and the F_4 nurseries at Kano failed. Some 280 S_2 lines were evaluated at Samaru and Kano; approximately 10% of the S_2 lines at Kano were selected for further use, while at Samaru selections were made on the basis of individual plants or plots to form four base composites.

Indications from the West African Regional trial, which consisted of 20 entries grown at two locations, were that many of the West African lines performed similarly to the locally adapted types and that grain yields were also similar. Several selections made at Hyderabad did not perform well, but the 3/4 Souna, 3/4 Seno, 3/4 HK, and 3/4 Bornu were promising. A series of international trials was conducted, and the results of these are given in the main millet breeding report. Some of the ICRISAT hybrids will be included in the state national program trials.

Progress in Millet Entomology

Work on millet entomology was limited to observations on ICRISAT trials for determination of pest species present at Bambey. It was obvious that the major pest on trials was *Raghuva albipunctella.* Damage to heads could be clearly detected by a spiral raised area caused by caterpillars severing the peduncles. There was considerable variation (8 to 80%) in the percentage of heads attacked. In general West African material grown in the trials was less attacked (below 20% of heads). The minimum was recorded in Nigerian C_3 bulk, but 3/4 Souna and 3/4 Ex Bornu were also only lightly attacked compared with most exotic hybrids and varieties. The mechanisms of resistance and the biology of the species will be studied regionally in collaboration with the national entomologists.

Progress in Millet Pathology

The West African locations provide a good opportunity for screening for the major diseases of pearl millet—downy mildew, ergot, and smut. As mentioned earlier, downy mildew was particularly severe at some sites.

The program in Upper Volta in 1978 included the usual screening of breeding material and disease nurseries as well as, for the first time, investigation of the use of chemicals for control of downy mildew. Work was carried out at Kamboinse and Farako Ba in Upper Volta and Koprokeniepe and Sotuba in Mali.

Downy mildew. The International Pearl Millet Downy Mildew (DM) Nursery was grown at Kamboinse and Sotuba; only one entry was free of infection at Kamboinse, but it was affected at Sotuba. The results indicate that reactions are different at the different sites and sometimes over seasons.

Trials were also carried out with local material—43 West African germplasm lines and 27 other lines including improved material from Ouagadougou. Several lines were found to be free of the disease at both Kamboinse and Samaru, including D 1148, D 1163, and P3. Others, such as D 1162, while DM-free at Kamboinse, were fairly heavily attacked at Samaru. Twelve entries of 23 showing a mean disease incidence of less than 5% originated from a small region in eastern Upper Volta, and of these, nine were from a small village 50 km south of Dori.

Observations on farmers' fields in the 400- to 600-mm rainfall zone of southeastern Mali and northern Upper Volta suggest that losses are higher there than in the 800-mm zone. Comparison of incidence in the same cultivars at Ouahigouya, Kamboinse, and Samaru suggest higher levels of inoculum pressure at Samaru. Ridomil was shown to be effective in reducing downy mildew incidence at three rates of application -0.5, 1.0, and 2.0 g a.i./kg of seed. Increase in yield ranged from 17% at the lowest to 58% at the highest rates. Results continue to indicate that success in the control of downy mildew will depend on efficient use of locally available sources of resistance tested at multiple locations.

Ergot. Two trials were grown at Kamboinse in an effort to locate sources of resistance. Entries comprised the International Pearl Millet Ergot Nursery and 82 lines selected from the West African germplasm collection grown the previous season. Heads were inoculated with dilute "honey dew" suspension shortly after 75% stigma emergence. At the end of the season, estimates were made of the percentage of surface covered by ergot sclerotia. Six lines were found completely free of ergot. J 2238 was the least severely attacked entry in three West African locations and was confirmed in the inoculation trials as having good potential as a resistance source for the breeding program. Observations were made on the breeders' trials and several lines with low (less than 10%) attack were identified. However, all 68 entries in the D_2 progenies trial were remarkably susceptible to ergot, no entry having less than 90% of the head surface with sclerotia. No entries were free of ergot in trials conducted in Samaru, the lowest infection (16%) was in 3/4 Ex Bornu.

Smut. The international smut nursery was grown at Kamboinse in Upper Volta and Koprokeniepe in Mali, and a further trial including 41 lines from the West African germplasm collection was grown at Kamboinse. The assessments made for smut infection in the two trials were not entirely satisfactory. Thirteen entries nevertheless appeared promising, having less than 10% incidence; this confirmed evidence from a trial carried out in 1977 in Senegal which showed that P10, P18, and P20 were superior to other entries.

In trials carried out in Samaru, inoculation techniques enabled high levels of attack to be achieved. One entry, 54-1-1, was found to be resistant at both Samaru and Kano.

Millet Agronomy

Few trials appear to have been carried out in the past on millet agronomy compared with sorghum agronomy. Several preliminary and basic trials were conducted this year in Upper Volta to determine the effects of various agronomic treatments on different millet cultivars. A test in which local photosensitive millet was compared with ICRISAT hybrid 118 indicated very wide differences in response to different management treatments. Early sowing was vital for the local material to maximize its yield through profuse tillering and avoidance of downy mildew, but the hybrid yielded as well as the local with early sowing, and did far better than the local with delayed sowing. Very late sowing of the hybrid caused severe reduction in seed set and ergot was a problem.

Experiments with sorghum and millet sown along the toposequence showed that yields of millet were lower further down the sequence, possibly because of increased vegetative growth. Other trials indicated considerable differences in response to plant densities between promising cultivars sown on deep soils; the same was not true on shallow soils. In general many of the cultivars used tillered well at the low plant density (20 000 plants/ha) and yields were as high or better than at high plant densities (120 000 plants/ha) on deep soils.

A number of intercrop trials were also conducted. One combination used was millet and groundnut. Eleven millet cultivars responded favorably to intercropping in these trials, performing best when grown in an alternate-row system. The results further indicated that millet at a low plant density (20 000 plants/ha) was most efficient for both crops. Similar trials were also conducted in Mali, particularly with millet and cowpea.

Farming Systems

Conditions on experiment stations, and in crop agronomy trials directed towards sole cropping are very different from the situation existing in farmers' fields. Significant progress was made this year, both in Mali and Upper Volta, in the study of local farming systems at the village level, and plans were made for on-farm experimentation in the 1979 season. Experiments were also laid down on research sites to study different systems of land management—forming it into ridges or hills or flat cultivation, etc.- to obtain maximum emergence and moisture infiltration and retention. In both Mali and Upper Volta, preliminary observations were started on forage legumes. In Mali, pigeonpea appeared to have possibilities, while in Upper Volta information was obtained on establishment and survival of various grasses and also legumes such as Siratro.

It is proposed to greatly expand the work on farming systems over the next few years, both on farmers' fields and on land resettlement schemes such as the valley management scheme in Upper Volta (AW).

East African Cooperative Program

Progress in Sorghum and Millet Improvement

Sudan. Sorghum is an extremely important crop in the Sudan, occupying about 3 million hectares. About 75% of the cereal production is obtained from this crop, with average yields of around 700 kg/ha. The season at Wad Medani was characterized by heavy rains immediately after sowing, which affected plant density. A sorghum breeder was present for only part of the season; nevertheless, it was a successful year. Seven hundred and twenty-eight experimental hybrids developed in 1977 were tested in observation plots and 62 were retained for further work, along with 67 selected from 980 supplied by the Ethiopian Sorghum Improvement Project. A wide variety of crosses (984) from ICRISAT Substations, from Sudanese lines, from local varieties, and from ALAD selections were evaluated, and 93 of them were retained for further experimentation. Eight international trials and nurseries from ICRISAT Center were sown, and varying numbers of entries were selected for growing in off-season nurseries, for seed multiplication or crossing. A large number of entries from the elite progeny nursery significantly outyielded the local checks, and some will be used in the national testing program. Five cultivars from the Uniform Sorghum Adaptation Trial distributed from Upper Volta will be retested in the Sudan -9289, CE90-324, SB722-67/2 VS-701 and SB722-106. Trials on *Striga,* and insects and diseases were provided to the national program for evaluation.

The pearl millet improvement program was expanded, using Wad Medani Center as the main site. International yield trials were also conducted at El Obeid. Material for the national program was grown at five sites representing typical millet-growing areas. Major problems were encountered with yield assessment owing to birds and drought.

The germplasm collection was further expanded by inclusion of 91 new accessions obtained by the IBPGR team. A total of 288 entries from the collection were evaluated and great genetic diversity was found; some 20 accessions were selected for further examination. A great deal of crossing was completed in the season, utilizing elite lines from local collections, material from India, and progenies from 1977 advanced segregating material and inbred trials. Some of the F_2 populations, such as Kordofani x 5054B, Kordofani x 67B, and Faki-abyad x 700657, produced segregants with useful characteristics. Selections were made from a number of trials received from ICRISAT Center; several from Serere Composite 1 and Super Serere Composite far outyielded local checks and will be used in the national breeding program. Some difficulty was experienced in obtaining reliable results from test locations in the millet-growing regions as stated above. However, Serere Composite 2 greatly outyielded the local checks both in favorable and unfavorable growth situations.

Tanzania. Under an agreement with IITA, an ICRISAT sorghum breeder continued to work at Ilonga Research Station, Kilosa. In this the first full year of the project, most emphasis was placed on introduction and evaluation of a wide range of local and exotic sorghum germplasm. A total of 2353 sorghum accessions were introduced from ICRISAT and from the former EAAFRO program at Serere, Uganda, and from other sources. Screening of this material enabled about 40 lines to be selected for subsequent evaluation in replicated trials. An additional 250 genotypes were retained as having various suitable genetic attributes in breeding. A good start was made on the crossing program, utilizing mainly material from the 2 K x derivatives and the indigenous collections. IS 7452C and IS 3964C from the Texas Conversion Program were also frequently used. Tests of 19 sorghum cultivars at six locations indicated that 5D x 135/13/1/3/1 was promising, yielding an average of 4000 kg/ha. This is a brown-seeded cultivar and is being bulked for release. 2K x 17/5 and 9D x 5/F5/38/1, both white-seeded cultivars, did well at some locations and require further testing. Several international trials and nurseries were grown at Ilonga and good results obtained especially from the East African Sorghum Variety Trial. A mean grain yield of 5100 kg/ha was obtained and 2K x 17/97-103 and 2K x 17 /B/1, both white-seeded types, gave outstanding yields of 6400 and 6200 kg/ha, respectively. Their yields were not significantly different from hybrids included in the trial. Valuable sources of resistance to pests and diseases were located in the pest and disease nurseries and will be utilized in the breeding program. A limited program of agronomic research was also initiated.

In a hand weeding trial, all weeded treatments outyielded the weedy checks, but none of the weeding treatments significantly outyielded one hand weeding 15 days after sowing. Fertilizer trials conducted at several sites showed that, although significant differences in yield were obtained, none gave a profit. Similar trials with millet also using organic and inorganic fertilizers, showed positive yield increments.

Ethiopia, Kenya, and Somalia. Close links were maintained with ongoing national programs in these countries. Cooperation with the Ethiopian program was particularly strong; this program contributed entries to several ICRISAT programs and trials in Africa. Various germplasm and breeding, pest, and disease nurseries were provided to these countries.

Asian Cooperative Programs

A major part of ICRISAT's cooperative research effort is focused on southern Asia, where nearly two-thirds of the population of the semi-arid tropics is concentrated. India, the base for ICRISAT's headquarters and much of its research, has 350 million people living in semi-arid tropical regions—56% of the total world SAT population. Other Asian countries have 7%. Most of these people are villagers and small farmers living and working at subsistence levels.

India

ICRISAT works closely with the Government of India, and with state governments in the Indian SAT, in carrying out its research. The Director General of the Indian Council of Agricultural Research is a member of the

ICRISAT Governing Board as is the Chief Secretary of the State of Andhra Pradesh, where Hyderabad is located. This year the Secretary of Agriculture, Government of India, was also appointed to the Governing Board, further strengthening the linkage between ICRISAT's research and Indian government programs in extension and development.

In addition to providing the 1394 ha site for ICRISAT Center near Hyderabad, the Government of India has helped the Institute to develop cooperative research substations at agricultural universities in four separate and distinct regions of the country to provide the range of environments required for work on improvements in sorghum, pearl millet, pigeonpea, and chickpea. These substations are at Bhavanisagar (UN), Dharwar (16 N), Gwalior (26 N), and Hissar (29 N). During the past year ICRISAT carried out development of land and permanent research facilities at Bhavanisagar, Hissar, and Gwalior, improvements that will benefit the research of the agricultural universities concerned as well as that of ICRISAT. Similar work is proposed for Dharwar in the next year. Without these substations ICRISAT could not fulfill its obligations to some of the African SAT regions, nor could it carry out breeding work on resistance to diseases and pests for which conditions at ICRISAT's Hyderabad location are not suitable. Results obtained from experiments at these Indian substations are discussed under the various crop programs in this report..

Long-term arrangements for an off-season chickpea nursery are being negotiated with the State of Jammu and Kashmir in northern India; in the meantime, exploratory trials were conducted this year at Tapparawaripura Farm near Srinagar in that state, with the cooperation of the Farm's agricultural chemist and the Jammu and Kashmir Department of Agriculture.

As recommended by the Quinquennial Review and Stripe Review panels, ICRISAT enlarged its on-farm research activity on farmers' fields in Sholapur, Akote, and Mahboobnagar districts in cooperation with Indian government research agencies and state agricultural universities. Some preliminary results of these studies are discussed in this report's "Farming Systems Research" section.

We have also intensified cooperative research projects in collaboration with the All India Coordinated Dryland Project at Sholapur, Bangalore, Hyderabad, Indore, Bellary, Bijapur, and Ranchi; some of the results of these studies are discussed under the land and water subprogram in the "Farming Systems" section.

ICRISAT's crop improvement programs have intensified their cooperation with the All India Coordinated Program on sorghum, millets, oilseeds, and pulses. This cooperation is taking the form of participation in workshops, exchange of elite material, coordination of joint trials and germplasm collection missions, and arrangement of field days for Indian scientists to visit ICRISAT experiments and to take any elite material from breeding plots they might consider of direct value.

Some of the promising material from ICRISAT has already entered minikit trials on farmers' fields; a good example of this is pearl millet line WC-C75. And Indian breeders have successfully used ICRISAT's breeding material to develop new hybrids and varieties with specific characteristics; one outstanding example, pearl millet hybrid MB1 + 110, is now a leading hybrid in the country. Details of such cooperation are discussed in the various program reports.

Of course, the interaction between ICRISAT and Indian programs is not a one-way operation; ICRISAT has gained immensely from these exchanges, which have been marked by a growing sense of participation and mutual cooperation.

A unique area of cooperation between Andhra Pradesh Agricultural University (APAU) and ICRISAT that has become more significant in recent years is the training of foreign students for their thesis research. ICRISAT participates in many ways in APAU's efforts to build excellence in postgraduate studies in dryland farming. ICRISAT and APAU scientists meet annually to review areas of research of common interest and to share materials and exchange ideas.

We have signed agreements for similar cooperation with Haryana Agricultural University, Tamil Nadu Agricultural University, University of Agricultural Sciences, Punjab Agricultural University, and Jawaharlal Nehru Krishi Vishwa Vidyalaya. Cooperative arrangements for on-farm research also exist with the agricultural universities in Maharashtra, particularly at Akola, Parbhani, and Rahuri.

Scientist-to-scientist cooperation in many research programs exists, though it may not have been formalized.

Other Asian Countries

ICRISAT also continued to expand this year its cooperative research activities with the neighboring countries of Bangladesh, Pakistan, Nepal, and Sri Lanka, providing technical assistance, training, and breeding materials to their scientists and exchanging with them germplasm and international nurseries of crops of particular interest to them. Exchanges of visits are also important to these relationships. Visits were made to ICRISAT this year by the President of Pakistan's Agricultural Research Council and by the Director General of Bangladesh's Agricultural Research Council, among others.

ICRISAT's cooperative work is extending to the Southeast Asian countries, particularly to Thailand, the Philippines, and Indonesia. Increasing interest has been shown by Thailand in sorghum and farming systems research, and they have also carried out some exploratory trials with chickpea, pigeonpea, and groundnut. We feel that our cooperation with the Southeast Asian countries will grow as more technical manpower interested in ICRISAT programs becomes available in this region. The interest of these countries in ICRISAT technology is primarily directed toward exploring the possibility of growing crops, like sorghum, for the export market. Secondly, they are keenly interested in making use of relevant farming systems technology to exploit the potential of soil and water under rainfed agriculture or in dry periods.

Cooperation with CIMMYT

ICRISAT receives generous backup and logistic support from CIMMYT in Mexico for its project on high-altitude, cold-tolerant sorghum project, which is funded by IDRC. The project is geared to produce sorghums to serve ecological zones where drought situations exist in highland areas around the world. Considerable progress has been made in identifying cold-tolerant sorghums of three maturity lengths, and two trials were distributed in 1976 and 1977 to sorghum breeders in Latin America to allow cooperators to select material for their programs. In 1978, efforts were made to change by crossing, the seed color of the cold-tolerant cultivars, from the predominantly brown-seeded to white- or yellow-seeded so that they become more suitable for human consumption. Making full use of the testing facilities available at the various altitudes in Mexico, early-maturing lines, drought-tolerant lines, and lines incorporating desirable characteristics were selected. Some useful selections were also produced for distribution in trials to lowland areas. These will be sent to cooperators in several areas to study their adaptation. Disease and pest resistant F_2 material was also produced, and work was initiated on development and selection of sorghums suitable for use in tortillas.

Cooperation with ICARDA

ICARDA/ICRISAT cooperation on chickpea improvement is now well under way. Emphasis in the breeding program is on the large-seeded kabuli types. The 3300 germplasm accessions are being screened for various characteristics including yield, cold tolerance, and resistance to *Ascochyta* blight. Experiments showed that very marked improvement of yield was obtained if chickpeas were sown in winter plantings (normally they are sown in spring) and if *Ascochyta* blight was controlled; with 36 lines, yields ranged from 53 to 89% higher. In the 1978-79 season, the 40 promising resistant lines obtained previously were reduced to 20 with confirmed resistance. Some fungicidal trials for *Ascochyta* control were also carried out. It was concluded that such protection was not completely reliable and that most effort should be placed on resistance breeding. Work on improving the plant structure of the crop is under way and multilocational yield trials are also in progress. Some agronomy work on plant densities for winter sowing and on nodulation of the crop has been initiated.

Cooperation with Other Organizations

ICRISAT continues to extend and foster its links with scientific laboratories in the host country, India, and in various other nations in the developing and developed world. Strong ties have been established with universities in Australia, the UK, and the USA. Collaborative research developed this year included staff deployment at ICRISAT for the growing season, in the environmental physics program with Nottingham and in the pigeonpea program with the University of Queensland. A useful cooperative program on genetic improvement of groundnut involves North Carolina State University, the University of Reading, and ICRISAT. There are continuing links with the University of Saskatoon on drought stress; joint meetings were held to assess progress and future research.

ICRISAT has cooperative links with several research institutes in the form of joint projects, e.g., viral control of *Heliothis armigera* using virus, with the Boyce Thompson Institute in the USA; biology of shoot fly, financed by IDRC, with the International Center for Insect Physiology and Ecology in Kenya; biology of *Chilo* stem borer, and plant resistance chemicals, with the Center for Overseas Pest Research (UK); *Striga* stimulants, through on ODA project, with the Weed Research Organization and Sussex University (UK); nitrogen fixation and *Rhizobium,* with CSIRO (Australia); plant chemicals and insect attractants, with the Max Planck Institute in Germany and many others. Such relationships are proving to be of great mutual benefit, and as more opportunities are identified these will be developed. Generally, financing of these projects is by donors interested in these particular research areas.

FELLOWSHIPS AND TRAINING

International internships, research fellowships, research scholarships, in-service training programs, and apprenticeships at ICRISAT Center provided opportunities for skill and concept development to 74 young scientists, most of them from SAT countries. Training programs enabled each trainee to follow an individualized study program most relevant to his abilities, background experience, and the sponsor's needs. The programs were related to ICRISAT's scientific expertise, germplasm resources, and research facilities. The trainees had direct contacts with ICRISAT's staff and became familiar with programs aimed at increasing and stabilizing food production in the rainfed semi-arid tropics.

In the 5 years since ICRISAT began training programs, 317 persons from 38 different countries have completed training, 287 in long-term and 30 in short-term programs. At the end of May 1979, 3 international interns, 2 research fellows, 8 research scholars, 38 in-service trainees, and 4 engineering apprentices were continuing their training activities at ICRISAT Center. Special training opportunities have also been provided by research and training staff* in each of the research and development programs of the Institute (Table 1).

Table 1. Persons completing long-term training programs during the 1978-79 report year.

Name	Country	Program
IN-SERVICE TRAINEES		
Gakale, Lucas	Botswana	Farming Systems
Otlhogile, Motswakwa		Cereal and Groundnut Improvement
Peter, Babu Magosi		-do-
Sebeela, Godson P.A.		Farm Operations and Management
Bordjim Laondjamaye	Chad	Pearl Millet and Groundnut Improvement
Loubazo, Rangai Tidayadi		Sorghum and Groundnut Improvement
Mario Alavarez	Chile	Chickpea Pathology
Asrat, Masresha	Ethiopia	Cereal Improvement
Rigoberto, Nolasco Pereira	Honduras	Sorghum Improvement
Ambalal, Patel Jelhabai	India	Pigeonpea Improvement
Chauhan, Vijay Bahadur		Chickpea Pathology
Gopinath, M		Farm Operations and Machinery
Rathi, Yesh Pal Singh		Chickpea Pathology
Sekhon, I.S.		Groundnut Virology
Sharma, Babu Lal		Chickpea Pathology
Singh, Ram Raj		-do
Taneja, Mukesh		-do-
Zote, Keshao Kashiram		-do-
Al-Talib, Navil Yahya Mohammad	Iraq	-do-
Gathaara, Moses Peris Hungu	Kenya	Farming Systems
Itabari, Justus Kubai		-do-
Kimani, Joseph Kamau		Sorghum Improvement
Kiptonui, Peter		-do-
Musembi, David Kasina		Farming Systems
Muthoka, Musyoka, S.		Cereal Improvement
Odipu. Peter Onyango		Sorghum Improvement
Issa Diakite	Mali	Cereal Production
Samba Traore		-do-
Diailo Ousmane	Mauritania	Cereal Improvement
Guerrero Ruiz, Jose Cosme	Mexico	Chickpea Pathology
Arzika, Zamna	Niger	Cereal Improvement
Hama Seiko		-do-
Maina, Laouel Abba Gana		-do-
Seydou, Doulaye		-do-
Arawore, Elvis Mudia	Nigeria	-do-
David, Adebola Alawode		Cereal Pathology
James B. Naman		Cereal Improvemet

Continued

Table 1 *Continued*

Name	Country	Program
Vincent Okpe Ameh		Cereal Pathology
Sagueye Samb	Senegal	Cereal Improvement
Binyahya, Hassan AIi	South Yemen	-do-
Salem, Saeed Khamis		-do-
Atta, Samhelfial Darrag	Sudan	-do-
Fakhreldin, Osman Ahmed Mehdi		Cereal Improvement
Freigoun, Sami Osman		Chickpea Pathology
Hamoda. Birair Ahdalla		Cereal Improvement
Kidir, Elrasheed Mahmad		-do-
Kapinga, Emil Batram	Tanzania	Cereal Improvement
Nanyanjee, Cuthberl Mfaume		Farm Operations
Pembe, Barnabas		Cereal Production
Suriyapee. Damri	Thailand	Cereal Improvement
Boro, Issa Sebastein	Upper Volla	Cereal Improvement
Mahamady, Ouedraogo		-do-
Napon. Seydou Marcellin		-do-
APPRENTICES		
Bhaskar Das	India	Farm Development and Operations
Chandra Prakash Bohra		-do-
Nazareth, Victor Anthony		-do-
Subramanya Reddy. R		-do-
Keil, Hans	W. Germany	Economics
Laubach, Elvira (Miss)		-do-
RESEARCH SCHOLARS		
Rathore Manohar Singh	India	Economics
Suwelo, Ismu Sukanto	Indonesia	Sorghum Improvement
Huibers-Govaert, Ingrid Irene Maria	Netherlands	Cereal Pathology
Davies, Ellis Llewelyn Price	UK	Weed Science
Caster, Loral, L	USA	Cereal Pathology
RESEARCH FELLOWS		
Calegar, Geraldo Magela	Brazil	Economics
Margolis, Elias		Farming Systems
Reddi. Kamireddi Chandra Sckhara	India	Farming Systems -Intercropping
Sreenivasulu, Pothur		Groundnut Virology
Thomas, George V.		Microbiology
Adesiyunn, A.A.	Nigeria	Cereal Entomology
Djigma, A	Upper Volta	Groundnut Improvement

In-Service Training

During the year, 53 in-service trainees from 18 countries completed training. Fifteen persons from Senegal, Mali, Niger, and Mauritania attended an 8-week intensive English language course conducted by Osmania University, Hyderabad; this enabled them to effectively work with our scientists and to participate fully in the training programs. The number of participants in the training programs was as follows:

Cereal Improvement	26
Cereal Production	3
Cereal and Groundnut Improvement	4
Pulse Improvement	1
Groundnut Virology	1
Cereal Pathology	2
Farming Systems	4
Farm Operations	2
Chickpea Pathology	10

Apprentices

Six apprentices completed an 8-week practical training program in Farm Development and Operations, Animal-Drawn Farm Machinery, Land and Water Management, and Economics.

Research Scholars

A scholar from India completed his thesis research work on "Relationships of Farm Size to Hill Agriculture" in our Economics Program. One scholar from the United States and another from the Netherlands completed their thesis research work in cereal pathology, and a third one from Indonesia worked on sorghum breeding to complete his training initiated in the United States. One scholar from the United Kingdom conducted research on weed science for his M.Sc. program. Thirteen scholars at ICRISAT Center were involved in training by research scientists and training staff.

Research Fellows

Seven research fellows holding postgraduate degrees obtained specialized practical and theoretical experience under the supervision of research scientists within the Farming Systems, Cereal Entomology, Groundnut Improvement, Groundnut Virology, Economics, and Microbiology programs and subprograms.

International Interns

Three recent recipients of Ph.D. degrees in agricultural science undertook specific research problems within the approved research programs in microbiology, pathology, and physiology. Their internships will continue for 2 years.

Followup

Liaison was continued with former trainees through correspondence and personal contact by ICRISAT scientists. Germplasm and research reports were the most common items requested from the research and training staffs. The former trainees continue to serve in national, regional, and international research and development programs.

Future Training Programs

The facilities at the research center can now accommodate an increased number of persons. The goal of having 75 to 80 persons in training at the peak periods of a year can now be attained for the years to come.

WORKSHOPS, CONFERENCES, AND SEMINARS

This year was an extremely active one in exchange of information. Five international workshops were held in addition to two consultants' group discussions and several field days. Proceedings of all of the workshops will be published during 1980.

International Workshop on the Agroclimatological Research Needs of the Semi-Arid Tropics

This workshop was held from 22 to 24 November 1978 at ICRISAT Center. Twenty-five participants from Kenya, France, Canada, Senegal, USA, Niger, Australia, Brazil, Upper Volta, Italy, and India attended; they represented among others, EAAFRO, ORSTOM, 1RAT, CSIRO, USAID, CNRA, and FAO. Sixteen papers were presented. Participants discussed the current status of agroclimatological research at ICRISAT and in the semi-arid tropics generally and offered suggestions for future climatological research. These included interdisciplinary research needs for agroclimatological studies at ICRISAT, the modelling approaches for making farming systems research more relevant for diverse agroclimates, and the minimum data set that should be collected at all the major ICRISAT crop research stations for crop/weather interaction research work.

International Workshop on Sorghum Diseases

The workshop, jointly organized by ICRISAT and the Texas Agricultural Experiment Station, Texas A & M University, was held from 11 to 15 December 1978. Additional travel and subsistence funds were provided by USAID, USDA, and IDRC, making it a truly cooperative venture. Participants reviewed the state of knowledge on certain internationally important sorghum diseases, particularly their identification and the use of host-plant resistance to combat them, and discussed establishment of a coordinated network for identifying stable resistance to sorghum diseases. Fifty-six papers were presented, including country reports from Asia, Africa, and the Americas. Sessions were held on individual diseases of sorghum—smuts, grain molds, downy mildew, head blights and stalk rots, ergot, leaf diseases, and virus diseases. Recommendations were made for research priorities for each group of diseases. The workshop further strengthened ICRISAT's cooperative relationship with sorghum scientists in Asia and Africa and established links with scientists from several Latin American countries where sorghum and sorghum diseases are of major importance.

International Workshop on Intercropping

Sixty-two scientists participated in this workshop, which was held from 10 to 13 January 1979. In 36 papers and in discussions, participants presented and examined current research findings in intercropping, defined research needs, and considered methods by which these could be met. The agronomy session highlighted the tremendous interest recently developed in intercropping and the rapid improvements being made in experimental approaches. The physiology session explored the mechanisms enabling superior yields to be obtained from intercropping compared with sole cropping. It was evident from the plant protection session that this is a critical area in which much more research is needed. The final session on evaluation of intercropping systems covered statistical aspects, yield stability, relevance of intercropping at the farmers' level, and the importance of operational constraints.

International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture

This workshop brought together economists and other social scientists—54 delegates and observers from 13 countries—from 17 to 23 February 1979. Participants discussed ways and means of overcoming the various socio-economic constraints in semi-arid areas identified during the course of their research. Papers and discussions focused on the role of new technology and/or policies in alleviating these constraints. Many complementarities between the situations in India, Latin America, and Africa were highlighted. Discussions showed clearly that many basic data are not available for African semi-arid situations and that a thorough study is needed of current practices such as mixed cropping, extensive versus intensive land usage, the relative impact on farmers welfare of cash and subsistence cropping, credit, and the utilization of animals for draft and other purposes. The transfer of some existing technologies from India to Africa may be worth considering, e.g., tank irrigation, market regulation, and animal-powered implements.

International Workshop on Chickpea Improvement

The main aim of this workshop, which was held from 28 February to 2 March 1979, was to critically assess the status of world research on the improvement of chickpea. Participants also considered future strategies of the ICRISAT/ICARDA programs, ways to encourage and promote cooperation in chickpea improvement, needs for training, and methods of improving communication and technical assistance in national programs. Breeders were able to visit ICRISAT experimental breeding fields and to inspect and select germplasm and breeding material for dispatch to their countries. Four working groups prepared separate reports on genetic resources, breeding, plant protection, and plant growth. Important areas for future research were identified and recommendations on implementation made.

Consultants' Group Discussions

In addition to the international workshops, two group discussions were held on topics of specialized interest. These involved small numbers of leading scientists from developed and developing countries. The first consultancy discussed "Resistance to Soilborne Diseases of Legumes" and involved ten scientists from Australia, India, the Netherlands, UK, and the USA. The recommendations made are being utilized to draw up future programs of research in soilborne diseases at ICRISAT.

Another group discussion was concerned with assessment of the need and potential for crop weather modelling research in ICRISAT's ongoing farming systems program. This meeting also involved ten scientists, mainly from Indian universities, with participation from Texas A & M and Missouri Universities from the USA.

Field Days and Visits

The very successful program of field days for scientists working on various crops within ICRISAT's mandate, initiated last year, was continued. Twenty-three scientists spent 2 days with the Pearl Millet Program in September. They inspected and commented on the research work in progress in all disciplines including breeding, pathology, and physiology. Twenty-nine scientists from India and one from Bangladesh participated in field days organized by the Pigeonpea Program in December. They were able to make selections from the breeding plots for inclusion in their own programs.

A very significant visit was made to ICRISAT by a team of four scientists from the Chinese Academy of Agricultural Science, Beijing, People's Republic of China. During a 3-week stay, the team participated in a program covering all aspects of the work at ICRISAT Center with particular emphasis on crop improvement. Keen interest was expressed in links between China and ICRISAT on cereal and groundnut improvement. Exchange of germplasm was arranged and plans were made for an exchange visit to China by a team from ICRISAT and development of closer liaison with the Academy.

PLANT QUARANTINE

Export of Seed Material

Export of ICRISATs germplasm is being expedited by recognition of the high phytosanitary standards of our Export Certification Quarantine Laboratory. ICRISAT was authorized by the Germplasm Resources Laboratory, United States Department of Agriculture, Beltsville, to send its seed materials directly to the USA Quarantine Center without the usual import permit. Similar special procedures were also approved by several other countries.

A total of 50 091 seed samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, minor millets, and some other crops were exported to 26 countries in Africa. 24 in Asia, 16 in the Americas, 6 in Europe, and 3 in Australasia this year (Table 1). By far the most of our

Plant Profection Advisor to Government of India inspects outgoing seed material in ICRISAT s Export Certification Quarantine Laboratory.

Table 1. Seed samples exported by ICRISAT during 1978 1979.

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets and other crops
AFRICA						
Algeria				192		
Botswana	637	167			45	20
Burundi	17					
Cameroun	228	156				32
Cape Verde Islands		1	20			
Egypt	34	31				
Ethiopia	2 503	156		471		92
Gambia	132					

Continued

Table 1 *Continued*

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets and other crops
Ghana	522	105				32
Kenya	1 326	390		174		41
Malawi	472	16				5
Mali	960	581	17		2	32
Niger	519	1 174	7			32
Nigeria	1 368	1 837	692			123
Rhodesia	176			49		
Senegal	1 124	1 846	5			32
Sierre Leone			1			
Somalia			10			20
Sudan	3 147	1 772		396		32
Tanzania	2 098	362	704	16		
Togo					50	
Tunisia				192		
Uganda		63	16			
Upper Volta	2 770		58		20	12
Zaire	6					
Zambia	119					
ASIA						
Afghanistan				153		10
Bangladesh	72		17	376	36	
Burma					165	
Democratic Republic of Yemen	156					
Indonesia	235		178		4	
Iran				487		
Iraq				208		
Israel	50					
Japan	67			3	7	
Jordan				384		
Korea	184					
Lebanon	1	1		330		
Malaysia	34		6			
Nepal	10		401	328	100	766
Pakistan	694	746	20	846	190	
People's Rep. of China		33	15	10	64	
Philippines	235	4		121	573	1
Quatar	85	2		3		

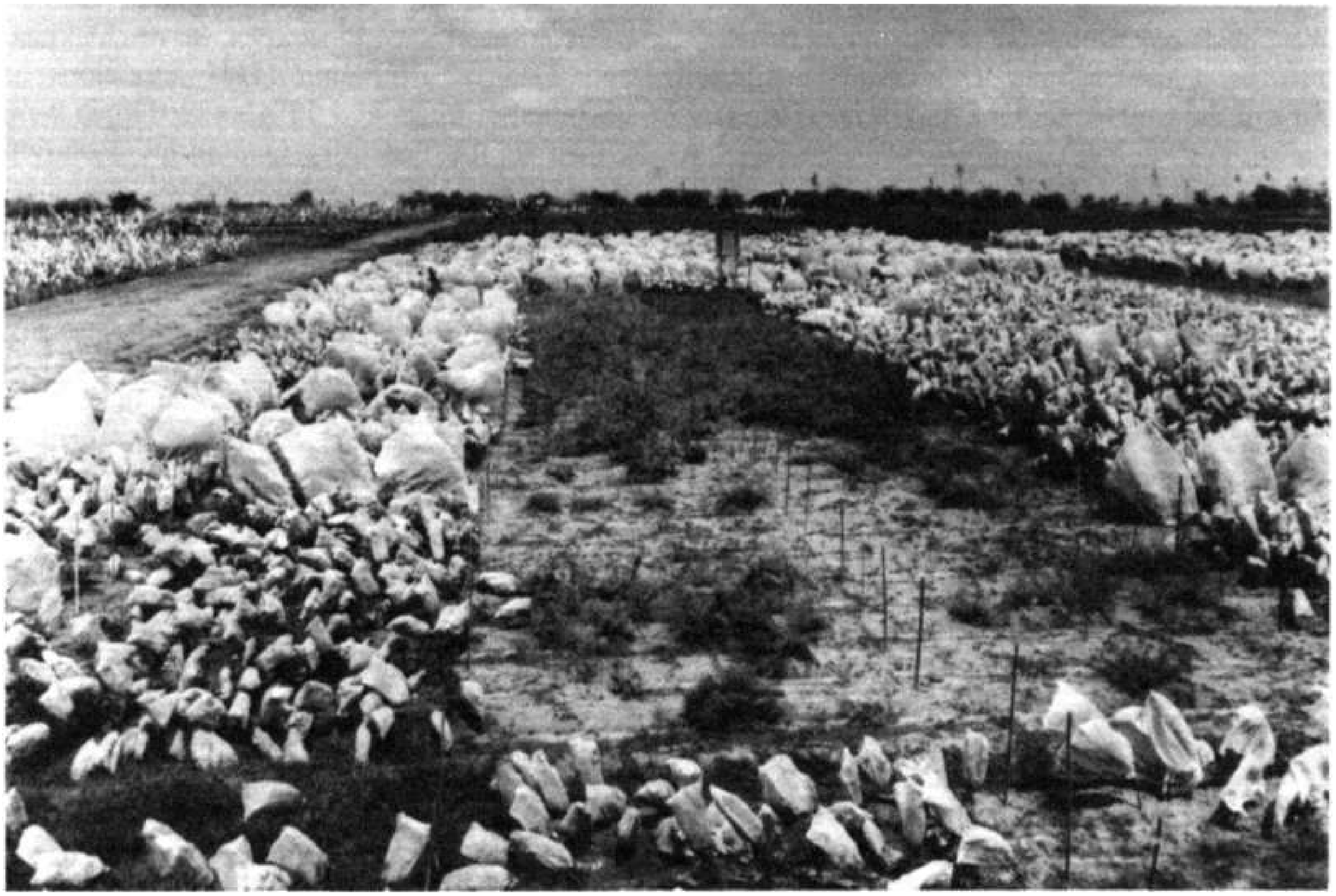
Continued

Table 1 *Continued*

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets and other crops
Saudi Arabia	19	6				
Sri Lanka	253		3	20	38	
Syria				2802		1
Taiwan	15		80			
Thailand	1 163		10		375	2
Yemen Arab Republic	20	72	30	218		
AMERICAS						
Argentina	273			202	100	
Brazil		353	10			2
Canada	6		15	98		
Chile	21			384		
Colombia						10
Dominican Republic			100			
Honduras	56	75	15	15		
Mexico	1 126	95	3	155		
Nicaragua		25				
Panama			4			
Paraguay			31			
Peru	20			174		
Surinam	28	10				2
USA	186	1	16	466	66	1
Venezuela	50	63	38			
West Indies	275	5	53	10	30	6
EUROPE						
Belgium	22					
Denmark	1					
England	207	32	2	15		4
Federal Rep. of Germany						9
Italy		83				
USSR	17	6				
AUSTRALASIA						
Australia	439		103	19		
Fiji			432			
New Zealand			31			
TOTAL	24 178	10 269	3143	9317	1865	1319

Table 2. Seed samples imported by ICRISAT during 1978 79.

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets and other crops
AFRICA						
Botswana	10					
Cameroon		137				
Central African Empire		58				
Ethiopia						4
Kenya	650	45				260
Malawai					123	
Mali		335				
Niger	344	500				
Nigeria	8	97			107	
Oasis Niger		20				
Rhodesia					151	
Senegal	211	307				
Sudan	183					
Upper Volta		17				
ASIA						
Indonesia			4			
Japan					35	
Pakistan	1			8		
People's Rep. of China	6				5	10
Philippines			13			
Syria		138		350		
Taiwan			3			
AMERICAS						
Chile				9		
Mexico	7					
Puerto Rico	608					
USA	171			15	1153	24
EUROPE						
England					1141	2
German Democratic Rep.				8		
Netherlands			6	24		3
USSR	37					
AUSTRALIA						
Australia			3			9
TOTAL	2236	1654	29	414	2715	312



Pigeonpea plants (raised from imported germplasm) bagged to prevent cross-pollination in ICRISAT's plant quarantine isolation area.

seed exports were sorghum and pearl millet breeding nurseries and trials sent to countries in Africa. We also filled a large number of requests from Syria for chickpea samples. And this year, the laboratory sent ICRISAT's first shipment of samples (groundnut and pearl millet) to the People's Republic of China.

Seed samples of minor millets, *Atylosia* spp, *Vigna* spp, *Lens esculantum, Stizolobium* spp, *Flamengia* sp, sunflower, soybean, tomato, and guar were sent to 25 countries; 11 of these countries also received 292 maize seed samples as a component of the *Striga* virulence test.

Four hundred and twenty-two *Rhizobium* cultures of chickpea, pigeonpea, and groundnut were dispatched to Bangladesh, England, Kenya, Panama, Syria, Thailand, and the USA for microbiological studies.

Import of Seed Material

During the year, 7360 samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, minor millets, and other crops were imported from 14 countries in Africa, 7 in Asia, 4 in the Americas, 4 in Europe, and 1 in Australasia (Table 2). The largest number of these were groundnut accessions from the USA and England.

The minor millets and other crops received' for utilization in the Genetic Resources Unit and Groundnut Virology Program at ICRISAT Center are: *Eleusine coracana, Setaria italica, Atylosia grandifolia, Eragrostis tef, Lycoper si-*

cumesculantum, Vigna spp, *Capsicumfrutescens, Nicotiana tabacum, Lens esculantum, Citrullus vulgaris, Cicer graecum, Gossypium hirsutism, Siratro, Melinus minutiflora,* and virus-indicator plants.

Postentry Quarantine

During the 1978 monsoon and postmonsoon seasons, 3576 accessions of sorghum, 1679 of pearl millet, 150 of pigeonpea, 88 of chickpea, and 2715 of groundnut (1141 accessions as unrooted cuttings and 1574 as seedlings) were grown in the Postentry Quarantine Isolation Area (PEQIA). These were subjected to cooperative inspections by the Government of India and ICRISAT quarantine staff for symptoms of exotic diseases until harvest and then released to ICRISAT crop improvement programs or to the Genetic Resources Unit.

COMPUTER SERVICES

The Computer Services Unit provides time-sharing services to ICRISAT personnel through the Research Sharing Time Sharing/Extended (RSTS/E) 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 (1) developing interactive systems that are easy to use, (2) providing data-entry services, and (3) conducting seminars on computer use and programming.

Current Stage of Development

Many additions and improvements were made to the Crop Research Integrated Statistical Package (CRISP), the statistical analysis system developed by ICRISAT Computer Services, from June 1978 to May 1979. An improved generalized analysis of variance routine for up to eight factors, a randomization routine for nursery trials, an analysis of variance for Federer-type augmented designs, a split-plot analysis of variance with a simple covariance option, and a completely rewritten step-wise regression program were incorporated into CRISP. Improvements to existing options included the addition of the Scott-Knott mean separation technique to the randomized complete block analysis of variance and the inclusion of Bartlett's test for homogeneity of variances in the one-way analysis of variance.

A data entry program that supports up to four terminals simultaneously was developed for entry of the Economics Program's Village-Level Studies data. The advantage of this program is that, with four persons entering data, the memory requirement is less than for one copy of the single-user data entry program. Systems programs to perform daily and weekly file-backup procedures were developed that operate two times faster than their company-supplied counterparts. The development of such programs has become necessary as the user demand for computer access has increased.

Several segments of the new ICRISAT Data Management and Retrieval System (IDMRS) were completed during September 1978. The system has been used to maintain ICRISAT's chickpea, pigeonpea, sorghum, and groundnut germplasm data. Special printing programs were developed to print the data sections of initial versions of the chickpea, pigeonpea, and sorghum germplasm catalogs. The textual portions of these catalog were typed, edited, and formated on the computer system using available word-processing software.

The use of word-processing software such as text editors and text formatters increased during the year. Additional user documentation was prepared on the computer as in the past, and the Research Editor used these facilities to prepare drafts of papers, word lists, and bibliographies. The instructions to cooperators for conducting the International Chickpea Nurseries were also prepared this way, and it was possible to include location-specific randomizations in the document. This technique thus permitted the creation of customized instructions for each cooperator.

The dynamic grain sorghum growth model of G. F. Arkin and R.L. Vanderlip was implemented on our computer system for use by the Agroclimatology and Cereal Physiology subprograms. The accuracy of the ICRISAT implementation was validated during the consultancy of G.F. Arkin at ICRISAT in March.

The major event of the year was the relocation of the computer system to ICRISAT Center in December 1978, providing easier access to scientists.

Dr Jerry A. Warren, Statistical Consultant from the University of New Hampshire, USA, returned to ICRISAT for 6 weeks during January-February 1979. He continued his research in statistical methods for eliminating differences in responses due to field variation and consulted with researchers concerning their statistical analysis problems.

CRISP was given to the Office of Rural Development, Suweon, Korea and has been successfully implemented on their PDP-11/70 computer system.

A poster presentation on CRISP was made at the Fall U.S. DECUS (Digital Equipment Corporation Users' Society) meeting held in San Francisco, 26 to 30 November 1978,

Looking Ahead

The following projects are scheduled for consideration during the coming year:

- Improvements of the data selection procedures and file structure in 1DMRS (ICRISAT Data Management and Retrieval System).
- Continued improvement of the statistical analysis package (CRISP).
- Development of systems programs that will help improve overall computer system performance.
- Considerations of alternatives for a new and larger computer system.
- Further development of the Fiscal Accounting System.

LIBRARY AND DOCUMENTATION SERVICES

The ICRISAT library and documentation services play a vital role in serving the Institute's scientists as a center for world literature on major and related scientific disciplines appropriate to ICRISAT's mandate. To the extent possible, the library also extends its services to all other SAT and non-SAT scientists by way of supplying information and/or loaning out literature to them.

Acquisition

The library has now acquired a major collection of research literature in the field of agriculture and sociobiology, comprising a wide variety of books, pamphlets, back volumes of periodicals, theses, etc. During the year under report, the library acquired 3168 documents, bringing the total collection to: 13 312 books, 7437 back volumes of periodicals, 1357 microforms, and 283 annual reports.

Annual Reports

Annual reports help scientists to avoid parallel research and to plan their research "in series." In view of this, the library has updated its collection of annual reports of 170 national and international institutes with areas of research similar to that of ICRISAT.

Current Periodicals

The ICRISAT library subscribes to various periodicals that cover ICRISAT's mandate crops, and special emphasis is given to procuring literature from SAT regions. By subject, available periodicals on hand include the following:

Subject	Indian	African	Other
Agricultural sciences	61	8	196
Biological sciences	15	3	70
Physical sciences	2	0	0
Social sciences, economics, statistics	24	1	47
Others	37	4	124
Total	139	16	437
Grand Total 592			

Exchange of Publications

A worldwide program of exchange of publications was launched during the year under report; exchange relationships were established with 195 institutes and organizations. We are now receiving nearly 200 periodicals/newsletters either in exchange for our publications or gratis.

Publications

The important publications issued during the period under report were the monthly list of additions of titles and *Indian Theses on Groundnut: A Bibliography, 1948-1977.*

Sorghum and Millets Information Center (SMIC)

SMIC holdings at ICRISAT contain 9908 references and 3631 mastercopies in sorghum and 5751 references and 1779 mastercopies in millets. Work on the following bibliographies continued:

1. *Bibliography on Sorghum (1970 to 1973)*
2. *Bibliography on Sorghum (1974-1976)*
3. Bibliography on Millets (1*970 to 1976)*

Annual bibliographies for 1977 and 1978 with abstracts on sorghum and millets are planned to be released soon.

The French version of the *Annotated Bibliography on Sorghum* (*1900-1976*) is in preparation. It includes 880 references supported by French and English annotations.

Preparations to compile the World Directory of Sorghum and Millets Research Workers are under way.

Mr Donald Leatherdale, Program Officer (Agric.) from IDRC, Canada, and Dr Fernando Monge, Communications Scientists from CIAT, Colombia, visited SMIC in July 1978. Mr Leatherdale presented to SMIC his provisional Thesaurus on Sorghum and Millets and demonstrated its use in indexing sorghum and millets literature. Dr Monge demonstrated the use of Termatrex, a semiautomatic device selected for information storage and retrieval *of literature on sorghum and millets.*

Our Documentalist (French) visited a number of institutions in France and the Netherlands to study documentation techniques and to collect literature available in French on sorghum and millets.