ICRISAT

ANNUAL REPORT 1979/80

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

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Published by
International Crops Research Institute
for the Semi-Arid Tropics
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The correct citation for this report is ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1981. Annual Report 1979/80. Patancheru, A.P. India: ICRISAT.

ICRISAT's Objectives

To serve as a world center to improve the 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 seventh Annual Report covers research by ICRISAT for the crop year beginning 1 June 1979 and ending 31 May 1980. 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. Individual program offprints of this Annual Report are also available.

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J.M. Peacock, Principal Plant Physiologist (from Nov 1979)
C.M. Pattanayak, Sorghum Breeder and Team Leader, Upper Volta
K. V. Ramaiah, *Stviga* Physiologist, Upper Volta
W. A. Stoop, Agronomist, Upper Volta
J. A. Frowd, Cereal Pathologist, Upper Volta
K. F. Nwanze, Cereal Entomologist, Upper Volta (from Aug 1979)
J. F. Scheuring, Sorghum/Millet Breeder, Mali
Gebisa Ejeta, Sorghum Breeder, Sudan
Vartan Guiragossian, Sorghum Breeder, Mexico
S. Z. Mukuru, Sorghum Breeder, Tanzania
Bholanath Verma, Plant Breeder
D. S. Murty, Plant Breeder
B. L. Agrawal, Plant Breeder
B.V.S. Reddy, Plant Breeder
M.J. Vasudeva Rao, Plant Breeder (as of June 1979)
N. Seetharama, Plant Physiologist
R. K. Maiti, Plant Physiologist
K. N. Rao, Plant Pathologist
S.R.S. Dange, Plant Pathologist
K. V. Seshu Reddy, Entomologist
H. C. Sharma, Entomologist (as of Dec 1979)
S. P. Jaya Kumar, Administrative Assistant (as of Mar 1980)

Pearl Millet

D.J, Andrews, Principal Plant Breeder and Leader (on sabbatic leave)
R.J. Williams, Principal Plant Pathologist and Acting Leader (from Sept 1979)
Aran Patanothai, Principal Plant Breeder
F. R. Bidinger, Principal Plant Physiologist
A. Lambert, Millet Breeder, Senegal (until May 1980)
R.T. Gahukar, Cereal Entomologist, Senegal
P. K. Lawrence, Millet Breeder, Upper Volta (until May 1980)
S. N. Lohani, Millet Breeder, Upper Volta (from May 1980)

P. G. Serafini, Agronomist, Mali
B. B. Singh, Millet Breeder, Niger
S. O. Okiror, Millet Breeder, Nigeria
N. V. Sundaram, Cereal Pathologist, Nigeria
R. P. Jain, Millet Breeder, Sudan
S. C. Gupta, Plant Breeder
K. Anand Kumar, Plant Breeder
B. S. Talukdar, Plant Breeder
K. N. Rai, Plant Breeder
S. B. Chavan, Plant Breeder (as of Sept 1979)
G. Alagarswamy, Plant Physiologist
V. Mahalakshmi, Plant Physiologist
S.D. Singh, Plant Pathologist
R. P. Thakur, Plant Pathologist
R.V. Subba Rao, Microbiologist (until Nov 1979)
S. P. Wani, Microbiologist

Pulses

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Y. L. Nene, Principal Plant Pathologist and Leader (from Mar 1980)
P.J. Dart, Principal Microbiologist
W. Reed, Principal Entomologist
K. B. Singh, Chickpea Breeder, Syria
H. E. Gridley, Geneticist-cum-Associate Chickpea Breeder, Syria (from Apr 1980)
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Onkar Singh, Plant Breeder, Chickpea
C. L. L. Gowda, Plant Breeder, Chickpea
S. C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea
Satish Rai, Plant Breeder, Pigeonpea
K. B. Saxena, Plant Breeder, Pigeonpea (on leave)
L.J. Reddy, Plant Breeder, Pigeonpea
S. C. Gupta, Plant Breeder, Pigeonpea
G. K. Bhatia, Plant Breeder, Pigeonpea
N. P. Saxena, Plant Physiologist
I. Madhusudhan Rao, 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
J.V. D. K. Kumar Rao, Microbiologist

Groundnut

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J. P. Moss, Principal Cytogeneticist
Duncan McDonald, Principal Plant Pathologist
K. Maeda, Visiting Scientist, Plant Physiology
N. Iizuka, Visiting Scientist, Virology
D.V.R. Reddy, Senior Plant Pathologist (Virology)
A.K. Singh, Cytogeneticist
D.C. Sastry, Cytogeneticist (as of June 1979)
S.N. Nigam, Plant Breeder
S. L. Dwivedi, Plant Breeder (as of Sept 1979)
A.M. Ghanekar, Plant Pathologist
P. Subramanyam, Plant Pathologist
V. K. Mehan, Plant Pathologist
P.T.C. Nambiar, Microbiologist
P.W. Amin, Entomologist
Ahmed Bin Mohammed, Entomologist (as of Mar 1980)

Farming Systems

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J. Kampen, Principal Agricultural Engineer, Soil and Water Management
S.M. Virmani, Principal Agroclimatologist
R.W. Willey, Principal Agronomist
G. E. Thierstein, Principal Agricultural Engineer, Small Implements Development
M.B. Russell, Consultant, Soil Physics (until Apr 1980)
J.T. Moraghan, Principal Soil Scientist (from Apr 1980)
S. M. Miranda, Principal Soil and Water Engineer (from May 1980)
M.C. Klaij, Assistant Agricultural Engineer, Small Implements Development

F.B. Huibers, Assistant Agricultural Engineer, Soil and Water Management
J. Ph. van Staveren, Assistant Agronomist, Upper Volta
S.V.R. Shetty, Agronomist
M.R. Rao, Agronomist
M.S. Reddy, Agronomist
M. Natarajan, Agronomist
M.V. K. Sivakumar, Agroclimatologist
A. K. Samsul Huda, Agroclimatologist
S.J. Reddy, Agroclimatologist
Piara Singh, Soil Physicist (on leave)
Sardar Singh, Soil Physicist
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S. K. Sharma, Senior Research Technician
Siloo Nakra, Executive Assistant

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J. McIntire, Economist, Upper Volta (from May 1980)
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B. C. Barah, Economist (until Dec 1979)
R. D. Ghodake, Economist
R.P. Singh, Economist (as of Nov 1979)
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L. J. G. van der Maesen, Principal Germplasm Botanist
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S. Appa Rao, Botanist
R.P.S. Pundir, Botanist (on leave)
P. Remanandan, Botanist
V.R. Rao, Botanist

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Umaid Singh, Biochemist
V. Subrahmaniam, Biochemist

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F.J. Bonhage, Construction Supervising Officer
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B. H. Alurkar, Senior Engineer
Manmohan Singh, Senior Engineer (until Sept 1979)
S.K. Tuli, Senior Engineer (until Apr 1980)
B. K. Sharma, Senior Engineer
T.J. Choksi, Senior Engineer
S.K.V.K. Chari, Senior Engineer
D.V. Subba Rao, Engineer
A.R. Das Gupta, Engineer
A.E. Jaikumar, Architect
V. Lakshmanan, Executive Assistant
P.M. Menon, Executive Assistant

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S. K. Pal, Plant Protection Officer
K. Ravindranath, Engineer (as of Apr 1980)
K. Santhanam, Executive Assistant

International Interns

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L. K. Fussell, Millet Physiology
D.J. Nevill, Groundnut Pathology
C. N. Floyd, Farming Systems
I. S. Campbell, Groundnut Physiology
T. Goto, Groundnut Pathology
W.R. Root, Sorghum Breeding, Upper Volta

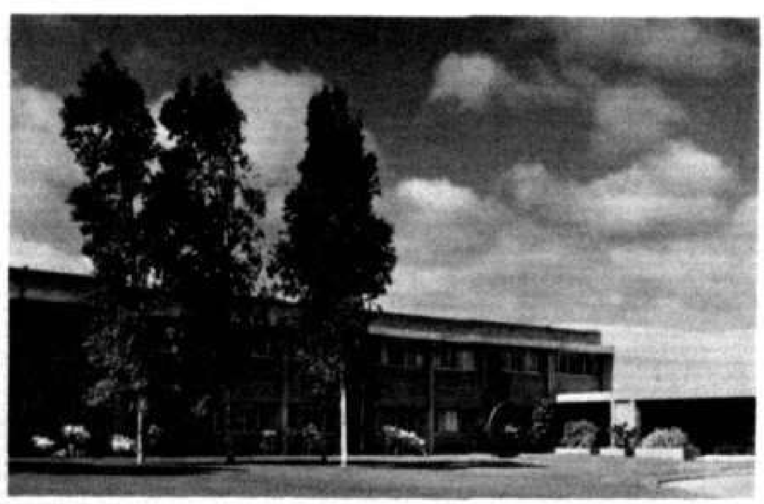
Acronyms and Abbreviations Used in this Annual Report

AICMIP	All India Coordinated Millet Improvement Project
AICRPDA	All India Coordinated Research Project for Dryland Agriculture
AICSIP	All India Coordinated Sorghum Improvement Project
ALAD	Arid Land Agricultural Development Program
BBF	broadbed-and-furrow
BHC	benzene hexachloride
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	Centro Internacional de Mejoramiento de Mais y Trigo
DAS	days after sowing
FAO	Food and Agriculture Organization of the United Nations
FESR	Federal Experimental Research Station, Puerto Rico
HYV	high-yielding variety
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in Dry Areas
ICRRWN	International Chickpea Root Rots/Wilts Nursery
ICSN-DL	International Chickpea Screening Nursery - Long Duration
ICSN-DS	International Chickpea Screening Nursery - Short Duration
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
IPMAT	International Pearl Millet Adaptation Trial
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery
IPMRN	International Pearl Millet Rust Nursery
IPMSN	International Pearl Millet Smut Nursery
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (Institute for Tropical Crops Research)
IRRI	International Rice Research Institute
ISPYT	International Sorghum Preliminary Yield Trial
LER	land equivalent ratio
OAU	Organization for African Unity
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (Overseas Scientific and Technical Research Office)
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	semi-arid tropics
SEPON	Sorghum Elite Progeny Observation Nursery
STRC	Scientific Technical and Research Commission
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VLS	village-level studies

ICRISAT's Five Crops

Latin				
Sorghum bicolor (L.) Moench	*Pennisetum americanum* (L.) Leeke	*Cajanus cajan* (L.) Millsp.	*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	Mil a chandelle	Pois d'Angole, pois cajan	Pois chiche	Arachide
Portuguese				
Sorgo	Painco perola	Guando, feijao-guando	Grao-de-bico	Amendoim
Spanish				
Sorgo, zahina	Mijo perla, mijo	Guandul	Garbanzo, garavance	Mani
Hindi				
Jowar, jaur	Bajra	Arhar, tur	Chana	Mungphali


ICRISAT CENTER



Introduction

ICRISAT Center was inaugurated this year. Finally after 7 years we have a home of our own: a fine set of laboratories, offices and training facilities, a library, a computer center, an auditorium, a canteen, and a printshop capable of printing our major institute publications (this annual report is an example). We are grateful to the donors of ICRISAT, to the Governments of India and the State of Andhra Pradesh, and to the many individuals who helped create ICRISAT and have sustained its growth. We express our gratitude to two Prime Ministers of India—Shrimati Indira Gandhi who laid the cornerstone for these facilities in 1975 and Shri Charan Singh who inaugurated them in August 1979.

During the week of Inauguration we held a seminar on the Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, provided opportunities for our many visitors to see our work on the farm and in the laboratories, and seized upon this important occasion to rededicate ourselves to our challenging mandate.

After 7 years of operation there is much evidence that the scientists who are our principal clients are pleased with what has been done. We have released cultivars of pearl millet, sorghum, and chickpea for testing by national research and extension networks. Our pearl millet hybrids and experimental varieties with good resistance to downy mildew have reached their way through several trial stages in India to farmers' field testing. Sorghum selections developed at ICRISAT are being tested in farmers' fields in Upper Volta and Mali. Our chickpea varieties are included in research trials in India, and in Syria this year our scientists, working with those of our sister institute ICARDA, gained substantially higher yields with chickpea cultivars *incorporating Ascochyta* blight resistance to make winter planting possible.

ICRISAT's output of breeding material has been substantial in all crops, and this material has been distributed throughout the semi-arid tropics. For example, we have supplied to national programs 10 500 items of pearl millet breeding material since 1974.

From the beginning ICRISAT has collected germplasm of our mandate crops to preserve for the future the genetic material of all

A large number of SAT farmers visited ICRISAT on the occasion of its Inauguration and showed keen interest in the experiments on crop improvement.

obtainable races of these crops, cultivated and wild. Cold storage facilities planned for ICRISAT Center in the future will permit the preserving of such material for 50 to 100 years without the need for rejuvenation. Our collection efforts and donations received this year yielded more than 17 000 samples of germplasm from 23 countries. The main thrust of collection continued to be on the African continent where Botswana, Somalia, Sudan, Tanzania, and Zambia were explored for original landraces of cereals.

We have developed a new system of farming that will enable better rainy-season use of the deep Vertisols (black soils) in areas of assured rainfall in India; millions of hectares of these lands, now left fallow in the rainy season, can produce two crops a year using the new technology. The technology includes improvements in cropping patterns, varieties, fertilization, cultural practices, land and water management, and agricultural implements. It is now on test in villages in India and by some extension and action agencies, and we hope some day to see it in widespread use by farmers. The technology incorporates results of many years of research, some of it conducted before ICRISAT was born, and many possibilities have been reduced to a few alternative combinations that look good.

Extensive improvements of laboratory and field facilities were made this year at the Upper Volta Government Station at Kamboinse where a multidisciplinary team of seven of our scientists works. Here, an ICRISAT pathologistdiscusses screening techniques in a millet nursery in that country.

Hundreds of visiting scientists, farmers, and administrators at the time of Inauguration, and at other times, have seen the new technology and taken away with them fragments or concepts for their own use. We will never be able to trace all the users of these outputs of ICRISAT.

ICRISAT's research objectives are calculated to serve the small farmers. In crop improvement, we are building into advanced breeding materials yield stability, disease resistance, and tolerance to pests. We are seeking to develop crops that will grow well under the drought and low/fertility conditions of the SAT. Intercropping, which reduces risk for the small farmer, is emphasized in our farming systems research.

Our research in Africa, which started in 1974, was considerably expanded this year. We now have 18 ICRISAT scientists working at national research centers, mostly in West Africa, and we expect to continue expansion of this program in the years immediately ahead. The Upper Volta Government Station at Kamboinse serves as base for seven of our scientists, the largest ICRISAT multidisciplinary team on the continent. Extensive improvements of this station's laboratory and field facilities were completed this year. An increasing number of international trials and nurseries is being conducted in Africa through an expanding network of ICRISAT personnel and cooperators working to improve sorghum and pearl millet, staple cereal crops of the Sahelian-Sudanian zone. We have recently added farming systems and economics research to the work previously done in Africa and we hope soon to include groundnut in our crop improvement efforts there.

From both India and Africa, and from other areas of the SAT, we are training research workers, technicians, and extension agents to work with our crops and to do watershed management research. Our training program has a practical orientation and concentrates on developing research and extension skills that can put this constantly improving technology in the hands of the small farmers who will be its principal beneficiaries.

L.D. SWINDALE
Director General

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.

LOCATION. 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.

SEASONS. 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 (ranging from 15 to 20°C) 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.

CROPS. The five ICRISAT crops have different environmental requirements that determine where and when they are grown. Millet and groundnut are sown on Alfisols during June and July, the beginning of the rainy season; at ICRISAT Center additional generations are taken under irrigation. Pigeonpea is generally sown at the beginning of the rainy season and continues growing through the postrainy season; an irrigated generation of early-maturing types is planted in December so as to provide additional genetic material for our breeding program. As in normal farming practice, two crops a year of sorghum can be grown, one during the rainy season and one on Vertisols in the postrainy season. Chickpea, a single-season crop, is sown during the postrainy season on residual moisture in deep Vertisols. At ICRE3AT, as in normal farming practice, these crops are often grown in various combinations and sequences, which we are working to improve.

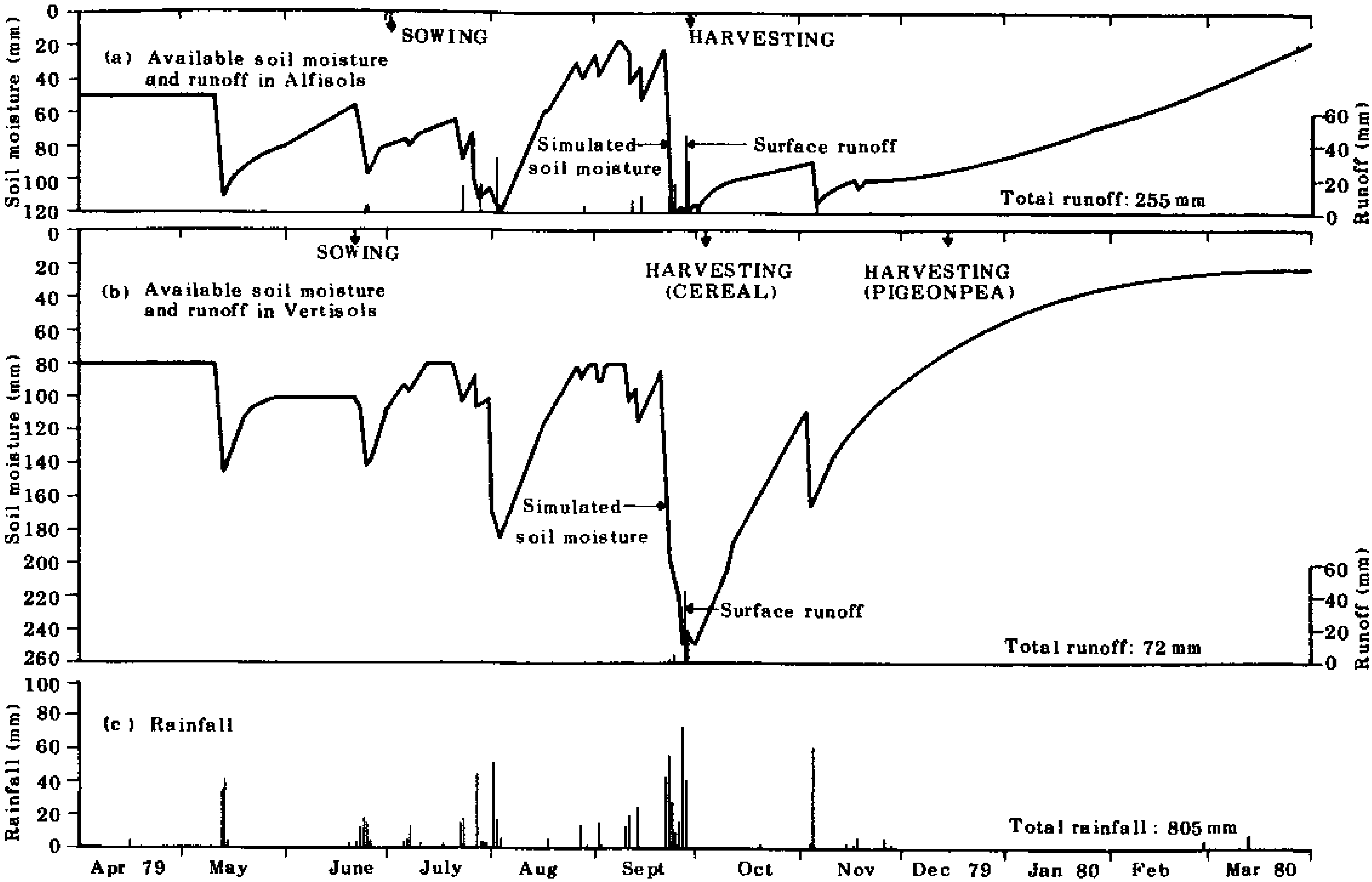
THIS YEAR'S WEATHER. The 1979 rainy season began on 20 June and ended on 1 October, producing a total rainfall of 630 mm for the season (normal 690 mm). Monthly rainfall and temperature data for 1979/80 are presented in Table 1.

Table 1. Rainfall and temperature at Hyderabad in 1979/80 crop year.

	Rainfall (mm)		Temperature (°C)			
			Normal[b]		1979/80	
Month	Normal[a]	1979/80	Max	Min	Max	Min
June	115	58	34	24	36	25
July	171	107	30	22	33	23
August	156	101	29	22	30	22
September	181	344	30	22	30	22
October	67	20	30	20	31	21
Rainy-season total	690	630				
November	23	80	29	16	29	19
December	6	0	28	13	28	15
January	6	0	29	15	29	15
February	11	4	31	17	32	18
March	13	9	35	20	35	20
April	24	7	37	24	38	25
May	27	18	39	26	40	26
Dry-season total	110	118				
Annual	800	748				

a. Based on 1901-70 rainfall data.

b. Based on 1931-60 temperature data.



(d) Pan evaporation (mm/month)

	Apr 79	May	June	July	Aug	Sept	Oct	Nov	Dec 79	Jan 80	Feb	Mar 80
1979/80	345	360	318	236	180	126	164	123	136	167	242	291
6-year average	318	375	276	174	130	138	149	132	146	158	188	291

Figure 1. Data for rainfall, runoff, and pan evaporation at ICRISAT Center, 1979/80, and simulated available soil moisture under: (a) sole-cropped pearl millet grown in Alfisols; (b) cereal/pigeonpea intercrop grown in Vertisols.

A generalized trend for simulated available soil moisture in Vertisols and Alfisols is given in Figure 1. The seasonal runoff was about 72 mm in Vertisols and 255 mm in Alfisols; it represented 11% and 40% of seasonal rainfall received. In both soils the available soil moisture was less than 50% of available water-holding capacity from mid-August to mid-September; in Vertisols it was below 50% in July as well. After the September rains the soil profile was nearly at field capacity at the harvest of the two cereal crops.

CROP SEASONS. The cropping schedules generally followed at ICRISAT are shown in Figure 2.

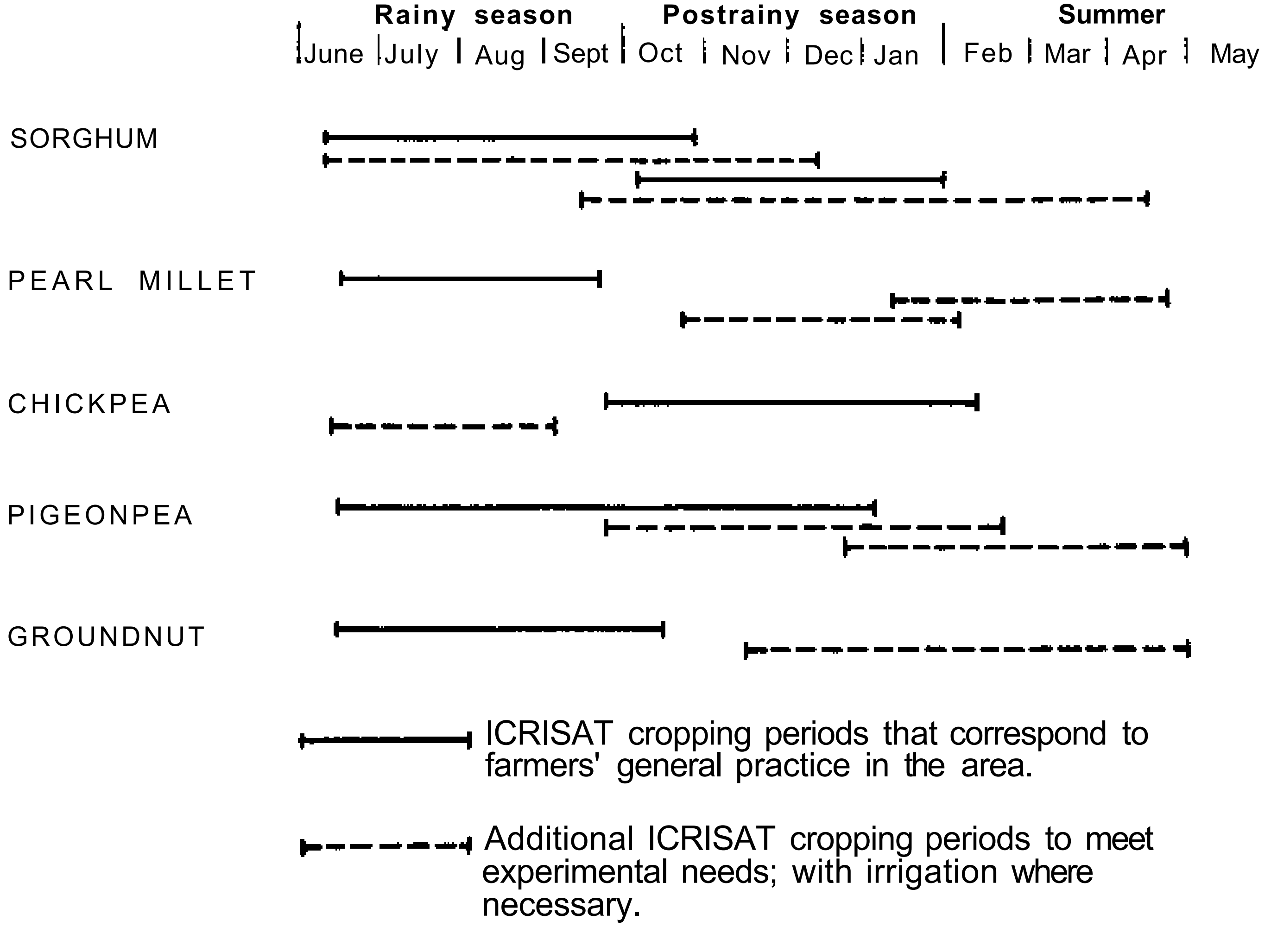
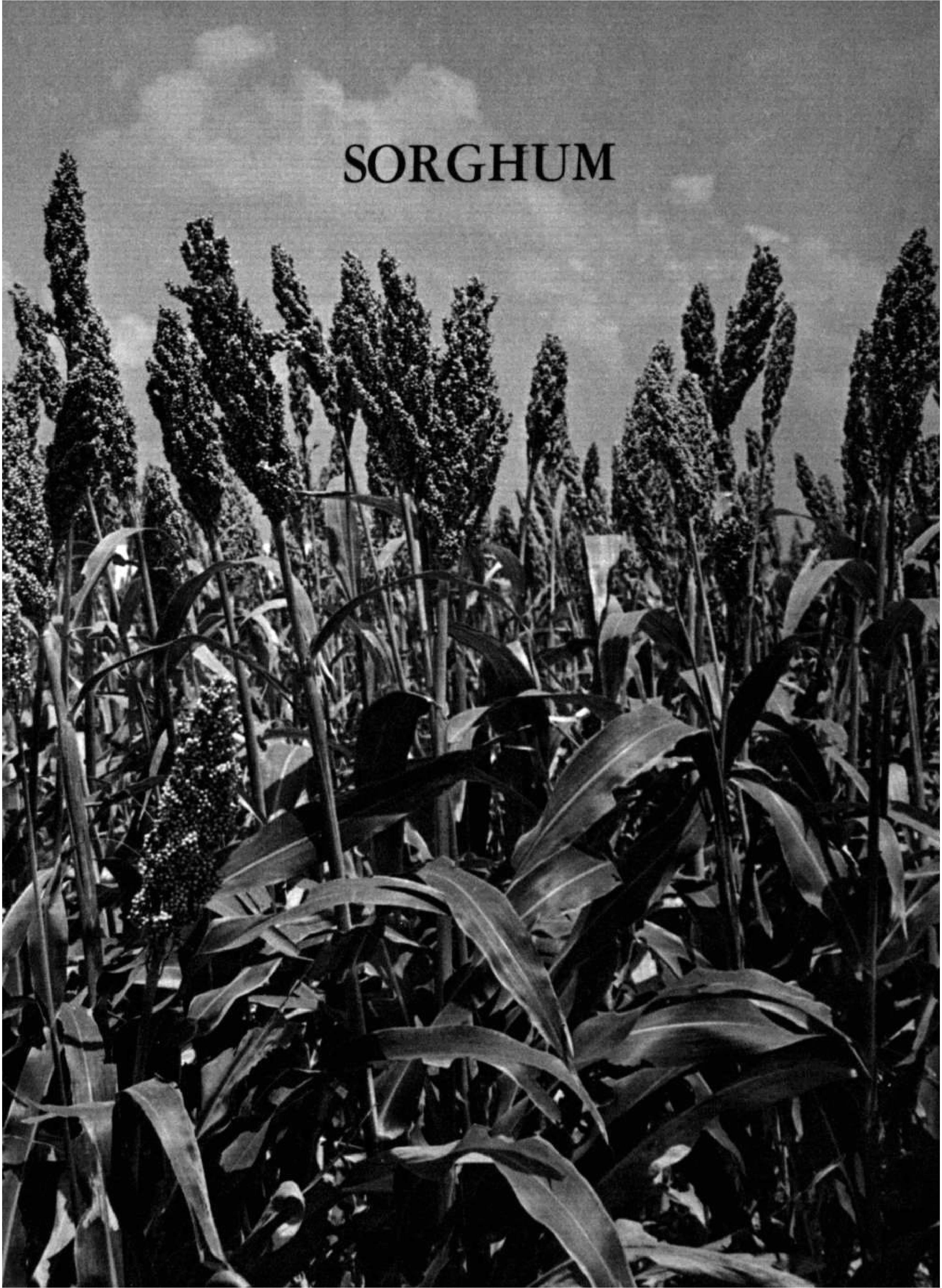


Figure 2. ICRISAT Center's cropping schedule.


SORGHUM

Contents

SORGHUM

International Yield Testing

International Sorghum Preliminary Yield Trial (ISPYT)

Based on our observations and results of past ISPYT trials, we divided the 1979 ISPYT into ISPYT-1, which included the early-maturity types, and ISPYT-2, which included the medium- to medium-late maturity types of sorghum.

1979 ISPYT-1. This trial consisted of 30 entries, including the local check, and was distributed to 38 locations in 20 countries. Data were received from only 16 locations in 10 countries.

Analyzed data of the most, promising nine entries are presented in Table 1. All these entries yielded around 3000 kg/ha or more, compared to 2470 kg/ha from the check entry CS-3541. The sister lines (FLR-266 x CS-3541)-4-3-1 and (FLR-266 x CS-3541) -4-3-7 performed consistently well across locations. FLR-1379-1-1, a derivative from the Fast Lane population, averaged 4310 kg/ha over Indian locations, compared to 2920 kg/ha for CS-3541, and also outyielded local checks in Sudan, Botswana, Malawi, Tanzania, and Thailand. (FLR-266 x CS-3541)-4-5-3 performed well in several African countries as well as in Thailand and Pakistan.

1979 ISPYT-2. This trial consisted of 60 entries, including the local checks, and was distributed to 38 locations in 20 countries. Data were received from only 15 locations in 8 countries.

Table 2 gives the analyzed data of the most promising entries. It is encouraging to note that two entries, (FLR-141 x CS-3541)-2-1-5 and (FLR-101 x CS-3541)-3-2-1, performed well across most Indian as well as African locations. The former entry outyielded the local checks at three Indian locations and the locations in Thailand, Botswana, and Malawi. Three entries, (FLR-101 x IS-1082)-4-5-3, Rs/B-8785-1-1-1, and Ind. Syn-387-3-1, performed well at Indian locations and were the top-yielding varieties at seven locations. (FLR-101 x CS-3541)-2-1-3 performed relatively well in several countries except India. Varieties that performed well only at specific locations included (FLR-101 x IS-1082)-4-5-3 (5070 kg/ha) at Ilonga, Tanzania; Ind. Syn-112-1 (7180 kg/ha) at Farm Suwan, Thailand; Ind. Syn-182-3 (2730 kg/ha) at Ngabu, Malawi; Ind. Syn-387-1 (4130 kg/ha) at Wad Medani, Sudan, and (FLR-101 x CS-3541)-1-1-2 (9050 kg/ha) in Zimbabwe. All these entries significantly outyielded the local checks. Lines (FLR-101 x IS-1082)-4-4-2, Rs/B-8785-1-1-1, and Ind. Syn-387-3-1 have been contributed to the Preliminary Variety Trial of the All India Coordinated Sorghum Improvement Project (AICSIP).

Sorghum Elite Progeny Observation Nursery (SEPON)-I979

We distributed seed of SEPON-1979 to 32 cooperators in 22 countries in the semi-arid tropics. The nursery comprised 60 entries including the hybrid check, CSH-6, and a local check. Among the test lines, 47 were derived from single and three-way crosses involving adapted, good grain, and low-mold-susceptible lines in their parentage. The remaining lines were selected from SEPON-1977 and SEPON-1978.

Grain mold severity and overall performance scores on SEPON-1979 were received from 18 locations. The analyzed data of the most promising entries are presented in Table 3. Average grain mold incidence across locations was least for

Table 1. Performance of selected entries from ISPYT-1 (1979).

Pedigree	Days to 50% flower-ing (17)[b]	Plant height (cm) (17)	Scores[a] Overall perfor-mance (9)	Borer (3)	Grain mold (1)	Zonate leaf spot (1)	Stalk rot (1)	Grain yield (kg/ha) Overseas locations (10)	Indian locations (5)	Overall (15)
(FLR-141 x CS-3541)-3-6-2[c]	72	165	3.3	2.0	4.0	4.5	1.5	2430	3950	2930
(FLR-141 x CS-3541)-2-1-10	73	167	3.2	2.1	2.5	4.5	2.0	2660	3860	3050
(FLR-266 x CS-3541)-2-1-1	66	174	3.6	2.7	3.0	4.0	2.3	2690	3790	3060
(FLR-266 x CS-3541)-4-3-1	76	150	2.6	2.3	2.0	3.5	1.5	2860	4130	3280
(FLR-266 x CS-3541)-4-3-7[c]	71	155	2.7	2.0	2.5	3.5	2.8	2890	4300	3360
(FLR-266 x CS-3541)-4-5-3	68	149	3.3	2.5	2.0	3.5	2.6	2860	3370	3030
(FLR-101 x CS-3541)-1-2-1	69	161	3.4	1.8	2.5	4.0	2.3	2470	4080	3010
(Bulk-Y-398-1045)-2-3-1	72	154	2.8	2.3	2.5	5.0	2.3	2680	3730	3030
FLR-1379-1-1	69	184	3.1	1.5	2.5	3.0	1.3	2520	4310	3120
CS-3541 (check)	73	124	3.4	2.6	3.0	3.5	3.0	2250	2920	2470
Local variety (check)	71	158	2.5	2.3	2.5	2.5	1.8			

a. All scores are on a scale of 1-5 (1 being the best).
b. Figures in parentheses are number of locations over which mean has been taken. CV for grain yield from individual locations ranged from 7 to 54%.
c. Selected lines in Mali.

Table 2. Performance of selected entries from ISPYT-2 (1979).

			Scores [a]					Grain yield (kg/ha)		
Pedigree	Days to 50% flowering (14)[b]	Plant height (cm) (14)	Overall performance (10)	Borer (2)	Grain mold (1)	Zonate leaf spot (1)	Stalk rot (1)	Overseas locations (7)	Indian locations (7)	Overall (14)
(FLR-141 x CS-3541)-2-1-5	76	208	3.4	2.3	2.0	2.0	1.0	3640	4160	3900
(FLR-101 x CS-3541)-1-1-2	73	137	2.7	2.5	3.5	4.5	2.5	3180	3730	3450
(FLR-101 x CS-3541)-2-1-3	72	130	3.0	2.4	4.0	5.0	3.0	3650	3780	3720
(FLR-101 x CS-3541)-3-2-1	72	178	3.1	2.4	2.5	3.0	2.5	3110	4010	3560
(FLR-101 x IS-1082)-4-4-2	79	151	3.0	2.5	1.0	2.5	3.0	2710	4020	3370
(FLR-101 x IS-1082)-4-5-3	74	160	2.7	3.0	2.5	4.5	3.3	2750	4370	3560
Rs/B-8785-1-1-1	67	188	2.7	2.8	3.0	3.0	1.8	2630	4350	3490
Ind. Syn-112-1	76	128	3.2	3.5	2.0	3.0	3.0	3190	3520	3350
Ind. Syn-387-3-1	71	190	2.9	1.9	2.0	2.5	1.8	2740	4290	3510
Ind. Syn-405-2-2	78	174	3.1	2.0	1.0	1.0	1.8	2800	3600	3200
Good Grain-1483	78	206	3.0	2.6	1.0	1.0	2.6	2170	4140	3160
CS-3541 (check)	73	135	3.6	3.5	4.0	3.5	2.5	2120	3870	2290

a. All scores are on a scale of 1-5 (1 being the best).
b. Figures in parentheses are number of locations over which mean has been taken. CV for grain yield from individual locations ranged from 6 to 40%.

lines [(SC-423 x CS-3541) x E-35-1]-2, [(SC-423 x CS-3541) x E-35-1] -9, and [(SC-108-3 x Swarna) E-12-5]-4. It is encouraging that the overall performance of (SC-423 x CS-3541) x E-35-1] -2 and (SC-108-4-8xCS-3541)-88 was the best, as these two entries were also low-mold-susceptible across locations despite being medium-maturity types.

We received grain yield data for SEPON-1979 from 14 locations; the top yielders are marked in Table 3.

Lines [(SC-108-3 x Swarna) x E-12-5]-4 and [(SC-423 x CS-3541) x E-35-1]-2 gave the highest mean yields at 10 African and Southeast Asian locations. At Ngabu, Malawi, line (SC-108-3 x CS-3541)-14 gave the highest yield (2200 kg/ha), while at Gaborone, Botswana, line [(SC-108-3 x Swarna) x E-12-5]-4 yielded 4490 kg/ha,

Table 3. Performance of selected entries from SEPON-1979.

Pedigree	Days to 50% flower-ing (17)[b]	Plant height (cm) (6)	Grain[a] mold (13)	Leaf blight[a] (1)	Overall perfor-mance (13)	Grain yield kg/ha (14)
[(SC-108-3xCS-3541)xE-15-5]-15	70	191	2.6	3	2.7	3090
[(SC-108-3xSwarna)xE-12-5]-4	73	243	2.2	4	2.6	3240
[(SC 10 8-3xSwarna)xCS-3541] -12	74	211	2.5	3	2.9	3150
[(SC-423xCS-3541)xE-35-1]-2[c]	73	216	2.1	4	2.1	3350
[(SC-423xCS-3541)xE-35-1]-9	79	210	2.0	5	2.7	3010
[(IS-12645CxCS-3541)xE-35-1]-1	71	208	2.4	4	3.0	3220
[(IS-12645CxCS-3541)xE-35-1]-4-1	69	218	2.8	4	3.0	3310
[(IS-12645CxCS-3541)xE-35-1]-4-4[C]	72	213	2.8	3	3.0	3360
[(CS-3541x2219B)xE-35-1]-9	73	200	2.7	3	3.3	3180
[(CS-3541xS-13)xCE-67]-10	71	233	3.1	3	3.0	3030
(IS-8272-1xCS-3541)-7	71	211	2.4	5	2.7	3150
(IS-8272-1xSC-108-5-8)-1	73	205	2.9	4	3.2	3070
(SC-108-3xUChV$_2$)-15-1	71	172	3.2	3	3.0	3170
(SC-108-3xCS-3541)-9-1	75	174	2.6	4	2.5	3260
(SC-108-3 x CS-3541)-14	72	156	3.0	5	2.8	3190
(SC-108-3xCS-3541)-21-1-1	71	185	3.0	3	3.0	3300
(SC-108-4-8x2219B)-32-1[C]	70	198	3.1	4	2.9	3470
(SC-108-4-8xCS-3541)-88[C]	75	211	2.2	2	2.4	3640
(SC-108 -3xCS-3541)-51-1	72	156	2.7	5	2.9	3020
CSH-6 (check)	61	164	2.9	4	2.8	3090
Local variety (check)	76	188	2.4	3	3.2	2710

a. All characters scored on a rating scale of 1-5 (1 being the best).
b. Numbers in parentheses indicate the number of locations over which the observations were averaged.
c. Top yielders over all locations.

against 3640 kg/ha for the local check. At Wad Medani, Sudan, [(IS-12645C x CS-3541) x E-35-I]-4-4 yielded 5760 kg/ha, while at Ilonga, Tanzania, line [(SC-423 x CS-3541) x E-35-1]-2 yielded 5970 kg/ha. Hybrid check CSH-6 gave the highest yield at Bambey, Senegal. At Nyankpala, Ghana, line[(SC-108-3 x CS-3541) x E-15 -5] -15, yielded better than the local check. (CS-3541 x IN-15-2)-26-1 was judged the most promising at Khon Kaen, Thailand, and also yielded better in SEPON-1978 at Khon Kaen and other locations. Similarly, lines (SC-108-4-8 x 2219B)-32-1, (SC-108-4-8 x CS-3541)-88, and (SC-108-3 x CS-3541)-9-1 proved to be relatively better in SEPON-1978 as well as SEPON-1979 trials.

Contribution of Varieties to AICSIP

Six ICRISAT lines were included in the All India Coordinated Sorghum Improvement Project (AICSIP) for preliminary yield trials in 1979. The grain yield performance of these lines in comparison with the check CSV-4 at various locations indicated that SPV-351 was the most promising line (Table 4). On-farm tests conducted by the Farming Systems Research Program also confirmed this observation. AICSIP has entered SPV-350, -351, -352, and -354 into their Advanced Yield Trials for 1980. In addition to low susceptibility to grain molds, these lines exhibit good grain and food quality characters.

Breeding

Population Improvement

Recurrent Selection

Improvement of sorghum populations by recurrent selection methods is one of the major components of the Sorghum Improvement Program. From an initial number of 13, five broad-based random-mating populations, Rs/R, Rs/B, US/R, US/B,

Table 4. Performance of ICRISAT entries in 1979 AICSIP trials.

Entry	Grain yield (kg/ha) All India average[b]	Grain yield (kg/ha) On farm estimate	Percent protein	Percent lysine	Days to 50% flowering[a]	Plant height[a] (cm)
SPV-350	3380	3190	11.5	1.91	60	155
SPV-351	3750	3700	10.5	1.79	65	202
SPV-352	3410		10.3	2.04	72	167
SPV-353	3410		11.2	2.17	69	188
SPV-354	3610	3540	11.5	1.91	66	199
SPV-355	3120		12.7	2.04	61	198
CSV-4 (check)	3280		13.9	1.70	66	154

a. Mean over three locations in India : Patancheru, Bhavanisagar, and Dharwar.
b. Mean over nine locations in India (reported by the AICSIP); CV for grain yield = 11-21% at various locations.

and West African Early, have been retained in the project. We are using the S_2 progeny testing procedure to improve the populations simultaneously for grain yield, grain quality, resistance to diseases and pests, and overall agronomic desirability. One cycle of S_2 testing is completed in 2 years using two seasons per year. Three cycles of recurrent selection have been completed in all the populations.

A preliminary study comparing eight original and improved populations after two cycles indicated that good progress had been made. The selection advance for grain yield ranged from -11.2 to +26%, with only one population showing a negative advance in grain yield. The plant height of all but one population was reduced by 11-30%. Significant progress has been made for grain quality and resistance to grain molds, leaf diseases, and to a lesser degree to shoot fly and charcoal rot.

S_2 PROGENY TESTING. During 1979, we conducted S_2 progeny tests for Rs/R and Rs/B populations. These tests included 195 S_2 progenies from each population, together with five check varieties. Rs/R population progenies were tested in five environments: Dharwar, Bhavanisagar, Khon Kaen University in Thailand, and two soil types at Patancheru—high-fertility Vertisols and low-fertility Alfisols. Rs/B population progenies were tested in similar environments except at Khon Kaen University. Based on these tests, we selected 31 progenies from Rs/R and 32 from Rs/B for recombination. Ten additional selected genotypes were recombined with Rs/R and 11 with Rs/B. The recombination cycles were carried out during the 1979 off-season.

Potential fertile plants from the S_2 progenies were advanced by pedigree selection with a view to generate new varieties and hybrid parents. We selected some 300 such plants from various test locations during 1979.

Population-derived Lines

Pedigree selection in improved populations leads to development of improved varieties. Population x variety crosses also provide a good source of material for pedigree selection. Where necessary the derived lines from these sources are improved further by selection in single crosses and backcrosses with appropriate material. At ICRISAT all these techniques are being used to exploit steadily improving populations.

Some 273 advanced generation lines from the above materials were evaluated in five regional trials at three locations in India. Several lines performed well and yielded significantly higher than the check CSV-4. Some of these produced numerically higher grain yield than CSH-6 and CSH-5 hybrids: Rs/B-8785 (5240 kg/ha), (Rs/R x CS-3541)-1525 (5750 kg/ha), (FLR-186 x CS-3541)-1-1 (5940 kg/ha), Ind. Syn-3-2 (6260 kg/ha), and Ind. Syn-387-1-4 (5260 kg/ha) were noteworthy. The lines exhibited a range in mean days to 50% flowering (60-73), plant height (130-242 cm), head shapes and sizes, and other plant characteristics.

The original Rs_1 x VGC, a population derivative that performed consistently well, particularly in Ethiopian trials, had poor grain quality and was susceptible to charcoal rot. The tan plants from the next cycle of selection produced lines with low charcoal rot susceptibility and improved grain quality. Yield level and adaptability were maintained.

Based on the results of the regional trials and international trials, we have entered seven lines in the AICSIP trials—SPV-393 to SPV-396 for the rainy season and SPV-422 to SPV-424 for the postrainy season.

Some lines have entered other national programs of the SAT. Noteworthy are Ind. Syn-387-1, which has been selected for on-farm testing in Kenya; Diallel-7-862, which has been distributed to farmers in

Ethiopian lowlands; and five lines that have been selected in Pakistan for trials.

Development of Hybrids

Superiority of sorghum hybrids over varieties, particularly in stress environments, has been recognized throughout the world, yet hybrids have been little used in the SAT. Recently, however, a few countries in the SAT that have potential to undertake production and cultivation of hybrids are becoming more interested in the hybrid program.

IMPROVEMENT OF FEMALE PARENTS. The major contribution from ICRISAT in the area of sorghum hybrid development is expected to come from the development of new female parents, a major problem in the production of good hybrids. About 140 new seed parents are being developed in our various breeding projects. Two nonrestorer populations are providing good sources of B-lines. We identified about 600 nonrestorer entries and selected 93 of these for conversion to A-lines. We have backcrossed 40 of these more than twice. The test-crosses of some promising nonrestoring derivatives from the population breeding project on existing A-lines were found superior to CSH-6 and CSH-5 hybrids, which indicates the value of developing seed parents from these lines. Twenty-eight nonrestorers were identified in the grain mold resistance project. These

Table 5. Performance[a] of ICRISAT sorghum hybrids contributed to 1980 AICSIP trials.

Entry	Grain yield (kg/ha) Bhavanisagar	Dharwar	Patancheru	Mean	Mean[b] Days to 50% flowering	Plant height (cm)
SPH-183	7420	5300	7180	6630	56	185
SPH-184	6760	7020	6950	6910	59	215
SPH-185	6950	6720	7230"	6970	55	188
SPH-186	6910	6650	7020	6860	58	196
SPH-187	5160	7190	7180	6510	62	216
SPH-188	6090	6240	6430	6250	65	231
SPH-189	4340	6530	6850	5910	64	217
SPH-190	6110	5280	6370	5920	57	171
SPH-191	4100	6030	5420	5180	60	166

a. The data were collected from different trials. Therefore CV (%), LSD, and check values would not be appropriate.
b. Over three locations : Dharwar, Bhavanisagar, and ICRISAT Center.

lines have a flowering range of 60-70 days and plant height of 85-145 cm. Fifteen lines from the drought resistance breeding project and one line each from the tetraploid project and the *Striga* resistance project are also being converted. All nonrestorers are being retained to test for resistance to priority yield-limiting factors.

IDENTIFICATION OF SUPERIOR HYBRIDS. At ICRISAT, the first hybrids evaluated in 1978 used 2219A and 2077A as parents. Experimental hybrids have now been made in several projects using these lines as well as 296A, an additional line from AICSIP. A large number of hybrids were evaluated during 1979 at ICRISAT Center and subcenters in India. Several hybrids gave higher grain yield than the check hybrids CSH-5 and CSH-6.

From the trials of 1979, we selected nine hybrids for entry in AICSIP trials. The performance of these hybrids is given in Table 5. All these hybrids gave higher grain yields in their respective trials than CSH-6, a hybrid released in India. Male and female parents that flower at the same time were selected for ease in the production of hybrid seed.

Seed of 42 selected hybrids from the grain mold resistance project and 25 from the population breeding project were despatched for observations to six cooperators in the SAT.

Breeding for Insect Pest Resistance

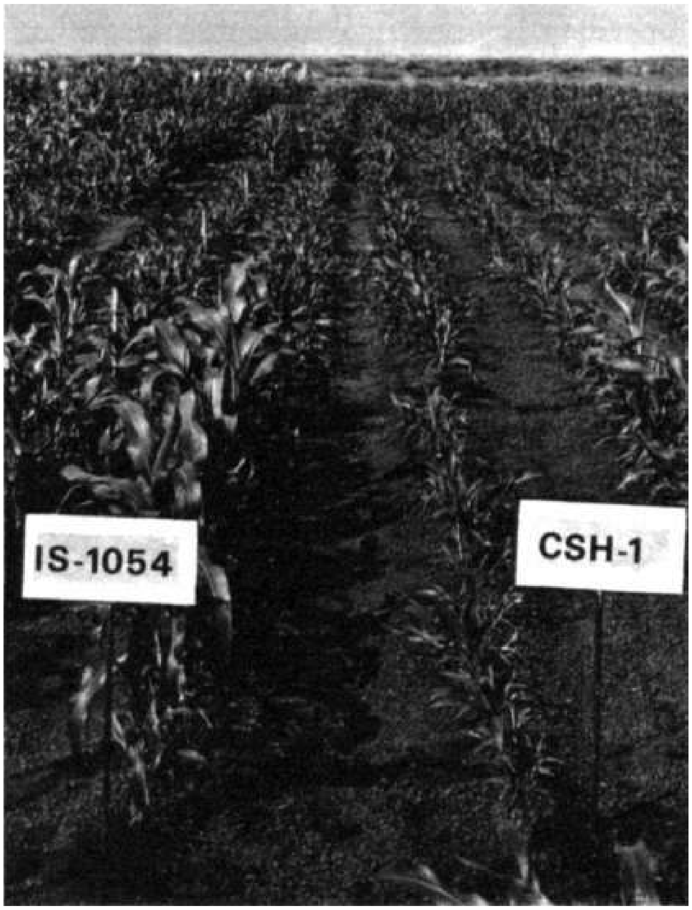
We are now concentrating efforts on breeding of sorghum lines resistant to two major insect pests — shoot fly and midge-and have stopped breeding activities against the stem borer until some good sources of resistance are identified (see Sorghum Entomology section).

There are two aspects of breeding for insect pest resistance: the first is to strengthen sources of resistance by accumulating genes from lines showing resistance and improving them agronomically, and the second is to incorporate available resistance to insects into agronomic ally superior backgrounds, i. e., to develop lines for farmers' use. We are using population breeding techniques as well as traditional methods of breeding in this project.

SHOOT FLY (*Atherigona soccata*). This pest is a considerable problem on sorghum in the seedling stage in much of India, parts of Africa, and Southeast Asia. Absolute resistance to shoot fly is not available, but the breeding program is using the best sources of resistance identified by our entomologists: IS-1054, IS-1082, IS-2312, IS-5604, and IS-5622. All these lines are of Indian origin except IS-2312, which is from Sudan but looks typical of the Indian postrainy-season type.

The 1978/79 ICRISAT Annual Report described the importance of trichomes (microscopic hairs on the abaxial surface of the leaf) in shoot fly resistance. Our experiments this year have now clearly established that most of the shoot fly tolerant genotypes possess trichomes. The trichomes contribute to oviposition nonpreference; the correlation has been observed to be nearly r = -0. 8, which is high enough to make this trait an important selection criterion. In the case of heavy infestation, eggs may also be laid on trichomed leaves, but fewer deadhearts occur than on plants with nontrichomed leaves. It is suspected that trichomes also offer mechanical resistance to migration of the maggot to its feeding point.

We indicated in our 1978/79 Annual Report that many of the shoot fly resistant genotypes express glossiness in the seedling stage (a light yellowish-green plant color and shiny leaf surface). A set of glossy and trichomed lines was tested in the field under high shoot fly pressure in 1978/79, and similar tests this year



A shoot fly resistant line of sorghum (IS-1054) showing good growth compared with the susceptible check CSH-1.

(Table 6) confirmed our earlier findings. Less than 1% of 12 000 lines screened this year expressed glossiness, and 85% of these had trichomes.

Over the past $2^1/_2$ years the use of the trichome and glossy traits and the identification of resistant plants in the seedling stage has proved to be a very effective and reliable system leading to development of several agronomically elite lines with a level of resistance exceeding that of the best resistant source varieties (Table 7). Many of these lines showed promise under severe shoot fly attack at Hissar in the 1979 summer season. The gain in resistance per cycle of selection continued to be good. Some entries with a high level of resistance (primary resistance) also produced a crop from tillers (recovery, or secondary resistance). This is encouraging as it indicates that genes for both primary and secondary resistance mechanisms can be pooled together in the same genetic background.

MIDGE (*Contarinia sorghicola*). A few stable and good sources of resistance to midge, like AF-28, DJ-6514, and TAM-2566, have been identified and utilized extensively in our breeding program. We made some progress in identifying promising lines with reasonable levels of resistance, but a major problem has been the identification of suitable screening locations. Dharwar appears to be a suitable location in the rainy season; if plantings here are delayed until the 1st week of August the incidence of midge has been severe. During the summer (February sowing), Bhavanisagar could be a good location, provided interlards are sown at periodic intervals to increase the midge population and incidence of the earhead bug *(Calocoris)*does not occur after midge damage. The test material should be sown in the 3rd week of March. We are planning experiments accordingly.

EARHEAD BUG (*Calocoris angustatus*). Several agronomically good sorghum

Table* 6. *Means of shoot fly incidence indices for all combinations of the glossy trait and the presence of trichomes.

Group	% Deadhearts (Mean SE ±)
1 Trichome - glossy	40. 6 ± 7.41
2 Trichomeless - glossy	69. 5 ± 3. 71
3 Trichome - nonglossy	75. 9 ± 4. 39
4 Trichomeless - nonglossy	91. 5 ± 2. 23

t - test:	2 vs 4	5. 091 (P< 0. 001)
	3 vs 4	3.175 (P<0.01)
	1 vs 2 + 3	5.000 (P< 0.001)

Table 7. Promising shoot fly resistant sorghum lines identified at ICRISAT Center in 1979/80 through screening and use of the glossy and trichomed traits.

Pedigree	% Deadhearts
(IS-5622 x 2KX6)-2-1-1-1-1-4	54.1
(IS-5622 x WABC-1121 x CS-3541) -16-1-2-1-1-1	59.8
(IS-1034 x IS-3691)-2-3-2-1-1-1	59.8
(IS-5622 x CS-3541)-11-1-1-1-1	50.7
(GG x 370 x EN-3363)-8-1-1-1-1	59.7
(IS-5622 x WABC-1121 x PHYR) -7-1-1-1-1	57.9
(IS-84 x IS-1082)-3-1-1-1	58.0
(IS-1054 x CS-3687)-1-1-1-1	58.8
(0222 x CS-3541-10 x IS-3962) -3-1-1-1	52.9
($UChV_2$ x IS-1054)-1-1-1-1	50.7
(UChV2 x IS-1054)-2-1-1-1	58.6
(UChV2 x IS-3962)-4-1-1-1	53.9
(UChV2 x IS-3962)-6-1-1-1	31.7
(UChV2 x IS-3962)-8-1-1-1	52.7
(Rs/R-S_7-188 x IS-2312) -1-1-1-3	56.0
(Rs/R-S_7-188 x IS-2312)-1-1-1-5	50.0
(CSV-3 x IS-5622)-3-1-1	55.9
(SPV-29 x IS-3962)-1-2-1	46.0
(IS-1082 x SC-108-4-8) x SC -108 x SC-108-4-8)-1-1-1	55.4
(ESGPC x IS-12573C)-3-1-1-3	42.7
(ESGPC x IS-12573C)-3-2-3-1	45.3
(ESGPC x IS-12573C)-4-1-1-1	54.5
(IS-2816C x 5D x Bulk)-2-1-1-1	42.3
(1S-2816C x 5D x Bulk)-2-2-1-1	27.7
(IS-2816C x 5D x Bulk)-2-1-1-1	60.0
IS-1054	85.3
IS-5604	85.5
IS-2312	90.7
IS-1082	89.3
CSH-1	100

breeding lines with reasonable levels of resistance to the earhead bug have been identified from the midge material (Table 8). IS-12573C, a source of midge resistance, is a frequent parent for these lines. Some selections are resistant to both earhead bug and midge. This gives the hope that there may be some common traits for resistance to both insects. Most of these tolerant lines have good grain quality.

*Table 8. **Promising earhead bug resistant lines of sorghum at ICRISAT Center, 1979/80.***

Pedigree
(IS-12573C x SC-108-3)-1-2-1-2-1
(IS-12573C x SC-108-3)-1-2-3-2-2-1
(A-30 x S-Birl-MR-1)-1-1-1-1
(Bulk-Y-S_6-55-2 x IS-2816C)-56-2-1-1
(S-13 x S-Girl-MR-1)-21-1-1-1
(NES-70 x 830 x IS-12573C)-2-1-1
(S-13 x IS-2816C)-10-1-1-1
(SC-108-3 x S-Girl-MR-1)-19-1-1-1
(Rs/R-S_7-188 x IS-2579C)-3-6-1
(FLR-S_4-275-1 x EN-3363)-9-3-1-1
(SC-423 x CS-3541 x 5D x Bulk)-9-1-1-1
(555 x IS-2816C)-6-1-1
(IS-12573C x SC-108-3) x(SC-108-3 x SC -108-3)-3-2-1-1
(IS-12573 x SC-108-4-8)-6-1-1

Breeding for Disease Resistance

Breeding for Resistance to Grain Mold

Selection for mold resistance from superior agronomic backgrounds in early-generation breeding material continued with particular emphasis on the fungus *Phoma*. In collaboration with pathologists, we screened 4265 progenies in F_4, F_5, and F_6 generations (see Sorghum Pathology section). Our efforts are under way to diversify the genetic base of breeding material possessing mold resistance and to incorporate moderate levels of resistance to other diseases and pests.

TESTING ADVANCED SELECTIONS. In the rainy season grain yield of 135 low-mold-susceptible lines in the F_6/F_7 generations and 116 lines in the F_5 generation was evaluated at three locations: Dharwar, Bhavanisagar, and Patancheru. Over 22 promising lines were tested in the summer season at Bhavanisagar and seven entries (SPV-386 to SPV-392) were selected and incorporated in the 1980 preliminary yield trials of AICSIP. Their mean performance in comparison with the checks is presented in Table 9. SPV-386 and SPV-387 also performed well across various locations in the international tests of SEPON-79.

INHERITANCE OF GRAIN MOLD RESISTANCE. We studied the inheritance of grain molds, *Curvularia* and *Fusarium,* in 12 crosses involving known resistant and susceptible parents. A genetic component study of the generation means of parental, F_1, F_2, and backcross data revealed that additive and dominance effects mostly account for the gene action governing the reaction of the grains to *Curvularia* and *Fusarium.* Duplicate types of interaction and an additive x dominance type of interaction were also statistically significant in several crosses.

Breeding for Resistance to Downy Mildew

Downy Mildew (DM), caused by *Perono-8clerospora sorghi,* is a destructive disease of sorghum and maize throughout the world. A breeding program to improve elite sorghum lines for DM resistance started last year.

Table 9. Performance of ICRISAT entries contributed to 1980 AICSIP.

Entry	Grain yield (kg/ha)				Mean	
	Patancheru	Bhavanisagar	Dharwar	Mean	Days to 50% flowering	Plant height (cm)
SPV-386	6030	6520	7700	6750	66	247
SPV-387	6830	4860	6990	6230	65	234
SPV-388	6330	5480	7290	6370	66	165
SPV-389	5790	5150	4860	5270	68	165
SPV-390	5320	5860	5130	5430	68	187
SPV-391	4690	4560	6150	5130	74	195
SPV-392	5060	4260	6450	5260	73	194
CSV-4	4320	4610	4950	4630	66	155
CSH-6	5590	3990	5900	5160	56	185

QL-3 and its sister lines have consistently demonstrated immunity to downy mildew but are agronomically poor; hence we are attempting to improve the quality of these source lines (see Sorghum Pathology section). Some leads have been obtained in understanding the genetics of DM resistance exhibited by QL-3, which may involve cytoplasmic effects.

Charcoal Rot Resistance

A potentially destructive disease in the semi-arid tropics of the world, charcoal rot is caused by a common soilborne fungus, *Macrophomina phaseolina,* which has a wide host range.

Our breeding work was initiated in 1977/78 with crosses involving known resistant lines including E-36-1, CS-3541, and 20-67, which are good combiners and are contributing significantly. Individual plant selections in the F_2 and F3 generations were generally based on agronomic attributes such as height, days to maturity, and good grain quality characters. Advanced selections in the F4 generation totalling over 2500 entries were screened with inoculation in replicated trials during the postrainy season (see Sorghum Pathology section).

Breeding for Resistance to Stress Factors

Drought Resistance

Drought is one of the most important factors known to limit sorghum production in the semi-arid tropics, The breeding procedure that we follow includes screening an array of diverse genotypes at various growth stages for drought resistance and multilocation testing.

RAINY-SEASON FIELD SCREENING. Several diverse genotypes were evaluated under drought stress situations at Patancheru and Anantapur in India and E1 Obeid, Sudan. Based on the yield and agronomic score, 32 promising genotypes were selected.

In general, indications are that the lines that performed well at one location did not yield well when they were grown in another drought-prone area. For example, the Karper line, 3-40, which yielded 5000 kg/ha in postrainy drought at Patancheru yielded less than 1000 kg/ha in the Sudan drought situation. This, coupled with earlier observations, has confirmed our belief that breeding a variety "universally" drought resistant is very difficult and that different locations are required to select for resistance to drought at different stages of plant development. Suitable locations have been identified for drought screening at Anantapur in India, E1 Obeid in Sudan, and Same in Mali. The appropriate locations for postrainy drought are Patancheru and Bijapur in India. Screening will also be carried out at Hissar and Sangareddy, India, under high temperatures during the summer.

We made approximately 2000 crosses in 1977 and 1978 involving drought-resistant, early, and high-yielding lines. Segregating progenies were grown under rainfed conditions and selections were made for agronomic desirability. In the 1979 rainy season 3100 progenies in the F4 generation were grown and they experienced drought conditions for 10-12 days in each of GS1 and GS2 stages. We selected nearly 600 individual progenies for evaluation in 1980.

In collaboration with Andhra Pradesh Agricultural University, Hyderabad, and ICRISAT's physiologists, 364 selections were grown in six separate experiments at Sangareddy (see Sorghum Physiology section) during the summer season. Twenty-two lines that exhibited outstanding recovery when the drought stress was relieved were selected.

Striga Resistance

Striga hermonthioa is a primary yield-limiting problem in Africa while *Striga asiatiea* is of significant economic importance in

India, Southeast Asia, Africa, and North Carolina in USA. Major activity of the ICRISAT *Striga* resistance program has shifted to Africa where we will concentrate on S. *hermonthiea.* Work on *S. asiatica* continues at ICRISAT Center.

LABORATORY SCREENING FOR LOW STIMULANT PRODUCTION. Of 3367 sorghum lines screened at ICRISAT Center for stimulant production in 1979/80, 112 were found to produce stimulant less than 10% of the control. Altogether, more than 14 000 germplasm lines have been screened and 646 lines have been identified as low stimulant producers in the past few years.

FIELD SCREENING. We modified the existing system of screening for field resistance to include a new set of criteria. Evaluation will be made only when *Striga* counts on the checks are high; then entries will be selected only if the *Striga* reaction (count) is less than 10% of the adjacent check in all replications. Test entries will be selected based on results across locations. We are developing an improved layout to have each test plot bordered by a susceptible check.

During 1979 rainy season, 56 advanced-generation progenies derived from crosses between *Striga* resistant and adapted parents were screened for resistance at Akola, Phaltan, and Bhavanisagar and seven entries were resistant at all three locations. The *Striga* level in these entries was less than 10% of the susceptible hybrid check, CSH-1. Similarly, a set of 56 entries identified as possible sources of resistance was evaluated at four locations in India—only two entries were found to be resistant across locations.

Although evaluation of resistance to *Striga* is difficult, results of screenings have increased our confidence in the resistance of several source lines (Table 10). Some of these *Striga* sources are agronomic ally poor, making it difficult to develop good lines. Nevertheless, we have made good progress in some cases.

Table 10. Sources of* Striga *res/stance.

N-13	IS-9830
IS-9985	SRN-4841
IS-3924	IS-534
SRN-4882B	IS-4202
555	IS-5603
IS-4242	Serena

Food Quality

Approximately 3000 selections in F_5, F_6, and F_7 generations from the grain mold resistance project were evaluated for grain, dough, and *chapati* (unleavened bread made in India from whole sorghum flour) quality attributes. Of these, 400 selections were further evaluated for their chapati quality. Thirty selections compared favorably to M-35-1 in chapati quality and these will be investigated further.

With the help of trainees from Upper Volta, preparation of *to* (a stiff porridge popular in Upper Volta) was standardized, and t6 prepared from 38 cultivars was evaluated for quality differences. The better local cultivars from Upper Volta were rated excellent.

In the southern parts of India, sorghum grain is dehulled and boiled like rice. In Tamil Nadu this food product is called *chorru.* Preliminary chorru quality studies of 21 genotypes indicated significant differences.

COLLABORATIVE STUDIES. A collaborative project with the Texas A&M University was initiated to study the physicochemical and food quality properties of sorghum. The project involved 12 cooperators in Africa and America.

An evaluation was made of 25 samples of several major food types popular across the SAT: chapati (India), *tortillas* (unleavened bread, Mexico), *injera* (leavened bread, Ethiopia), *kisra* (leavened bread,

A taste panel of trainees from Kenya evaluating* ugali *at ICRISAT Center.

Sudan), to (Mali and Upper Volta), *bogobe* (porridge, Botswana), and *ugali* (porridge, Kenya). A brief summary of the original data for overall food quality of the grain from the 25 cultivars is presented in Table 11. In general, grains with medium-corneous, pale yellow endosperm, colorless thin pericarp, and no subcoat were suitable for good quality chapatis. Similarly, grains with least polyphenols, less corneous endosperm, and a thin pericarp were suitable for good tortillas. Very soft endosperm types with low polyphenol content and good fermentation characters were best suited for injera; floury endosperm types were suitable for kisra. Thick porridges like to and ugali were best produced by highly corneous grains. Cultivars like CSH-5 and M-35-1 were found to be suitable for a range of products. The texture of the endosperm seemed to be a useful criterion in selecting grains suitable for specific food products.

***BASMATI* SORGHUMS.** Recently the staff of the Genetic Resources Unit at ICRISAT collected sorghums from Madhya Pradesh State in India, whose seeds are dimpled, white, and emit a mild scent, typical of that of *basmati* rice. Food recipes prepared from the basmati sorghum grains also emit the distinct basmati aroma. We found that

Table 11. Overall food quality[a] characters of 25 sorghum cultivars.[b]

Genotype	*Chapati*	*Tortilla*	*Injera*[c]	*Kisra*	*Ugali*	*Tô* (Mali)	*Tô*[c] (Upper Volta)	*Bogobe*	*Fermented Bogobe*
M-35-1	1.0	1.5	1.5	2.2		1.0	2.2		
CSH-5	1.0	1.2	2.0	2.3	2.0	1.0	1.9	1.0	1.0
M-50009	1.5	1.5	1.5	3.4	2.5	5.0	1.7		
M-50013	1.5	1.5	3.0	2.7	2.5	1.0	2.2		
M-35052	2.5	1.5	4.0	2.8		1.0	1.4	1.0	1.0
M-50297	1.5	3.0	4.0	2.2	2.3	1.0	2.5		
P-721	5.0	4.0	4.5	2.5		5.0	3.0		
CO-4	3.0	4.0	1.0	2.0	2.7	1.0	2.7	1.0	1.0
P. Jonna	3.0	4.0	4.0	2.1		1.0	3.0		
Mothi	1.5	2.0	4.0	2.5		4.0	2.2		
E-35-1	1.5	2.0	3.0	2.1	2.0	2.0	1.1	1.0	1.0
IS-158	4.0	3.0	5.0	4.3		5.0	4.0		
WS-1297	4.0	5.0	1.0	3.8	4.0	1.0	3.7		
Swarna	1.0	4.0	1.5	2.7	2.0	1.0	3.5	1.0	1.0
S-29	2.5	2.5	4.0	2.0		1.0	1.2	3.0	1.0
S-13	2.5	2.5	3.5	3.2		1.5	1.5	1.0	1.0
IS-2317	3.5	4.0	4.5	2.6		1.0	2.2		
IS-7035	3.5	4.0	3.5	3.1	3.5	1.0	4.0	1.0	3.0
IS-7055	4.0	4.0	4.5	3.4		1.0	4.2	1.0	3.0
IS-9985	1.5	2.5	1.5	2.7		1.5	1.5	1.0	1.0
IS-8743	3.5	4.0	1.5	3.3		1.7	4.0		
Dobbs	5.0	5.0	5.0	4.4		3.0	3.2	3.0	3.0
CS-3541	2.5	2.0	4.0	3.0	2.5	2.0	2.7		
Segaolane	1.5	1.5	2.0	3.3	2.3	1.7	1.6	1.0	1.0
Market-1	2.0	3.0	4.5			1.5	1.0		

a. Overall food quality scores were compounded on a 1-5 scale (1 = good) from the original data on several parameters like cooking quality, taste, texture, and keeping quality.

b. Source of original data: *chapati*—D.S. Murty; *tortilla*—L.W. Rooney, A. Iruegas and Vartan Guiragossian; *injera*—Brhane Gebrekidan; *kisra*—H.P. Perten and S. Badi; *ugali*—D.S. Murty; *tô* (Mali)—John Scheuring; *tô* (Upper Volta)—C.M. Pattanayak; *bogobe*—Nancy Eisener.

c. Grain samples evaluated for *injera* and *tô* (Upper Volta) originated from 1980 harvest, while the others were from 1979 harvest.

treating leaf discs with 1.5% potassium hydroxide and smelling the characteristic aroma that comes only from basmati plant parts can be used as a screening technique, as is done with rice. Observations on F_2, F_3, and backcross generations of basmati x normal crosses showed that the character is governed by a single recessive gene.

Breeding for Postrainy Season

We initiated a breeding project in 1977 with the main objective of developing high-yielding, stable varieties and hybrids with good crop establishment and good grain quality for the postrainy season in India. Initially, dates-of-sowing experiments were conducted to understand the genotype x environment interactions for the postrainy season. Results showed that in general grain yield as well as dry-matter production declined with delayed planting. The adapted postrainy-season varieties were generally more stable in performance at later dates of sowing than the rainy-season adapted varieties.

This year we made several crosses that involved the known adapted postrainy-season varieties (M-35-1 and SPV-86) and lines screened for drought resistance during the postrainy season. Several progenies selec-

Table 12. Physicochemical characteristics of sorghum.[a]

Component	Range	Mean
100-seed weight (g)	2.30 - 5.52	3.83
Grain hardness, breaking force (kg)	2.96 - 11.78	6.62
Water-soluble flour fraction (%)	19.40 - 35.40	26.27
Protein (%)	8.70 - 14.50	10.90
Water-soluble protein (%)	0.30 - 0.90	0.57
Water-soluble protein (g/100g P)	2.55 - 7.96	5.27
Starch (%)	62.56 - 73.25	68.34
Total amylose (%)	21.2 - 30.20	26.59
Water-soluble amylose (%)	4.37 - 12.65	8.32
Total sugars (%)	0.81 - 1.58	1.08
Reducing sugars (%)	0.05 - 0.43	0.12
Fat(%)	2.31 - 4.68	3.26
Ash(%)	1.30 - 2.15	1.59

a. Based on 60 sorghum cultivars.

ted from the segregating populations now in the fourth generation look promising and will be evaluated in the 1980 postrainy season.

In an attempt to expand the genetic variability that is generally lacking for the postrainy-season sorghum lines, we evaluated a large number of germplasm lines and lines from various breeding projects. The useful material identified will be utilized in the program. Three varieties from the population breeding project have been included in the AICSIP trials for testing during the 1980 postrainy season.

Biochemistry

Physicochemical Characteristics of Sorghum

Physicochemical characteristics were determined on 60 sorghum germplasm accessions from different parts of the world that were grown at ICRISAT Center (Table 12). We also evaluated the dough and chapati quality of these cultivars using a taste panel improved by inclusion of regular consumers of sorghum. Results of this study and the relationship between the physicochemical properties and chapati quality are being examined. Based on these results, we will attempt to devise a rapid method for screening large numbers of samples from the breeding material.

We also carried out particle-size studies on the 60 sorghum cultivars. The samples were ground and passed through sieves of different mesh sizes and the percentage distribution of various fractions was determined. The starch damage and protein content in the different fractions were also determined (Table 13). The flour particle distribution pattern and starch damage in various fractions showed a wide variation in the sorghum genotypes, while the variation in protein content of the flour fractions was relatively small.

PROTEIN AND LYSINE. In our analysis of 3450 samples from the germplasm accessions and breeding material, the protein content ranged from 4.8 to 19.1% and lysine (g/100g P) from 1.4 to 4.1%.

Table 13. The distribution of particle size, starch damage, and protein contents in different sorghum flour fractions.[a]

Particle size	Fractions (%)		Starch damage (%)		Protein (%)	
	Range	Mean	Range	Mean	Range	Mean
Retained in 45 mesh	0.9- 3.7	2.0	6.3-16.5	9.8	8.4-19.1	12.4
Retained in 60 mesh	8.3-18.6	11.7	7.6-21.9	12.3	10.1-17.6	13.0
Retained in 80 mesh	9.4-23.6	14.9	7.9-25.4	15.1	9.5-18.0	12.8
Retained in 100 mesh	6.3-26.4	10.4	8.7-32.2	18.1	9.1-17.0	12.0
Passed through 100 mesh	35.7-70.6	60.2	12.0-46.1	26.8	6.8-13.5	10.0
Whole flour			10.2-37.4	22.0	8.0-14.0	10.9

a. Based on 60 sorghum cultivars.

FRACTIONATION OF PROTEIN. Protein fractionation studies were carried out using the Landry and Moureaux procedure. The first fraction represents the albumins, globulins, and free amino acids, soluble in sodium chloride. The classes of proteins solubilized by isopropanol (fraction II) and isopropanol containing mercaptoethanol (fraction III) are referred to as kafirins and cross-linked kafirins, respectively. Fraction IV which contains protein soluble in borate buffer and mercaptoethanol is described as glutelinlike proteins. Fraction V which was extracted in borate buffer containing mercaptoethanol and sodium dodecyl sulphate, represents glutelins. Besides this, as a modification of the above procedure, the residue remaining after extraction of fraction V was extracted with 0.1 N NaOH; this fraction is referred to as NaOH-soluble protein. The distribution of nitrogen in the various solubility fractions is given in Table 14. The proportion of fraction I was higher in high lysine Ethiopian lines (IS-11167 and IS-11758), while that of fraction II was higher in CSH-6 and RY-49. The distribution of nitrogen in fractions III and IV of various cultivars did not vary appreciably. The proportion of nitrogen in fraction V was the highest for M-35-1. It was interesting to note that the nitrogen distribution in the alkali-soluble fraction showed a wide range (from 6.6 to 18.5%) for these cultivars.

Physiology

Selection for Nitrogen and Phosphorus Efficiency

The differential response of sorghum genotypes to the same level of applied nitrogen (N) and phosphorus (P) is well known. This suggests that genotypic differences exist in the efficiency of N and P uptake and transfer to the grain. Our 1975/76 Annual Report lists such differences for three characters concerned with nitrogen physiology: total uptake by the plant, efficiency of transfer of N to the grain, and percentage N in the grain. That and subsequent studies showed

Table 14. Nitrogen distribution in whole sorghum kemels.[a]

Fraction	CSH-6	CSH-8	M-35-1	CSV-3	RY-49	P-721	IS-11167	IS-11758
I	15.6	17.8	17.1	17.3	18.6	19.4	22.4	24.4
II	14.4	5.6	5.2	8.4	15.8	8.2	9.7	7.4
III	18.1	18.7	18.2	19.5	19.8	16.2	17.9	14.6
IV	3.5	3.4	4.2	4.4	3.4	3.4	2.9	3.5
V	33.3	35.0	38.3	33.7	30.4	35.4	18.9	23.1
VI	6.6	10.7	10.4	10.7	9.5	9.3	17.3	18.5
Total	91.5	91.2	93.4	94.0	97.5	91.9	89.1	91.5

a. Percent of total nitrogen.

that N and P uptake was closely correlated to crop dry weight (r = 0. 73 P< 0. 001 for N, and 0.55 at *P*< 0. 01 for P) and efficiency of translocation of these minerals was also highly correlated to harvest index (HI) (r = 0. 89 at *P*< 0. 001 for N, and 0.90 at *P*< 0. 01 for P). This may suggest that (1) selection for crop growth and grain yield may automatically include selection for efficient N and P uptake and that (2) genotypes with a better HI will also have a higher ability to transfer the minerals to the grain.

However, by carefully choosing the contrasting genotypes from the initial study and by repeatedly evaluating them under different environments, we found that genotypes with approximately the same biomass and HI could vary considerably in nutrient uptake and transfer to the grain. Such differences are usually masked when the data for the whole set of heterogeneous genotypes are analyzed together. For example, P-721 and Diallel 642 both have similar dry weights (60. 6 and 61. 5 g/plant, respectively), but P-721 takes up 39% more nitrogen than Diallel 642 (0. 78 and 0. 56 g N/plant, respectively) and has 9% greater nitrogen transferability. Similarly, IS-858 and Diallel 642 have nearly the same HI (36% and 34%, respectively), but the P translocation index for IS-858 is 16% greater than for Diallel 642 (62% and 46%, respectively). In order to determine whether such differences are of any significant concern in a practical breeding program, we made crosses between contrasting parents and selected F_2 plants for a range of dry weights per plant and HIs.

In F_3 progenies, estimates of dry weight, grain yield, and N and P in the grain and whole plant were made. The biomass and total nutrient taken up by F_3 progenies in each family were again strongly correlated (e.g., in the case of IS-2223 x IS-6380 the correlation coefficient (r) between dry weight and total nitrogen was 0. 91 and phosphorus, 0.86; P<0.01).

We observed similar relationships even for the transfer efficiency (r between HI and nitrogen translocation index = 0. 88 at P < 0. 01; HI and the phosphorus translocation index = 0. 73 at P<0.01). Hence we concluded that selection for-biomass and HI also effectively includes selection for traits concerned with nutrient (N and P) efficiency.

Postrainy-Season Adaptation

Sorghum grown on stored soil moisture during the postrainy season is of considerable importance to SAT India. As pointed out in our 1977/78 Annual Report, the crop experiences low night temperatures and moderate to severe moisture stress particularly at the end of the season. We have investigated the physiological basis of productivity during the postrainy season using a number of rainy and postrainy-season cultivars with an aim to establish the plant types suitable for the postrainy season.

During 1978 and 1979 postrainy seasons, a set of nine genotypes was planted on deep Vertisol fields fully saturated with water (about 220 mm available water up to 1. 5-m depth) at planting. During the 1979 postrainy season, the same set of genotypes was also grown with and without two irrigations.

While the early genotypes (such as CSH-6; about 60 days to flower) were efficient only in grain production, some of the late ones (postrainy-season types like CSH-8R, SPV-86; 70-75 days to flower) were efficient in producing both grain and dry matter. Yield was generally lower during the 1978 postrainy season, although the differences in the soil moisture extracted during both years by nonirrigated crops were negligible. The differences in grain yield and biomass resulted mainly from the pattern of soil-water use during the 2 years. During 1978, the leaf area started increasing much earlier in the season since the crop was sown a month earlier and it experienced 2-3°C higher temperatures. Consequently more soil water was extracted in 1978 during the early period of growth, leaving very little for use during filling, thus reducing the seed size (by about 15%; there was no difference between the 2 years in seed number).

It was pointed out in our 1977/78 Annual Report that if the photosynthate to fill the grain is lacking under stress, the carbohydrates stored in the stem up to the flowering stage can be translocated to the grain, thereby ensuring reasonable stability in yield. The current study revealed that such a phenomenon is not universal; it occurs only in genotypes with larger sink strength, since mobilization was noticed even in the irrigated crop, when the seed number was large (as in CSH-8R). The maximum amount of reserves mobilized was about 30% of grain yield, but such a process may predispose the plant to charcoal rot and thus reduce the value of the fodder.

Several short-term measurements were made (leaf-water potential, osmotic potential, leaf temperature, stomatal resistance, etc.) to quantify the level of stress the crop was undergoing and were related to the final biomass and grain yield. None of them proved helpful, however, except osmotic potential measurements. We have noted that postrainy-season genotypes, such as CSH-8R, SPV-86, and M-35-1, have greater capacity for osmotic adjustment to maintain the turgor than rainy-season types. The usefulness of measuring osmotic potential to screen for postrainy-season adaptation will be tested with a larger number of breeding lines.

Drought Screening Under Severe Stress During Summer

As indicated in our 1976/77 Annual Report,

In a screening experiment on **Sorghum bicolor** *for heat and drought resistance, selection D71305 (left) showed severe leaf firing, while D71152 (right) showed dark green leaves.*

conditions of high evaporative demand and temperature are more conducive to drought resistance screening than the mild postrainy season. Under field situations, heat stress invariably accompanies water stress, and many literature reports have pointed out the usefulness and practicability of testing for both kinds of resistance traits together. In collaboration with Andhra Pradesh Agricultural University (APAU) and our sorghum breeders, 364 of our selections were screened under the hot and dry summer conditions at Sangareddy (20 km from ICRISAT Center). Seeds were planted in April with a single irrigation. No further irrigation was given to the stress plots, and only two irrigations were given to the control at about 3-week intervals. The plants underwent severe stress, and desiccation occurred within a week after planting. The stress continued until early June with the onset of the northwest monsoon, when 60 mm of rain was received. After this the differences in the effect of stress on the genotypes were quite apparent. Genotypes that were severely damaged because of stress did not recover, and parts or whole leaves remained white ("fired"). In contrast, other genotypes resumed growth with little leaf area fired.

Scores for leaf firing or scorching were given on a scale of 1 to 5 (1 = least scorched and 5 = severely scorched and no recovery or regrowth), and these were plotted against leaf temperature (e.g., Fig. 1). Leaf and air temperatures were measured up to the onset of rains. The leaves of the entries with a score of 1 were cooler than air, and entries with higher degrees of scorching had hotter leaves. It is encouraging that the 22 entries showing the least leaf firing were also agronomically good. Leaf temperature is easy to measure with an infrared thermometer, so the technique will be used along with scoring leaf scorching for preliminary drought resistance screening in the field and greenhouse.

In addition, our preliminary results show good correspondence between the scores at

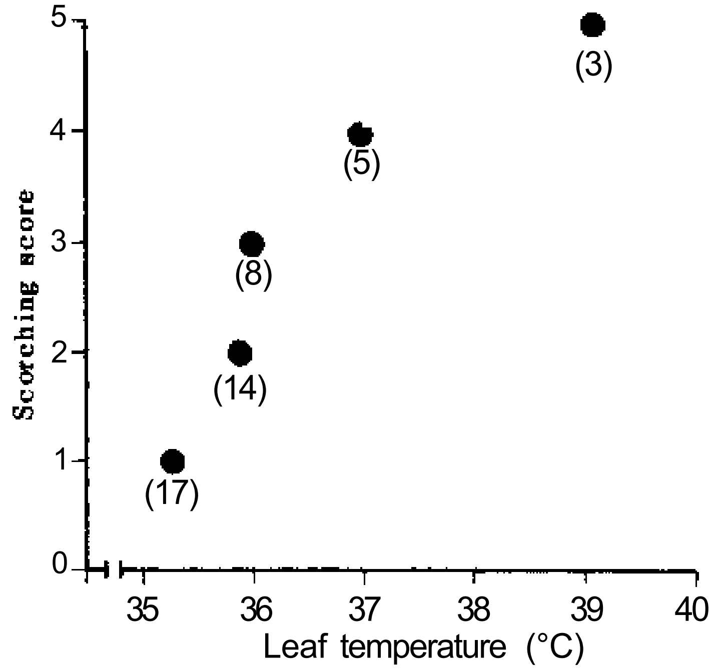


Figure 1. Relationship between scorching score and leaf temperature (between 1420 and 1440 hr; mean air temperature 36°C) at Sangareddy, India, 1980 summer. The number of genotypes in each group is shown in parentheses.

Sangareddy in the summer and at Anantapur in the rainy season under naturally occurring drought.

Factors Affecting Crop Establishment

Crop establishment is a major problem in the semi-arid regions of the world where uncertainty of rainfall is a major limitation to crop production. The main objective of our studies on the factors affecting crop establishment is to develop simple and reliable screening methods for evaluation of germplasm and elite materials and also to identify sources of resistance with good agronomic background.

HIGH SOIL TEMPERATURE. During summer 1980, seedling emergence was studied over a wide range of soil surface temperatures. Thirty lines selected on the basis of resistance or susceptibility to drought in the seedling stage were sown at 50 mm depth in Alfisol beds. Charcoal, light kaolin, and heavy kaolin were used as surface covers to modify temperature (range 52-65°C). The results indicated that high soil temperatures were associated with late and poor emergence. In the charcoal treatment, where the temperature reached 65°C at 5 mm depth, emergence did not occur at all.

SOIL CRUSTING. Soil crusting is a major limitation on seedling emergence. We are developing and field testing a technique for investigating emergence ability through a simulated crust. The technique involves preparing the land to a fine tilth, careful leveling and controlled perfo-spray irrigation. In one treatment a light roller (15 kg) is used to compact the upper layer. Two experiments were conducted in summer 1980 with 100 lines, using rolled and nonrolled treatments. Results indicated that genotypes showed significant variability ($P<0.01$) in seedling emergence through the crust. Further improvement of the technique is required as the coefficients of variation were quite high (28-33%). Significant rank correlations of seedling emergence in different genotypes between rolled and nonrolled treatments exist ($r = 0.74$, $P< 0.01$). Seedling vigor (seedling dry weight) was positively correlated to the ability to emerge through a crust ($P<0.01$).

Drought Resistance at the Seedling Stage

Drought is an important factor affecting crop establishment in sorghum, even at the seedling stage. We have developed techniques to evaluate genotypes for drought resistance in field and semicontrolled conditions. In all these techniques water is given only once following sowing, and no further watering is provided until the seedlings show severe wilting. Visual scores for wilting, recovery, and survival percentage are taken as indices of drought tolerance. The correlation coefficients between different drought response indices for the different techniques are given in Table 15.

We observed that lines with glossy leaves were more resistant to drought than those with nonglossy leaves. A t-test revealed significant differences between the two morphological classes for different drought response indices.

Using a scanning electron microscope (SEM), we observed that glossy lines dif-

Table 15. Correlation coefficients among different drought parameters.

Parameters	Wooden flats	PVC cylinders
Visual score for wilting vs recovery score	0.73**	0.90**
Visual score for wilting vs percent survival	-0.74**	-0.90**
Recovery score vs percent survival	-0.89**	-0.99**
Visual score for wilting: wooden flats vs PVC cylinders		0.65**
Recovery score: wooden flats vs PVC cylinders		0.56**

** P<0.01

fered from nonglossy ones in the structure of epicuticular wax—glossy lines showed smooth wax and large-sized irregular crystals, whereas nonglossy lines showed no smooth wax but presence of small needle-shaped crystals.

Entomology

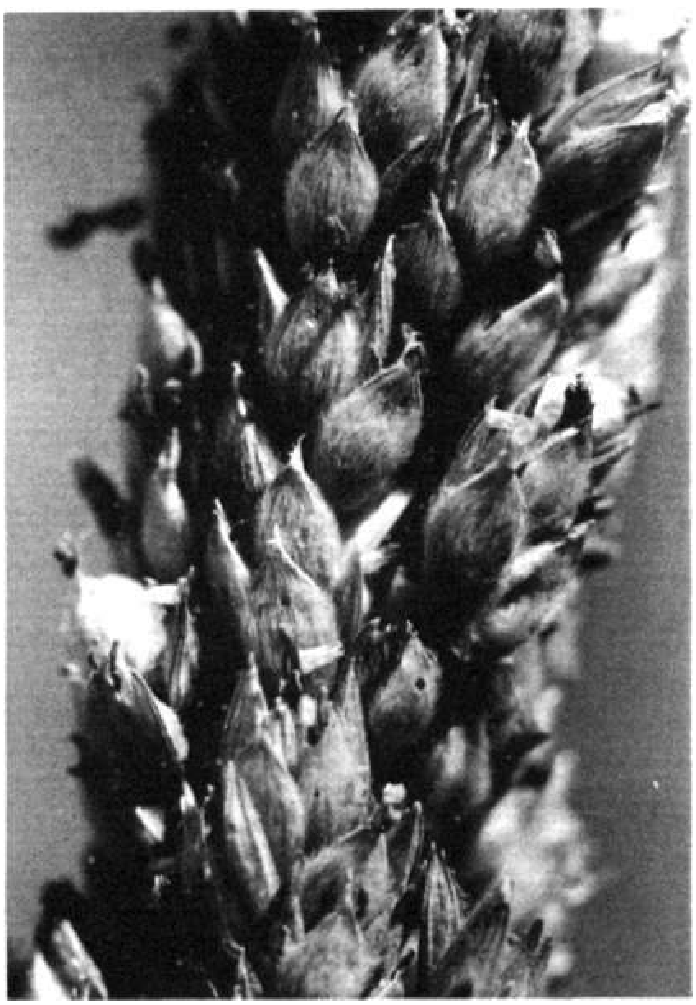
Pest Assessment

In both the rainy and postrainy seasons, we observed the activity of important insect pests on three cultivars of sorghum (CSH-1, Swarna, and local). The sorghum shoot fly (*Atherigona soccata*) started laying eggs 1 week after crop emergence. Incidence was much higher (up to 50% oviposition) in the postrainy season than in the rainy season (1.4%). Only 5% of the plants examined had deadhearts in the rainy season compared to 69% in the postrainy season.

As usual, stem borer (*Chilo partellus*) attacked the crop later than shoot fly. Slight damage caused by larvae was observed 3 weeks following emergence. The maximum leaf damage recorded was 21% during the rainy season and 59% during the postrainy season. The deadheart figures were *1%* and 21%, respectively. Up to 10% of the plants were infested by the pink borer, *Sesamia inferens.*

Damage by the armyworm (*Mythimna separata*) was more severe in the rainy season (87% of the plants attacked) than in the postrainy season (10%). Earhead bug (*Calocoris angustatus*) attack started 8 weeks from germination. Midge (*Contarinia sorghicola*) attack was very low in the rainy season (less than 1%) and reached up to 26% in the postrainy season.

Other pests recorded included aphids (*Rhopalosiphum maidis*) and shoot bugs (*Peregrinus maidis, Heliothis armigera, Dysdercus* sp, *Celama analis,* and *Cyptoblabes* sp).



Sorghum head damaged by midge (Contarinia sorghicola). *The pin holes in the florets show the pest's emergence holes.*

Shoot Fly Biology

The adult female fly was found to lay a maximum of 110 eggs in 30 days. As many as 22 eggs were laid on one plant in the net house. However, an average of only one larva per plant was able to survive.

During October, about 9% of the shoot fly eggs collected from the field were found to be parasitized by *Trichogramma japonicum* and an unidentified species of Trichogrammatidae.

Trapping of shoot flies using fish meal bait continued for the 7th year at ICRISAT Center. The identification of 325 336 trapped shoot flies indicated that there were 35 species belonging to two genera, *Atherigona* and *Acritochaeta,* and 17 of them were yet undescribed. Fly populations were very low during April to June.

Identification of shoot fly species recovered from six traps between 17 January and 16 July 1980 showed that, although 21 species of flies were trapped, most female flies were *Atherigona falcata, A. soccata, A. punctata, and Acritochaeta orientalis.* Of the male flies trapped, 62% were *Atherigona soccata.* The fly population was low till June, but after the break of the rainy season, the number of flies trapped increased considerably.

Our screening program to identify sources of shoot fly resistance from germplasm obtained from several countries continued. The spreader row/fish meal technique was used in both seasons. Of 5805 germplasm lines screened, 323 lines were selected for further testing. Three shoot fly resistant lines identified at ICRISAT (IS-923, IS-2195, and IS-2312) were included in the All India trials. It was found that the oviposition and deadheart percentages were significantly lower in these lines than in the susceptible check.

Stem Borer (*Chilo partellus*)

In our preliminary observations on the biology of the borer, it was found that females mated only once. Males were able to mate several times with virgin females. The preoviposition period was 1 day. The oviposition period was about 3 days, and eggs were usually laid between 0600 and 2000 hr. Mating occurred from midnight up to 0600 hr, and moths remained in copulation from 1 to 3 hr.

Carryover studies of the stem borer were continued on stalks of CSH-1, Swarna, and local cultivars. Two hundred stalks of each of these cultivars were examined monthly. In addition, we also examined stalks of sorghum cultivars collected from neighboring farmers' fields in March, April, and May. Over 38% of the 1793 larvae collected from 11216 stalks in the sampling period produced adult moths. Data showed that larvae were recovered from CSH-1 and Swarna stalks for a longer period than from local cultivars.

In the course of our survey work, we recorded several species of natural enemies of *Chilo* (Table 16). A routine study on the alternative host plants of *C. partellus* continued, and we recorded five cultivated and six wild host plants (Table 17).

Using the synthetic pheromone developed by the Tropical Products Institute, London, our regular monitoring of the stem borer population continued. We detected three periods of activity—August, November, and February (Fig. 2).

In the past year the Entomology Subprogram has been involved in a major effort to develop methods for field screening of sorghum germplasm against the stem borer. A procedure for mass rearing of stem borer has been stabilized and the rearing laboratory

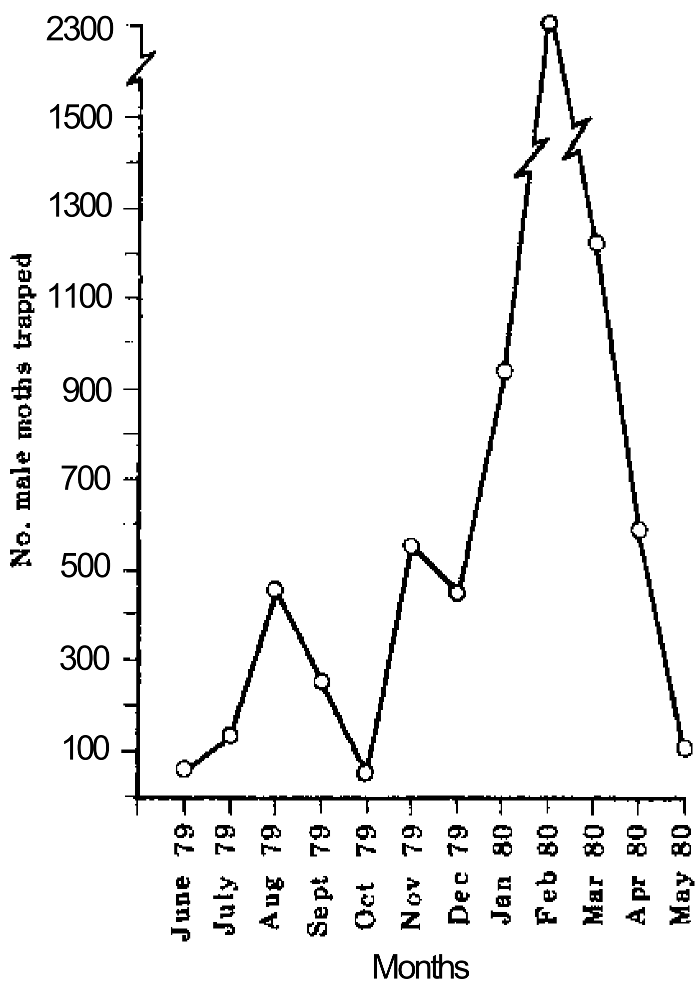


Figure 2,* Chilo *catch in pheromone traps at ICRISAT Center from June 1979 to May 1980.

Table 16. Natural enemies of stem borer* (Chilo partellus) *recorded at ICRISAT Center.

Name	Family	Stage of host attacked
A. Parasites		
Carcelia sp	Tachinidae	Larva
Halidaya luteieornis	Tachinidae	Larva
Sturmiopsis inferens	Tachinidae	Larva
Thelaira sp	Tachinidae	Larva
?Pseudalsomyia sp	Tachinidae	Larva and pupa
Apanteles flavipes	Braconidae	Larva
Bracon albolineatus	Braconidae	Larva
Bracon chinensis	Braconidae	Larva
Glyptomorpha deesae	Braconidae	Pupa
Trathala flavoorbitalis	Ichneumonidae	Larva
Xanthopimpla stemmator	Ichneumonidae	Pupa
		Pupa
Hyperchalcidia soudanensis	Chalcididae	Pupa
Invreia sp	Chalcididae	Pupa
Tetrastichus ayyari	Eulophidae	Pupa
Trichogramma chilonis	Trichogrammatidae	Egg
B. Predator		
Menochilus sexmaculatus	Coccinellidae	Larva

Table 17. Host plants of* Chilo partellus *recorded at ICRISAT Center.

A. Cultivated hosts

Eleusine coracana
Pennisetum americanum
Setavia italica
Sorghum bicolor
Zea mays

B. Wild hosts

Chloris barbata
Cymbopogon caesius
Dinebra retroflexa
Heteropogon contortus
Sorghum almum
Sorghum halepense

was considerably expanded. The newly hatched larvae (mixed with finger millet seed) were introduced to leaf whorls of 20- to 25-day-old sorghum plants with the help of a modified CIMMYT dispenser. Two applications per plant at a week's interval were made on material under test. This screening method gave rapid and repeatable results.

During the postrainy season 1979/80, 6600 lines from germplasm were sown for stem borer screening with artificial infestation, and 1110 lines were selected as less susceptible for further testing. These 1110 lines will be planted during the 1980 rainy season, both at ICRISAT Center under artificial screening conditions and at Hissar under natural heavy infestations.

Sorghum head damaged by earhead bugs.

Earhead Bug

Entomological studies on the biology of the head bug complex were initiated this year and techniques for screening are being developed. Cultivars of differing maturity dates sown as spreader rows 2 weeks earlier than the test material have shown promise. In general, the compact-head types have been found to be more susceptible than the open-head types.

Shoot Bug

Shoot bug, *Peregrinus maidis,* causes considerable damage to sorghum planted during August for shoot fly resistance screening. It is also common in the postrainy season. This pest is becoming important particularly in southern India. Both nymphs and adults suck sap from leaves, especially inside leaf whorls or on inner sides of leaf sheaths; the plants become stunted and, in severe cases, no earheads emerge.

Our preliminary observations on the biology of the shoot bug revealed that a single female laid up to 254 eggs in 2 days. The white banana-shaped eggs were deposited in groups of two (rarely one or three) in the depressions on the dorsal midrib and covered with a white gummy substance. Just before hatching, the eggs changed to yellow, with a reddish-brown spot at one end. Incubation took about 7 days. There were five nymphal instars, which occupied 16-20 days.

Pathology

Grain Molds

RESISTANCE SCREENING AT ICRISAT CENTER. Large-scale field screening of grain mold resistance breeding progenies and lines from other breeding projects for resistance to major mold-causing fungi (*Fusarium moniliforme, F. semitectum, and Curvularia lunata*) was carried out using techniques described in our previous annual reports. Results are summarized in Table 18. The significant point in these results is that a higher percentage of lines developed from mold-resistant sources were selected in both preliminary and advanced screening than lines developed in other breeding projects.

MULTILOCATIONAL TESTING. The International Sorghum Grain Mold Nursery (ISGMN) was grown in India at Akola, Bhavanisagar, Coimbatore, ICRISAT Center, Pantnagar, and Rajendranagar; at Mokwa and Samaru in Nigeria; at Sotuba in Mali; and at Farako-Ba in Upper Volta. It comprised 27 test entries that had shown low susceptibility to grain molds at ICRISAT Center, and 3 (early, medium, and late) susceptible checks.

Table 18. Results of screening of sorghum lines for resistance to grain molds at ICRISAT Center in the 1979 rainy season.

Source of sorghum lines	Number of lines screened	Number of lines selected[a]	Percent selected
Advanced screening			
a. Sorghum breeding progenies	1220	763	62.5
b. Grain mold resistance breeding progenies	2089	1536	73.5
Preliminary screening			
a. Sorghum breeding progenies	59	16	27.1
b. Grain mold resistance breeding progenies	630	431	68.4
Total	3998	2746	

a. Selection based on field grain mold scores of 2 or 3 on a 1-5 scale where 1 is least molded and 5 is most molded.

Results confirmed previous years' findings: IS-14332 was the best entry across all locations with a mean grain mold rating of 2 on a 1 to 5 scale (1 being least and 5 the most molded surface). Again, the other good entries were IS-2328, IS-9225, IS-2327, M-64083, and E-35-1, with mean grain mold ratings of 2.5 and 3 across all locations.

Charcoal Rot

(*Macrophomina phaseolina*)

RESISTANCE SCREENING AT ICRISAT CENTER. More than 2500 sorghum lines comprising germplasm and breeding material grown in the postrainy season under irrigation were screened for resistance to charcoal rot. Irrigation was withdrawn at 50% flowering to induce moisture stress, which is essential for disease development. Two weeks later, plants were inoculated by toothpick inoculation (as described in our previous reports) and evaluated at maturity. Our assessment of resistance was based on the extent of colonization of the pathogen up the stem from the point of inoculation and the softness of the colonized area. Using these criteria, 715 lines in which pathogen colonization was restricted to the node of inoculation, were selected as low susceptibles to charcoal rot.

MULTILOCATIONAL TESTING. The International Sorghum Charcoal Rot Nursery (ISCRN) was grown at ICRISAT Center, and by cooperators at Dharwar, Bijapur, Madhira, and Nandyal in India; at Kamboinse in Upper Volta; and Gedarif and Wad Medani in Sudan. The Madhira Research Station relied on natural infection; at other locations all entries were toothpick-inoculated with the charcoal rot pathogen 2 weeks after 50% flowering. Maximum disease pressure was obtained at Wad Medani and Gedarif. Even with inoculation, the infection level at ICRISAT Center, Kamboinse, Nandyal, and Bijapur was low, possibly due to inadequate moisture stress (a prerequisite for disease development) during grain filling.

The two locations in Sudan had high incidence of charcoal rot, with the pathogen growth extending over a mean of four nodes up the stem from the point of inoculation on the second internode (i.e., four mean nodes crossed), and none of the test entries had low susceptibility to charcoal rot. However, four entries-BJ-111, E-36-1, BJ-112, and IS-3443-had less than one mean node crossed at the remaining six locations.

Downy Mildew

(*Peronosclerospora sorghi*)

RESISTANCE SCREENING TECHNIQUE. During 1979 rainy season we attempted to screen for sorghum downy mildew (SDM) resistance at ICRISAT Center using the infector-row inoculation technique. Although infector rows of the highly susceptible DMS-652 and IS-643 sorghum lines developed 55 and 68% downy mildew infection, respectively, conidial production was sparse, and less than 5% infection occurred in indicator rows. It was therefore not possible to evaluate test entries for resistance. Large-scale field inoculation of seedlings with conidia also failed to produce high levels of infection in susceptible checks, largely due to temperature and humidity conditions unfavorable to infection. We concluded from these and previous tests that ICRISAT Center is unsuitable for large-scale field screening for SDM resistance. In the future most such field screening will continue at other locations in India.

In order to provide uniform conidial inoculum, germinated seeds of test entries were sandwiched between systemically infected sorghum leaves and incubated for 20-24 hr at 20°C under high humidity, after which they were planted in pots. After 5-6 days, infected plants showed typical systemic symptoms of SDM infection. This technique, though a severe test, proved effective in confirming-the high level of resistance to SDM of QL-3 and its sister lines 2-7, 2-26, 3-23, and 3-36.

MULTILOCATIONAL TESTING. In the 1979 International Sorghum Downy Mildew Nursery (ISDMN) grown at eight locations in Asia and Africa, QL-3 continued, for the 4th year, to be free from downy mildew at all locations. Table 19 gives data on the performance of the best entries (less than 10% infection) in the ISDMN from 1976 to 1979.

Leaf Diseases

RESISTANCE SCREENING AT ICRISAT CENTER. We field screened more than 1400 sorghum lines against anthracnose (*Colletotviahum gvaminicola*), leaf blight (*Exserohilum turcicum*), and rust (*Puccinia purpurea)* . The whorl inoculation method (in which inoculum is placed in the whorls of plants at different growth stages) was used for anthracnose and leaf blight, and sprinkler irrigation was run for 1 hr in both mornings and evenings on rain-free days in order to provide high humidity essential for disease development. We relied on natural infection for rust screening. Rust disease pressure was high, as shown by susceptible checks planted throughout the test entries.

Results (Table 20) indicated that a number of sorghum lines have high levels of resistance to the isolates of leaf disease pathogens present at ICRISAT Center. Test entries IS-2007, IS-9784, IS-9738, IS-5507, IS-3955-C, IS-7907-C, IS-3868, and P-39653 were free from all three leaf diseases. The first seven entries were also free from leaf blight and rust in the previous year.

MULTILOCATIONAL TESTING. The 1979 International Sorghum Leaf Disease Nursery (ISLDN) was grown at 12 locations in Asia, Africa, and America to evaluate the spectrum and stability of resistance to various leaf diseases in 30 test entries, including 7 susceptible checks. Sufficient disease to enable the evaluation of test

Table 19. Across-location[a] mean percentage infection of selected entries in the ISDMN from 1976 to 1979.

Entry	Across-location entry mean % infection				Overall % infection
	1976	1977	1978	1979	
QL-3	0	0	0	0	0
CSV-4	0.3	5.6	2.7	4.0	3.1
$UChV_1$	2.3	3.6	3.1	5.4	3.6
IS-2223	ND	ND	3.6	6.3	4.9
IS-5273	1.6	6.4	7.4	5.9	5.3
SC-120-14	0	11.6	6.3	3.9	5.4
IS-2042	1.9	8.3	7.9	4.1	5.5
$UChV_2$	1.9	11.1	1.8	7.8	5.6
IS-173	2.9	8.9	2.2	8.4	5.6
DMS-652 (check)	50.0	78.0	56.1	90.6	68.7

a. Locations : India (Dharwar, ICRISAT Center, Mysore, Coimbatore, Digraj, Rajendranagar), Venezuela (Maracay), Botswana (Gaborone).

ND = No data; not included in the trial.

Table 20. Sorghum lines resistant[a] to one or more leaf diseases (anthracnose, leaf blight, and rust) in field screening at ICRISAT Center in the 1979 rainy season.

Source of sorghum lines	No. of lines screened	Anthracnose (A)	Leaf blight (LB)	Rust (R)	A+LB	A+R	LB+R	A+LB+R
Selections from 1978 screening	699	134	204	34	45	3	11	4
Pest resistant lines	420	83	36	6	5	1	4	4
Population breeding progenies	309		24	3			2	
Total	1428	217	264	43	50	4	17	8

a. Resistance based on grades of 1 and 2 on a 1-5 scale where 1 = highly resistant and 5=highly susceptible.

b. Not screened against anthracnose.

entries developed for anthracnose at six locations, grey leaf spot at five locations, leaf blight and zonate leaf spot at four locations each, rust at three locations, and rough leaf spot and sooty stripe at two locations each. Many lines proved to be resistant to the leaf diseases across years and locations (Table 21),

Microbiology

In a long-term experiment started in 1978 to measure the nitrogen balance in sorghum production in an Alfisol under rainfed conditions, plant dry-matter production and nitrogen uptake, and soil nitrogen changes, are measured. The same eight cultivars (Table 22) are grown each year on the same plots. The range of nitrogenase activity in the cultivars selected was from 9 to 96 ug/core per day. Fertilizer nitrogen is added as urea at the rate of 0, 20, and 40 kg N/ha. Initial soil nitrogen content of the unfertilized soil ranged from 0.020 to 0. 049%,

In the second season in 1979, there were significant differences between the cultivars in grain yield and nitrogen uptake, but no significant effect of nitrogen fertilizer, probably because of variability in stand establishment. With no nitrogen fertilizer addition, plant dry matter production varied from 3. 05 to 10. 65 tonnes/ha with grain yields of up to 3. 98 tonnes/ha (Table 22). Nitrogen uptake in dry matter varied from 33 to 72 kg/ha (Table 23). IS-15165 is a late-maturing, photosensitive African entry which produced virtually no grain at Hyderabad in this season. In 1980, total dry matter yields for the unfertilized plots were again considerable, ranging from 4.33 to 7.4 tonnes/ha. Cumulative dry matter yields over three seasons ranged from 11.1 to 23.4 tonnes/ha. These are surprisingly high yields for soil

Table 21. Across-location mean[a] and range of disease score [b] of seven leaf diseases[c] in selected sorghum lines in the ISLDN from 1977 to 1979.

Entry	Mean and range of disease [c] score						
	A	LB	R	RLS	ZLS	GLS	SS
IS-7254	1. 8(1-4)[d]	1. 8(1-5)	1.5(1-2)	1.0(1-1)	1.8(1-3)	2.1(1-3)	1.5(1-3)
IS-7322	1.5(1-3)	2. 2(1-4)	2.0(1-4)	1.5(1-2)	1.3(1-2)	1. 8(1-3)	2.2(1-4)
CS-3541	1. 8(1-4)	2.4(1-3)	1.7(1-3)	1.4(1-2)	1. 9(1-3)	1.7(1-4)	1.4(1-3)
IS-4150	1. 9(1-4)	2.1(1-3)	2. 1(1-4)	1.6(1-2)	1. 6(1-3)	1.9(1-3)	1.5(1-4)
IS-3925[e]	2.0(1-4)	2. 7(1-4)	1. 9(1-3)	1.1(1-2)	2.0(2-2)	2.7(2-4)	2.1(1-3)
IS-115[e]	1.5(1-3)	2. 8(1-5)	2.4(1-4)	1.6(1-4)	1.7(1-2)	2.0(1-4)	1.7(1-3)

a. Data based on the results from 6 locations in 1977, 8 locations in 1978, and 12 locations in 1979.
b. Disease score on 1-5 scale, where 1 = highly resistant and 5 = highly susceptible.
c. Leaf diseases : anthracnose (A), leaf blight (LB), rust (R), rough leaf spot (RLS). zonate leaf spot (ZLS), grey leaf spot (GLS) and sooty stripe (SS).
d. Figures in parentheses indicate the range of disease score.
e. Entries introduced in 1978 nursery.

with low fertility. In the absence of nitrogen fixation associated with the sorghum roots, such levels of nitrogen depletion by the crop should result in a significant decrease in soil nitrogen content and a trend of decreasing yields over time.

In pot culture studies, the response of sorghum to inoculation with nitrogen-fixing bacteria varied with the growth medium and amount of nitrogen fertilizer added. Increases in dry-matter production and nitrogen uptake occurred in an Alfisol soil following inoculation. Addition of nitrogen fertilizer produced a lower response.

This year we developed a method for assaying intact plants for nitrogenase activity. Plants are grown in plastic pots, and before assay, the gas phase in the root system is isolated from the top of the plant by a silicone rubber sealant around the stem of the sorghum plant. The same plant can be assayed several times during its growth cycle and seed can also be obtained*

Looking Ahead

BREEDING. We will continue to distribute promising cultivars and hybrids with good food quality grain as international trials, nurseries, and in response to seed requests. Promising seed parents for hybrids will soon be made available for wide-scale distribution. Emphasis on developing cultivars and hybrids for the postrainy season will increase in close association with the re-

Table 22. Grain and dry matter yield (tonnes/ha) for sorghum in the second season (1979) in long-term nitrogen balance trial at ICRISAT Center.

	Grain yield			Total dry matter		
	-N applied (kg/ha)-					
Cultivar	0 N	20 N	40 N	0 N	20 N	40 N
Dobbs	0.89	1.15	1.21	10.65	12.44	11.68
IS-2333	1.76	1.68	2.37	9.91	9.08	10.85
CSH-5	3.98	3.11	3.83	9.16	8.03	9.16
IS-15165				8.60	8.17	8.01
Diallel-642	2.68	2.95	3.27	7.41	8.31	8.11
CSV-5	1.45	2.21	2.18	6.63	7.58	7.78
FLR-101	2.22	2.71	3.51	6.05	6.95	7.80
IS-889	1.39	1.74	1.93	3.05	4.29	5.28

Standard error for comparing cultivar differences in grain yield means at different N levels: 0.35; standard error for comparing cultivar differences in grain yield means at a particular N level: 0.32; standard error for comparing cultivar differences in total dry matter yields at different N levels: 1.05; standard error for comparing cultivar differences in total dry matter yields at a particular N level: 0.91.

search project on moisture stress. The program will continue to contribute to regional variety and hybrid trials of the All India Coordinated Sorghum Improvement Project. More of our varieties and hybrids will be entered into regional trials of other national programs; for example, Ethiopia, Kenya, Thailand, and Venezuela.

Our studies on the inheritance behavior of the glossy trait will be continued in order to identify the most satisfactory source for shoot fly resistance. We will use diverse cultivars to enhance the level of resistance in source material. Agronomically good cultivars with high levels of shoot fly resistance will be increasingly available for international use. Breeding for stem borer resistance will be resumed following the identification of useful source cultlvars.

We have now included *Phoma* in the inoculum to evaluate resistance to grain mold. This should improve the capability to breed cultlvars with better levels of resistance than are now available. The genetics of immunity to downy mildew in QL-3 and its sister lines is under study. Efforts will be made to improve the techniques to screen for *Striga* resistance.

PHYSIOLOGY. Priorities in the Sorghum Physiology Subprogram have been established, and our research effort will be directed to two areas of research: (1) factors affecting crop establishment, and (2) response and adaptation to water, heat, and nutrient stress.

Table 23. Nitrogen uptake (kg N/ha) by sorghum cultivars in the second season (1979) of the long-term nitrogen balance experiment at ICRISAT Center.

	N in grain			N in dry matter		
	N applied (kg/ha)					
Cultivar	0 N	20 N	40 N	0 N	20 N	40 N
Dobbs	15.8	19.4	21.6	61.3	68.5	92.6
IS-2333	27.3	31.8	41.1	58.6	65.9	82.7
CSH-5	45.9	42.9	51.9	72.1	72.9	77.3
IS-15165				37.4	61.9	67.6
Diallel-642	35.0	41.6	54.0	56.7	67.4	81.0
CSV-5	20.4	36.2	37.1	56.4	78.4	90.1
FLR-101	25.4	36.1	51.5	45.5	63.6	82.8
IS-889	22.4	31.7	34.1	33.3	50.1	62.2

Standard error for comparing cultivar differences in nitrogen uptake in grain at different N levels: 5.91; standard error for comparing cultivar differences in grain nitrogen uptake at a particular N level: 5.32; standard error for comparing cultivar differences in uptake of nitrogen in the dry matter, at different N levels: 9. 92; standard error for comparing cultivar differences in total nitrogen uptake in the dry matter, at a particular N level: 8.34.

Our major objective will be to provide breeders with simple, repeatable, and inexpensive selection criteria in order to evaluate a wider range of germplasm and breeding lines. Evaluation of material in SAT environments will be increased now that additional sites in India and Africa have been identified.

BIOCHEMISTRY. Our studies to find simpler methods for evaluating food quality will continue. We will evaluate the nutritional traits of advanced breeding stocks as a contribution to breeders' efforts to improve the nutritional quality of the grain.

ENTOMOLOGY. Our studies on the shoot fly will be phased down to permit greater emphasis on stem borer and midge; however, routine screening of breeding stocks for shoot fly resistance is expected to increase. We will continue evaluation of the germplasm collection for resistance to the *Chilo* stem borer and will increase evaluation of breeding lines. Efforts will be made to learn more about the *Sesamia* borer, head bugs, and midge in different environments; techniques to improve the screening opportunity for these will expand. A close working relationship with the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, is anticipated for both stem borer and shoot fly studies. Work will continue with the Max-Planck Institute, West Germany, to evaluate the chemicals in fish meal that attract the shoot fly. Studies on chemicals responsible for host-plant resistance will be carried out in collaboration with the Centre for Overseas Pest Research (COPR), London, and ICIPE, Nairobi. The shoot bug is causing increasing damage to the crop at ICRISAT Center, and attention, over time, will be given to determine its importance to our research activities.

PATHOLOGY. Our future effort will include: (1) screening for resistance to grain-mold-causing fungi (other than *Curvulavia, Fusarium,* and *Phoma*), such as species of *Alternaria* and *Trichothecium,* (2) studies of the interaction and sequence of infection by various grain mold fungi on the developing sorghum grain, (3) studies of the relationship between stress factors, crop management, and development of charcoal rot disease, and (4) improvement in screening techniques for resistance to SDM and leaf diseases.

MICROBIOLOGY. We will examine tube and pot culture methods of screening for nitrogenase activity using plants grown in a glasshouse to see if this reduces variability between plants. Field experiments will be initiated to measure the response of sorghum to inoculation with nitrogen-fixing bacteria. We will also study the effect of location on nitrogen fixation in plantings at Hissar, ICRISAT Center, and Bhavanisagar.

Publications

Institute Publication

House, L.R. 1980. A guide to sorghum breeding. Patancheru, A. P., India: ICRISAT.

Journal Articles

Davies, J.C., Seshu Reddy, K.V., and Reddy, Y.V.R. 1980. Species of shoot flies reared from sorghum in Andhra Pradesh, India. Tropical Pest Management 26:258-261.

Maiti, R.K., and Bidinger, F.R. 1979. A simple approach to the identification of shoot fly tolerance in sorghum. Indian Journal of Plant Protection 7(2):135-140.

Prasada Rao, K.E., and Murty, D.S. 1979. A *basmati* (scented) sorghum from Madhya Pradesh. Current Science 48(18): 824-825.

Subramanian, V., Jambunathan, R., and Suryaprakash, S. 1980. Note on the soluble sugars of *Sorghum bicolor* (L.) Moench. Cereal Chemistry 57:440-441.

Conference Papers

Bhola Nath and House, L.R. 1980. Relevance of population breeding to national programs in sorghum. Presented at the Annual Workshop of the All India Coordinated Sorghum Improvement Project, 12-14 May, Coimbatore, India.

Davies, J.C., and Seshu Reddy, K.V. 1980. Shoot fly species and their graminaceous hosts in Andhra Pradesh, India. Presented at the International Study Workshop on the Sorghum Shoot Fly, ICIPE, 5-8 May, Nairobi, Kenya, 17 pp.

House, L.R. 1980. Generation and transfer of technology in the Americas. Pages 151-157 *in* Proceedings of the International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, Patancheru, A.P., India.

House, L.R. 1980. ICRISAT participation in research and development of sorghum with special reference to Africa. Presented at SAFGRAD Meeting, 26 Feb-1Mar, Mombasa, Kenya.

House, L.R. 1980. Sorghum Improvement Program. Presented at the Thai Corn and Sorghum Workshop, 24 Mar, Chiang Mai, Thailand.

Malti, R.K. 1980. The role of 'glossy' and trichome traits in sorghum crop improvement. Presented at the Annual Workshop of All India Sorghum Improvement Project, 12-14 May, Coimbatore, India.

Maiti, R.K., Raju, P.S., and Bidinger, F.R. 1979. Studies of germinability and some aspects of preharvest and postrainy physiology of grain sorghum. Presented at the National Seminar on Physiological Basis of Crop Productivity and Harvesting Solar Energy in Relation to Agricultural Development, Aligarh University 19-21 Mar, Aligarh, U.P., India.

Reddy, Belum V.S., Seetharama, N., Maiti, R.K., Bidinger, F.R., Peacock, J.M., and House, L.R. 1980. Breeding for drought resistance in sorghum at ICRISAT. Presented at the Annual Workshop of the All India Coordinated Sorghum Improvement Project, 12-14 May, Coimbatore, India.

Reed, W., Seshu Reddy, K.V., Lateef, S.S., Amin, P.W., and Davies, J.C. 1980. Contribution of ICRISAT to studies on plant resistance to insect attack. Presented to the Scientific Working Group on the Use of Naturally Occurring Plant Products in Pest and Disease Control, 12-15 May, Nairobi, 14 pp.

Seshu Reddy, K.V., Skinner II, J.D., and Davies, J.C. 1980. Attractants for *Atherigona* spp including sorghum shoot fly (*Atherigona soccata* Rond., Muscidae: Diptera). Presented at the International Study Workshop on the Sorghum Shoot Fly, ICIPE, 5-8 May, Nairobi, Kenya, 16 pp.

Subramanian, V., and Jambunathan, R. 1980. Traditional methods of processing sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum amerioanum*) grains in India. Presented at the International Association of Cereal Chemistry Symposium-"Sorghum and Millets," 5-6 May, Vienna.

PEARL MILLET

Contents

PEARL MILLET

International Trials

IPMAT-5, comprising 20 test entries and a local check, was sent to 41 locations in 22 countries in 1979. The entries included hybrids, synthetics, and experimental varieties contributed by cooperators and ICRISAT. We received results from 30 locations in 9 countries, of which 29 locations reported grain yield data (Table 1).

Hybrid UCH-4 contributed by Tamil Nadu Agricultural University was the highest yielding entry, with a mean yield over 29 locations of 2020 kg/ha. The lowest yielding entry was NHB-3 (1460 kg/ha), a commercial Indian hybrid that was withdrawn from production because of its high susceptibility to downy mildew; it is included in this trial because it best indicates the downy mildew pressure. The top grain yields at individual locations ranged from 280 kg/ha (WC-C 75 at Manga, Ghana) to 4620 kg/ha (ICH-165 at Anand, India). At only 4 of the 29 locations did the local check give the highest yield.

At locations in India, the hybrids UCH-4 and MBH-110 were the highest yielding entries, and WC-C75, ICH-241, and IVC-5454 also produced comparable yields. At locations in Africa, ICMS-7819, UCH-4, ICH-165, IVS-P77, IVC-5454, and ICMS-7818 showed good performance. All these entries (except UCH-4, whose pedigree is unknown) have been bred using totally or partly African germplasm.

Apart from IPMAT-5, we also sent some 70 sets of multilocational trials of composite progeny and products, inbreds, synthetics, and hybrids to cooperators in 10 countries. Most of these, particularly the large trials, were grown by ICRISAT's country-based staff in Africa. These trials were organized as part of the multilocational selection and testing scheme for evaluating the stability and adaptability of breeding lines and products and assessing the stability of resistance to diseases, especially downy mildew. The trials also serve as a means to distribute useful genotypes to national programs and to promote communication among cooperating scientists internationally, an important function of ICRISAT.

In 1979, we contributed 19 entries (three hybrids, two synthetics, seven experimental varieties, and seven restorer lines) to the AICMIP National Yield Trials. Performance of these entries in the AICMIP trials is presented in their respective "Breeding" sections.

Breeding

Our breeding objective is to improve grain quality and to produce genotypes with high yield potential combined with broad adaptability; location-nonspecific resistance to downy mildew, ergot, smut, and rust; and tolerance to drought and low fertility. From the inception of the program, we have generated variability by both conventional and population breeding approaches, using simultaneous evaluation of early-generation material at several locations. Location differences at first included productivity levels and latitude contrasts (ICRISAT Center, Bhavanisagar in South India, and His sar in North India) and the downy mildew nursery at the Center; later, cooperative program sites in Africa, which are particularly important for disease resistances, were included.

Considerable progress has been made on yield potential, adaptability, and downy mildew resistance. Through an international cooperative network, established over the years since 1974, we have supplied several elite downy mildew resistant products and breeding lines, which are being utilized in national programs. Now that sources of ergot and smut resistance have been developed, breeding for resistance to these is

Table 1. Mean grain yield (kg/ha) of IPMAT-5 entries over Indian, African, and all locations.

Entry	Sources[a]	Indian locations (17) Mean	Rank	African locations (10) Mean	Rank	All locations (29)[b] Mean	Rank
UCH-4*	TNAU	2350	1	1370	3	2020	1
MBH-110*	MAHYCO	2310	2	1210	9	1980	2
IVS-P77	ICRISAT	2170	7	1330	5	1950	3
IVC-5454	ICRISAT	2210	5	1270	6	1930	4
ICH-241*	ICRISAT	2230	4	1140	15	1890	5
ICMS-7818	ICRISAT	2100	12	1210	10	1880	6
WC-C75	ICRISAT	2240	3	1160	14	1880	7
WC-B77	ICRISAT	2160	8	1220	8	1880	7
ICH-220*	ICRISAT	2200	6	970	19	1860	9
ICMS-7803	ICRISAT	2080	14	1180	11	1850	10
ICMS-7703	ICRISAT	2150	9	1160	13	1840	11
ICH-165*	ICRISAT	2050	17	1360	4	1840	12
MBH-124*	MAHYCO	2090	13	1180	12	1840	13
ICMS-7817	ICRISAT	2020	18	1270	7	1820	14
MC-K77	ICRISAT	2080	15	1100	17	1780	15
SSC-H76	ICRISAT	2110	11	1000	18	1740	16
NEC-H76	ICRISAT	1800	20	920	20	1540	17
NHB-3*	AICMIP	1800	21	840	21	1460	18
PHB-12*	PAU	2110	10				
PSB-8	PAU	1860	19				
ICMS-7819	ICRISAT			1380	2		
PHB-14*	PAU			1140	16		
Local check[c]		2070	16	1500	1		
Mean		2110		1170		1830	

* Hybrid.

a. TNAU - Tamil Nadu Agricultural University.
MAHYCO - Maharashtra Hybrid Seed Company.
AICMIP - All India Coordinated Millet Improvement Project.
PAU - Punjab Agricultural University.

b. Only for the common 18 entries; CV(%) over all 29 sites ranged from 6.7 to 71.5.

c. Different checks at individual locations.

receiving higher priority in our program. We are also giving increased attention to breeding for drought resistance, utilizing the summer drought nursery at ICRISAT Center.

Source Material

We are increasingly utilizing the great range of variability that is being accumulated in the Pearl Millet World Collection by ICRISAT's Genetic Resources Unit. Each year in our source material project, systematically selected germplasm lines are crossed with a range of adapted lines. The progenies serve several purposes. They are utilized in the ICRISAT variety and hybrid programs and ICRISAT's West African breeding programs, and are passed to other breeders by means of an annually distributed Uniform Progeny Nursery (UPN).

This source material project is paying off in several ways. A synthetic (ICMS-7819) derived from the source population Ex Bornu performed well in the 1979 Advanced Synthetic Trial and was selected for the 1980 Pearl Millet African Regional Trial (PMART). Hybrid ICH-241 (5141A x Serere 38-142) performed well in the Initial Hybrid Trial of the 1979 All India Coordinated Millet Improvement Project (AICMIP), achieving a mean yield of 2310 kg/ha, and was retained for further testing. Four other hybrids whose pollinators were derived from source material were promising in our own hybrid trials in 1979. Source material progenies have been valuable sources of downy mildew and smut resistance and have contributed agronomically useful material to the International Disease Testing Program.

The source material project also makes crosses between identified local varieties and exotic material at the request of ICRISAT scientists in Africa. We supply these as F_1s or F_2S. A return flow of material selected from these crosses and others has also commenced from West Africa, and in 1979 we received for use at ICRISAT Center 192 lines from four West African breeding programs.

Composite Breeding

This comprises recurrent selection within populations (principally to produce varieties) and between population pairs (mainly to produce hybrid parents).

Improvement in 11 composites was continued through multilocational progeny testing. We started a new composite, the Smut-Resistant Composite (SRC), using 37 diverse elite lines identified in the smut screening nursery at Hissar. Products of composite breeding — experimental varieties (formed from intermating 6-10 best progenies) and progeny varieties (where one elite progeny is increased by sibbing alone) — continued to perform well in 1979 ICRISAT and AICMIP trials (Table 2). WC-C75 gave a good performance in the AICMIP population trials,

ICRISAT pearl millet variety WC-C75 is being multiplied in prerelease Indian national trials. It is both high yielding and resistant to downy mildew.

where it is now a standard check entry, and in the second-year minikit tests. Experimental varieties developed subsequently from the World Composite (such as WC-B77) and from other composites (MC-P76, SSC-H 76, and IVC-5454) have also succeeded in initial AICMIP tests. IVC-5454, a progeny variety, averaged 1930 kg/ha over 29 test sites in the fifth International Pearl Millet Adaptation Trial (IPMAT-5), compared to 1880 kg/ha for WC-C75. Similarly in our Elite Variety Trial, which compared 25 hybrids, varieties, and synthetics at four locations, IVC-5454 ranked second (2600 kg/ha) and WC-B77 fourth (2570 kg/ha), both significantly outyielding the commercial hybrid check BJ-104 (2420 kg/ha).

We completed the third and final backcross on seven composites to produce dwarf versions in a uniform dwarf (d_2) height background. Progenies from this backcross have already gone into the UPN, and several dwarf synthetics have been made.

Improvement between population pairs continued, but recovery of useful maintainer progeny from B-composites has been low. We will undertake a further generation of inbreeding and test-crossing to improve the frequency of nonrestorer genes. Progenies identified from the R-populations

Table 2. Performance of pearl millet populations in Advanced AICMIP trials.

Population[a]	Grain yield (kg/ha) 1977	1978	1979	Mean	% BJ-104	Downy mildew (%) 1977	1978	1979	Mean
Group A									
PSB-3	1570	1900	1700	1720	92	9	12	4	8
PSB-8	1530	1800	1490	1610	87	5	7	5	6
Group B									
WC-C75	1630	2070	1760	1820	98	2	3	1	2
Group C									
IVS-A75	1380	2010	1710	1700	91	2	2	2	2
DC-3	1580	1980	1690	1750	94	5	3	6	5
MC-C75	1330	1970	1720	1670	90	4	5	3	4
Group D									
BJ-104	1790	1970	1810	1860	100	8	10	14	11
HB-7	1700	2080	1820	1870	101	7	6	3	5
Local	1360	1920	1610	1630	88			10	
Mean	1540	1950	1680	1720	93	94[b]	68[b]	42[b]	68[b]

Source: Coordinator's Review, AICMIP Workshop, April 1980, Hissar, India. CVs over all the trials ranged from 5 to 59%.

a. Group A. Varieties promoted to Minikit tests in 1978.
B. Varieties promoted to Minikit tests in 1979.
C. Entries found promising in AICMIP in 1979.
D. Checks.

b. Susceptible check HB-3.

have, however, produced good hybrids with yields equivalent to or better than that of BJ-104, and superior in downy mildew resistance.

Variety Crosses and Synthetics

In this project we make crosses between a range of material likely to produce variability that can contribute parental lines for synthetics— between germplasm stocks, source material progeny, population progeny, and parental lines of previous synthetics. As in other projects in the breeding program, the most promising material is derived from mixed African x Indian parentage.

Synthetic ICMS-7703 continued to perform well in advanced tests and in AICMIP trials. We developed this synthetic from seven parental lines, each derived from crosses between Nigerian and Indian breeders' lines. In ICRISAT trials in 1979/80, 14 new synthetics of diverse origin and phenotype equalled the yields and downy mildew resistance levels of WC-C75.

Hybrids

All variability generated in our breeding program is sampled for its potential in hybrid combinations, and thus hybrids are developed from source material progeny, composite population progeny, etc. However, crosses are also made to improve existing parents and between parents known to give good hybrids. Hybrids move through initial and advanced testing phases, and the best ones then go into international testing and AICMIP trials.

Three ICRISAT hybrids were tested in the 1979 AICMIP. In the Advanced Trial ICH-154 gave a performance lower than the trial mean and was dropped. In the Initial Trial, ICH-226[5141Ax (J1623 x 700490)] ranked second and ICH-241 (5141A x Serere 38-142) ranked eighth, with mean grain yields over 29 test locations of 2500 and 2310 kg/ha, respectively, compared to 2390 kg/ha, for the commercial hybrid check BJ-104, Hybrid ICH-241 also performed well in IPMAT-5, ranking fourth over 17 locations in India and fifth over all 29 locations. In the Elite Variety Trial ICH-241 ranked first (2650 kg/ha) and ICH-226 ranked third (2590 kg/ha), compared to WC-C75 at 2420 kg/ha and BJ-104 at 2400 kg/ha.

SEED PARENTS. Only three male-sterile lines (seed parents) of pearl millet are widely available in India for making hybrid combinations. We have therefore become increasingly involved in breeding new seed parents. This involves the discovery of new maintainer lines and the development of male-sterile lines by backcrossing, the incorporation of disease resistance and certain other traits into existing male-sterile lines, and the development of disease-resistant maintainer bulks. Using only downy mildew resistant plants throughout, five maintainer lines from four different sources are in the fifth backcross stage, and their combining ability is being tested. Of 77 "sterile" hybrids that we identified in 1978, none maintained sterility in 1979. Of 94 additional "sterile" hybrids identified in the 1979 rainy season, only 27 maintained sterility in postrainy-season plantings, and these were backcrossed.

We made good progress in the development of downy mildew resistant versions of $23D_2A$ and B lines by using irradiation and subsequent plant x plant backcrossing in the downy mildew nursery. Four downy mildew resistant A/B pairs were selected from the fifth backcross in 1978, from which one was multiplied in the 1979 postrainy season for use in our hybrid program in 1980. The remaining three will be multiplied in the 1980 postrainy season. Some of the initial test crosses made on these male-sterile lines have shown good performance at ICRISAT Center and in Senegal. The sixth plant-to-plant backcross was made for these four pairs during the 1979 rainy season, and 47 derived pairs were selected. We will plant these in the rainy season of 1980 and select phenotypically similar lines for bulking to form four to five A/B pairs.

The improved $23D_2$ progenies took 48-66 days to flower and were resistant to downy mildew but highly susceptible to smut. To incorporate earliness and smut resistance, we made crosses in the postrainy season of 1978, using an early line from USA and five smut-resistant lines as sources. The F_1s were planted at Hissar in the 1979 rainy season, and the F_2S will be planted there in 1980 to screen for the dwarf lines with smut resistance and earliness.

In the rainy season of 1979, crosses were made between maintainer lines and lines with low susceptibility to ergot developed by our pathologists. The derived progenies will be screened for low ergot susceptibility and maintainer reaction.

Distribution of Seed Material

During 1979/80, over 1000 seed samples of breeding material (F_3 and F_4 progenies, inbreds, restorers, population bulks, population progenies, and source material) and finished breeding products (hybrids, synthetics, and experimental varieties) were distributed to requesters in 25 countries. These do not include requests for germplasm lines (handled by the Genetic Resources Unit) or entries in international trials.

In an attempt to assess the use and impact of the material supplied and to identify deficiencies, we developed and mailed a questionnaire to recipients of our pearl millet material. All those who returned the questionnaire indicated that materials supplied by ICRISAT are useful to their programs and that they would like to receive more. Some recipients also listed the useful traits of certain lines.

Biochemistry

Protein and Lysine Contents

Rapid-method analysis of 6400 pearl millet samples from the germplasm accessions and breeding material revealed a wide range in protein and lysine contents. This indicates good potential for improvement of these traits in pearl millet. Several inbred lines with high protein content (up to 21.3%) were identified, and further studies on protein quality and the utility of these lines in the breeding program is in progress.

Grain Quality

Results from the above analyses of grain samples from advanced trials at ICRISAT Center indicate that most of our elite varieties and hybrids have protein contents of over 10% and are thus comparable to commercial varieties and hybrids.

We are now attempting to exploit the weak relationship previously reported (ICRISAT Annual Report 1978/79) between grain yield/grain weight and prote in/lysine contents,

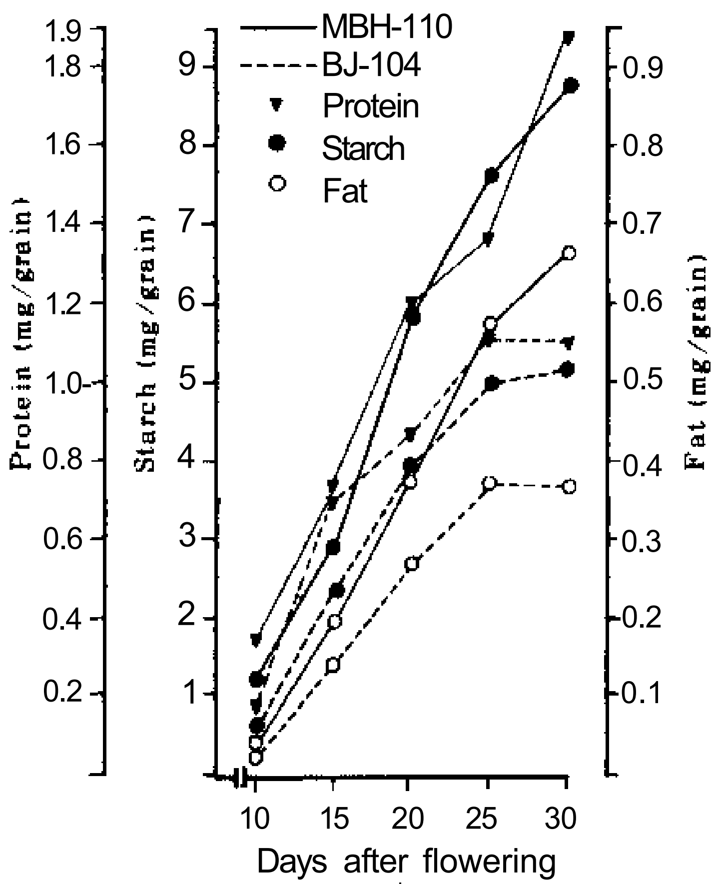


Figure 1. Changes in starch, protein, and fat contents of millet hybrids during grain maturation.

which suggested that, at low to moderate levels of productivity, yield and protein content could be improved simultaneously through breeding. We made crosses between high protein, low protein, high lysine, high grain weight, and some elite breeding lines to study the inheritance of protein and lysine content and subsequent selection in segregating progenies. Progenies from these crosses are now in the F3 stage, and we will use the selected lines to produce synthetics and hybrids. Recurrent selection for both yield and protein level is also being conducted through progeny testing of the World Composite. From the fourth cycle of selection, 22 high-yielding, full-sib progenies with above-average protein content (mean, 12. 9%) and a good level of estimated lysine (2. 9% of protein) were selected for recombination to begin the fifth cycle, after which S_2 progeny testing will follow.

Biochemical Changes During Grain Maturation

The biochemistry laboratory conducted grain maturation studies on five leading millet cultivars-BJ-104, MBH-110, BK-560, BD-763, and PHB-14. Grain samples were collected at 5-day intervals from 10 to 30 days after 50% flowering. The rate of starch, protein, and fat accumulation was higher in the grains of MBH-110 than in the other cultivars, as reflected in their 1000-seed weight at maturity (13.4 g for MBH-110 and 6.1-9. 2 g for the others). The changes in fat, protein, and starch contents during maturation for MBH-110 and BJ-104 are shown in Figure 1. The percentage of starch and fat in grain tends to increase with the advancement of maturation period and that of protein and sugars to decrease during the same period.

Physicochemical Characteristics

We determined some of the physicochemical characteristics in 30 selected millet cultivars comprising popular hybrids and local types. A few of these characteristics were found to be related to the chapati quality of millet in our earlier study. The swelling capacity of flour and the water-soluble protein in these cultivars showed a wide range in values. Further analysis and evaluation of chapati qualities of these millet cultivars is in progress.

Physiology

Cultivar Performance in Low-Fertility Conditions

Because pearl millet is grown mainly in areas where soils are low in natural fertility and chemical fertilizers are not widely used, variety performance under these conditions is more important than variety performance in optimum conditions. The millet breeding program regularly tests breeding materials and finished products under both high- and low-fertility conditions; acceptable performance in low-fertility conditions is an important criterion in the advancement of breeding material to the final product stage.

Little is known, however, about the factors that affect genotype performance in low-fertility environments and how (or even if) such knowledge might be utilized in a breeding program. The Millet Physiology Subprogram has been conducting studies on this problem for several years with two objectives. The first of these is to determine if useful genetic variability exists in the crop for performance under low-fertility soils and whether such variability is simply a reflection of basic genetic yield potential or if it represents a specific adaptation to such conditions. The second objective, which is being pursued jointly with the breeding subprograms, is to evaluate the possibility of directly improving performance of breeding material in low-fertility conditions. For this purpose, we are selecting progeny from three variety crosses and one composite under both high-and low-fertility conditions. Products from each selection environment will be compared for performance over environments beginning in 1982.

To accomplish the first objective, we have developed a test location at ICRISAT Center that provides permanent high- and low-fertility blocks in a replicated design to permit direct statistical comparison of genotype performance in the two fertility conditions (Fig. 2). This location is being utilized to test a set of cultivars and lines from our working collection. Selective crop sampling and nutrient analyses are carried out on the experiments to gain insight into how superior yields could be achieved in both fertility conditions.

CULTIVAR DIFFERENCES IN HIGH AND LOW FERTILITY. In the initial experiment we compared 40 lines representing a wide range of origin, plant type, and degree of eliteness under high-fertility conditions (HF) created by the application of 100 kg/ha nitrogen (N) and 27 kg/ha phosphorus (P) and under low-fertility conditions (LF) of 20 kg/ha N and 9 kg/ha P. The fertility treatment differences were large, whether measured by crop growth, grain yield, or nitrogen taken up by the crop (Table 3). The mean amount of nitrogen taken up by the crop (above-ground parts only) exceeded the amount applied in both fertility treatments (12. 5 g/m^2 vs 10. 0 g/m^2 in H F and 3. 8 g/m^2 vs 2.0 g/m^2 in LF). This may have been due to residual soil N, as soil analysis in subsequent years has indicated the presence of substantial amounts of nitrate in the profile at the beginning of the season. Mean yield levels (Table 3) were 2360 kg/ha for HF and 960 kg/ha for LF. The HF results compare favorably with results of breeding program tests of yield potentials, and the LF results are of the order of mean yields in farmers' fields. There were significant cultivar differences for all crop and nutrient variables measured, including the ability to obtain nitrogen from the soil (rate of N uptake) and the efficiency of utilization of N for growth (dry weight/unit N and grain weight/ unit N, Table 3). Separate analyses of individual fertility treatments confirmed the existence of cultivar differences under LF conditions for all variables measured.

Where cultivar differences under low fertility exist, it is important to know if they are simply a reflection of similar cultivar differences under nonlimiting fertility conditions (i.e. , differences in genetic

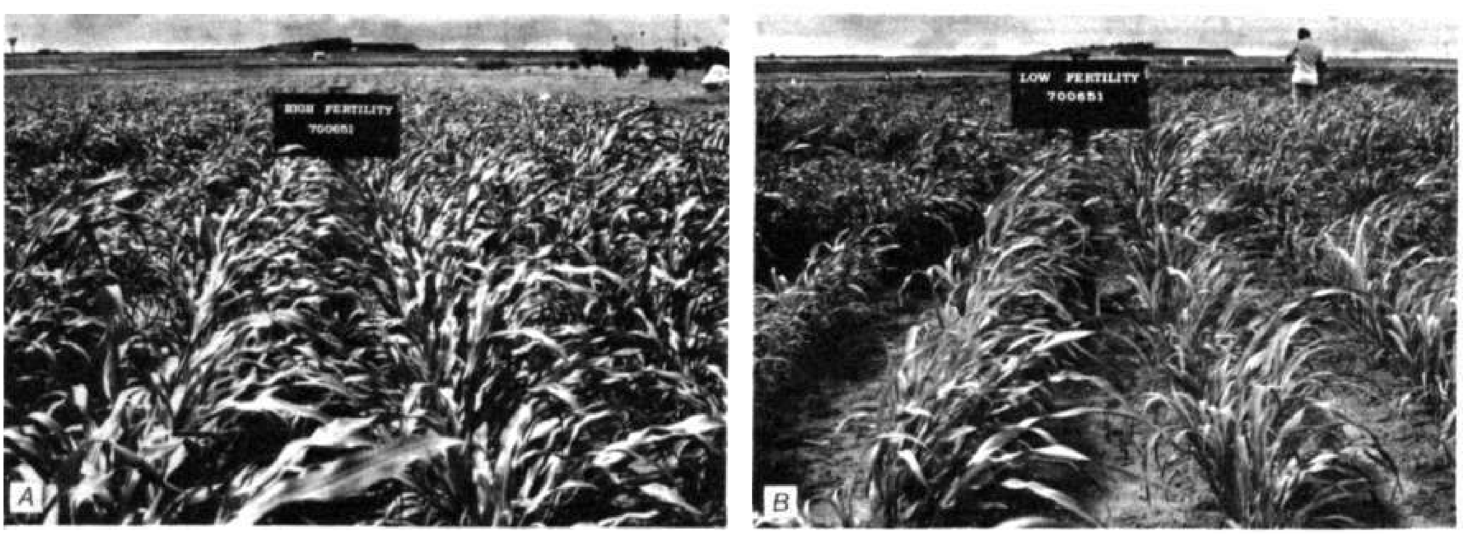


Figure 2. Source material line 700651 under high-(A) and low-(B) fertility conditions at ICRISAT Center.

potential for growth or yield) or if their differing responses are due specifically to the low-fertility conditions. This was examined in two ways —by analyzing cultivar x fertility interactions (Table 3) and by calculating correlation coefficients between HF and LF results (Table 4). A significant cultivar x fertility interaction was measured for the variable of major interest-grain yield— but not for the component processes of grain yield such as rate of nitrogen uptake and efficiency of grain production per unit of nitrogen taken up. Why this should have occurred is not clear; possibly small (nonsignificant) differences in cultivar response to fertility in some of the component processes of grain yield combined to produce a significant difference in the response of grain yield itself to the fertility level.

Correlation coefficients between HF and LF results suggest that the predictability of performance in one fertility level from results measured in the other is not particularly good, although cultivar performance in the two fertility levels is statistically correlated (Table 4). The variability in LF accounted for by the corresponding variability in HF ranged from a low of 15% for total N uptake to a high of 43% for grain yield.

In practical plant breeding terms, however, overall correlations are less important than the ability to identify the best performing lines. Simple comparison shows that the number of lines selected as the 10 best (25% selection pressure) in both HF and LF ranged from a minimum of two for the N uptake rate to a maximum of six for grain yield (Table 4). The data indicate that in general a breeder should be able to identify approximately half of the best performing lines in LF by selecting on the basis of performance in HF; the other half would not be selected.

Taken together, these results (Tables 3 and 4) provide support for the practice of

Table 3. Ranges of cultivar means and analysis of variance for cultivar and cultivar x fertility interactions for nitrogen uptake, crop yield, and nitrogen efficiency variables, ICRISAT Center, 1979/80.

Parameters	Cultivar means		F ratios	
	HF	LF	Cultivar	Cultivar x fertility
Total dry weight (g/m^2)	866	314	**	NS
Grain dry weight (g/m^2)	236	96	**	**
Total crop N (g/m^2)	12.5	3.8	**	NS
Grain N (g/m^2)	4.5	1.4	**	**
Dry weight/unit N (g/g)	71	104	**	NS
Grain weight/unit N (g/g)	19	27	**	NS
Rate of N uptake (g/m^2 per day)	0.17	0.05	**	NS

** $P < 0.01$; NS = Not significant.

Table 4. Correlation of cultivar performance in high-fertility (HF) and low-fertility (LF) conditions and the number of lines in the best 10 in both HF and LF.

Parameters	Correlation of HF and LF values	No. of lines in best 10 in HF and LF
Total dry weight (g/m^2)	0.59	4
Grain dry weight (g/m^2)	0.66	6
Total crop N (g/m^2)	0.39	4
Grain N (g/m^2)	0.50	4
Dry weight/unit N (g/g)	0.39	5
Grain weight/unit N (g/g)	0.60	5
Rate of N uptake (g/m^2 per day)	0.41	2

testing breeding materials in both high- and low-fertility conditions since performance in the latter condition is an important factor in overall cultivar suitability.

BASIS OF CULTIVAR PERFORMANCE IN LOW FERTILITY. The data taken on nitrogen uptake and distribution in the crop permitted analyses of some of the factors responsible for cultivar differences In growth and yield under LF conditions. As an initial hypothesis, total crop dry matter and grain yield were considered to be a product of the following factors:

1. the duration of the crop season during which the crop could obtain nitrogen from the soil,
2. the rate of nitrogen uptake from the soil during that period (assumed to be linear), and
3. the efficiency of production of dry matter or grain from each unit of nitrogen taken up.

We used these three parameters as independent variables (logarithmic form) in a linear multiple regression equation, theresuits of which are presented in the form of the percentage of the total sums of squares accounted for by each factor (Table 5). Interestingly, the results were nearly identical for both HF and LF. Variation in rate of nitrogen uptake was the major determinant of variation in total dry matter produced by the crop. In the case of grain yield, however, variations in both rate of uptake and efficiency of utilization of nitrogen were equally important in explaining variation in grain yield. In neither case did variation in season length contribute to variation in crop growth or yield.

We are continuing these studies in order to determine if the patterns observed in the initial experiment are repeatable over time and over varying weather conditions. In addition, crosses have been made with several of the lines that showed good yields in LF, and a selection experiment has been initiated to compare the effects of direct selection in LF conditions with those of the normal procedure of HF selection.

Table 5. *Percent of sums of squares for both total growth and grain yield accounted for by season length, rate of nitrogen uptake, and efficiency of dry-matter production per unit of nitrogen (all variables in logarithmic form: Regression model $Y=b_1x_1 + b_2x_2 + b_3x_3$).*

Parameters	Duration	Rate of uptake	Efficiency of production
Total dry weight			
HF	6	70	24
LF	0	77	23
Grain yield			
HF	2	55	43
LF	4	49	47

Entomology

Insect Pest Incidence

Insect pest incidence was monitored on pearl millet hybrids BJ-104 and ICH-105 and on experimental variety WC-C75 in an effort to quantify pest problems in the 1979 postrainy season and to assess the relative abundance of different insect species. About 25 insect species were observed feeding on the crop at different growth stages. *Rhopalosiphum maidis, Peregrinus maidis*, *Oxycarenus leatus, Calocoris angustatus*, *Agrotis* sp, and *Thrips* sp were common. The known pest species, *Athevigona approximata* and *Chilo partellus* did not cause appreciable damage this season. Generally, plants were able to cope with the insect populations recorded, but heavy thrips incidence on earheads did reduce seed set in some genotypes. Coccinellid predators *Chilomenes sexmaculata* and *Illeis indica* kept aphid populations under control.

Wireworm

In preliminary studies on the nature of damage caused by wireworm grubs and their response to moisture and farmyard manure (FYM), we found that both grubs and adults feed on the germinating seeds and cut the seedlings at the soil surface. Later, on surviving seedlings, the roots are damaged. Wireworm damage usually occurs in patches. Moisture did not attract the grubs, but they moved into FYM. Further studies will be carried out to utilize the attractant properties of FYM to design appropriate control measures.

Host-Plant Resistance

Observations were made on cutworm (*Agvotis* sp) incidence in some pearl millet and minor millet genotypes. The pearl millet lines were least attacked; finger and proso millet were more susceptible.

We observed heavy thrips incidence on earheads during March 1980. Thrips populations were estimated in pearl millet genotypes by oil smearing and alcoholic immersion techniques. There were an average of 7.0, 7.3, and 3.1 thrips in the top, middle, and lower portions, respectively, of ICH-105 earheads. Entries SAR-1805, P-3, NEP 11-5003, ICI-7530, and BJ-104 showed fewer than 10 thrips perearhead compared to fewer than 50 thrips on SAR-116, SAR-1254, and ACC-154.

Pathology

Downy Mildew

(*Sclerospora graminicola*)

Resistance Screening at ICRISAT Center

We screened approximately 7000 pearl millet breeding lines, hybrids, experimental varieties, and germplasm accessions for downy mildew (DM) resistance in our 6-ha DM-screening nursery in the rainy season 1979 and again in the postrainy season 1979/80, utilizing the infector-row inoculation system. The susceptible indicator rows planted at frequent intervals developed high DM incidence, indicating adequate inoculum pressure on the test entries.

Of 693 germplasm entries, all of African origin, 492 were DM-free and 145 had low susceptibility (< 10% DM incidence). One selection, J-1798, was highly susceptible (72% DM incidence).

A view of the 6-hectare downy mildew screening nursery at ICRISAT Center. Dark-tipped pegs indicate the position of infected seedlings. Resistant material is seen in the background.

Of 64 ergot and smut low-susceptible lines, 31 were DM-free and 17 others were classed as low-susceptible.

We also screened 103 entries from the All India Coordinated Millet Improvement Project. Three hybrids (MBH-121, CD-24, and MBH-110) were DM-free, and many had low susceptibility. No entry in the population trials was DM-free, though many had less than 10% DM.

Multilocational Testing

We examined the stability of DM resistance through a system of cooperative multilocational testing with the participation of scientists in national and regional programs in India and Africa. Promising entries are first tested at a few key DM hot-spot locations in West Africa and in India in the Pre-IPMDMN. Entries that perform well in the Pre-IPMDMN go forward to the IPMDMN the following year and are tested by scientists in many countries.

THE 1979 PRE-IPMDMN. ICRISAT scientists evaluated the 150-entry trial in Upper Volta (Kamboinse), Nigeria (Samaru), and India (Hissar and ICRISAT Center). No entry was DM-free. Fourteen entries had less than 10% DM at all locations, and 31 entries had maximum DM severity between 10 and 15%. Several entries showed distinct location-specific reactions.

THE 1979 IPMDMN. We sent the 45-entry trial to cooperators at 26 locations in 8 countries in Asia and Africa and received results from 13 locations in 4 countries. Of the 45 entries, 37 had across-location mean severity values of less than 5%, and 7 entries (SSC-7218; T-128-3 x 700404-1-5-5; 700651; J-1586 x 700787-2-10; NC-7174, B-Senegal-2-5; and MPP-7147-2-1) had less than 5%) DM infection index at any location. The performance of the seven entries that have been included in 4 years of IPMDMN tests is shown in Table 6.

Table 6. Performance of entries Included in the International Pearl Millet Downy Mildew Nursery (IPMDMN) over 4 years.

	Mean severity (%)				Max. severity (%)			
Entry	1976	1977	1978	1979	1976	1977	1978	1979
SDN-503	<1	1	3	3	2	8	10	14
700251	1	2	2	1	5	9	11	5
700516	1	3	2	1	15	35	12	6
P-7	3	2	3	3	11	11	12	8
P-10	4	3	4	1		24	12	7
700651	<1	3	4	1	3	28	29	3
SDN-347-1	3	3	4	3	13	16	24	14
J-1593[a]	31	28	14	8	78	78	38	27

a. Susceptible check.

Identification of Differential Hosts

In the 1976 and 1977 multilocational testing program for identification of resistance to DM, several entries showed variation in DM reactions at different locations. We pooled together these entries and initiated an International Pearl Millet Downy Mildew Differential Trial (IPMDMDT) in 1978. In 1979 we sent a 25-entry IPMDMDT to cooperators at six locations in India and West Africa and received results from five locations, including Hissar where the disease pressure was not sufficient to detect any difference in cultivar reactions. The entries that showed variations in reaction among locations in both years (Groups C-H in Table 7) will be used along with some checks from the universally resistant (Group A) and susceptible (Group B) material as a set of differential hosts in race identification work, at the University of Reading, U. K.

Alternative Control

In 1979 we tested three metalaxyl formulations from Ciba Geigy Ltd- Ridomil 25% wettable powder; Apron 35% a. i. seed dressing; and a 25% a. i. liquid formulation - for effectiveness of downy mildew control on four pearl millet cultivars that varied considerably in DM susceptibility.

None of the treatments affected the time to 50% flowering or time to 50% grain maturity. The seed dressing formulation had an increasingly detrimental effect on germination and emergence with increases in the application rate, and cultivars varied in sensitivity to it, with BJ-104 the most affected and NHB-3 the least affected.

All the treatments significantly reduced downy mildew compared to the nontreated check, but the degree of control varied considerably with formulation and cultivars. All treated plots of ICH-105, the most resistant cultivar, remained free from downy mildew throughout crop development. In the treated plots of the other three cultivars, the most downy mildew developed with the liquid formulation and the least with the seed dressing formulation at 4 g a. i. /kg seed. The degree of control was acceptable for ICH-105, BJ-104, and NHB-3 (Table 8) but in the highly susceptible 7042 even the least infected plots had an unacceptably high level of downy mildew (incidence of 47% and infection index of 25%).

Table 7. Downy mildew reactions of promising 1978 and 1979 IPMDMDT entries at ICRISAT Center, Kamboinse, Samaru, and Kano.

Entry	Group[a]	ICRISAT Center		Kamboinse	Samaru		Kano
		1978	1979	1979[b]	1978	1979	1979[b]
700516	A	R	R	R	R	R	MR
700251		R	R	R	R	MR	R
ICI-7530X3/4EB 21-11			R	R		R	R
P-10		MR			MR		
P-7		R	R	R	MR	MR	R
SSC-C x 75		R			MR		
J-1593	B	S	MR	MS	S	S	S
7042		S	S	S	R	s	S
BJ-104		s	S	MR	R	s	s
ICH-105	C	R	R	MR	S	s	s
MC-P x 76			R	R		s	MS
SC-2			MR	MR		s	MS
IP-2045			R	R		MS	MS
2778-22ME			R	R		MS	S
SDN-503		MR			S		
111-B	D		R	MR		S	R
ICI-7620-5			R	MS		s	MR
SSC-H x 76			R	MR		MS	MR
J-2000-1			R	R		MS	R
ICH-107	E	S	R	S	R	R	MR
NEC-7120			R	S		MR	MR
NWC-7085	F		S	R		R	R
J-1399	G		MS	R		S	MS
BD-111		MS	MR	R	S	s	MS
Cassady 87-2-2-5	H		S	S		MS	MR

a. Group A = re8iatant, Group B = susceptible, Groups C through H = variable reactions over locations.
b. Trial not planted in 1978.
R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.
Blank spaces = not tested.

The effect of metalaxyl on yield varied with cultivar, formulation, and application rate. All the treated plots of 7042 and NHB-3 (except NHB-3 plots with 25% w. p. seed treatment) gave significantly higher yields than their respective untreated plots (Table 8). However, the percent increase in yield of treated plots over untreated plots was greater for 7042, and the plots sown to seed treated with seed dressing formulation at 4 g a. i. /kg seed yielded significantly more than the plots with other treatments. ICH-105 and BJ-104 showed no significant differences between the yields of treated and

Table 8. Downy mildew incidence, downy mildew infection index, and grain yield in four pearl millet cultivars grown from seed treated with three formulations of metalaxyl and from untreated seed.

Cultivar	Formulation	Rate (g a. i. /kg)	Downy mildew incidence (%) at 26 days	47 days	73 days	Infection index (%)	Grain yield (g/plot)
ICH-105	Seed dressing	4	0	0	0	0	940
	Seed dressing	2	0	0	0	0	816
	25% w. p.	2	0	0	0	0	853
	Liquid	1.5	0	0	0	0	953
	Untreated		3.2	3.3	3.5	2.7	967
	SE ±[a]		(0. 53)	(0. 53)	(0. 59)	(0. 57)	(57. 8)
BJ-104	Seed dressing	4	0	0	0.6	0.2	995
	Seed dressing	2	0	0	0.9	0.4	985
	25% w. p.	2	0	0.7	1.5	0.9	971
	Liquid	1.5	0	1.9	3.5	1.8	1107
	Untreated		63.9	64.3	65.0	64.3	893
	SE ±[a]		(0. 72)	(1.20)	(1.63)	(1.40)	(85.4)
NHB-3	Seed dressing	4	0	1.9	9.9	4.2	831
	Seed dressing	2	0.1	5.5	14.7	6.4	790
	25% w.p.	2	0.1	4.6	18.2	7.4	772
	Liquid	1.5	0	15.4	27.0	11.2	834
	Untreated		80.4	81.7	87.5	83.2	580
	SE ±[a]		(1.01)	(2. 36)	(1. 63)	(1. 50)	(64. 7)
7042	Seed dressing	4	0	7.9	47.0	25.3	383
	Seed dressing	2	0	43.1	72.2	54.2	228
	25% w.p.	2	0	49.5	76.0	59.9	216
	Liquid	1.5	0.4	65.5	88.1	70.9	225
	Untreated		70.8	95.7	98.1	96.8	96
	SE ±[a]		(7.44)	(6. 79)	(4.52)	(4. 68)	(38.1)

a. Standard error of mean, based on arcsin transformation of the percentage values, except for grain yield.

untreated plots, despite heavy downy mildew incidence in the untreated plots of the latter.

Ergot (*Claviceps fusiformis*)

RESISTANCE SCREENING. In the 1979/80 crop year we screened about 1700 West African germplasm lines, breeders' selections from Upper Volta, ICRISAT Center breeding lines, and AICMIP trial entries in unreplicated initial screens (Table 9). From the entries with variable ergot reactions about 180 ergot-free/less susceptible single heads were selected for 1980/81 advanced screening.

The. 751 ergot-free single heads selected from the 1978 initial and advanced screenings were evaluated in head-to-row progenies in five advanced screening trials. Of these, we selected about 100 ergot-free single heads for further evaluation.

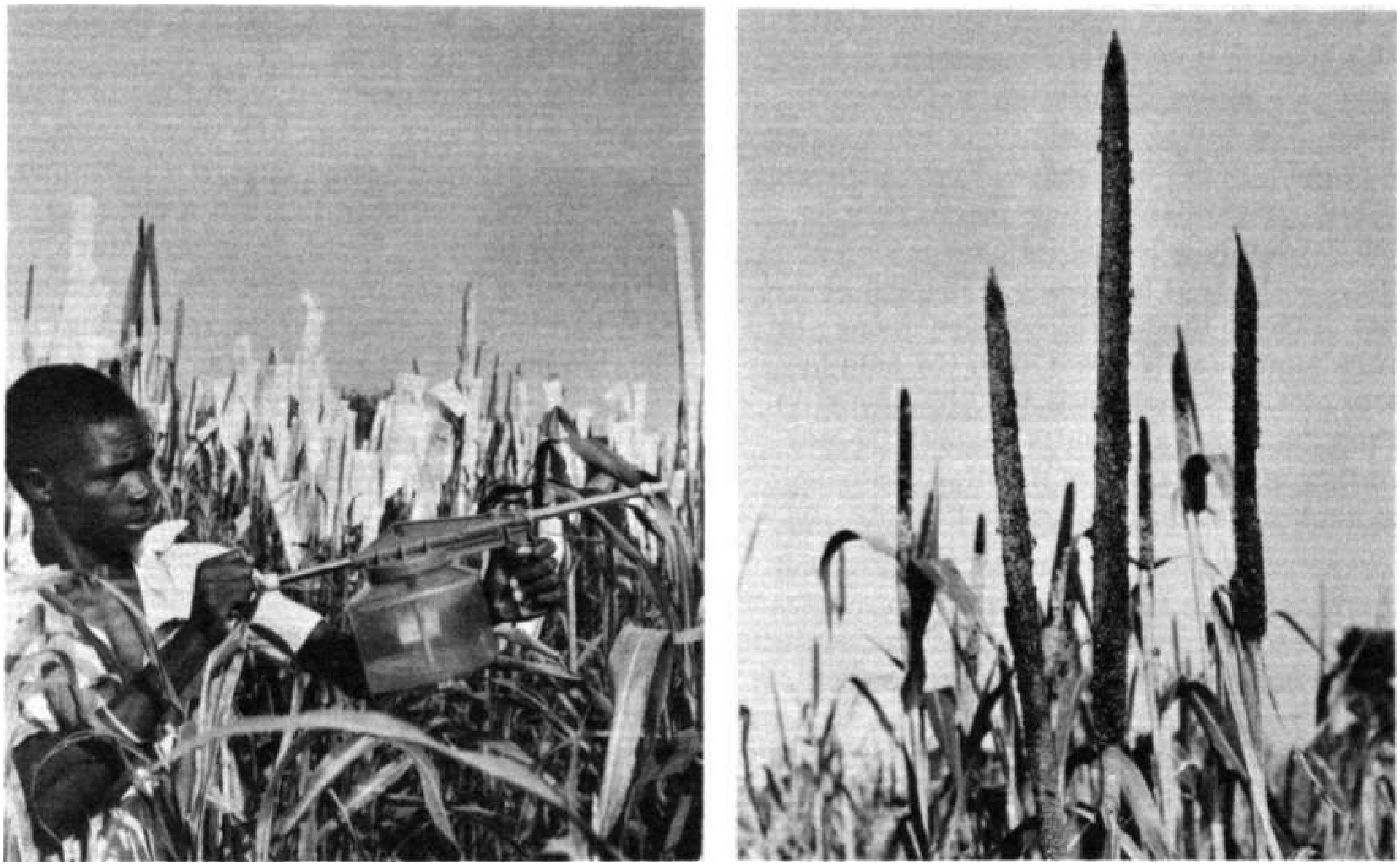
The 27-entry 1979 International Pearl Millet Ergot Nursery (IPMEN) was tested at one West African and 10 Indian locations. Four entries (700457-E-1-DM-4; SC-2(M)-5-4-E-1-6; J-2238 -2-E-4-1; and ExBouchi 700638-3-2-E-1-DM-4) were promising, with across-location mean ergot severities of not more than 11%. These four entries were among the 10 ergot least-susceptible entries in the 1978 IPMEN, and three of them were also resistant to smut and downy mildew in India.

RESISTANCE DEVELOPMENT. In an attempt to assemble scattered resistance genes, 20 pearl millet lines identified as apparently less susceptible in the 1975 and 1976 screenings were intermated during the 1976/77 postrainy season. We continued pedigree selection under artificial ergot inoculation from the F_2 to the F_6 generation (1978-1980), and obtained lines with high levels of ergot resistance (Table 10). In addition to the ergot resistance screening, selected lines (F_4 and F_6) were also screened for downy mildew and smut resis-

Table 9. Percent of peart millet lines in various categories of mean ergot severity, ICRISAT Center, June 1979 to April 1980.

Screen and trial	No. of entries	Mean ergot severity (%) 0-<1	1-10	11-20	21-30	>30
		Percentage of entries				
Initial[a]						
Germplasm lines	368	0	0	1.9	3.5	94.6
Upper Volta selections	651	0	0.9	2.0	3.2	93.9
ICRISAT breeding trials	509	0	0	0.6	2.3	97.1
AICMIP trials	149	0	0	0	0	100.0
Advanced[b]						
Ergot selections	728	0.3	6.4	8.8	12.4	72.1
PMEN[c]	23	0	8.7	13.0	8.7	69.6

a. Based on 10-20 inoculated heads per entry.
b. Based on 20-40 inoculated heads per entry per entry in two replications.
c. Pearl Millet Ergot Nursery.



Pearl millet material being screened in Upper Volta for ergot resistance by artificial inoculation method. At right,ergot-infected millet heads.

Table 10. Development of ergot-resistant lines through selection from F_2 to F_6 generations, 1978 to 1980.

Mean ergot severity class (%)	Generation of selection[a] F_2	F_3	F_4	F_5	F_6
	Percentage of lines in severity class				
<1	0	0	0	1	14
1-10	0	2	15	14	56
11-20	0	6	21	19	18
21-30	6	11	28	16	9
31-40	9	16	22	20	2
41-50	18	16	9	15	<1
>50	67	49	6	16	0

a. F_2 = 33 populations; F_3 = 657 lines; F_4 = 472 linos; F_5=220 lines; F_6 = 572 lines.

tance; a number of ergot-resistant F_6 lines were found to possess good levels of resistance to downy mildew and smut.

RESISTANCE UTILIZATION. The ergot resistance sources that we have developed are being utilized in our breeding projects to produce disease-resistant hybrids and synthetics. Seed of ergot-resistant lines was also distributed to several scientists for utilization in the Indian national program.

CONTROL THROUGH POLLEN MANAGEMENT. Based on the results of the preliminary experiments in 1978, we conducted a replicated trial during the 1979 rainy season at ICRISAT Center. Hybrid ICH-220 was sown in 12 isolation plots (24 m x 20 m) with the pollen donor line SC-2 (M)5-4 planted in every third row in six plots, and without the pollen donor in the remaining six. Three plots with, and another three without, the pollen donor were twice spray-inoculated with honeydew conidial suspension at 2-day intervals during the protogyny-flowering stage. The remaining six plots were water-sprayed to serve as checks. Ergot incidence and severity observations were taken on 200 randomly selected inflorescences per plot. Both ergot incidence (55%) and severity (12%) in the hybrid + pollen donor plot were significantly lower than the sole hybrid plot (90% incidence and 26% severity). Thus the 2 years' results support the possibility of utilization of a pollen donor as a control measure for ergot in hybrids.

Smut

(*Tolyposporium penicillariae*)

RESISTANCE SCREENING. Like ergot resistance screening, smut resistance screening is divided into three phases: initial, advanced, and multilocational testing. The initial and advanced screenings are conducted at Hissar during the rainy season.

Spore balls from freshly collected smut sori from infected earheads are soaked in tap water for about 24 hr. The sporidial suspension so obtained is injected into the boot of each plant, which is then covered with a white parchment paper bag. Smut scoring is done at crop maturity using the system followed the previous year (ICRISAT Annual Report 1978/79, p 77). Smut-free single heads (which of course bear selfed seed) are selected for further evaluation as head-to-row progenies.

We screened about 1100 pearl millet germplasm lines, selections from Upper Volta, and ICRISAT Center breeding lines for smut resistance in the 1979 rainy season initial screen at Hissar. Of 359 West African germplasm lines, 26% were smut-free and only 10% of the lines had more than 10% smut. About 7% of the Upper Volta selections were smut-free, and more than 50% of the lines had 5% or less smut. Among the ICRISAT breeding lines, all the hybrids and male sterile lines were highly susceptible (>20% smut), but 6 of the 23 inbreds were smut-free.

Of 790 entries selected from the previous year's initial screening, 21% were smut-free, 66% had mean smut severities between 0.1 and 10%, and only 13% had more than 10% smut in 1979. In the 28-entry Pearl Millet Smut Nursery (PMSN), five entries (18%) were smut-free and the remaining entries had less than 10% smut.

The 37-entry 1979 International Pearl Millet Smut Nursery (IPMSN) was tested at two Indian and two West African locations. Five entries (ICI 7517-S-1, P-10-S-1, WCFS 151-S-1-1, SSC FS 252-S-4, and EB 229-4-1-S-6-1) were highly resistant, with across-location mean smut severities of less than 1%. In addition, these entries were also resistant to downy mildew in India.

RESISTANCE DEVELOPMENT AND UTILIZATION. We tested 167 F_2 populations from crosses between smut-resistant lines and selected more than 500 smut-free single heads for further evaluation at the F_3 stage. Identified resistance sources are being utilized in the ICRISAT breeding projects to develop smut-resistant hybrids and varieties. Seed of smut-resistant lines was supplied to several scientists for utilization in the Indian national program.

Rust (*Puccinia penniseti*)

INITIAL RESISTANCE SCREENING. During the 1979 rainy season, we evaluated 698 entries for rust resistance at ICRISAT Center. Under severe rust pressure, 30entries (all from West Africa) were rust-free and 84 entries had less than 10% rust on the upper four leaves at flowering.

MULTILOCATIONAL TESTING. We sent a 45-entry International Pearl Millet Rust Nursery (IPMRN) to cooperators at 13 locations in India and one location each in Kenya and Malawi. Results were received from five locations in India. Moderate rust pressure developed at all locations except Hissar, where 39 entries had no rust. No entry was rust-free at all locations, but 20 entries had 10% rust or less at all locations. Of these, eight entries had previously performed well during the 1977 and 1978 testing seasons.

Microbiology

Nitrogen-fixing Bacteria

Large populations of bacteria capable of growing in air on nitrogen-free media exist in soil. Use of the acetylene reduction assay indicated nitrogenase activity for about 60% of these presumptive nitrogen fixers. The number of colony types and the population sizes varied with the carbon in the medium. About four times as many bacteria grew on a sucrose-based medium (a maximum population of 1.3×10^9/g soil) than on one based on malate. Adding a small amount of yeast extract (100 mg/liter) doubled their number on both media. About 50% of these isolates were nitrogen-fixing bacteria. The number in the top 40 cm of soil was about ten times greater than that in the zone from 40 to 60 cm. There were over a million Enterobacteriaceae/g soil, several species of which are known to fix nitrogen anaerobically.

Stimulation of presumptive aerobic nitrogen fixers occurs in the rhizosphere of several plants. Using the cross between *Pennisetum purpureum* and *P. americanum* (Napier Bajra line NB-21), the number of easily recognizable types of bacteria from the root surface that grew on nitrogen-free media was ten times as great (8.3×10^7) as the population growing in the soil away from the roots. A selection for particular types of bacteria also occurred in the root zone, resulting in less than half the types found in the bulk soil. Some bacteria were very

Table 11. Population of aerobic heterotrophs[a] in the rhizosphere and roots of Napier Bajra.

Part	No./g fresh weight	Approximate no. of colony types
Rhizosphere	72.5×10^7	8
Rhizoplane	3.0×10^7	6
Rhizoplane (shaking with glass beads)	7.0×10^7	9
Roots (5 min sterilization[b])	20.0×10^7	7
Roots (15 min sterilization)	7.0×10^7	7
Roots (1 hr sterilization)	4.0×10^5	7
Nonrhizosphere, 0-15 cm	8.0×10^7	17
Nonrhizosphere, 0-30 cm	6.5×10^7	18

a. Counted on nitrogen-free agar medium containing sucrose.
b. Sterilization with 1% chloramine T.

closely bound to the root and perhaps even in the root tissues. After shaking the root with glass heads to remove surface-attached bacteria and then thoroughly sterilizing the root surface with 1% chloramine T for 1 hr, we recovered more than 400 000 bacteria per gram of fresh root from the root macerate (Table 11).

Nitrogenase Activity

We have developed a nitrogenase assay method for intact plants in pots, where only the root system in the pot is exposed to acetylene. The nitrogenase activity is several times greater when acetylene is injected at the bottom of the pot than at the top. The variability between plants grown and assayed in pots was much less than between field-grown plants.

In a screening trial in the field, only 6 of 101 pearl millet lines stimulated a significant amount of nitrogenase activity. The proportion of active lines in the minor millets (consisting of *Eleusine coracana, Panicum* spp, P. *miliaceum,* and *Setaria italica*) was greater (50% active).

Nitrogen Fixation

In pot trials, responses to inoculation of seed with nitrogen-fixing bacteria were obtained with three different media. In nonsterilized soil, inoculation with a mixed inoculum (extract of Napier Bajra roots) increased dry matter by 32% over noninoculated control plants. Inoculation with *Azotobacter chroococcum* also increased growth (by 15%), as did *Azospirillum lipoferum* (by 13%).

In our irrigated long-term nitrogen balance trial with several tropical grasses, maximum dry-matter production has been obtained on small plots (5.4-12m^2) with the

Table 12. Dry matter production and nitrogen uptake by some forage grass species.

Entry	Growth period (months)	Dry matter production Cumulative tonnes/ha	Dry matter production Per day kg/ha	Nitrogen uptake Cumulative kg/ha	Nitrogen uptake Per day kg/ha
Pennisetum purpureum x P. *americanum* (cv JVM-2)	30	136.1	148	1185	1.29
P. *purpureum* (cv Pusa Giant Napier)	42	127.8	100	831	0.65
P. *squamulatum*	42	106	83	744	0.58
P. *purpureum* x P. *squamulatum*	42	85.2	66	667	0.52
P. *massaicum*	42	55.6	44	370	0.29
Cenchrus ciliaris	42	43.3	36	297	0.25
Panicum antidotale	42	27.1	21	198	0.16

Values derived from unreplicated plots of size 5.4 m^2 to 12 m^2 given no nitrogen fertilizer.

hybrid *Pennisetum americanum x P. purpureum* (JVM-2), where an equivalent of 136 tonnes/ha dry matter containing 1185 kg nitrogen have been harvested in 30 months (Table 12). Several other grasses, including other hybrids between pearl millet and Napier grass, have also produced large amounts of dry matter in these plots, which received a total of 120 kg P_2O_5/ha and no nitrogen fertilizer in the 30 months and in which the soil nitrogen content was low (less than 0. 06% nitrogen). Some entries produced much less dry matter, for instance, *Panicum antidotale:* only 27.1 tonnes/ha with 198 kg nitrogen/ha.

Looking Ahead

BREEDING. The breeding program will continue its production of new elite breeding material and to a lesser extent the generation and testing of new hybrids, synthetics, and experimental varieties with stable performance and disease resistances to provide to breeders in the national programs. Intensive efforts will be made to transfer and make available new variability present in unadapted germplasm into adapted backgrounds and also to breed new seed parents. Since full-scale multilocational progeny testing is a resource-consuming activity in the recurrent selection approach, on some composites we will utilize modified methods that permit more selection for plant type and seedling performance under stress.

We will focus on incorporation of identified stable resistance to ergot and smut into breeding material and will study the nature of resistance. Lines identified as "avoidant" and "tolerant" to drought stress will be used in crosses with elite breeding material. Using the pedigree and recurrent selection approaches, breeding will continue, on a limited scale, to examine the possibility of improving both yield and protein content together.

PHYSIOLOGY. Work on evaluation of drought resistance/susceptibility of advanced breeding materials will be expanded. We will conduct all three standard trials (hybrids, synthetics, and experimental varieties) in the summer season stress/no-stress comparisons. These trials will also be grown under naturally occurring stress conditions at the Anantapur Research Station of the Andhra Pradesh Agricultural University in the drought-prone Rayalaseema region of India.

Testing the effectiveness of selection under both low fertility and drought situations will continue, with initial testing of selections expected in 1982.

Our research on millet crop establishment will be intensified in order to improve our ability to select for genetic differences in establishment capability, to ensure that new cultivars will establish as well as the farmers' traditional cultivars.

ENTOMOLOGY. Insect pest problems are not a major limiting factor in pearl millet production in India, unlike Africa, where such insects as borers and head caterpillars can cause severe damage. At ICRISAT Center, our activities will continue to be largely observational, monitoring pest problems on this crop. Germplasm material will also be surveyed. However, no breeding work on insect-pest resistance in India is envisaged unless there are clear indications of specific pests becoming constraints in pearl millet production.

PATHOLOGY. The large-scale downy mildew (DM) screening nursery will continue to operate at ICRISAT Center and the cooperative international Pre-IPMDMN and IPMDMN programs to evaluate the stability of identified resistances will also continue. Studies will be initiated to evaluate the rapidity with which (a) breakdown of resistance occurs in DM-resistant cultivars, and (b) a highly DM-susceptible cultivar can be converted to a DM-resistant cultivar through progeny selection. The IPMDMDT will be continued to confirm differential responses and identify useful new differential hosts, in order to assist the research effort under way at the University of Reading in identification of physiological races of DM.

Multinational evaluation of lines resistant to ergot and smut will be continued through IPMEN and IPMSN, respectively. We will continue screening ergot-resistant lines for multiple disease resistance and will initiate studies on the genetics of inheritance of ergot resistance. A major effort will be made to incorporate ergot resistance into hybrid parents.

For rust, large-scale screening of germplasm at Bhavanisagar and ICRISAT Center and through IPMRN will be continued.

MICROBIOLOGY. As in sorghum, we will concentrate on testing the reliability of our new screening methods and assessing the heritability of the ability of plants to stimulate root-associated nitrogen fixation. Using ^{15}N to label organic matter, we will develop techniques for measuring nitrogen fixation in soil and for monitoring the transfer to plant tissues of $^{15}N_2$ fixed in the root zone. The response to inoculation by nitrogen-fixing bacteria will be examined in field experiments at Hyderabad, Hissar, and Bhavanisagar. We plan to initiate work in West Africa, where sorghum and millet growth without added fertilizer in sandy soils low in nitrogen indicates that considerable nitrogen fixation is occurring.

BIOCHEMISTRY. Studies on the relationship of physicochemical and chapati characteristics of pearl millet will be extended to more pearl millet cultivars in order to verify our findings. Attempts will be made to test the response of consumers in a predominantly millet-consuming area. We will also initiate preliminary studies to evaluate some of the African products.

Publications

Institute Publications

Maiti, R.K., and Bisen, S.S. 1979. Pearl millet anatomy. Information Bulletin No. 6. Patancheru,A. P., India: ICRISAT.

Journal Articles

Thakur, R. P., and Williams, R.J. 1980. Pollination effects on pearl millet ergot. Phytopathology 70:80-84.

Conference Papers

Bidinger, F. R. 1978. Water stress effects on crop-environment interactions. Pages 147-153 *in* Proceedings, Agroclimatological Research Needs of the Semi-Arid Tropics, ICRISAT, 22-24 November 1978, Hyderabad, India.

Subramanian, V., and Jambunathan, R. 1980. Traditional methods of processing sorghum *{Sorghum bicolor)* and pearl millet ((*Tennisetum amevicanum*)) grains in India. Presented at the International Association of Cereal Chemistry Symposium, "Sorghum and Millets,'' 5-6 May, Vienna, Austria.

Miscellaneous

Bidinger, F. R. 1979. Breeding for drought resistance. Pages 452-454 *in* Adaptation of plants to water and high temperature stress (eds. N. C. Turner and P. J. Kramer). New York, USA: Wiley Interscience.

CHICKPEA

Contents

CHICKPEA

International Collaborative Research

International cooperative work continued through the distribution of international trials and nurseries and contact with other programs by meetings and visits. Collaboration increased particularly with the Bangladesh Agricultural Research Institute.

INTERNATIONAL TRIALS AND NURSERIES. We dispatched 86 sets of international trials and nurseries to 41 locations in nine countries (Table 1).

Early-generation Multilocational Trials (MLT) were extended to the F_3 generation, with 12 populations selected on the basis of F_2 performance at several locations. The mean seed yields of the F_2 and F_3 populations in 1978/79 and 1979/80, respectively, are shown in Table 2. Cross numbers 761467 and 761778 gave significantly higher yields than the checks, Annigeri and G-130, in both seasons; but other crosses fluctuated considerably relative to the controls in the 2 years, indicating the importance of tests in more than one season.

The ICSN-DS included 60 lines and the ICSN-DL included 80, both sown as augmented designs. Several lines gave improved yields relative to the controls, particularly in the long-duration group, and will be included in international nurseries or trials in 1980/81.

Sixteen lines were tested in International Chickpea Cooperative Trials—Desi short- and long-duration (ICCT-DS and ICCT-DL). Three were selected for inclusion in the 1980/81 Gram Initial Evaluation Trial (GIET), and other good performers will be repeated in international trials.

DISTRIBUTION OF BREEDERS' MATERIAL. In addition to the trials, we filled requests for 633 samples of parental lines, 112 elite cultivars, 8 F_1s, and 526 segregating bulks and progenies, including breeding lines for high yields, disease resistance,

Table 1. International chickpea trials and nurseries operated by ICRISAT in 1979/80.

Country	F_2 MLT	F_3 MLT	ICSN-DS	ICSN-DL	ICCT-DS	ICCT-DL	Total
Bangladesh			5		4		9
Ethiopia			1		2		3
India	11	10	11	13	4	5	54
Mexico				1		3	4
Nepal				1		1	2
Pakistan				4	1	5	10
Philippines					1		1
Tanzania					1		1
Yemen Arab Republic					1	1	2
Total	11	10	17	19	14	15	86

Table 2. Seed yields (kg/ha) and ranks of F_2 (1978/79) and F_3 (1979/80) populations in trials at several locations in India.

Cross no.	Pedigree	F_2[a] Yield	F_2[a] Rank	F_3[b] Yield	F_3[b] Rank
76153	Annigeri x SL-972-A	2345	6	1124	14
76258	G-130 x 850-3/27	2138	12	1571	3
76655	JG-62 x Annigeri	2350	5	1528	5
76705	K-468 x Annigeri	2343	7	1392	11
76793	BG-203 x P-1181-A	2309	8	1528	5
761106	P-2236 x (H-208 x NP-34)	2227	10	1437	7
761172	Chafa x (P-30 x P-458)	2243	9	1427	9
761354	P-436 x F_5 (JG-62 x Radhey)	2614	2	1278	13
761373	P-3552 x F5 (850-3/27 x F-378)	2453	3	1421	10
761467	F_2 (T-3xP-36)-1 x F_2 (JG-62xP-36)-1	2412	4	1696	2
761778	F_2 (P-1363 x E-100)-2x F_2 (C-235x L-550)-3	2792	1	1745	1
762010	F_5 (RS-11 x C-214) x H-208	2193	11	1537	4
G-130	(check)	1950	13	1434	8
Annigeri	(check)	1679	14	1299	12
Mean		2289		1458	

a. Average of five locations. b. Average of eight locations.

high protein, plant type, *Heliothis tolerance,* and other useful characteristics. The requests came from chickpea scientists in 42 locations in 21 countries. Locations in India receiving our material this year were Dholi, 50; Ranchi, 100; Sardarkrishinagar, 19; Junagadh, 5; Hissar, 63; Palampur, 172; Gulbarga, 42; Rahuri, 8; Jabalpur, 36; Imphal, 11; New Delhi, 38; Nayagarh, 4; Gurdaspur, 13; Pantnagar, 38; Varanasi, 13; Berhampore, 21 samples.

COOPERATION WITH ICARDA. We selected 18 advanced lines from our kabuli breeding program for inclusion in ICARDA's international nurseries. In addition, four F_2 populations of the desi type from two *Ascochyta*-resistant parents were sent for testing for resistance screening.

COOPERATION WITH AICPIP. Cooperation with the All India Coordinated Pulse Improvement Project continued. Eight ICRISAT breeding lines (ICCC-14 to -21) were included in the 1979/80 GIET, but due to emergence problems none were promoted to Gram Coordinated Varietal Trial (GCVT) for 1980/81. Two of the five lines already in GCVT-ICCC-4 and ICCC-13-which were among the top entries in the peninsular and central zones of India, will be continued for another year. ICCC-4, for which this will be the 3rd year, will be a candidate for release in these zones in 1981/82 if its performance is maintained. In addition three kabuli lines (ICCC-24, -25, and -26) are included in the coming season's kabuli trial. One set each of GIET and GCVT was grown at Hyderabad. ICRISAT staff participated in the All India Rabi Pulse Workshop at Hissar in September.

BREEDERS' MEETINGS. The Sixth International Chickpea Breeders' Meeting held at ICRISAT and Haryana Agricultural University, Hissar, is discussed in the "International Cooperation" section of this Annual Report.

TRAINING. Two trainees from Sudan and Afghanistan attended a 6-month training course at ICRISAT Center on chickpea breeding techniques (more details under "International Cooperation").

Breeding

The development of early desi genotypes adapted to peninsular Indian conditions continued at Hyderabad (17°N), and work on late desi and kabuli genotypes for north Indian conditions proceeded at Hissar (29° N). We also initiated testing of desi genotypes at a third location, Gwalior (26°N), representative of central India. Development of kabuli genotypes adapted to western Asia continued in our joint program at ICARDA (Aleppo, Syria). In addition, lines and segregating populations were tested by cooperators at centers in India and elsewhere.

Breeding Methods

The F3 generations of six crosses advanced by single-seed descent or by pedigree or bulk methods were grown. The F4 populations will be space-planted in 1980/81 for single-plant selection.

The value of multiple crossing was evaluated in single, three-, and four-way crosses involving Annigeri, ICCC-1, ICCC-2, and 850-3/27.

Rapid Generation Turnover

Our previous studies have demonstrated that generation turnover, and thereby the rate of genetic improvement, may be increased by hastening maturity of chickpea by extending day length with artificial light (see Chickpea Physiology section for details) and by raising off-season nurseries in Kashmir, or at Hyderabad, provided the crop is protected from rainfall.

OFF-SEASON NURSERIES. We advanced 221 F_1, 73 F_2, and 650 F3 to F_8 bulks and progenies in an off-season nursery of 0.4 ha at Tapparwaripora in Jammu and Kashmir state, India. Sowing was completed in the 1st week of June, and the crop was protected against diseases and insects. Crop growth and development were excellent, although the high nitrogen application (100 kg N/ha) slightly delayed maturity. The seed harvested was sown at Hyderabad and Hissar by early October and gave excellent germination.

At ICRISAT Center, chickpea has been largely unsuccessful during the rainy season (June to September)due to high temperatures and foliar diseases associated with rainfall. Rain shelters were used again this year: 45 F_1, 58 F_2, and 503 F_3 bulks and progenies were sown in the 3rd week of July under 25 shelters, each 10-m long and 6-m wide, of polythene-covered conduit-pipe arches erected over about 0. 2 ha of

A view of the expanded chickpea breeding fields at Hissar.

Table 3. The numbers of desi populations and progenies grown at Hyderabad and Hissar, 1979/80.

Generation	Hyderabad Replicated trials	Hyderabad Nonreplicated rows Populations	Hyderabad Nonreplicated rows Progenies	Hissar Replicated trials	Hissar Nonreplicated rows Populations	Hissar Nonreplicated rows Progenies
F_1	171	227		220	45	
F_2	413	33		531		
F_3	204	55		172		
F_4		30	2560		40	1146
F_5			2137			2388
F_6			2001			390
F_7			2661			231
F_8^+			26			214
Total	788	345	9385	923	85	4369

Alfisol. Here too the crop was protected against diseases and insects, and acceptable yields of good quality seeds were obtained for sowing by November.

Breeding Desi Types

In the desi project we made 206 crosses to combine high and stable yield, disease and insect resistance, and desirable seed characteristics.

Table 3 shows the number of segregating populations and lines from previous crosses. F_1 and F_2 tests of diallel and line x tester sets indicated that genetic variation for important characteristics was predominantly additive.

Early generations continued to be handled by bulk methods: 162 F_2 and 12 F_3 bulks were tested in replicated trials at Hyderabad, Gwalior, and Hissar. Of these, we also distributed 46 F_2 and 12 F3 populations to seven cooperators in India for testing and selection for yield and other characters.

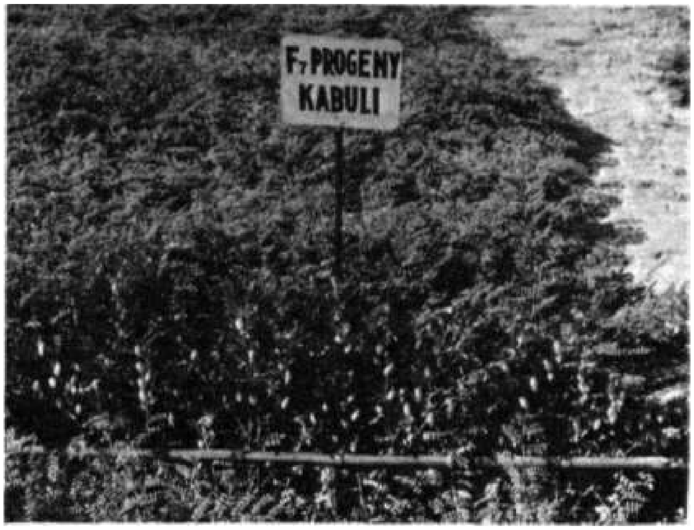
Single plants were selected in the F4 and more-advanced generations; and promising uniform progenies were bulked in the F_5 and more-advanced generations for inclusion in the desi short-duration (45 lines) and long-duration (60 lines) International Chickpea Screening Nurseries (ICSN-DS and ICSN-DL), respectively, in 1980/81.

Breeding Kabuli Types

Our kabuli breeding program in India is now conducted entirely at Hissar and has expanded this year. (See also ICARDA section in International Cooperation report.) We made 70 kabuli x kabuli and desi x kabuli crosses to combine high yield and other desirable agronomic characteristics.

The numbers of segregating populations and progenies of previous crosses are shown in Table 4. As in the desi project, selection in early generations was based on replicated bulk tests. Single plants from rows giving seed yields higher than the moving average of the checks in F3 and more-advanced progenies were selected for further progeny tests and replicated yield trials in 1980/81.

We included 201 F_4 and more-advanced lines in replicated trials and selected superior kabuli and near-kabuli types for further testing. And 25 advanced-generation lines



A high-yielding kabuli line of chickpea developed at ICRISAT.

Table 4. The numbers of kabuli populations and progenies grown at Hissar in 1979/80.

Generation	Populations	Progenies
F_1	143	
F_2	245	
F_3	61	88
F_4	81	905
F5	49	721
F_6+	71	206
Total	650	1920

that gave yields significantly higher than the check L-550 will be included in replicated trials in the coming season.

Extending Adaptation of Chickpea

We continued our investigations to identify genotypes adapted to new cropping systems and environments.

EARLY SOWING IN LOWER LATITUDES. In peninsular India rapidly increasing temperatures and moisture stress terminate crop growth in February, The season may be extended by advancing the sowing of chickpea from October to mid-September, just before the end of the rains. This practice may also be expected to result in improved germination and better use of conserved moisture.

We evaluated 63 lines identified in 1978/79 (mostly of intermediate duration and better adapted to earlier sowing) along with 247 germplasm lines not formerly screened in early-sown conditions. These were grouped in five trials according to growth duration.

The seed yields of the three highest yielding entries in each trial are compared with those of G-130 and Annigeri in Table 5. The highest yields were recorded in trials 2 and 3, comprising lines of intermediate growth duration. In contrast to normal (mid-October) sowing, the long-duration G-130 gave seed yields higher than the short-duration Annigeri in four of the five trials. The lower mean seed yields of G-130 (560 kg/ha) and Annigeri (807 kg/ha), sown at the normal time in an adjacent field, indicate a substantial advantage for the early-sown crop. We have selected 47 highest yielding entries for comparison in early- and normal-sown conditions in 1980/81.

LATE SOWING IN HIGH LATITUDES. For north India there is an increasing interest in chickpea genotypes that maintain yield with late sowing after the rainy-season crops: sorghum, pearl millet, maize, or paddy.

Previous years' tests of 12 contrasting genotypes sown at the usual time and late at Hissar indicated little interaction between genotypes and sowing dates for most characteristics. This year the comparison failed due to poor emergence and variable growth in the late-sown treatment and will be repeated in 1980/81. Consistent performers in 3 years' tests of 188 desi and kabuli germplasm and breeding lines will

Table 5. *Seed yields of best entries and G-130 and Annigeri controls in early-planted experiments on chickpea at Hyderabad, 1979/80.*

Trial 1 (108 DM)[a]		Trial 2 (116 DM)		Trial 3 (132 DM)		Trial 4 (140 DM)		Trial 5 (152 DM)	
Entry	Yield (kg/ha)	Entry	Yield (kg/ha)	Entry	Yield (kg/ha)	Entry	Yield (kg/ha)	Entry	Yield (kg/ha)
7357-22-3-B-BH-BH	1290	P-1329	1635	73111-8-2-B-BP	1696	Check-2	1561	PUSA-63	1403
P-1292-1	1248	P-4089-1	1559	P-1067-1	1606	P-156	1554	73187-3-3-3H-BP	1294
73129-16-1-B-BP	1239	P-1515-3	1534	73154-12-1-1P-BP	1468	P-1430	1485	P-476	1272
G-130	880		1167		1321		1408		1242
Annigeri	958		993		1015		906		893
LSD (0.05)	252.4		320.7		328.0		292.4		245.9
CV(%)	15.8		16.2		19.1		18.8		21.1

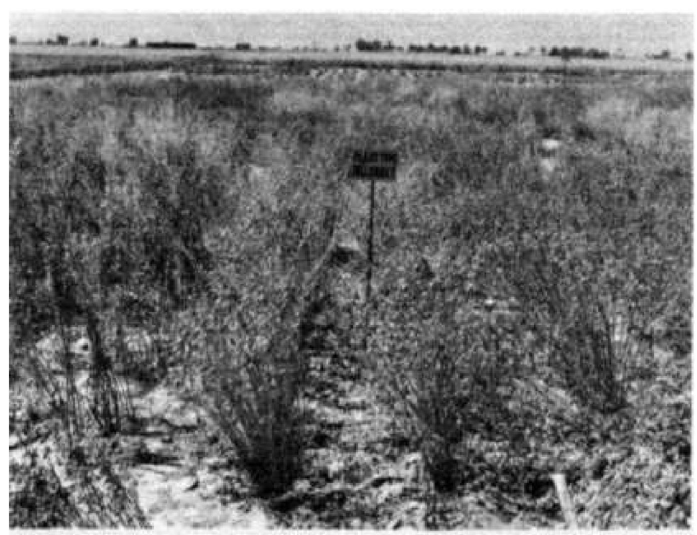
a. DM = Mean number of days from sowing to maturity.

also be compared under early- and late-sown conditions.

Plant Type

PLANT HABIT. The development of tall plant types better suited to mechanical harvesting and with improved yield potential received increased attention. Sixty crosses were made between conventional and tall plant types. F_1 tests of diallel and line x tester sets enabled identification of good combiners and confirmed that genetic variation for most characters is predominantly additive. Bulk selection of tall types in the F_2 was followed by single-plant selection in subsequent generations. We bulked 24 uniform and more advanced lines for plant-type x density trials at Hyderabad and Hissar.

Plant-type x density trials were conducted in collaboration with the Physiology subprogram. Mid-tall, compact F_6 lines were compared with conventional types at three plant densities (8, 33, and 67 plants/m^2) at Hyderabad and Hissar. Four lines at Hyderabad and six at Hissar gave yields comparable to the best local checks and have been included in the crossing block to



The development of tall, erect plant types of chickpea suited to mechanical harvesting and with improved yield potential is receiving increased attention at ICRISAT.

start a second cycle of crossing to improve yielding ability.

MULTISEED AND DOUBLE-PODDED TYPES. Thirty-two crosses were made to combine the multiseeded and double-podded characters and to incorporate them into improved agronomic backgrounds.

Breeding for Disease Resistance

Using pedigree and backcross methods, we continued to incorporate resistance to *Fusarium* wilt, *Ascochyta* blight, chickpea stunt, and dry root rot into adapted genotypes.

***FUSARIUM* WILT.** We made 42 crosses involving wilt-resistant parents, and advanced the F_1 generations of previous crosses in off-season nurseries. More than 5000 single plants and 214 progeny rows were selected for further testing from 171 F_2 populations and 2070 single-plant progenies of F_3-F_8 generations screened by pathologists in wilt-sick plots. In addition, four advanced-generation, wilt-resistant lines that gave higher yields than Annigeri and CPS-1 in replicated trials will be further tested in the coming season.

A notable achievement is the identification of two advanced-generation kabuli lines with wilt resistance. These lines are ICCL-80002, from a cross between K-4 and WR-315, and ICCL-80004 from a cross between L-550 and USA-613. ICCL-80004 and two desi types (ICCL-80001 and ICCL-80003) will be included in the International Chickpea Root Rots/Wilts Nursery (ICRRWN) and in the International Chickpea Screening Nursery with five other desi types in 1981.

CHICKPEA STUNT. Caused by the pea leaf-roll virus, this disease is an important virus problem of chickpea. Several crosses were made with stunt-resistant parents, notably P-4353-1; and F_1 and F_2 generation material was tested at Hissar, where natural disease pressure provides adequate screening for resistance. Resistant segregates were harvested and will be further selected for resistance and agronomic characters in the coming season.

***ASCOCHYTA* BLIGHT.** This disease is a major factor limiting chickpea production in western Asia, and incorporation of resistance to it is primarily the responsibility of the ICARDA team. The F_2 populations of crosses made at ICRISAT, involving two lines identified as resistant in isolation plant propagators, were screened at ICRISAT, at ICARDA, and in Pakistan. Resistant segregants were identified principally in crosses involving ICC-1903.

DRY ROOT ROT. Lines resistant to root rot were identified among advanced-generation progenies of parents identified by our pathologists as resistant to *Rhizoctonia* as well as *Fusarium,*

COMBINED DISEASE RESISTANCE. Crosses are being made between parents resistant to wilt, *Ascochyta* blight, or chickpea stunt; and segregating populations are being screened to combine resistance to the three diseases.

Breeding for *Heliothis* Resistance

We made 26 crosses between adapted parents and lines identified by the entomologists as having reduced susceptibility to *Heliothis.* Further evaluation will be made of 121 individual plants with reduced pod borer damage selected from seven F_2 populations of earlier crosses.

Protein Content

Thirty-three crosses made in 1977/78 and 1978/79 for improved seed protein content were advanced to the F3 generation. Because of their late maturity the populations were harvested as bulks for selection for agronomic characteristics and seed protein at Hissar in 1980/81.

Seed protein contents were determined for seeds of entries in international trials and nurseries in several locations in 1977/78 and 1978/79. The results indicate that, while there were large differences in protein content between locations, genotype x location effects were small, and improved lines emerging from the breeding programs were at least similar in seed protein content to existing cultivars such as Annigeri.

Inheritance Studies

MALE STERILITY. Among F_3 progenies of 379 fertile F_2 plants of crosses involving two male sterile plants, 136 were fully fertile and 243 segregated for male sterility. While these and earlier data indicate that inheritance may be controlled by a single recessive allele, the variation in sterility suggests that modifiers or environmental effects may be operating. We have made crosses to transfer the character to adapted cultivars.

DISEASE RESISTANCE. F_1 and F_2 generations of crosses for resistance to *Fusarium* wilt, *Ascoohyta* blight, and stunt were sown in the absence of disease pressure to obtain F_3 progenies. F_2 data indicate that resistance to wilt is conferred by a single recessive gene, and to *Ascoohyta* blight by a single dominant gene.

NODULATION. The F_2 generations of five crosses made for improved nodulation were grownat ICRISAT. Nodule number and weight varied widely in the 100 plants of each population rated. We will next rate parents, F_1, F_2, and F3 progenies for nodulation under controlled conditions. F_3 progenies will also be grown in the field for performance rating.

Biochemistry

In addition to routine screening for protein content, we carried out studies on cooking quality and on antinutritional factors that we have found in some chickpea cultivars.

Cooking Quality

This year we used more cultivars to evaluate the cooking quality of chickpea. Nitrogen solubility index and in vitro protein digestibility studies were carried out, and unlike in pigeonpea, no significant correlation was observed between these variables and cooking time. Using the Instron food testing machine, several tests of texture measurements on cooked, uncooked, and soaked chickpea dhal, and whole-seed samples, were conducted to find out if any correlation exists between cooking time and objective measurements. Results will be reported when our analysis of the data is completed.

Antinutritional Factors

Several antinutritional factors (Table 6) were found in desi and kabuli cultivars of chickpea. The levels of some of the antinutritional factors were higher in desi than in kabuli cultivars. Levels of polyphenolic compounds in whole-seed samples were significantly higher in desi than in kabuli cultivars.

We also observed that most of the polyphenolic compounds were located in the seed coat, and seed coat color appeared to be associated with the concentration of polyphenols, which appeared to have inhibitory effects on the activity of digestive enzymes. Our in vitro protein digestibility studies showed large differences among the whole-seed samples of desi and kabuli cultivars. Polyphenolic compounds exhibited a negative correlation ($P < 0.01$) with in vitro digestibility of proteins and a positive correlation ($P < 0.05$) with trypsin and chymotrypsin inhibitor activities.

Chemical Changes in Developing Pod Walls and Seed

An increase in the accumulation of starch in the seed, accompanied by a decline of

***Table* 6. *Levels of antinutritional factors in decorticated* (*dhal*) *samples of desi and kabuli chickpeas.*[a]**

Component	Desi Range	Desi Mean	Kabuli Range	Kabuli Mean
Trypsin inhibitor[13]	10.0-14.6	12.0	6.7-12.3	9.4
Chymotrypsin inhibitor[b]	7.1- 9.0	7.7	5.7- 9.4	6.5
Amylase inhibitor[b]	7.9-10.4	9.0	5.5-10.0	7.4
Stachyose (g/100 g sample)	1.1- 1.9	1.3	0.8- 1.4	1.1
(g/100 g sugars)	25.0-42.8	30.0	17.9-28.9	23.4
Raffinose (g/100 g sample)	0.4- 0.7	0.5	0.4- 0.6	0.5
(g/100 g sugars)	8.9-13.0	11.1	6.7-11.5	9.3
Polyphenols (mg/sample)[c]	4.1- 6.1	4.7	1.9- 2.3	2.1
In vitro digestibility (%)[c] of protein	52.4-69.0	63.1	70.3-77.6	72.7

a. Based on eight desi and seven kabuli cultivars. b. Units inhibited/g sample.
c. Whole-seed samples.

starch in the pod wall during the early stages of development, indicated that the seed and pod wall did not compete with each other for the accumulation of starch (Fig. 1). In addition, these studies indicated that the decline in the levels of total soluble sugars during the early stages of maturation is due to the decrease of reducing sugars in the seed and nonreducing sugars in the pod wall during the same period. In the seed, the oligosaccharides (raffinose and stachyose) accumulated during the later stages of development, and the accumulation was associated with the decline of mono- and disaccharides during the same period.

Routine Screening

Protein analysis of about 1000 samples representing several cultivars grown at different locations during the 1978/79 postrainy season showed very large differences between locations. The protein content of several cultivars grown at ICRISAT Center under saline field conditions was considerably reduced. Whole-seed samples of about 3000 accessions were analyzed for protein content, which varied from 15. 7 to 27.3%.

Physiology

Flowering Response to Varying Light Intensity

Chickpea is a quantitatively long-day plant: it flowers at a range of photoperiods, but flowering is earlier in long days than in short days. Scientists take advantage of this in rapid generation turnover at ICRISAT, making it possible to harvest more than one crop a year.

To determine the effects of varying light intensities on chickpea flowering time, we mounted two light sources (1000 watt bulbs) on supports 1.5 m from the ground. Four cultivars of decreasing time to first flower (in the order G-130, K-850, CPS-1, Chafa) were planted in 50-m-long rows in the direction of decreasing light from each light source; light intensity decreased geometrically as a function of distance.

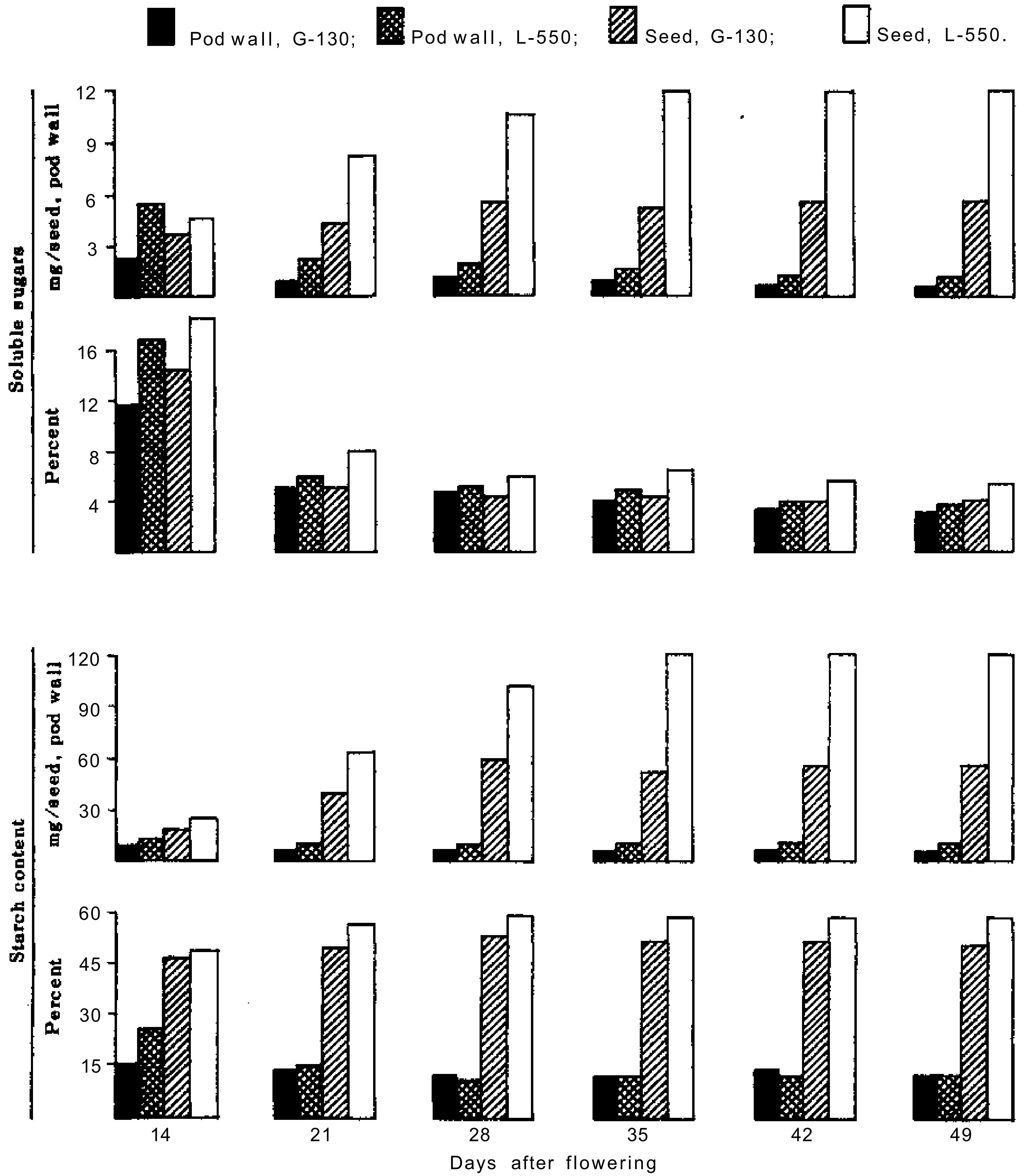


Figure 1, Levels of soluble sugars and starch in pod walls and seeds of chickpea during maturation.

Nearest to the source of light, all four cultivars flowered within 3 days of one another; the range in time to flower increased with decreasing light intensity (Fig. 2). The sensitivity of the cultivars to decreasing light intensity seemed to be related to their duration to flower in natural daylength. The progressive delay in flowering in Chafa commenced below a light intensity of 1-2 lux, whereas in cultivar G-130 the progressive delay in flowering occurred below a light intensity of 5-6 lux. The critical light intensity thus seems to be higher for cultivars of late duration than for early cultivars. These data indicate that it is not necessary to use light intensity higher than 6 lux to induce early flowering.

Germination of Cultivars with Limited Moisture

The often poor chickpea stands in farmers' fields seem to be caused by nongermination of seeds owing to limited seedbed moisture. ICRISAT therefore seeks to develop cultivars that will germinate at low water potentials.

Our earlier studies relied on laboratory tests using osmotic solutions to identify cultivar differences in germinability. In

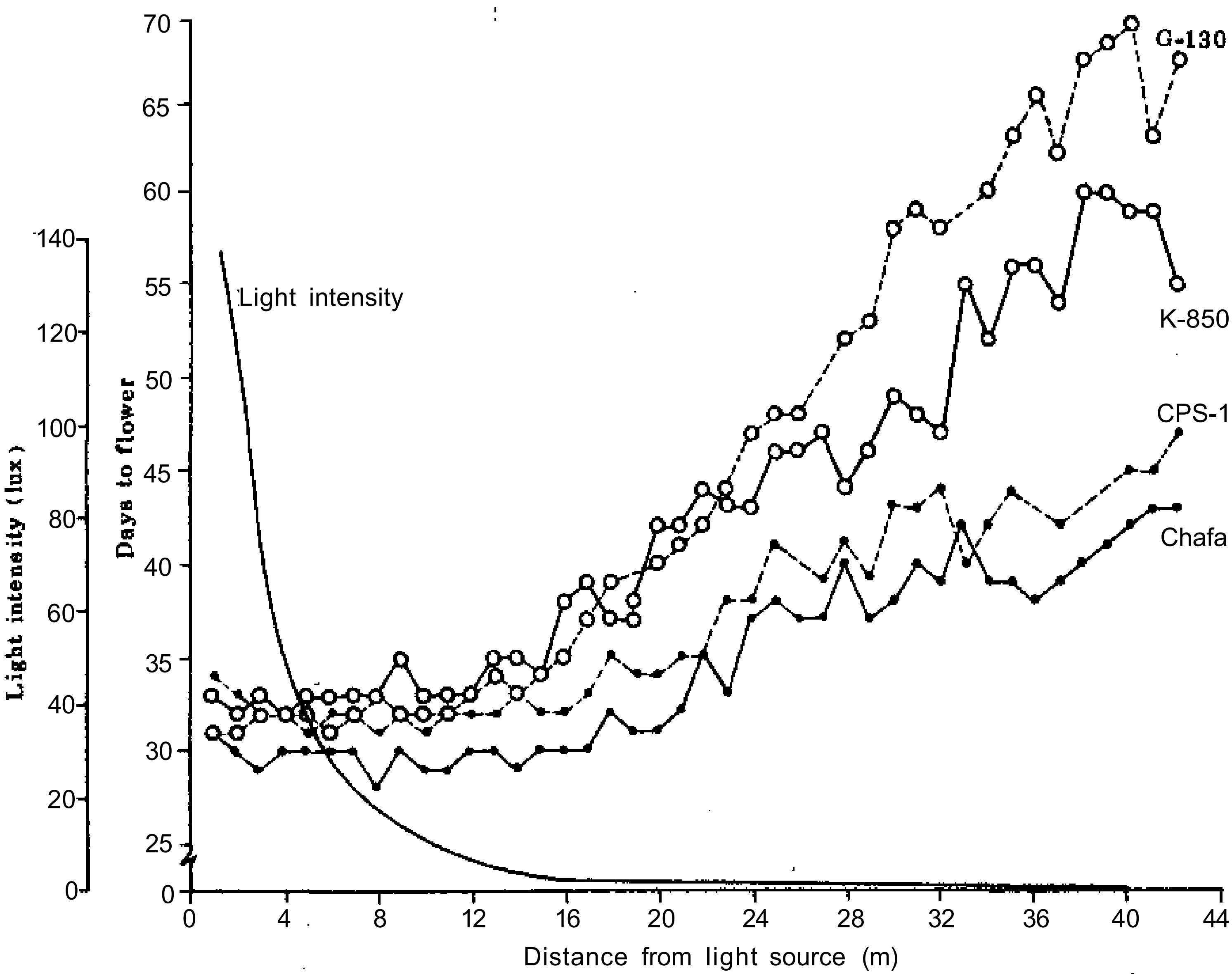


Figure 2. Effect of light intensity on flowering of chickpea cultivars of different durations.

subsequent studies, soils were brought to different moisture tensions in the laboratory, using the relationship between moisture tension and the gravimetric percent moisture content (Fig. 3). They were then packed in seed germination trays at a bulk density of 1.1. The field capacity of the Vertisol used was around 34% moisture content (w/w) and the permanent wilting point was 19%. No seedling emergence occurred under 20% moisture content, but we observed cultivar differences at 21% and 22% (Table 7). Further germplasm screening will be done at 21% moisture content on this Vertisol.

Receding Moisture Effects on Yield

The chickpea genotypes existing in peninsular India exhibit a big response to irrigation compared with those in northern India (ICRISAT Annual Report 1978/79). This response was observed in spite of the fact that the total rain received in the pre-

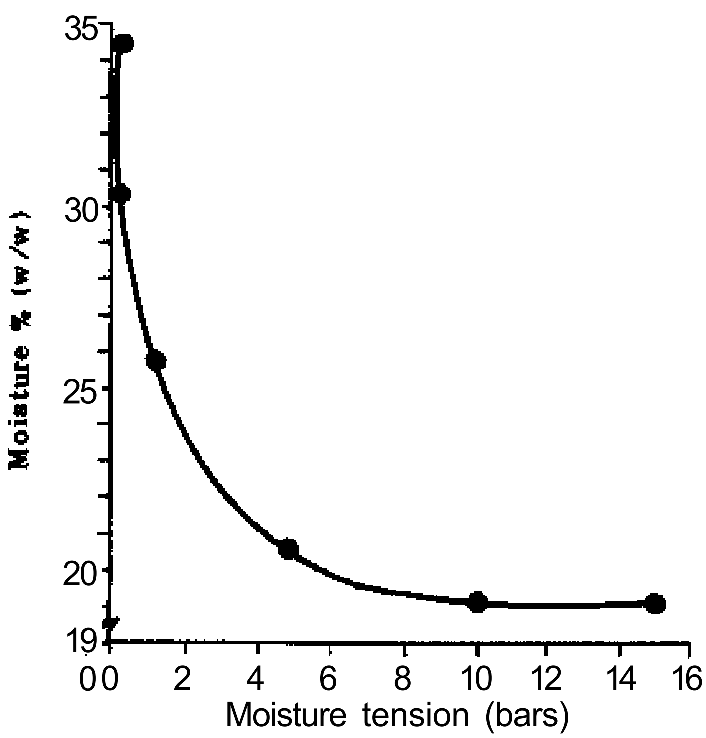


Figure 3. Relationship between moisture tension (bars) and percent moisture contents (w/w) in 0-15 cm layer of the deep Vertisol at ICRISAT Center.

Table 7. Effect of differences in soil moisture content (%) on percent seed germination in laboratory tests at ICRISAT Center, 1979/80.

Moisture %	Chafa	Annigeri	JG-62	CPS-1	K-850	G-130	H-208	Rabat	L-550	NEC-1572	Means for moisture
21	73	20	80	85	60	58	72	25	23	42	54
22	100	88	98	97	77	98	100	65	33	75	83
Means for cultivar	87	54	89	91	68	78	86	45	28	58	

	SE±
Moisture percent	3.9
Cultivars	8.6
Cultivars in a moisture percent	12.1
Moisture percent in a cultivar	12.2

planting season and during crop growth was greater at Hyderabad (860 mm) than at Hissar (400 mm). The cumulative open-pan evaporation values for the short growing season at Hyderabad (112 days) is around 640 mm, which is similar to that at Hissar (632 mm), but at Hissar the crop growth duration is 180 days. The maximum and minimum temperatures during the crop growth period are also higher at Hyderabad than at Hissar. A diurnal measurement of shoot water potential of both irrigated and nonirrigated chickpeas at Hyderabad also reveals that even irrigated chickpeas experience progressively increasing moisture stress during the day, reaching a maximum between 1200 and 1400 hr. As crop growth advances, the plants are under a progressively increasing water deficit.

To evaluate the relative drought tolerance of chickpea, we grew cultivars with and without irrigation on an Alfisol with low water-holding capacity, and also on a Vertisol. The yield under nonirrigated conditions expressed as a fraction of the yield under irrigation was taken as an index of drought tolerance.

A negative correlation exists between days to flower and yield under stress and the drought tolerance index of the cultivars both on an Alfisol (Fig. 4) and a Vertisol (Fig. 5). This relationship indicates that the early cultivars tend to escape drought because they are harvested before the severe soil and atmospheric water stress towards the end of the season. The stress and nonstress yield were positively correlated (r=0. 72, $P < 0.01$), suggesting that yield potential with irrigation can give some indication of performance under nonirrigated conditions. The performance of cultivars without irrigation was closely and positively correlated (r=0.90, $P < 0.01$), with the drought tolerance index in both the Alfisol and the Vertisol. The cultivar ranking for nonirrigated yield as well as the drought tolerance index were fairly closely related between the Alfisol and Vertisol (Table 8).

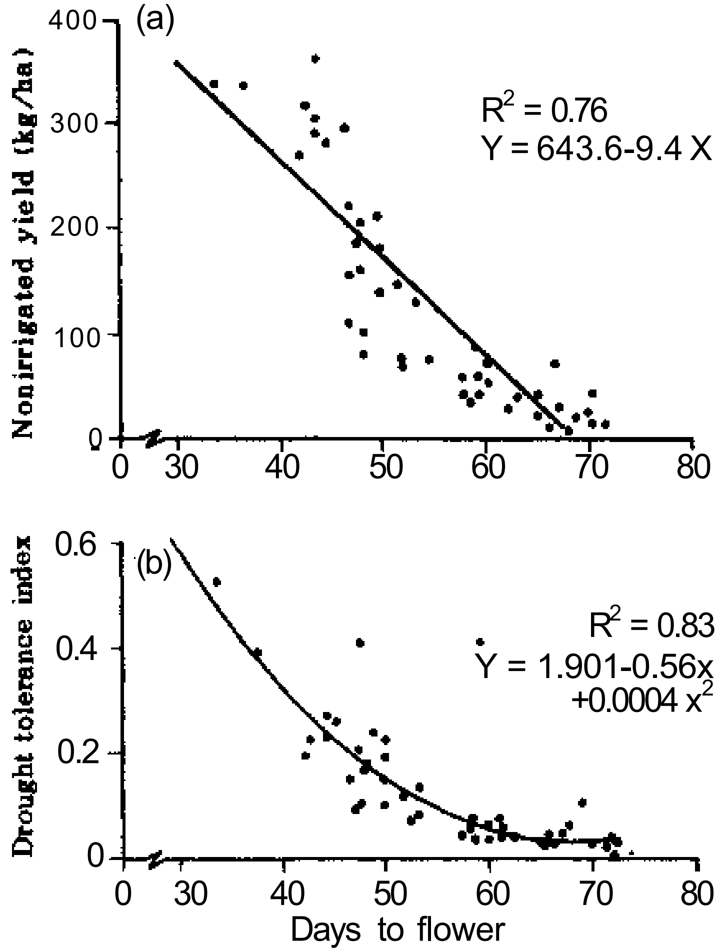


Figure 4. Relationship between days to flower and (a) nonirrigated yield, and (b) drought tolerance index (ratio of non-irrigated/irrigated yield) at ICRISAT Center on an Alfisol, 1979/80.

Drought response was also measured by a multiple regression analysis, which took account of the effects of escape and the yield potential of each cultivar. Yield under stress was considered as a function of yield potential and time to flower. The variation unexplained by this multiple regression was used as a measure of drought tolerance.

On the basis of these two calculations of the drought tolerance index, cultivars K-850, Annigeri, and NEC-229 exhibited fairly consistent drought tolerance over 3 years in four different trials. But further confirmation of the reproducibility of the results of this screening procedure is necessary before it can be put to use in breeding programs.

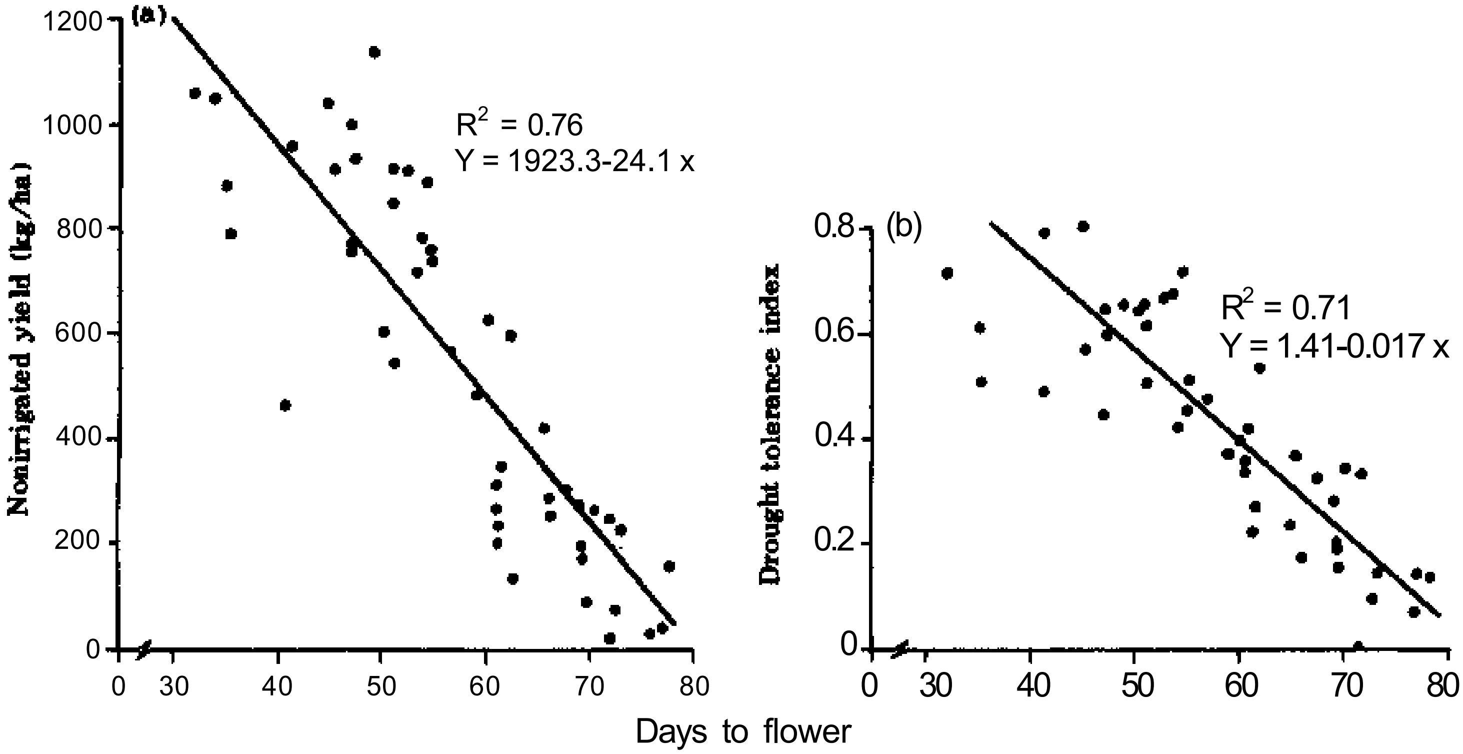


Figure 5. Relationship between days to flower and (a) nonirrigated yield, and(b) drought tolerance index (ratio of non irrigated/irrigated yield) at ICRISAT Center on a Vertisol, 1979/80.

Table 8. Correlation in yield and drought tolerance between an Alfisol and a Vertisol at ICRISAT Center, 1979/80.

	1	2	3	4
1. Nonirrigated yield,Vertisol	1.0			
2. Nonirrigated yield, Alfisol	0.88**	1.0		
3. Drought tolerance - Nonirrigated/ Irrigated yield, Vertisol	0.93**	0.85**	1.0	
4. Drought tolerance - Nonirrigated/ Irrigated yield, Alfisol	0.86**	0.98**	0.85**	1.0

**P< 0.01.

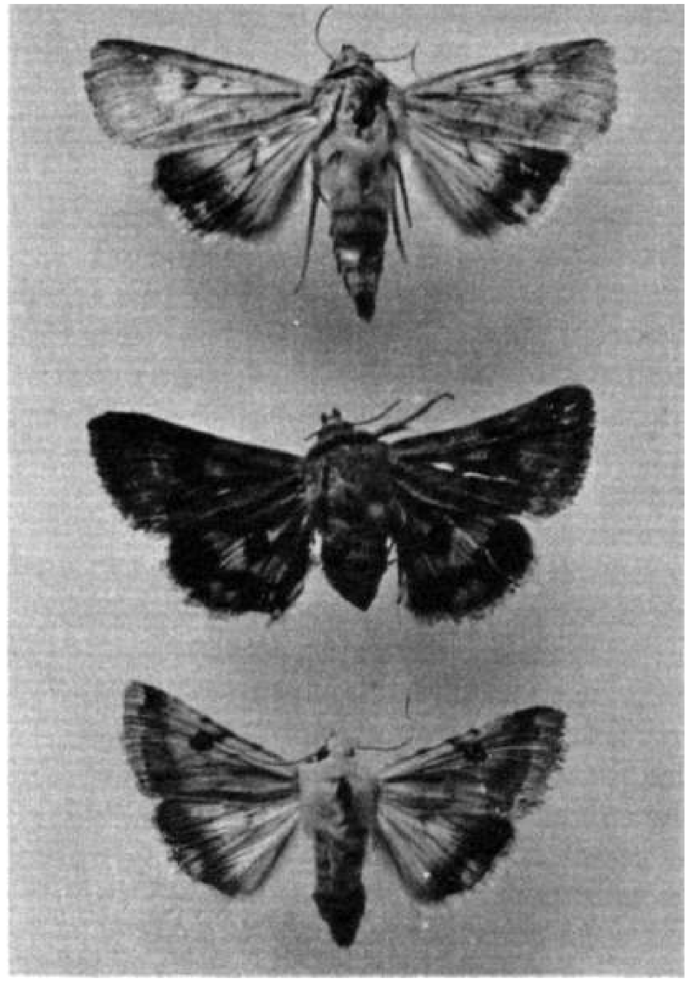
Entomology

Pest Damage Surveys

In our continuing efforts to determine the pest damage patterns in chickpea across India, we surveyed the crop in several areas during the vegetative stage and at maturity. In our vegetative-stage surveys we visited a total of 40 farmers' fields in six states (Andhra Pradesh, Haryana, Karnataka, Madhya Pradesh, Maharashtra, and Rajasthan). *Heliothis armigera* was particularly common, feeding on leaves, flowers, and young pods in the southern states, but was rare at this time in the major chickpea-growing areas of the north. Cutworms, mostly *Agrotis* spp, and termites were found to be of local importance, killing several plants in some fields, but wilt and root rots were far more common. The overall plant density recorded from these surveys was 19 plants/m^2, in contrast to the commonly recommended density of 33 plants/m^2.

In our surveys that were timed to coincide with crop maturity, we visited 115 farmers' fields across eight states (Andhra Pradesh, Haryana, Karnataka, Maharashtra, Punjab, Rajasthan, Tamil Nadu, and Uttar Pradesh). Pesticides had been used on only five of the farms visited. In these surveys we found the greatest percentage of pod damage (mainly caused by *Heliothis)* in the northern states, particularly in Rajasthan, where an average of 21% of the pods were destroyed. Reports from other entomologists indicated very severe pod damage by *Heliothis* in some areas of the northern states, with crops completely destroyed in one area of Uttar Pradesh. Birds and rats were also recorded to be locally important in damaging pods in some areas.

At ICARDA in Syria in cooperation with its food legume entomology staff we surveyed the incidence of pests and their natural enemies on farmers' fields and on the research farm. The dominant pests were *Heliothis* spp and the leaf miner, which the Commonwealth Institute of Entomology in London identified as *Liriomyza cioerina,* apparently the first confirmed record of that pest from Syria. We plan future work on assessment of leaf miner yield losses and control. Three species of *Heliothis* were found on the crop: *H. armigera, H. viriplaca,* and *H. peltigera.* Many farmers in Syria use "cotton dust," a mixture of DDT and BHC, to protect their chickpea crops against these pests.



Adults of the three species of Heliothis *found on chickpea at ICARDA, Syria: top,* H. armigera; *middle,* H. viviplaca; *bottom,* H. peltigera.

Host-Plant Resistance

At ICRISAT Center the sowing of our host-plant resistance trials was delayed. Most of our materials were not sown until early November, but we were fortunate in receiving late rains and so experienced a generally successful season. *Heliothis* larvae were common on all of our chickpea fields from the seedling stage, with an average of up to five larvae per plant in some plots in early December. As in previous years, all our trials contained selections of a narrow maturity group, with a well-known cultivar of the appropriate maturity as a check. Once again we found that the earlier maturing cultivars yielded best, but with a greater percentage of pod damage (Fig. 6).

In this season we screened 393 new germplasm accessions, and have now screened a total of 11 480 accessions against *Heliothis* over the past 5 years. We reject all accessions that are more damaged and yield less than the common check cultivars and retest the remainder in replicated trials. We have recorded consistent differences in the susceptibility of several selections over the years.

Table 9 shows the data from the screening of our most promising early-maturing desi selections. IC-73128,entered as a "high borer" selection, was the only entry with a greater percentage of pod damage than the common check cultivar Annigeri. The selection from ICC-506 has consistently given the highest yield and a relatively low percentage of pod damage in all unprotected tests in which it was entered at this Center in the past 3 years. Tests by our biochemists show that this selection has a relatively high polyphenol content,

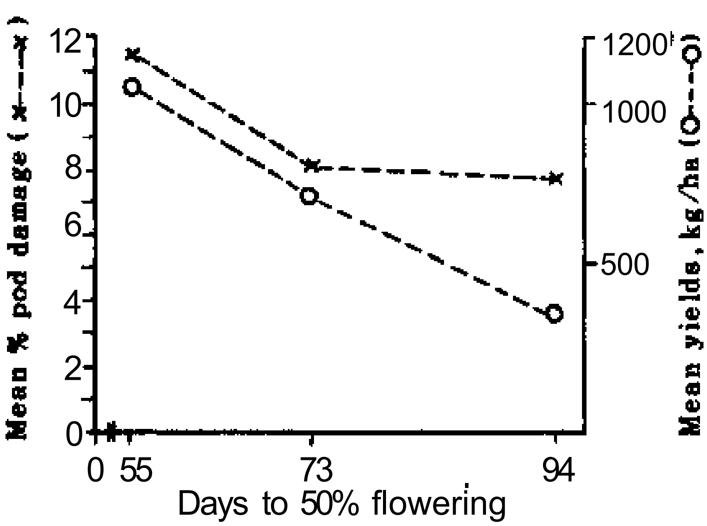


***Figure* 6. *Mean percentage of pods damaged by* Heliothis *and mean yields in kg/ha of the early-, mid-, and late-flowering entries in the unprotected host-plant resistance trials at ICRISAT Center,* 1979/80.**

Table* 9. *Pod damage and yield data from a balanced lattice-square design, pesticide-free trial* (*5 replications*) *of early-maturity desi types selected for differences in susceptibility and tolerance to* Heliothis *damage at ICRISAT Center, 1979/80.

Selections tested	Mean pod damage (%)	Mean yield (kg/ha)
ICC-8334	12.2	879
ICC-1403	7.9	656
IC-73128-5-1-2P-BP	17.7	992
JG-1252	12.3	1071
Phule G-4	14.4	1071
444	9.5	823
IC-73136	11.9	921
ICC-506	5.7	1333
Phule G-1	11.7	988
IC-738	5.7	1053
IC-7394-18-2-1P-BP	8.0	1021
IC-7394-18-4-B	13.2	899
ICC-5639	8.2	784
ICC-5800	10.7	808
ICC-1381	12.0	905
Annigeri-1	15.8	1047
SE ±	0.23	49.4
CV(%)	18.8	11.8
Efficiency (%) compared with RBD	118	150

but as it is mainly concentrated in the seed coat, this is unlikely to be a major disadvantage, for the desi-type chickpeas are mainly consumed as dehusked split seeds (dhal).

In cooperation with the Max-Planck Institute, Munich, we will further investigate this selection's mechanism of resistance, for it also has an obvious advantage in the vegetative stage, being outstandingly tolerant to *Heliothis* larval damage early in the season* We now intend to multiply this selection for more extensive testing in large plots and at several locations.

In general the kabuli types are more susceptible than desi types to *Heliothis* attacks, and at ICRISAT Center we have had less success in the selection for resistance among such types. In our tests this year, however, we were able to confirm that some of our previous selections were relatively less damaged and higher yielding.

In addition to screening selections from the germplasm, we also screen the materials generated by our breeders and pathologists each year and feed the most promising of these into our advanced-stage replicated tests. In turn we supply our breeders and pathologists with seed of the best performing selections for crossing and selection against the important pathogens. We are presently screening the F_2 populations of crosses made by the breeders of our *Heliothis*-resistant selections, and our preliminary observations indicate that there are promising segregants among these populations.

This year we extended our host-plant resistance testing to our subcenter at Hissar, using materials selected at ICRISAT Center in previous years. Soil problems resulted in uneven growth across these trials, but some lines gave promising results, with a selection from ICC-5800 giving the highest yield: more than 2600 kg/ha with a relatively low percentage of pod damage. This entry (ICC-5800 in Table 9) gave a relatively low yield when tested at ICRISAT Center this year, which emphasizes the necessity for multilocation testing and screening of the materials.

We also sent some of our selections for testing at ICARDA in Syria. *Heliothis* were not common when these selections were podding, and differences in susceptibility between the lines were not obvious. Resistance to leaf miner will be of greater interest in the ICARDA region, and we were able to help with the initiation of screening against this pest there.

Ecology and Biology

Again this year our studies on the effect of plant spacing on populations of *Heliothis* larvae showed a large increase in larvae per square meter at closer spacings. At densities of 8, 33, and 67 plants/m^2 we recorded 9, 26, and 45 *Heliothis* larvae/m^2, respectively. In an attempt to identify factors contributing to the formation of the larger populations of *Heliothis* in the more closely planted plots, we recorded the incidence of parasites of *Heliothis;* there was a tendency for parasitism to be greater in larvae collected from the wider-spaced crop.

In our comparisons of pests and natural enemies on pesticide-free crops on and outside our Center, we were surprised to find that early in the season the *Heliothis* attack was lower and parasitism was greater on our research fields than on farmers' fields. During the vegetative stage of the crop the predominant parasite of *Heliothis* was the hymenopteran *Diadegma* sp or *Campoletis ehlovideae* , but later in the season the dipteran parasite *Eucaroelia illota* was most common. Overall parasitism rates varied between 10% and 20%.

Pest Management

Our plant protection unit monitors the pests in our fields and applies pesticides according to the counts and the research objectives of each crop. The entomologists work in close cooperation with the plant protection unit, and we improve our pest management operations and knowledge each year.

This year we tested samples of one of the new synthetic pyrethroids through controlled droplet applications at ultra-low volume

Table 10. Yields from unprotected and endosulfan-sprayed chickpeas at ICRISAT Center, 1976-1980.

	Yields (kg/ha)			
	Desi		Kabuli	
	Unprotected	Sprayed	Unprotected	Sprayed
1976/77	1324	1408	626	972
1977/78	403	527	263	336
1978/79	879	955	632	915
1979/80	1296	1910	1054	1356

and found them to be exceptionally effective. Unfortunately this new generation of pesticides is likely to remain relatively costly, even at the extremely low dosages required, and so will be of little benefit in the near future to SAT farmers. They will continue to use DDT or BHC until a less polluting pesticide with a similar cost/benefit ratio becomes available. Utilization of the controlled droplet applications, which rely upon light breezes to carry the droplets to the crop, will be of limited use in areas such as that surrounding ICRISAT Center, for here the wind speeds for much of each day throughout the crop-pest seasons are in excess of those suitable for this type of pesticide application.

In an annual trial of insecticide use where we compared large plots of protected and unprotected desi and kabuli types, this year's yields were unusually high despite late sowing. In this trial we sprayed according to counts of *Heliothis* larvae, using endosulfan at 0. 5 kg/ha in 100 liters of water. The yield returns from spraying over the past few years (Table 10) have been variable, always positive, but generally insufficient to justify the costs.

Pathology

Surveys

Surveys conducted in three North African countries—Algeria, Morocco, and Tunisia-revealed widespread incidence of *Asoochyta* blight and stunt. Wilt and root rots were minor problems. In Bangladesh, collar rot by *Solerotiwn rolfsii* was common. In India wilt and several root rots were observed, and rust and *Stemphyllium* blight were severe in the chickpea crop at Dholi (Bihar).

Wilt

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

SCREENING FOR RESISTANCE. Of the more than 2600 germplasm accessions screened for resistance to wilt, 133 were found promising (less than 20% wilt incidence, compared to nearly 100% in susceptible lines). These will be tested again. None of the lines that are resistant to stunt disease (pea leaf-roll virus) were found wilt resistant. ICC-3935, which is resistant to *Asoochyta* blight, was also resistant to wilt.

So far, we have identified 41 wilt-resistant lines through repeated screenings. These have been deposited with the Genetic Resources Unit of ICRISAT and are available on request.

BIOLOGY AND EPIDEMIOLOGY. Studies to identify races of *F. oxysporum* f. sp. *ciceri* were continued (see ICRISAT Annual Report 1978/79). Based on results of repeated tests, the following classification of the fungus is proposed: race 1 —the ICRISAT Center, Jabalpur, and Hissar isolates; race 2—Kanpur isolate; and race 3—Gurdaspur isolate. The cultures of these races have been deposited with the Commonwealth Mycological Institute, U.K., and the Indian Agricultural Research Institute.

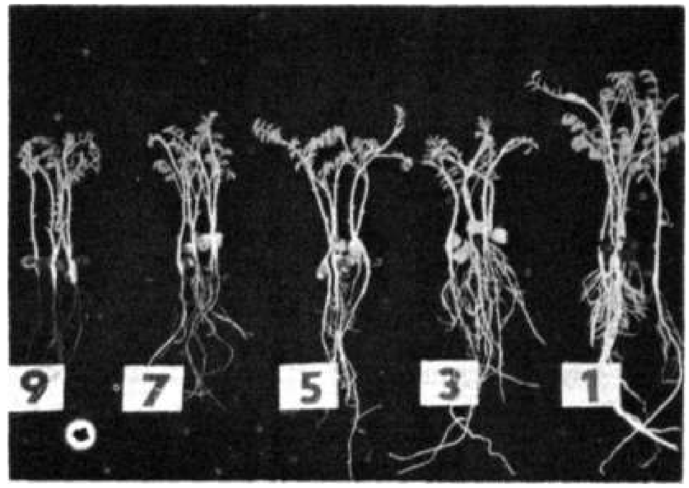
In continuing studies on the survival of *F. oxysporum* f. sp. *ciceri,* we buried infected roots of wilted chickpea plants in soil and removed them every 3 months to attempt fungus isolations. Samples tested after 27 months indicated survival of the pathogen in the host roots. The experiment is continuing.

In order to develop a wilt-sick plot, it is necessary to build up inoculum of the fungus to a level at which the susceptible check lines show near 100% wilt incidence. A study was initiated to quantify the "sickness" in terms of the number of *F. oxysporum* f. sp. *ciceri* propagules. Results of these studies indicated that 3000 fungus propagules/g of soil were sufficient to cause 100% wilt incidence in a susceptible cultivar. Propagule numbers less than 3000 were not tested, and studies will be continued to find out the minimum propagule number for making a soil wilt-sick. The wilt-sick plots at ICRISAT Center contained on an average 4500 propagules/g of soil, which is clearly more than the minimum required.

Dry Root Rot

(*Rhizoctonia bataticola*)

Dry root rot is one of the important diseases of chickpea in the semi-arid tropics. However, no laboratory technique was available to screen germplasm and breeding materials for resistance to this disease. We developed and standardized a simple "blotting paper technique": 5-day-old chickpea seedlings are inoculated by immersing the roots in the inoculum suspension and are incubated in moist blotting paper for 8 days at 35° C. Seedling roots are then examined for damage and scored on a 1-9 scale, where 1 means



Disease rating scale followed for scoring dry root rot of chickpea produced by the use of a laboratory screening technique. 9 = susceptible; 1 = resistant.

no visible infection and 9 means complete rotting. Laboratory screening was initiated first with the known wilt-resistant lines, and lines ICC-554 and ICC-6926 were found resistant also to dry root rot.

Multiple Soilbornc-Disease Screening

A multiple-disease sick plot has been developed at ICRISAT Center. The fungi present in this plot, in order of prevalence, are *F. oxysporwn* f. sp. *ciceri, R. bataticola, Sclerotium rolfsii, R. solani, F. solani,* and a sterile seed/seedling-rotting fungus. Of the 354 wilt-promising lines screened, 195 showed less than 10% mortality. These lines will be tested once more and resistant lines will be included in the ICRRWN of 1981/82. We also screened several lines at ICRISAT Center for cooperators from Badnapur, Delhi, Gurdaspur, and Kanpur in India.

Ascochyta Blight

(*Ascochyta rabiei*)

SCREENING FOR RESISTANCE. At ICRISAT Center, we continued screening kabuli germplasm accessions in isolation plant propagators. Of 743 accessions screened for the first time, only ICC-8078 was found resistant, while 16 lines were moderately resistant. An additional 99 lines were found tolerant. All these lines will be rechecked for their resistance or tolerance.

Of the 195 accessions that showed promise last year, resistance of ICC-3582 and moderate resistance of ICC-3141, -3296, -3377,-3576, -3578,-3585,-3586, -3597, -3599, -3724, -3916, -6840, -6847, and -7676 were confirmed.

Seven lines that were found resistant at ICARDA (Aleppo, Syria) and 19 at Gurdaspur (India), were found susceptible to the IARI isolate of *A. rabiei,*indicatingpossible existence of races of this fungus.

Large-scale field screening of the germplasm and breeding materials was carried out by ICRISAT staff at ICARDA, and 156 resistant lines of both desi and kabuli background were identified.

LEAF EXUDATES AND *ASCOCHYTA* **BLIGHT RESISTANCE.** In an attempt to ascertain the role of leaf exudates in blight resistance, we studied the effect of leaf exudates from resistant and susceptible lines on the germination of *Ascochyta* spores. The data are presented in Table 11. Of the three resistant lines used, only the exudates from ICC-8227 inhibited germination. This study must be extended to include all the known resistant lines so that any differences between their exudates can be observed.

To ascertain if the pH of exudate solutions from resistant lines differed from that of a susceptible line, we measured the pH of the exudates of the lines listed in Table 11. The pH of exudates of 3-month-old Pb-7 (susceptible) plants ranged between 3. 8 and 4.1 during the day, and the pH of the exudates from the three resistant lines ranged between 3. 6 and 3. 8. Thus no clear cut difference in the pH was observed.

Table 11. Influence of leaf exudates[a] of blight susceptible and resistant chickpea lines on germination of* Ascochyta rabiei *spores.[b]

Line	Spore germination[c] (%)
Pb-7 (S)	79.9
ICC-1256 (R)	71.6
ICC-4112 (R)	78.2
ICC-8227 (R)	45.0
Control (distilled water)	88.3

a. 1g leaves, collected from 30-day-old seedlings, immersed in 1 ml water.
b. Spores were collected from 15-day-old fungus cultures.
c. The number of conidia examined ranged between 1100 and 2400.
S = Susceptible; R = Resistant.

Colletotrichum Blight

This blight causes severe damage in early-planted (Aug-Sept) chickpea. Identification of resistance is essential if early planting is to be recommended. All crossing block entries (416) were screened at ICRISAT Center. Only entries ICC-341, -693, -893, and K-1170 showed tolerance; all others were susceptible.

Stunt (Pea Leaf-Roll Virus)

A large number of germplasm accessions and breeding materials were screened at Hissar. To increase natural incidence of the disease in the nursery, several hosts of the virus and its aphid vectors were planted in advance as interlards. Lines that showed 10% or less infection (low infection) in the previous year were selected for further testing.

The 18 lines that showed low infection in four consecutive seasons (1976-80)—ICC-2233, -2385, -2430, -2925, -3034, -3133, -3718, -3735, -6433, -6934, -10490, -10495, -10508,-10586, -10587, -10592,-10594,

-10800—have been used in making crosses. The 26 entries in the crossing block nursery that showed low infection for three consecutive seasons (1977-80) are: NEC-2368, C-235, RS-11, Coll. 327, P-1774, P-2202-2, P-4353-1, G-24, G-130, G-543, Pant G-115, NEC-472, NEC-550, NEC-701, NEC-746, NEC-1135, NEC-2296, BG-482, F-61, F-370, P-1092, P-1781, P-2019-1, T-3, Coll. 238, and ICCC-5.

International Nurseries

Detailed results of the International Chickpea Root Rots and Wilt Nursery (ICRRWN) for 1978/79 are available separately (Pulse Pathology Progress Report-7). We sent 63 entries originating in 6 countries and ICRISAT to 37 locations in 19 countries. Data were received from 16 locations in 7 countries. Four entries (ICC-391, -519, -858, and -7248) performed well across 7 locations, and 8 entries did well across 6 locations (ICC-229, -267, -2104, -2668, -7254, -8933, -10104, and -10394).

Microbiology

Rhizobium Strain Collection

We are maintaining a *Rhizobium* collection representing the major chickpea growing areas of India and six other countries. These strains are available to any interested user. We have sent *Rhizobium* strains or peat inoculants to seven countries including India during 1979/80.

Rhizobium Populations

Population counts of *Rhizobium* in the paddy field at ICRISAT Center (ICRISAT Annual Report 1978/79, p 134) were measured at two intervals after the chickpea crop had been harvested. Although the numbers were relatively high under chickpea, in the subsequent fallow the population of chickpea *Rhizobium* declined 30-fold at the surface

Table 12. Changes in chickpea* Rhizobium *populations with time and soil depth in a paddy field at ICRISAT Center, 1979/80.

Soil depth (cm)	Numbers of rhizobia per gram of dry soil (Log_{10} MPN)[a]				
	Jan 79 (harvested paddy)	Mar 79 (standing chickpea)[b]	June 79 (fallow)	Aug 79 (standing paddy)	Nov 79 (harvested paddy)
0-5	0.43	3.94	2.54	1.75	2.87
5-15	0.32	4.06	2.19	1.75	2.98
15-30	1.25	3.57	1.42	ND	0.92
30-60	ND	3.08	0.45	ND	0.82

a. MPN = Most probable number, estimated by a soil-dilution/plant-infection technique.
b. Chickpea seeds were coated with *Rhizobium* peat inoculant before sowing.
ND = No data – observations not made.

Table 13. **Rhizobium** ***distribution in chickpea field at the end of the growing season; cultivar CPS-1 grown in single rows on ridges 60 cm apart (means of three estimates) at ICRISAT Center, 1979/80.***

Distance	Log_{10} MPN/g dry soil[a]	
	Irrigated 14 times	Irrigated twice
Site of plant	6.10 ±0.36	3.29 + 0.0
15 cm sideways	2.40 ± 0.20	0.21± 0.37
30 cm sideways (bottom of the furrow)	2.09 + 0.17	0.00

a. MPN = Most probable number, estimated by a soil-dilution/plant-infection technique.

and more rapidly with depth. A further decrease was registered when the field was under paddy (Table 12). We are continuing to monitor the *Rhizobium* population under these conditions, but it appears that inoculation may be necessary each time chickpea is sown after paddy.

We also looked at the spread of *Rhizobium* cells in the field from seeds to the soil. The *Rhizobium* peat inoculant was coated on seeds with methyl cellulose sticker. The field used was virtually free of chickpea rhizobia. The spread of *Rhizobium* cells between two plant rows was greatly improved with frequent irrigation (Table 13). This phenomenon has significance since chickpea is mostly grown as an unirrigated crop using only residual soil moisture, and it will be studied further.

Nodulation and Nitrogen Fixation

As reported previously (ICRISAT Annual Report 1978/79, p 134), the nodules on chickpea sown after the rainy season are normally formed within 2-3 weeks after sowing. In our studies at ICRISAT Center this year on cultivar 850-3/27, nodulation was quite poor, probably due to higher soil temperatures prevailing around planting time. Nitrogen-fixing activity as measured by the acetylene reduction technique was also low on plants grown on residual moisture but increased greatly with irrigation every 10 days. Nodules continued forming up to 47 days with moisture, but ceased forming after 34 days without irrigation (Fig. 7). A maximum of 40-fold more nodule weight was recorded with irrigation, and the result was similar with nodule number. Nodule number and weight declined after the plants were 66 days old, and the lowest figures were recorded at 85 days in the irrigated plots.

On residual soil moisture, the cultivar reduced a maximum of only 41 µmol of ethylene/g of dry nodules per hour 35 days after planting. With irrigation, the peak activity of 150 µmol/g nodules per hour was obtained 48 days after planting (Fig. 7), and measurable activity continued up to 85 days.

The differences in the nodulation and nitrogen fixation were very clearly reflected in the grain yields. In the absence of irrigation, cultivar 850-3/27 produced 1.3 tonnes/ha of grain, while 3.0 tonnes/ha could be harvested with irrigation. The yield obtained with irrigation at ICRISAT Center is equal to or slightly higher than that often obtained at Hissar. The nodulation and nitrogen fixation patterns at Hissar and at ICRISAT Center indicate wide differences at the two locations, and comparisons

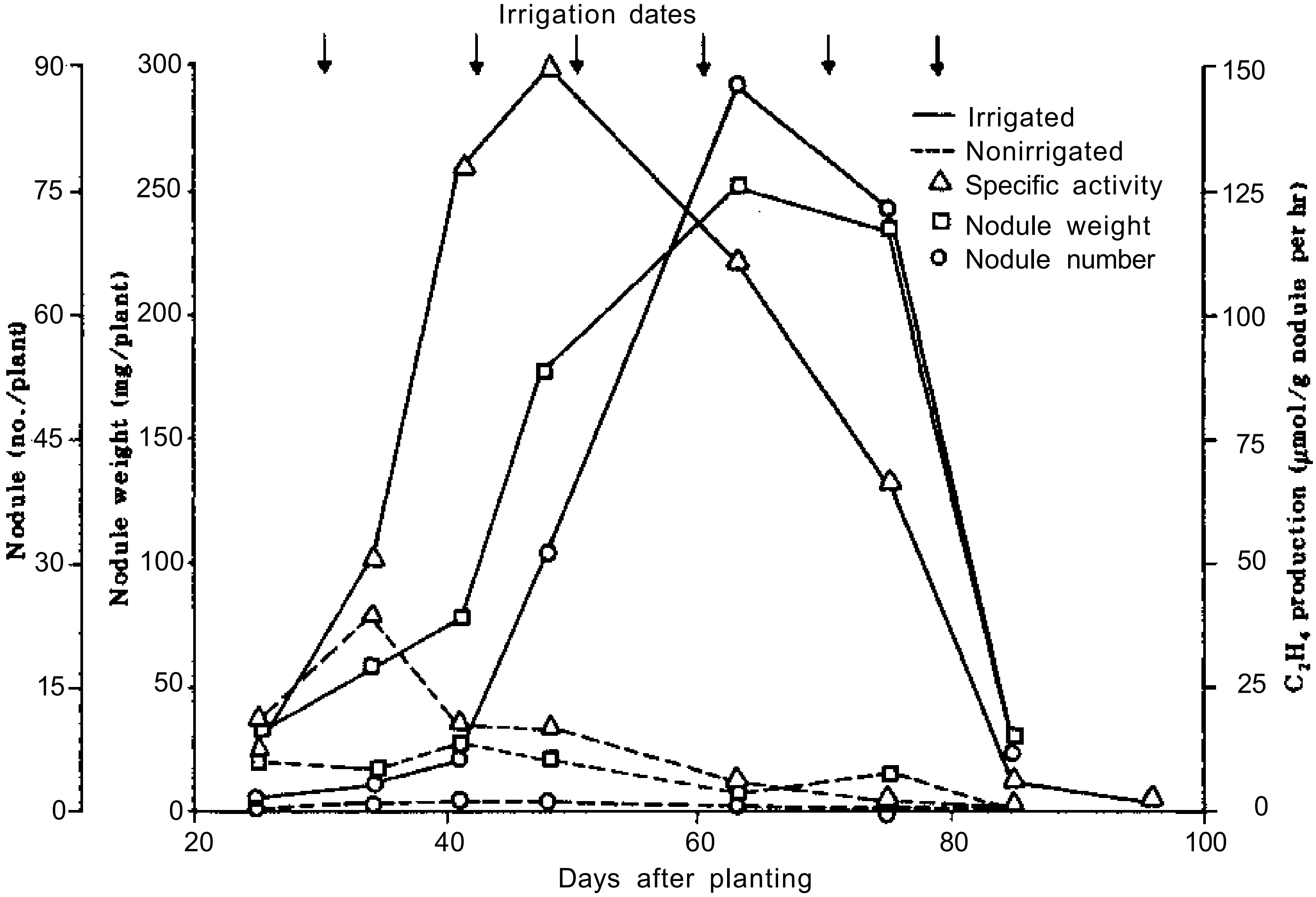


Figure 7. Nodulation and nitrogen fixation with and without irrigation in a Vertisol at ICRISAT Center by cultivar 850-3/27, 1979/80.

of the two sites are continuing.

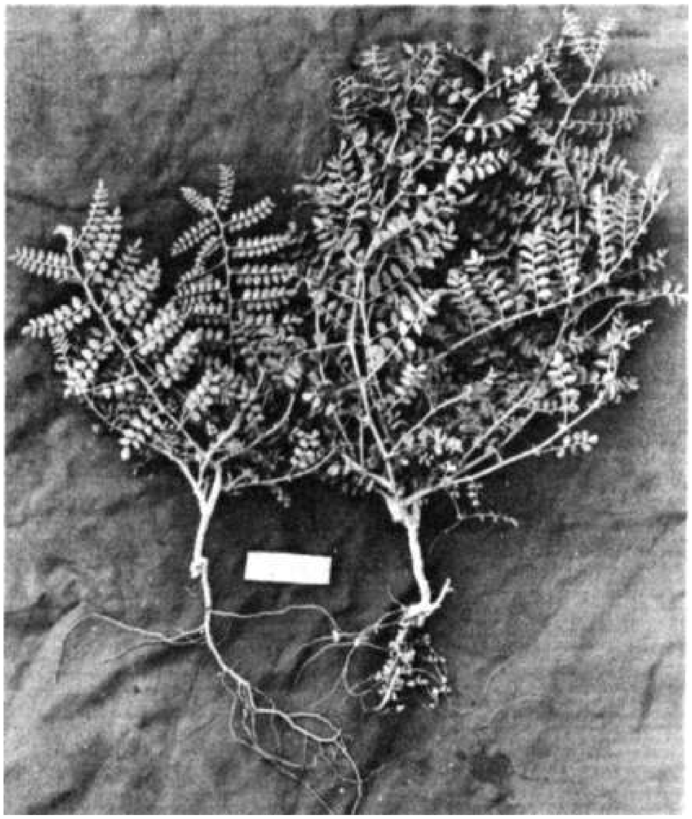
Genetic Variability for Nodulation

By visual scoring of nodulation, 366 lines (including earlier promising lines) were evaluated. Only 22 lines scored equal to or better than the check 850-3/27, which has been one of the best nodulating lines observed so far. High nodulating lines have further been checked for nodulation and nitrogen fixation under controlled conditions in a glasshouse. Two lines (ICC-435 and ICC-685) have been found to be consistently superior. Examination of F_2 populations from crosses between high and low nodulating lines indicated segregation for this character with a wide range of nodule formation.

Because of the need to uproot a plant to observe nodulation, we are working on techniques to keep the selected plant alive and so obtain seeds for future study.

Looking Ahead

Selecting for high yield in crosses among desi and kabuli genotypes will be intensified, and we will continue breeding for disease resistance, both at ICRISAT and ICARDA. We will attempt to incorporate *Heliothis* tolerance that is now available. International testing of breeding materials of various generations will be continued. We will investigate genotype responses to early



Segregation for nodulation in F_2 population of a cross between K-850-3/27 (parent with good nodulation) on the right and 12-071-04244 (poor nodulation).

sowing in peninsular India and to high inputs and late planting in north India. Our work on the epidemiology of diseases, particularly wilt, root rots, and stunt, will be intensified. Methods already developed to screen for nodulation will be applied to breeding materials.

Publications

Institute Publications

ICRISAT. 1980. Proceedings, Consultants' Group Discussion on the Resistance to Soil-borne Diseases of Legumes, 8-11 Jan 1979, ICRISAT, Patancheru, A. P. India (ed. Y. L. Nene).

Journal Articles

Haware, M. P., and Nene, Y. L. 1979. Nonseed-borne nature of powdery mildew of chickpea. PANS 25:464-465.

Nene, Y. L., and Haware, M.P. 1980. Screening of chickpea for resistance to wilt. Plant Disease 64:379-380.

Saxena, N. P., and Sheldrake, A. R. 1980. Effects of pod exposure on the yield of chickpeas (*Cicer arietinum*). Field Crops Research 3:189-191.

Saxena, N. P., and Sheldrake, A. R. 1980. Iron chlorosis in chickpea (*Cicer arietinum* L.) grown on high pH calcareous Vertisol. Field Crops Research 3:211-214.

Singh, U., and Jambunathan, R. 1980. Biochemical changes in the developing seeds of chickpea (*Cicer arietinwn* L.) and pigeonpea (*Cajanus cajan* L.) (Indian Journal of Biochemistry and Biophysics 17:95. (Abstract.)

Singh, U., and Jambunathan, R. 1980. Evaluation of rapid methods for the estimation of protein in chickpea (*Cicer arietinum* L.). Journal of the Science of Food and Agriculture 31:247-254.

Conference Papers

Jambunathan, R., and Singh, U. 1980. Studies on desi and kabuli chickpea cultivars; I. Chemical composition. *In* Proceedings, International Workshop on Chickpea Improvement, ICRISAT, 28 Feb-2 Mar 1979, India. Available from ICRISAT.

Kumar, J., and Green, J. M. 1979. A brief report of the Fourth International Chickpea Trials and Nurseries conducted in India 1978/79. Presented at the AICPIP Rabi Pulses Workshop, 20-23

Sept, Haryana Agricultural University, Hissar. 36 pp.

Kumar, J., and Smithson, J. B. 1980. A brief report of the Fifth International Chickpea Trials and Nurseries conducted in India, 1979/80. Presented for the AICPIP Rabi Pulses Workshop, 16-19 Sept, Rajasthan College of Agriculture, Udaipur, India.

Reed, W., Lateef, S. S., and Sithanantham, S. 1980. Constraints to effective pest management in pigeonpea. Presented at the Conference on Future of Integrated Pest Control, 30 May-4 June, International Organization for Biological Control, Bellagio, Italy.

Reed, W., Seshu Reddy, K. V., Lateef, S. S., Amin, P.W., and Davies, J. C. 1980. Contribution of ICRISAT to studies on plant resistance to insect attack. Presented to the Scientific Working Group on the Use of Naturally Occurring Plant Products in Pest and Disease Control, 12-15 May, Nairobi.

Rupela, O. P. 1980. Strain typing in *Rhizobium* using intrinsic resistance to antibiotics—methodology. Presented at the Fifth Southern Regional Conference on Microbial Inoculants in Crop Production, ICRISAT, 20-22 Mar, Patancheru, India.

Rupela, O.P., and Dart, P.J. 1980. Research on symbiotic nitrogen fixation by chickpea at ICRISAT. *In* Proceedings, International Workshop on Chickpea Improvement, 28 Feb-2 Mar 1979, Hyderabad, India. Available from ICRISAT.

Rupela, O. P., and Dart, P.J. 1980. Chickpea rhizobia—selection and testing. Presented at the Fifth Southern Regional Conference on Microbial Inoculants in Crop Production, ICRISAT, 20-22 Mar, Patancheru, India.

Rupela, O. P., Toomsan, B., and Dart, P.J. 1980. Chickpea *Rhizobium* distribution. Presented at the Fifth Southern Regional Conference on Microbial Inoculants in Crop Production, ICRISAT, 20-22 Mar, Patancheru, India.

Saxena, N. P., Natarajan, M., and Reddy, M. S. 1980. Growth and yield of chickpea, pigeonpea and groundnut. Presented at the Symposium on Potential Productivity of Field Crops under Different Environments, 22-26 Sept, IRRI, Manila, Philippines.

Williams, R.J., and Kumar, J. 1979. Multilocational testing in the ICRISAT Crop Improvement Programs. Presented at the Conference on the Concept and Philosophy of International Testing, 14-18 Aug, CIMMYT, E1 Batan, Mexico.

Miscellaneous

International Chickpea Newsletter No. 2 (June 1980), 27 pp.

PIGEONPEA

Contents

PIGEONPEA

International Trials

We again made available for the 1979/80 year two international trials of vegetable-type lines. Results from four locations showed that some of our entries (ICPL-106, ICPL-16, ICP-6997, and ICPL-25) gave large seed size, early maturity, and high yield when compared with local checks.

In 1979 there were no All India Coordinated Trials. However, several breeders in India accepted our multilocation tests for early- and medium-maturing advanced lines, which provided us with information for entering several new lines in next year's trials. These include two inbred lines from each of eight cultivars, three early-maturing lines, and several medium-maturing lines.

Breeding

Lines

MEDIUM-MATURING. At ICRISAT Center the development of locally adapted medium-maturity (160-170 days) pigeonpea receives the major emphasis in our breeding program. In the 1979/80 crop year we made progress incorporating into promising genotypes disease resistance, lower susceptibility to pod borers, and increased potential for yield.

LATE-MATURING. At Gwalior, in northern India, we continued our research on improving late-maturing genotypes adapted to the traditional production systems of northern India.

EARLY-MATURING. At Hissar, also in northern India, we made considerable progress in developing very early and early-maturing cultivars. Such types of cultivars are being developed to fit into rotation with wheat where irrigation is available. To be most successful in this rotation, which is rapidly gaining acceptance, pigeonpea must mature in less than 150 days. Farmers practicing this rotation generally apply more inputs than those who grow pigeonpea as a sole crop under solely rainfed conditions.

Our program is concentrating on producing very early maturing lines with large seed size and high yield. Two contrasting lines have shown considerable promise—ICPL-81, an indeterminate type, earlier maturing, and higher yielding than the standard check UPAS-120; and ICPL-87, a determinate type, with large seed and earlier maturity, and higher yield than UPAS-120. These lines, plus three others of our very early maturing selections will be grown in next year's All India Coordinated Trials. In addition, in our multilocation test program, several breeders in northern India will be growing our very early maturing lines to assess their performance.

VEGETABLE TYPE. Although pigeonpeas are used mainly as a pulse crop, in some areas they are harvested while the pods are still green and are used as a vegetable. There is considerable scope for the development of this crop as a vegetable. As a first step, our program has developed early-maturing material with large seed size. We are also attempting to incorporate large pod size into these lines. In addition we have initiated a program to screen lines for their quality as green peas.

Populations

As a part of our breeding strategy, we have been advancing by single pod descent unselected bulk populations from several crosses. This procedure allows us to advance a large number of crosses with a minimum of effort and permits us to provide other breeders with material that has not been specifically selected for our conditions. This year none of the 28 medium-maturing F_5 unselected bulk populations consistently yielded as well as the check C-11 at four locations. However, 10 of the 48 single-plant progenies selected from a similar medium-maturing bulk population significantly outyielded the check cultivar.

Hybrids

Crosses with the genetic male sterile lines that we have on hand were tested further for yield in our continuing search for lines that show high specific combining ability. As a result, one cross that has consistently shown good performance is being multiplied for multi-location testing. In addition we have produced several new hybrids and will test them at ICRISAT Center. These now include male sterile lines in an early-maturing background. Several breeders have taken our male sterile lines and are either developing them further or incorporating the male sterile characteristic into locally adapted varieties.

One of our concerns has been that the cost of hybrid seed production will be too high for farmers. However, tests indicate that the cost of hybrid seed, using our genetic male sterile lines, should not pose any problem for the acceptance of these hybrids by farmers (Table 1).

The existence of cytoplasmic male-sterile lines, which we reported last year, has been confirmed, and we have identified the cultivar C-11 as a restorer of fertility.

Natural Outcrossing

As we reported previously, pigeonpea flower structure suggests that this crop should be self-pollinated, but varying incidence of outcrossing has been reported in this crop. We are attempting to determine exactly the extent of outcrossing that exists under different conditions, as this information is im-

Table 1. Cost[a] of hybrid pigeonpea production (MS-3A x C-11-medium maturity).

	ICRISAT Center (1978/79)	MAHYCO, Ltd. , Jalna, Maharashtra (1979/80)
Area (m)	625	558
Proportion of rows		
Female	3	3
Male	1	1
Total seed yield (kg)	47	45
Yield (kg/ha)	752	806
Cost of cultivation (Rs/ha)	1160	1450
Cost of hybrid seed (Rs/ha)	1.54	1.80

a. Estimated cost (does not include land and supervision, but other costs such as land preparation, fertilizers, insecticides, pulling out normal plants in the female rows, and harvesting and threshing charges are included).

portant in designing breeding procedures and in producing breeders' seed.

In addition to the outcrossing information (21% at ICRISAT and 27% at Varanasi) given in our 1978/79 Annual Report, we have more data for 1978. At Badnapur the outcrossing ranged from 0 to 8% with a mean of 2. 9%, and at Coimbatore from 10 to 70% with a mean of 40.2%. These results indicate that location can have a strong effect on the extent of outcrossing in this crop. Under sprayed conditions at ICRISAT Center we obtained an average of 2% outcrossing for the first harvest and 7% for the second. Under unsprayed conditions the harvests from the second and third flushes were 15. 8% and 17.0% outcrossed, respectively. We obtained an average of 24% outcrossing in another test in which the dominant purple-stemmed plants flowered earlier than the recessive green-stemmed plants. These results indicate that many factors can affect percentage of outcrossing in this crop. We are repeating these tests next year.

We also found that the percentage of outcrossing in the center rows of 4-, 6-, and 8-row plots was not reduced compared with the outer rows. This result is disappointing if we expect to harvest seed that has a lower outcrossing percent from the center of a plot. However, these results do help to explain why we have been able to produce hybrid seed using only one pollen row to six male sterile rows.

Disease Resistance

For stability of yield and wide adaptability of genotypes in India, it is essential that cultivars be developed with resistance to the three diseases: wilt, sterility mosaic, and *Phytophthora* blight. In the long run, developing dependable resistance to these diseases will require finding genes for resistance to different races of the pathogens. However, we are presently developing multiple-disease-resistant lines by using parents carrying wilt resistance, plus resistance either to sterility mosaic or to blight. Three progenies of such a cross (ICP-7065 x ICP-7035) have shown promise for multiple disease resistance. These lines will be evaluated for their yield performance at ICRISAT Center under disease-free conditions. In addition we have a backcross program to incorporate sterility mosaic resistance into BDN-1, a cultivar resistant to wilt and blight. Two backcrosses have been made, and progenies appear promising.

We have initiated a program to incorporate wilt resistance into a wider diversity of genetic backgrounds. For this we have begun a systematic program of crosses, and the F_2 will be put into a wilt-sick plot next year.

New Plant Types

Problems have been encountered in the production of pigeonpea because of its tallness, which interferes with spraying for insect control and with mechanical harvesting of the crop. Last year (1978/79) we reported on a series of genetic dwarf lines that we had developed. In a cross between dwarf D_2 x normal plants we have now derived lines of intermediate height that also have increased branching. The preliminary yield results from these lines are very encouraging.

We also identified germplasm lines with a very high degree of branching. We made crosses between this germplasm material and normal lines with a view to increasing the yield of the normal lines by increasing their branching. This material is now in the F3 generation.

Self-Pollination

The partial outcrossing found in pigeonpeas creates problems for maintaining pure lines. Therefore, identification of a mechanism that would ensure self-pollination in this crop could simplify the breeding procedures for developing lines. We have identified two floral morphological modifications that appear to ensure self-pollination.

"FREE STAMEN" MODIFICATION. We found this morphological variation at ICRISAT Center in an interspecific cross between T-21 x *Atylosia lineata.* In addition to having free stamens, flowers on this plant have a split keel that encloses the wing petals and traps the standard petal, preventing the opening of the flower until well after the pollen has been shed onto the stigma. Even after opening, the wings remain within the keel (Fig. 1).

"WRAPPED FLOWER" MODIFICATION. We found this variation in the cultivar Royes at the University of Queensland. This floral modification is characterized by overlapping lobes of the standard petal that appear to hold the flower closed until after self-pollination has taken place (Fig. 2). Even male sterile plants with the wrapped flower characteristic produce few pods under open pollination. In contrast, normal male sterile plants pod heavily due to cross-pollination.

The free stamen characteristic appears to be controlled by at least two genes, while the wrapped flower characteristic appears to be simply inherited and dominant. We are backcrossing both these characteristics into a number of elite lines. These two floral morphological changes need extensive testing internationally to confirm their effectiveness for causing self-pollination under all environmental conditions.

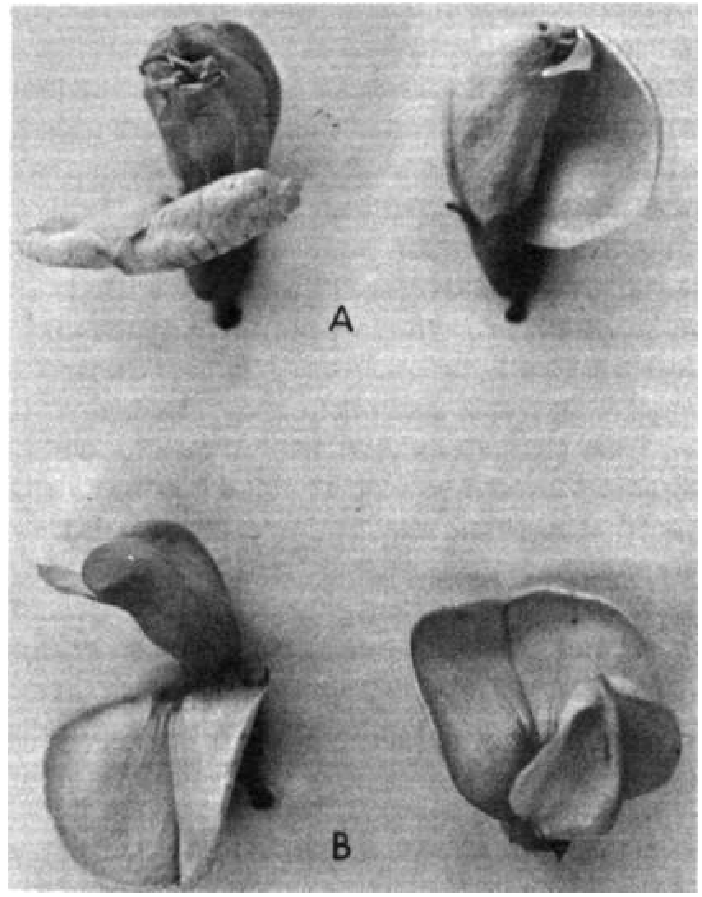


Figure 1. "Free stamen" (A) and normal (B) pigeonpea flowers.

Male Sterility

Our knowledge about genetic male sterility has been broadened by three findings made in our studies at the University of Queensland in Australia. We identified the male-sterile gene for the translucent anther trait

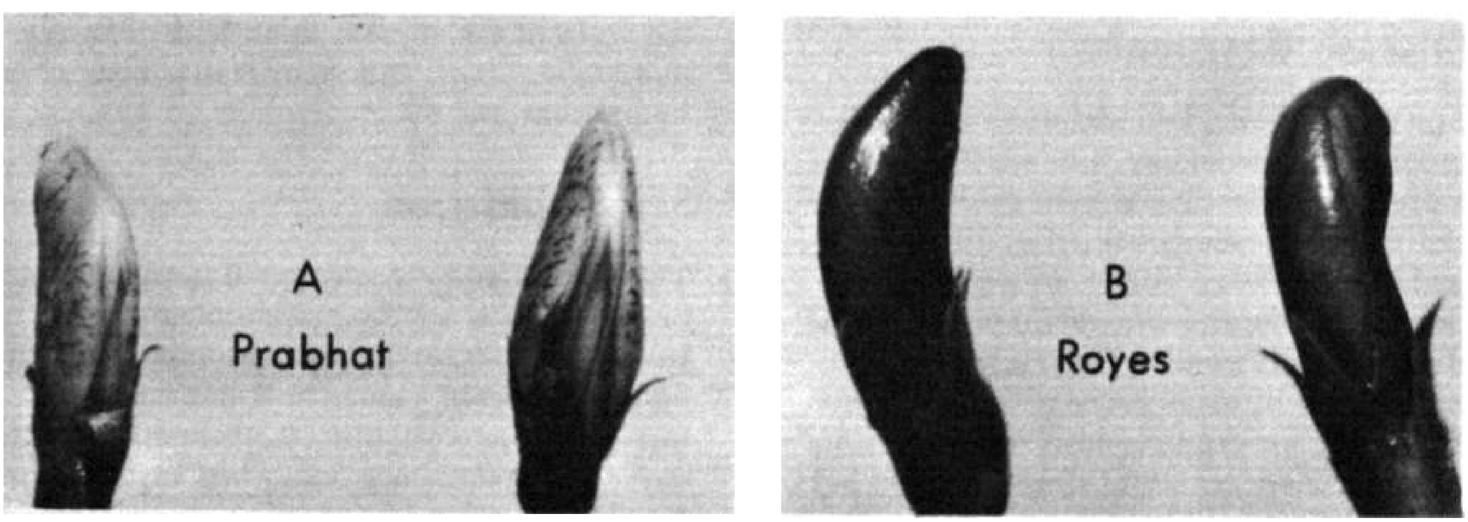


Figure 2. Normal pigeonpea flower (A, cv Prabhat) and "wrapped flower" (B, cv Royes).

in a genotype with a photoinsensitive background. This was isolated from a cross between MS-3A x QPL-1; Also we found an entirely new source of genetic male sterility in material selected from cv Royes. Cytological examination of this material clearly indicates that the sterility mechanism is different from that of the translucent anther type. This source of genetic male sterility, designated B-15-B, is being maintained in 10 genetic backgrounds of varying phenology. Another new form of genetic male sterility has been isolated from the photoinsensitive line QPL-1 and is cytologically different from both the translucent and the B-15-B types. All these new sources of male sterility will be integrated into the breeding program.

Work in Fiji

Cooperative research started in 1978 by ICRISAT in cooperation with the University of Queensland and the Fiji Ministry of Agriculture has enabled the Native Land Development Corporation in Fiji to successfully mechanically harvest a crop of 40 ha of the cultivar Royes. This seed was sold to a local dhal manufacturer who reported excellent consumer acceptance. As a result, there has been considerable renewed interest in the growing of pigeonpea in Fiji.

Distribution of Breeding Materials

We continued to distribute on request breeding materials to our cooperators. During the year we provided more than 3600 samples of seed to cooperators in 36 countries throughout the world, most going to India, Kenya, Ghana, and Australia. In India requests for about 2500 samples came from workers in 17 states; locations receiving most samples include Dholi, 770 samples; Faizabad, 251; Palampur, 199; Hissar, 301; Sehore, 110; Kanpur, 152; and New Delhi, 106.

Biochemistry

Cooking Quality

In addition to the several physicochemical properties of pigeonpea dhal (dried split seeds) that were observed to be correlated with cooking time (ICRISAT Annual Report 1978/79), the nitrogen solubility index (%) and nitrogen content of the solids dispersed (%) also exhibited negative and significant correlations with the cooking time. In 1979/80 we also studied the cooking time of 25 whole-seed pigeonpea cultivars. Similar to dhal samples, the water-absorbing capacity of whole seed was negatively correlated (-0. 695, $P< 0.01$) with the cooking time.

We conducted texture measurements of cooked, uncooked, and soaked dhal and whole-grain samples of pigeonpea using an Instron food testing machine. Attempts were made to standardize the procedure, using the back extrusion cell technique, and cultivars with different cooking times were used. This preliminary study indicated that additional load cells and other accessories are needed to obtain meaningful data with pigeonpea.

Milling Characteristics and Consumer Acceptability

We conducted a survey of milling methods and consumer acceptance of pigeonpea in India, covering three states (Madhya Pradesh, Maharashtra, and Uttar Pradesh) that together account for about 75% of the total production of pigeonpea in the country. Several commercially operated dhal mills (large-scale processing units) were contacted, and their views on milling efficiency, yield losses, and grain preferences were recorded. Information on kinds of village-level processing units and consumer preferences was collected from 130 households in several villages of these states. The survey revealed that seed size, shape, and hardness of pigeonpea grains are considered

Table 2. Factors reported to Influence the dhal yield and consumer acceptance of pigeon pea in three Indian states, ICRISAT 1979/80 survey.

Factors	% responses confirming factor influence		
	Dhal production		
	Large-scale miller (n=46)[a]	Small-scale miller (n=130)	Consumers (n=130)
1. Crop			
Variety	b	45	74
Location	40	25	65
Maturation (early, medium, and late)	20	30	70
2. Grain characteristics			
Size	84	55	50
Shape	72	45	b
Color	50	42	60
Texture (hard/soft)	65	40	55
Flavor (taste, smell, feel)	b	b	60
Cooking time	b	b	40
3. Storage period (exceeding 6 months)			
Dhal	b	b	76
Whole grain	40	68	70
4. Pretreatment			
Oil	100	30	25
Water	100	85	36
Salt solution	b	25	30
5. Milling operation			
Type of machine (roller/chakki)[c]	80	20	b
Abrasion type	100	25	b

a. n = Total number of interviews conducted.
b. Influence may exist but is not relevant to miller/consumer,
c. Chakki = Hand-operated grinding mill.

important factors and reportedly influence dhal production by both large- and small-scale processing methods; and flavor characteristics appear to be as important as the cooking time of pigeonpea from the consumer's point of view (Table 2).

Antinutritional Factors

Several antinutritional factors have been reported to be present in legumes. We studied only the trypsin and chymotrypsin inhibitors in pigeonpea and in some of its wild relatives. Although pigeonpea has lower levels of trypsin and chymotrypsin inhibitor activities than soybeans, some of the wild relatives of pigeonpea were found to contain high concentrations of these inhibitors (Table 3). The highest trypsin and chymotrypsin inhibitor activities were observed in *Rhyncosia rothii,* and this species also showed the lowest value for the in vitro protein digestibility.

The function of polyphenolic compounds (loosely termed tannins) in the bioavailability of nutrients of pigeonpea is not clear and should be investigated, particularly in those areas where pigeonpea is consumed as whole green peas. Analyses of four pigeonpea cultivars with seed coat colors ranging from white to red showed that the seed coat contained the highest proportion of polyphenols. Red seed appeared to have a higher proportion of polyphenols than white seed. Preliminary in vitro studies indicated that the polyphenolic compounds may affect the function of some of the digestive enzymes. Further work is in progress.

Routine Screening

To test whether the relationship between whole seed and dhal protein content can be affected by the percentage of seed coat and seed weight, we analyzed 83 germplasm accessions with a wide range in grain weight for protein content, dividing them into low, medium, and high groups based on their

Table 3. Protein contents, levels of trypsin and chymotrypsin inhibitors, and protein digestibilities in cultivars of pigeonpea and its wild relatives.

Species	No. of samples	Protein (Nx6.25) (%)	Trypsin inhibition Units/mg meal	Trypsin inhibition Units/mg protein	Chymotrypsin inhibition Units/mg meal	Chymotrypsin inhibition Units/mg protein	In vitro protein digestibility (%)
1. *Cajanus cajan*							
Mean	3	24.6	13.5	69.4	4.2	22.1	60.5
Range		23.1-26.2	12.5-15.1	67.1-71.3	3.5-5.0	15.3-27.8	57.9-64.1
2. Wild species							
(a) *Atylosia* spp							
Mean	6	28.4	17.6	76.0	14.2	61.8	61.1
Range		27.8-29.3	13.3-25.8	54.5-121.4	5.9-22.0	24.2-92.4	52.6-68.1
(b) *Rhynchosia rothii*	1	27.6	82.4	445.7	20.9	113.2	40.9

seed weight. Whole-seed and dhal protein values showed a higher correlation coefficient ($r = 0.927$, $P < 0.01$) for the medium group than that of low and high groups, thus indicating a variability in relationship among the groups. Also, the correlation coefficient ($r = 0.869$, $P < 0.01$) of all three groups together was low. In the case of the medium group, about 86% variation in dhal protein content appeared to be associated with the variation in whole-seed protein content. In the case of the low group, only 63% of variation in dhal protein was associated with the variation in the whole-seed protein, which might be due to the observed negative correlation between seed weight and percentage of seed coat. This study indicated a variability in the relationship among the three different groups based on the seed weight.

About 1300 dhal samples from the breeding program and 900 whole-seed samples from germplasm were analyzed for protein content, which varied from 15. 5 to 25. 3%.

Physiology

Growth Analysis

Dry-matter accumulation, yield, and yield components were studied in two hybrids (MS-4A x C-11 and MS-3A x ICP-7035) and four parents (MS-4A, C-11, MS-3A, and ICP-7035) grown in the rainy season on a Vertisol. The hybrids did not give significant advantage over their best parents in growth, total dry-matter production, and yield (Table 4).

Cultural Practices

RESPONSE TO SPACING. Farmers usually sow pigeonpea in rows with close plant-to-plant spacings, while in breeding plots they are usually thinned to 20-50 cm. This year we conducted experiments to evaluate the response of pigeonpea in varied row-to-row and plant-to-plant spacings, first to aid breeders in standardizing spacings in yield tests of segregating populations, and second to examine the effects of plant population and planting geometry on grain yield (Fig. 3).

Two medium-duration cultivars (C-11 and BDN-1) were planted on a Vertisol, and one early (T-21) and one medium-duration (BDN-1) on an Alfisol. The design of the experiment was a split plot with cultivars as main plot treatments and spacings as subplot treatments in three replicates. Varied row-

Table 4. Differences in growth, yield, and yield components of pigeonpea sown on a Vertisol at ICRISAT Center, 1979.

Plant character	C-11	MS-4A	MS-4A x C-11	ICP 7035	MS-3A	MS-3A x ICP-7035	SE ±
Plant height (cm)	174	172	170	133	179	156	7.04
Primary branches/plant	9	14	15	6	11	11	1.9
Secondary branches/plant	26	45	47	8	28	27	6.2
Total dry matter (kg/ha)	6193	5771	6426	3131	5594	4980	513
Yield (kg/ha)	1390	976	1257	756	1162	1068	119
Harvest index (%)	21	17	20	23	21	21	1.6
Pod number/plant	129	133	111	30	110	120	17.9
Seed number/pod	2.6	2.7	2.6	3. 5	3.0	2.8	0.2
100-seed weight (g)	9.7	7.3	8.0	16. 3	7.1	7. 9	0.4

to-row (30, 60, and 120 cm) and plant-to-plant (2.5, 10, and 25 cm) spacing treatments gave a range of eight different populations (33 000 to 1333 000 plants/ha) with nine possible combinations of spacing.

Yield did not differ significantly among the row-to-row and plant-to-plant spacings

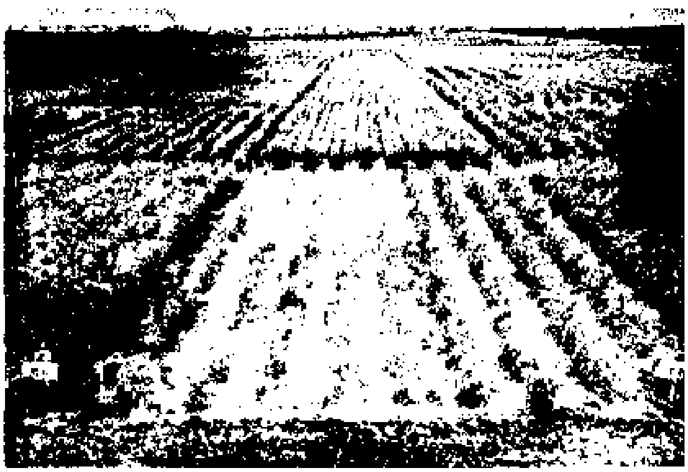


Figure 3. Effect of row-to-row and plant-to-plant spacing on the growth of pigeonpea.

tested both on Vertisol and Alfisol, indicating considerable plasticity of the plants in response to population density under these conditions. The interaction of row-to-row and plant-to-plant spacing was negligible, as was also the yield response between cultivars. This year the rainfall was slightly below normal (732 mm), and the season was particularly dry during the early growing period. It seems that the pattern of rainfall distribution could be an important factor affecting the yield response to planting patterns. Further research is in progress to evaluate the spacing and plot size interactions in different field environments.

EFFECT OF IRRIGATION AND FOLIAR NUTRIENT SPRAYS. Soils at ICRISAT Center are generally low in phosphate, but experiments with soil-applied fertilizers have failed to increase yields. In the past 3 years we investigated the effects of foliar sprays of nitrogen, phosphorus, and potas-

Table 5. Effect of irrigation and foliar application of nutrients on yield of late-planted postrainy-season pigeonpea grown on a Vertisol at ICRISAT Center, 1979/80.

Treatments	Grain yield (kg/ha)		
	Irrigated	Nonirrigated	Mean
Control	1083	619	851
Urea	1132	511	821
Single superphosphate	1081	634	857
Urea + single superphosphate	1055	548	802
Urea + single superphosphate + micronutrient mixture (Agromin)	1175	558	866
Micronutrient mixture (Agromin)	1131	565	848
Mean	1110	573	
LSD (0.05)			
Irrigation (groups)	187		
Treatments	NS		
Means within groups	NS		
Means of different groups	NS		
CV (%) subplot	13		

slum applied to rainy-season pigeonpea on both Vertisols and Alfisols and found no response to these applications. This year-we tested the response of late-planted (November) postrainy-season pigeonpea to irrigation and foliar sprays of nitrogen, phosphorus, and mixtures of essential micronutrients. Irrigation was applied three times, and nutrients were applied four times during the crop growth period. There was a large increase (94%) in seed yield due to irrigation. However, no significant effects resulted from foliar application of nutrients (Table 5).

Screening for Salinity Tolerance

Some of the soils in pigeonpea-growing areas are saline, thus salinity-tolerant cultivars for such soils would be advantageous. Experience in previous years has indicated that genotypic differences in salt tolerance exist in pigeonpea. This year we carried out a field screening with advanced lines of pigeonpea, using a naturally saline field with tolerant and susceptible checks planted in rows on either side of the test lines. Several lines with a relatively high degree of salinity tolerance were identified. These will be tested for one more season.

Entomology

Survey of Insect Pests

In continuation of our surveys of the major pigeonpea-growing areas of India that were initiated in 1975, this year we surveyed the pod damage caused by insect pests in farmers' fields in 10 states in India. In these surveys we cooperate, wherever possible, with the national pulse entomologists in the areas being sampled. Pigeonpea fields, selected as randomly as circumstances permit, are visited just before harvest, and samples of pods are collected and then examined in our laboratories for pest damage. Our staff can determine the identities of the pests causing the damage, based on the characteristics of the damage on and in those pods. The data from these analyses are summarized in Table 6.

MAJOR PESTS. The dominant pests damaging the pods are the pod borer *Heliothis armigera,* and the podfly *Melanagromyza obtusa;* the latter is more common in the long-duration cultivars in central and northern India. Other lepidopteran pod borers, including the larvae of the plume moth (*Exelastis atomosa*) and the blue butterflies (*Catochrysops strabo* and *Lampides boeticus) are* also locally damaging. Bruchid beetles (*Callosobruchus* spp), which are better known as pests of stored grains, are commonly found damaging seeds in the ripe pods, particularly in the southern states. *Tanaostigmodes* sp, a hymenopteran pest, is currently of little importance, but may be of increasing concern if selective pesticides are widely used, for this pest has built up to devastating populations under such conditions at ICRISAT Center.

In this year's surveys we again found that

Table 6. Percentage of pigeonpea pods damaged by insect pests in India: ICRISAT surveys of farmers' fields 1975-80.

Location	Lepidopteran borers	Podfly	Hymenopteran	Bruchid
Northern states (272 fields sampled)	12.6	19.1	0.1	0.3
Central states (289 fields sampled)	30.0	24.8	3.0	3.6
Southern states (363 fields sampled)	34.1	9.0	2.1	7.2

Heliothis had devastated pigeonpea in large areas of southern India, leaving some farmers nothing but the plant stems. We also found this year that birds had caused considerable pod damage, particularly in the states of Madhya Pradesh and Uttar Pradesh.

FARMERS' PRACTICES. In addition to collecting pod samples for pest analysis, we also record data on cropping patterns and soils. Wherever the farmer or one of his family is present, we obtain details of his farming practices, including use of pesticides and other purchased inputs. Little more than 20% of the fields surveyed over the past 5 years were of sole cropped pigeonpea, for this crop is generally intercropped with cereals or cotton. There appears to be a recent trend away from intercropping in some areas. Very few farmers, less than 6% of those interviewed, used any pesticide on their pigeonpea, and almost all of these used BHC and/or DDT, as dusts or wettable powders.

We have now gathered data from farmers' fields in most of the districts in India that have substantial areas of this crop, and during the coming year we will complete this phase of our work and publish the results. We then hope to monitor the pest problems and pest management practices in selected areas throughout each season and over several years.

PESTS IN AFRICA. We collected information on insect pest problems and their management on pigeonpea in other countries through visitors, correspondence, and literature. Colleagues who toured through East Africa reported extensive pest damage caused by *Heliothis,* podfly, and termites. In perennial plants, which are often grown in kitchen gardens, an unidentified stem borer was seen to cause damage in several areas of Tanzania.

Host-Plant Resistance

Most of our screening for plant resistance to insect pests is in our pesticide-free fields at ICRISAT Center, where the major pod borers and the podfly have built up adequate, or more than adequate, populations in each of the past few years. The severity of the pest attacks varies with time, so we cannot compare the susceptibilities of cultivars of differing maturities in the same trials. We group materials of similar maturities into separate trials, using a well-known cultivar of the appropriate maturity as a check in each trial. Our early testing is of unreplicated plots, from which we reject all entries that are both more severely damaged and yield less than the checks. Later-stage testing is with increasing replication in randomized block design trials. The most promising materials are tested in balanced lattice square design trials, for we have found that such designs give increased precision which more than compensates for the constraints these designs impose. This year such trials gave increased efficiencies of up to 120% when compared with randomized block design analyses of those same trials. We screen populations and progenies from single-plant selections.

In 1979/80, we further screened the materials selected in previous years and also tested 943 new germplasm accessions and the many selections provided by our breeders and pathologists. As in previous years, pod borers and podflies were abundant in our pigeonpea fields at the Center, so our materials were again subjected to severe attacks.

COMPENSATION. Peak populations of *Heliothis* larvae again occurred in November, coinciding with the flowering and podding of the medium-maturity cultivars. At this time almost all flowers and green pods were destroyed, the larvae then turning their attention to the leaves, which they skeletonized. None of the medium-maturity, less-susceptible selections possessed sufficient resistance to withstand such a level of attack, and most gave little or no yield from the first flush of flowering. These selections continued to grow, giving a second flush of flowers and pods after *the Heliothis* populations declined, thus allowing a reasonable crop to be harvested in February.

Table 7 gives data from one such trial. As in previous years there were substantial differences between the ability of different selections to grow on and produce this compensatory crop. The retention of such a compensatory ability is of obvious importance to those farmers who are not able to protect their crops with pesticides in areas where *Eeliothis* can be devastating.

PODFLY AND HYMENOPTERA. Both early- and late-maturing cultivars may partially escape the peak *Heliothis* attacks at ICRISAT Center, but the early types usually yield relatively poorly, and the later types are subject to substantial attacks by the podfly. Data from a set of late-maturity selections tested in both pesticide-free and protected trials are summarized in Table 8. Here the recommended pesticide, endosulfan, reduced the *Eeliothis* damage but was not very effective against podfly. There was a massive increase in the attack by the hymenopteran pest *Tanaostigmodes* sp in this and all other sprayed trials, probably because the pesticide killed off the natural control elements which normally ensure that this insect is of minor importance. Endo-

Table 7. Pest damage and yields in the first and compensatory flushes on medium-maturity pigeonpea selected for differences in susceptibility to pest attacks at ICRISAT Center.

	1st picking (11 Dec 1979)			2nd picking (18 Feb 1980)			
	Pod damage (Mean %)		Mean sample[a] yield (g)	Pod damage (Mean %)		Mean sample[a] yield (g)	Total yield (kg/ha)
Entry	Borer	Podfly		Borer	Podfly		
6982-6	95	6	0	55	21	236	667
2223-1-E18	98	2	7	52	17	354	886
810-E1	100	1	0	55	18	246	761
2223-1	90	4	2	27	17	156	377
4167-E1	100	0	0	55	16	241	868
1691-E1	100	1	4	47	13	152	539
PPE-50-E1	95	8	1	57	14	107	420
3228-E1	96	3	32	48	8	93	414
2617-E1	99	2	5	40	17	191	582
2588-E1	100	0	0	48	26	272	860
5766-E1	100	1	0	36	25	191	594
2169-E1	100	0	0	40	18	259	710
4123-E1	99	0	0	38	28	224	811
4745-10-E1	100	0	0	39	18	207	567
APAU-2208	100	0	0	55	14	205	727
JCP-1- Check	100	1	1	56	12	202	563
SE ±				8.0	3.4	52.4	119.9

a. Samples taken from six plants per plot.

Table 8. Pest damage and yields from pesticide-tree and endosulfan-protected trials of late-maturing pigeonpea that were previously selected for differences in their susceptibility to the pests at ICRISAT Center.

Entry	Unprotected Pod damage (mean %) Borer	Unprotected Podfly	Unprotected Hymenopteran	Unprotected Yield (kg/ha)	Protected Pod damage (mean %) Borer	Protected Podfly	Protected Hymenopteran	Protected Yield (kg/ha)
8102-E1	26	22	4	721	15	17	35	1108
4745-9-E1	25	30	4	638	15	24	29	864
PPE-36-1	22	28	13	770	13	29	58	569
PPE-37-3	21	29	6	666	14	21	27	895
4185-E1	26	21	2	649	15	22	33	869
7176-5-E1	41	14	2	538	20	19	24	792
7194-1-S4	28	11	3	608	20	14	38	880
4745-2	21	26	1	779	15	24	18	933
8614	25	27	8	732	10	21	51	1029
8619	23	23	7	801	13	17	51	858
7537-E1	20	28	2	858	15	19	28	1487
PPE-38-1	27	32	6	716	10	22	50	835
7176-18-E2	24	26	3	700	19	15	28	1049
7041-E1	24	24	2	822	18	19	22	1244
7197-Check	27	30	2	853	12	24	38	1132
NP(WR)15-Check	20	21	6	876	13	16	53	1059
SE ±	2.1	2.0	0.1	54.5	2.4	2.4	5.0	111.4

sulfan is well known to have a relatively low toxicity for Hymenoptera, and this is normally of major advantage, for many of these insects are pollinators and parasites, and only few are pests. 7176-5-E1 and 7194-1-S4, which had been selected for their relative resistance to podfly in previous tests, had the lowest podfly infestation in the unsprayed trial, but both are relatively susceptible to *Heliothis,* In most trials we generally find a negative correlation between *Heliothis* and podfly damage. There are obvious and consistent differences in the susceptibility of different selections to *Tanaostigmodes,* but as this insect is not normally a major pest in most farmers' fields, we are paying less attention to this aspect.

TRIALS AT SUBCENTERS. This year we also grew trials of selections at our Gwalior and Hissar subcenters in an initial attempt to test the pest susceptibility of our selections in other environments. At Gwalior, where late-maturity cultivars are grown by the local farmers and podfly is the dominant pest, we tested our late-maturity selections. Here we were pleased to find that some of the progenies that had been selected for their relative resistance to podfly at ICRISAT Center also suffered relatively less damage at this location. In the trial at Hissar, our entries that were intended to be of early maturity proved to have a large range in days to flowering, thus limiting the utility of the pest damage data recorded. Here the local cheeks were more heavily attacked by borers and podfly, but were substantially earlier and higher yielding than most of our selections.

BREEDING AND TESTING. In spite of 5 years screening, we are still a long way from having selections that are highly resistant to *Heliothis* or podfly, but we do have selections that have shown consistent lower susceptibility to these pests and yielded more in unprotected fields. These selections are now being utilized by our breeders in their program and are also being tested at several locations across India by national breeders.

WILD RELATIVES. Some of the *Atylosia* spp, which are close relatives of pigeonpea, are markedly resistant to both *Heliothis* and podfly. In cooperation with our breeders, we are continuing our attempts to transfer this resistance into pigeonpea, seeking plants that will give a good yield of edible seed and will also be less susceptible to pests. In this year some of our F_8 derivatives gave lower pest damage and substantially higher yields than the pigeonpea cultivars that were included as checks.

Mechanisms of Resistance

Our open-field testing and screening under natural pest infestations is limiting: we can select in only one generation in each year, and the incidence of escape makes single-plant selection unreliable. The identification of the mechanisms of resistance would be of major benefit, for we could then select single plants within progenies with more confidence and efficiency and in more than one generation a year, even in the absence of the pest. We are developing cooperation, in the biochemical analyses of our more- and less-susceptible selections, with the Max-Planck Institute for Biochemistry at Munich in West Germany. In addition we are utilizing the relatively less sophisticated analytical capability currently available at our Center.

"POD WASHING." These trials as described in previous reports were continued, and there were again large increases in podfly infestations in the water-washed pods of some cultivars. Preliminary analyses of walls of young pods by our biochemists indicated a substantial reduction of polyphenols in the washed samples, thus further supporting our earlier observations that the amount of polyphenol in the pod walls is a factor responsible for differing susceptibilities among our selections.

SCREENING FOR ANTIBIOSIS. In feeding tests using laboratory-bred *Heliothis* larvae, we made further progress in a method for screening for antibiosis. The only marked antibiosis recorded, however, was again in *Atylosia scarabaeoides,* and there were no significant differences between our more- and less-susceptible pigeonpea selections.

Biological and Ecological Studies

We continued to monitor the populations of the insect pests and their natural enemies throughout the year on pigeonpea and on the available alternative hosts. We do this by regular sampling of the insects from various traps and from the plants, bringing samples to our laboratory for parasite studies.

PHEROMONES. In recent years we have been cooperating with the Tropical Products Institute of London in an attempt to develop a *Heliothis* pheromone that would at least be useful as an attractant in monitoring traps. We send pupae to Dr. Brenda Nesbitt of that Institute, who identifies the chemicals present in the pheromones of the females emerging from them and then sends us vials containing synthetic chemical mixtures, which we test in traps in our fields. Until recently we had little success with such traps, but from the middle of this year, using higher loads of a new improved chemical mix, we have been catching more *Heliothis* males in our pheromone traps than in traps containing virgin females. We hope that improve-

A funnel and bag pheromone trap, used for monitoring H. armigera *male moths in collaborative investigations with the Tropical Products Institute, and the Centre for Overseas Pest Research, London, being tested in an ICRISAT field. The trap was designed by Dr.* D. *Campion of COPR.*

ments in the synthetic pheromone and the traps will provide us with a means of monitoring *Heliothis* moth populations that will be superior to our present light trap monitoring, which has several disadvantages.

LIGHT TRAP SURVEYS. This year we operated light traps at our Hissar and Gwalior subcenters to monitor *Heliothis* moths. It is already clear that the pest population patterns differ markedly from area to area, and it is essential that we record the seasonal incidence of the pests to enable us to plan our pest management strategies. We are attempting to understand the effects of cropping, climate, and natural enemies on the pest populations with the long-term objective of predicting damaging attacks.

NATURAL ENEMIES OF THE PESTS. In our studies of the natural enemies of the pests, we again recorded the buildup of parasites of *Heliothis* and other lepidopteran borers. *Heliothis* larvae reached peak populations on our pesticide-free pigeonpea fields in November, but the natural parasitoid incidence in the larvae at that time averaged only 3%. The rate of parasitism then increased, to reach a peak in February of 42% that reduced the *Heliothis* attacks, thus allowing reasonable yields from our late-maturity selections and from the compensatory flush on the medium-maturity cultivars. We are recording parasitism in larvae collected from both pesticide-free and protected fields, and this year the reduction of parasitism by pesticide use was not strongly evident. This may be attributed to our success in incorporating alternative elements of pest management, which has allowed a reduction in the frequency of pesticide use in our fields.

As in previous years, we found that the *Heliothis* eggs collected from pigeonpea were free from parasitism, whereas those collected from other crops are reported to have quite high parasitism levels. The introduction of an insect that would parasitize *Heliothis* eggs on pigeonea would be of obvious benefit. We are investigating this possibility and are attempting to find out why the eggs on pigeonpea and chickpea are not parasitized by native insects.

PARASITE AUGMENTATION. We are also investigating the potential for augmenting natural control elements and introducing exotic biological control agents. This year we succeeded in rearing substantial populations of *Euoelatoria* sp on *Heliothis* larvae in our laboratory throughout the year (Fig. 4). *Euoelatoria* sp, a dipteran parasitoid, was imported from the USA and is being reared and released at ICRISAT and other centers

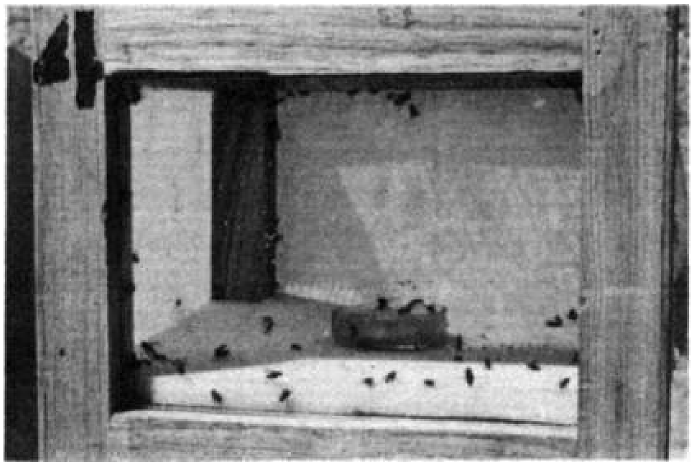


Figure 4. **Eucelatoria** ***adults being multiplied in the laboratory.***

in India in the hope that it might become established. We found that when given a choice it prefers to parasitize *Heliothis* larvae on pigeonpea rather than on chickpea. The preliminary attempts to establish this parasitoid in our fields show some promise, but unless this insect has the ability to survive the long hot dry season, when *Heliothis* larvae are scarce, it will be of little utility.

Nodule-damaging Fly

We continued to record the seasonal incidence of the nodule-damaging fly at ICRISAT Center in a cooperative study with our microbiologists. The identity of the insect has now been confirmed as *Rivellia angulata* Hendel by the Commonwealth Institute of Entomology. We used sticky cylindrical traps to monitor the populations of the adults of this pest and found that yellow surfaces attracted more than green. The first catches were in mid-June, then reached a peak in late August, when most pigeonpea plants were about 7 weeks old, and declined to low numbers in October. Greatest catches were from Vertisol fields sown with sole-cropped pigeonpea.

Pest Management Studies

In cooperation with our plant protection unit we study the use of pesticides on pigeonpea. We find it very difficult to apply pesticides, except when using a high-clearance tractor-mounted sprayer. Pesticides are normally required at the flowering stage to control *Heliothis* larvae, which infest the crop at that time. At the flowering stage most of the pigeonpea cultivars form a dense, interlocking barrier, up to 2 m high. Efficient coverage of such a crop is all but impossible with the normal hand-operated sprayers and dusters available to farmers. Intercropped pigeonpea can be protected more easily, for the companion crop is often removed before the pigeonpea flowers, but here again the target (the flowers and pods) is usually at or above shoulder level, thus making spraying difficult and hazardous. We had some success this year using controlled droplet applications at low volume. Unfortunately, machines giving the required droplet spectrum are not locally available, nor are the oil-diluted pesticides that are required for this type of application.

Given the problems and costs of pesticide use on pigeonpea, it is not surprising that most farmers use no pesticides. Our breeders and physiologists are now attempting to develop plants and cropping systems that can be conveniently treated with pesticides. Such a crop would be a meter or less tall at flowering, with a short, synchronous flowering and podding period that can be protected by only one or two pesticide applications. Even on the tall landrace cultivars, we often obtain very large yield increases from two or three pesticide applications, so the development of a crop that can be easily protected would appear a worthwhile venture. But this will not diminish our attempts to improve the traditional crop by incorporating pest resistance and utilizing other low-cost pest management strategies.

Pathology

Surveys

We carried out roving surveys in the Indian states of Gujarat, Rajasthan, and Bihar from January through March 1980. In Gujarat sterility mosaic and wilt were important, and there was low incidence of *Macrophomina* stem canker, bacterial stem canker, *Phoma* stem canker, white root rot, and foliar diseases. In Rajasthan, we recorded high incidence of sterility mosaic in some districts, and low incidence of wilt, *Macrophomina* stem canker, yellow mosaic, and foliar diseases. In Bihar, sterility mosaic, wilt, and *Macrophomina* stem canker were important, and *Alternaria* leaf spot appeared to be a potentially important problem of postrainy-season pigeonpea; incidence of yellow mosaic, *Phytophthora* blight, and foliar diseases was low. Data on sterility mosaic and wilt, the two most prevalent diseases in these states, are given in Table 9.

Pigeonpea is not an important crop in Bangladesh. In a survey trip to this country we found a disease resembling Witches' broom to be common; it seems to have the potential of becoming an important problem. Low wilt incidence was evident, but sterility mosaic was not seen.

Wilt (*Fusarium udum*)

SCREENING FOR RESISTANCE. We continued to give priority to work on resistance. Germplasm and breeding materials screened in our wilt-sick plots included 2149 germplasm accessions and a large number of F_2 bulks, backcrosses, F_3 to F_8 progenies, and sterility mosaic and *Phytophthora* blight resistant progenies. Of the germplasm screened, 67 accessions showed low wilt incidence. We identified 15 lines with combined resistance to wilt and sterility mosaic and three lines with resistance to wilt and *Phytophthora* blight.

More than 2000 additional germplasm accessions were screened in pots, and 47 were identified as low wilt lines. We will screen these in the sick plot next season. Of the six species of *Atylosia* (wild relative of pigeonpea) screened, only one, *A. volubilis,* was found resistant.

MULTILOCATIONAL TESTING. Fourteen wilt-resistant entries from ICRISAT were tested at 12 locations in India in cooperation with the All India Coordinated Pulse Improvement Project. ICP-8863 (Fig. 5) showed low wilt incidence (0-10%) at 11 locations and ICP-8860, ICP-8867, and ICP-8869 at nine locations. The multilocation test has now been extended to other countries such as Kenya and Malawi, where wilt is a serious problem.

EFFECT OF INTRAROW SPACING. Within-row spacings of 5, 10, 20, and 30 cm

Table 9. Summary of pigeonpea wilt and sterility mosaic incidence in Bihar, Gujarat, and Rajasthan states of India.

State	No. of districts surveyed	Total no. of locations examined	Distance travelled in state (km)	Wilt		Sterility mosaic	
				Average (%)	Range in farmers' fields (%)	Average (%)	Range in farmers' fields (%)
Bihar	26	68	3120	18.3	0-87	21.4	0 - 100
Gujarat	11	42	1389	5.4	0-46	12.2	0-92
Rajasthan	12	31	1576	0.1	0-4	5.4	0-68

Figure 5. A dried out susceptible pigeonpea cultivar ICP-2376 (left) and resistant cultivar ICP-8863 (right).

were compared for wilt incidence in a wilt-sick plot in two pigeonpea lines, ICP-6970 (resistant) and No. 1258 (susceptible). The incidence of wilt was not influenced by within-row spacings in a sick-plot situation: ICP-6970 remained resistant and No. 1258 remained equally susceptible at all spacings.

INFLUENCE OF CROP ROTATION AND INTERCROPPING. A 4-year experiment to study the effect of crop rotation and intercropping on the incidence of wilt was initiated in a sick plot, in close collaboration with agronomists. In this first year the wilt incidence in pigeonpea (ICP-6997) intercropped with sorghum was less (54%) than in sole pigeonpea (86%).

OTHER HOSTS OF *Fusarium udum.* A systematic study was initiated to find out if *F. udum* survives in other plant species. As a first step, we checked 35 weed species that were common in a wilt-sick plot by plating surface-sterilized root pieces on potato-dextrose-agar. None of them yielded *F. udum.* These investigations will continue and will include crop species also.

SURVIVAL IN STUBBLE. In a 5-year replicated experiment initiated in November 1974, we buried roots from wilted plants in large pots with Alfisol and Vertisol. After every 6 months, decomposing roots were removed from sets of pots and checked for the presence of *F. udum.* The fungus could be isolated up to 3 years in Vertisol and 2. 5 years in Alfisol. This experiment has now been concluded.

Sterility Mosaic

SCREENING FOR RESISTANCE. We screened a large number of germplasm accessions and breeding materials in the field by using the infector-row technique. Of the 2152 new germplasm accessions screened, 28 resistant accessions were identified. We also screened 1398 single-plant progenies of resistant plants selected from germplasm lines in previous years, and identified 773 progenies of 283 lines showing resistance.

MULTILOCATIONAL TESTING. In 1978/79, 12 resistant lines from ICRISAT were found susceptible at Dholi in Bihar State, India. This crop year, to identify lines that would be resistant both at ICRISAT and Dholi, 248 lines found resistant at ICRISAT were screened at Dholi in cooperation with scientists of the Rajendra Agricultural University. Only 18 lines showed 0-10% infection and were considered promising. These will be retested next year through a joint ICRISAT - ICAR disease nursery.

EFFECT OF INTERCROPPING. Incidence of sterility mosaic in a susceptible cultivar, BDN-1, was studied in sole and intercropped situations. We conducted a preliminary trial on a large plot (196 m^2) near a sterility mosaic screening nursery that served as the source of inoculum. Observations recorded at the time of maturity indicated higher disease incidence in the intercropped pigeonpea than in the sole pigeonpea (Table 10). Forty days after planting, the intercropped pigeonpea was subject to much reduced wind velocity, slightly higher relative humidity, but little difference in

Table 10. Sterility mosaic incidence and weather factors in sole and intercropped pigeonpea at ICRISAT Center, rainy season 1979/80.

Cropping pattern	Total plants	Infected plants	Percent[a] infection	Wind[b] velocity (km/h)	Relative[b] humidity (%)	Temperature (°C)
Sole pigeonpea	4973	791	15.6	12.9	59.5	34.0
Intercropped pigeonpea (1 row pigeonpea:4 rows sorghum)	1049	1021	97.3	1.6	65.5	34.8

a. From final readings at maturity, b. Forty days after planting,
c. Pigeonpea cultivar BDN-1 and sorghum ICH-6.

temperatures. Reduced wind velocity probably permitted better spread of the mite vector and caused more infection.

Phytophthora Blight

SCREENING FOR RESISTANCE. Materials field-screened during the year were 121 F_3 progenies, 574 F_4 progenies, 230 lines found promising in 1978/79, 91 wilt-resistant progenies, and 126 sterility mosaic resistant lines. To date we have identified 122 lines with resistance to blight and 20 lines with additional resistance to wilt or sterility mosaic. Our breeders advanced 281 F3 and F_4 progenies for further testing.

Over 750 additional germplasm accessions were screened in pots, and 49 lines with low susceptibility (up to 10% infection) were identified.

Multiple Disease Resistance

Materials were screened for multiple disease resistance (wilt, sterility mosaic, and *Phytophthora* blight) in a field nursery. These included seven progenies of ICP-5097, three F_2 populations, 520 progenies promising against *Phytophthora* blight, and 197 promising against sterility mosaic and blight. We advanced 40 promising materials for further studies.

We retested in the multiple disease nursery 121 progenies that showed promise against the three diseases in 1978/79. Of these only 14 showed combined resistance to the three diseases. These are now being used by our breeders.

Microbiology

Soil Populations of Cowpea Group *Rhizobium*

We examined soil samples collected from several ICRISAT fields for rhizobia of the cowpea group, which includes the rhizobia that nodulate pigeonpea. Most probable numbers were estimated by the serial-dilution/plant-infection method, with siratro (*Macroptilium atropurpureum,* a fodder legume) as the test plant. Soil samples taken from different depths of four different fields in all seasons showed that changes in population occurred between sites and with soil depth. Samples were also collected from three outstation locations (Warangal, Gwalior, and

Hissar in India) to study their distribution in different soils. At all the locations, including the three outstations, the population ranged from 0 to 10^6 rhizobia/g soil in the top 30 cm soil profile, but populations were generally lowest at Gwalior and Warangal. Of particular significance, however, is that about 25% of the ICRISAT isolates from soils obtained by serial dilution with siratro plants were positive in nodulating siratro but negative on pigeonpea cv ICP-1. This suggests the possibility of specificity of pigeonpea within the cowpea group of rhizobia, and now we make all estimates of soil populations using both siratro and pigeonpea as test hosts.

Pigeonpea *Rhizobium* Collection

During the year, 132 *Rhizobium* strains were added to our collection, making a total of 480. We obtained 30 isolates from soils of ICRISAT, Gwalior, Hissar, and Warangal; 29 from pigeonpea nodules from Madhya Pradesh; 61 from the University of West Indies; and 12 from the University of Panama.

The strains were all purified, authenticated by nodulation of siratro and pigeonpea in the laboratory, and characterized for efficiency on pigeonpea in the glasshouse.

RHIZOBIUM **CULTURE SUPPLY.** We supplied cultures on request either as agar slants or peat inoculants to scientists in India, Senegal, Peru, Indonesia, Australia, and Fiji.

Rhizobium-induced Leaf Curl

Two *Rhizobium* strains isolated from two Vertisol fields were found to induce leaf curl on pigeonpea grown in Leonard jars. The symptoms started on the second or third trifoliate leaf. Leaf margins curled inwards. As the plants grew older, all the new leaves showed curling and the growth rate was reduced. After about 6 weeks, further apical growth of the plant was checked, and axial buds and leaves developed. These still showed the curling symptoms, Nodulation was normal. In order to see whether the effect was cultivar-specific, we tested the two strains on 27 pigeonpea genotypes representing different maturity groups and found that leaf curl occurred on all.

Pigeonpea with leaf curl (A), induced by Rhizobium *strain IHP 342, compared with a normal plant (B) nodulated by strain IHP 195.*

Our interest in this phenomenon is particularly related to the possibility of using the symptom as a marker for nodulation by inoculant strains. Preliminary studies conducted in pots with nonsterile sand, Alfisols, and Vertisols indicated that these two strains were not competitive in Alfisols and only poorly competitive in Vertisols. However, further tests will be conducted under field conditions.

Selection of *Rhizobium* Strains

This year we field-tested 12 *Rhizobium* strains, including the six best strains from field trials conducted in 1978, five promising strains from testing in the glasshouse, and one exotic strain from the West Indies. Pigeonpea cv ICP-1 seeds were inoculated with peat inoculants, providing a population of about 10^5/seed, which were sown in one Alfisol and two Vertisol fields. There was no response to inoculation as determined by nodulation, nitrogenase activity, and plant dry-matter production around 40 days after planting. However, in one of the Vertisol fields at maturity, four *Rhizobium* strains (IHP193, IHP170, IHP100, and IHP69) produced significantly more dry matter (28-41%) and grain yield (26-44%) than the non-inoculated control (Table 11). *Rhizobium* strain IHP147 significantly increased only total dry matter. Those strains found most effective in the previous year (Annual Report 1978/79) proved to be less so in this year's experiment. Such differences may well be due to changes between years in the constitution of the natural *Rhizobium* populations, so that the introduced strain faces different competitive situations each year. The application of typing techniques based on differential inherent antibiotic resistance (already in use at ICRISAT with chickpea) provides an opportunity to characterize the natural populations and examine this hypothesis.

Table 11. Effect of seed inoculation with* Rhizobium *on total dry matter and grain yield of pigeonpea cv ICP-1 at ICRISAT Center in 1979/80.

	Soil					
	Vertisol 1		Vertisol 2		Alfisol	
Rhizobium strain	Grain yield	Total dry matter	Grain yield	Total dry matter	Grain yield	Total dry matter
			(kg/ha)			
IHP193	2059	8275	1241	8 878	1679	5273
IHP170	1967	8364	1538	8 875	1564	4958
IHP100	1833	7588	1909	8 874	1647	5432
IHP69	1796	7898	1715	10 190	1696	5574
IHP147	1702	7713	1405	9 531	1595	5320
WI10013	1642	7415	1537	8 537	1497	4776
IHP24	1637	6776	1830	9 153	1626	5462
IHP195	1629	7292	1868	10 151	1691	5475
IHP67	1543	6614	1552	9 274	1508	5003
IHP71	1528	6847	1825	9 216	1561	5075
IHP229	1520	6341	1738	9 781	1671	5537
IHP35	1442	6203	1518	8 514	1779	5707
IHP213					1776	5828
Control	1427	5930	1515	8 518	1469	4748
LSD (0. 05)	362	1538.7	NS	NS	NS	NS
CV (%)	15.1	14.9	25.5	10.1	9.9	10.6

NS = Not significant.

Although the results in the other two fields were not statistically significant, there was some increase in grain yield and total dry-matter production with almost every strain. There is some evidence of site x strain interaction with IHP193, which was best in Vertisol field 1 and worst in Vertisol field 2.

We usually initially test *Rhizobium* strains in sand in sterile Leonard jars and in non-sterile soil in pots under glasshouse conditions. Those performing best are then tested under field conditions for final evaluation of infectiveness, and effectiveness in nitrogen fixation. However, we tested 32 *Rhizobium* strains in both Alfisol and Vertisol fields after they had been evaluated only under sterile sand conditions. Seed inoculation did not give statistically significant improvements, but a grain yield increase of up to 48% and total dry-matter increase of up to 17% in the Vertisol indicate that many of these strains deserve further investigation.

Nitrogen Supply to Pigeonpea

This year we repeated our examination of the effect of different levels of nitrogen and

Table 12. The effect of nitrogen supply and inoculation on nodulation and yield of a range of pigeonpea cultivars in a Vertisol.

	Time of sample 40 days					195 days (maturity)	
	Nitrogenase activity		Nodule no./ plant	Dry weight of nodules/ plant (mg)	Shoot dry weight/ plant (g)	Seed weight[a] (kg/ha)	Total dry matter (kg/ha)
Treatment	μmol C_2H_4/ plant/hr	μmol C_2H_4/g dry nodule/hr					
Nitrogen (kg/ha)							
0	4.0	107	18	30.0	3.7	1830	8 730
20	1.8	82	15	16.0	3.9	1890	8 430
200	0.2	29	10	8.4	4.4	2230	10 930
LSD (0.05)	1.5	29	3.6	9.0	0.4	305	1 033
Inoculation							
Inoculated	2.2	73	15	17.1	4.0	2050	9 840
Noninoculated	1.8	72	15	19.6	4.0	1920	8 880
LSD (0.05)	NS	NS	NS	NS	NS	NS	844
Cultivar							
ICP-1	2.3	87	18	18.6	4.5	1930	10 080
BDN-1	4.7	94	24	39.3	4.6	2040	8 640
T-21	0.4	43	8	8.7	3.6	a	a
Prabhat	0.6	66	8	6.8	3.2	a	a
LSD (0.05)	1.7	34	4.1	10	0.46	NS	844
CV (%) per plant	131.3	70	42.4	84.2	17.5	18.1	13

a. Since earlier cultivars were severely damaged by pod borer they were excluded from the analysis of seed weight or top dry matter.

of inoculation on nodulation, growth, and yield responses of two medium-duration cultivars, ICP-1, and BDN-1, and two early-duration cultivars, T-21 and Prabhat, in an Alfisol as well as in a Vertisol. Data from the Vertisol are presented in Table 12. At 40 days after planting in both soils, nodulation and nitrogenase activity per plant was significantly reduced, but shoot weight was stimulated by application of 200 kg N/ha. Also, in both soils, nodule number and weight and nitrogenase activity per plant were significantly greater in medium-duration cultivars than in early-duration cultivars. In the Vertisol, application of 200 kg nitrogen increased grain yield of medium-duration cultivars by 22% and total dry matter by 25%, suggesting that nodules were not supplying enough nitrogen to the plant (Table 12). *Rhizobium* inoculation resulted in more plant dry matter but not more seed yield. In Alfisol, there was also a trend towards increase in grain yield and total dry matter of pigeonpea supplied with 200 kg N/ha.

Nitrogen Uptake and Fixation by Pigeonpea

We are investigating techniques for determining the amount of nitrogen fixed by pigeonpea. A simple technique involves comparison of total nitrogen uptake by pigeonpea and by a nonlegume. Ten cultivars of pigeonpea representing different plant growth habits (determinate and indeterminate) and maturity groups were planted on an Alfisol during the 1977 rainy season in an attempt to measure total nitrogen uptake and nitro-

Table 13. Estimates of nitrogen fixation by a range of pigeonpea cultivars, calculated by subtraction of the nitrogen uptake of sorghum, on an Alfisol at ICRISAT Center, rainy season 1977.

Cultivar	Plant growth habit	Maturity (days)	Total uptake of N[a] (kg/ha)	Estimate of N fixed (kg/ha)
Pigeonpea				
Prabhat	DT[b]	115	69.1	+ 4.4
Pant A-3	DT	115	71.6	+ 6.9
T-21	NDT	130	107.9	+43.2
UPAS-120	NDT	125	91.8	+27.1
BDN-1	NDT	130	118.2	+53.5
No. 148	NDT	150	119.8	+55.1
JA-275	NDT	170	77.9	+13.2
ICP-7035	NDT	170	101.0	+36.3
ICP-7065	NDT	175	107.7	+43.0
T-7	NDT	215	134.1	+69.4
NP(WR)15	NDT	240	114.3	+49.6
Sorghum		175	64.7	

a. Based on all plant parts, including roots, nodules, and fallen leaves of pigeonpea.
b. DT-Determinate; NDT -Nondeterminate.

gen fixation, using an Ethiopian line of sorghum, IS-11758, as a control. Results of this experiment became available this year: At maturity, total nitrogen uptake by different cultivars of pigeonpea ranged between 69 and 134 kg/ha per season as against 64.7 kg N/ha per season by sorghum (Table 13). The differences between the uptake of the pigeonpea cultivars and sorghum were attributed to nitrogen fixation by the legume.

Other workers have shown in soybean research that at least some of the nitrogen fixed in nodules is exported to above-ground plant parts in the form of allantoin. The percentage of nitrogen as allantoin in the xylem sap or in other plant tissue may be an indication of the proportion of the plant nitrogen that has been fixed as a result of nodulation. Sampling pigeonpea under field conditions for nodulation and nitrogenase activity is difficult because of the large, sparsely nodulated root system; therefore an alternative is of particular interest. We have found that pigeonpea xylem sap contains a considerable amount of allantoin. In studies so far there appears to be a positive relationship between the allantoin concentration in the xylem sap and nodulation and nitrogenase activity per plant. These studies are being continued.

Looking Ahead

We will widely test newly developed short-duration pigeonpea and intensify screening of late-maturing pigeonpea in the intercropped situation. The hybrid program will be strengthened through development of more lines carrying genetic male sterility.

Development of additional multiple-disease-resistant lines will receive emphasis; medium-maturity lines carrying resistance to wilt and sterility mosaic will be tested at several locations. We also expect to expand the development of pest management elements, including resistance to pod borer and podfly,

We will continue screening for tolerance to salinity and waterlogging. Cropping practices for maximum production will be further evaluated, and our search for efficient host genotypes and *Rhizobium* strains will also go forward.

Publications

Institute Publications

Dahiya, B.S. 1980. An Annotated Bibliography of Pigeonpea, 1900-1977. ICRISAT, Patancheru P.O., Andhra Pradesh, India.

ICRISAT. 1980. Proceedings, Consultants' Group Discussion on the Resistance to Soil-borne Diseases of Legumes, 8-11 Jan 1979, Patancheru, Andhra Pradesh, India (ed Y. L. Nene).

Journal Articles

Kannaiyan, J., Ribeiro, O. K., Erwin, D. C., and Nene, Y. L. 1980. *Phytophthora* blight of pigeonpea in India. Mycologia 72: 169-181.

Singh, U., and Jambunathan, R. 1980. Biochemical changes in the developing seeds of chickpea (*Cicer arietinum* L.) and pigeonpea (*Cajanus cajan* L.). Indian Journal of Biochemistry and Biophysics 17:95. (Abstract).

Conference Papers

Kumar Rao, J.V.D.K. 1980; Ecology of *Rhizobium* in soil. Presented at Fifth Southern Regional Conference on Microbial Inoculants in Crop Production held at ICRISAT, 20-22 Mar, Patancheru, India.

Kumar Rao, J.V.D.K. 1980. Pigeonpea

Rhizobium strain selection and testing. Presented at Fifth Southern Regional Conference on Microbial Inoculants in Crop Production held at ICRISAT, 20-22 Mar, Patancheru, India.

Kumar Rao, J.V.D.K. 1980. Techniques for measuring N_2-fixation of pigeonpea. Presented at Fifth Southern Regional Conference on Microbial Inoculants in Crop Production held at ICRISAT, 20-22 Mar, Patancheru, India.

Kumar Rao, J.V.D.K., and Dart, P.J. 1979. Biology of nodulation of pigeonpea *Cajanus cajan* (L.) Millsp. Presented at Sixth Australian Legume Nodulation Conference, 21-24 Aug, Perth, Australia.

Kumar Rao, J.V.D.K., and Dart, P.J. 1979. Intraspecific variability in nodulation of pigeonpea. Presented at Sixth Australian Legume Nodulation Conference, 21-24 Aug, Perth, Australia,

Kumar, Rao, J.V.D.K., and Dart, P.J. 1979. Population dynamics of cowpea *Rhizobium* in semi-arid tropic soils. Presented at Sixth Australian Legume Nodulation Conference, 21-24 Aug, Perth, Australia.

Kumar Rao, J.V.D.K., and Dart, P.J. 1980. Report of microbiology experiments conducted at ICRISAT. Presented at All India Kharif Pulses Workshop, 7-10 Apr, Kanpur, India.

GROUNDNUT

Contents

GROUNDNUT

Groundnut production is the largest of any legume crop in the semi-arid tropics (SAT), where it is an important source of food and also an important cash crop. Although two-thirds of the world's groundnut is produced in the SAT, diseases, pests, and unreliable rainfall patterns impose severe limitations on production, which averages around 800 kg/ha, compared with 3000 kg/ha or more in developed countries.

Groundnut is a latecomer among ICRISAT's mandate crops, with fullscale research beginning only in 1977. We are now nearly adequately staffed, except for the Physiology and Entomology subprograms; a physiologist has been recruited and will join *in* October 1980 and a position for a principal entomologist has been budgeted for the fiscal year 1981.

Of several management strategies used by the Groundnut Improvement Program to raise the low yields obtained by small farmers in the SAT, the main one is to breed into the crop stable resistance or tolerance to the major yield reducers.

Breeding

Cooperation with National Programs

COORDINATED TRIALS. During the 1979 rainy season six yield trials sponsored by the All India Coordinated Research Project on Oilseeds (AICORPO). were conducted on Alfisols at ICRISAT Center under rainfed and nonprotected conditions. The yields ranged from 135 to 1281 kg/ha. Yield levels were low due to severe attacks by rust, leaf spots, bud necrosis disease, and a drought during most of October. The Spanish Cultivars (G 201, J 1, Dh 4, and Ah 8446) and the Virginia cultivars (48-74, M 13, Robut 33-1, and 39-2) were the most promising. Of the confectionery varieties, cultivars Ah 114 and M 13 were superior to other entries.

DISTRIBUTION OF BREEDING MATERIAL. During the 1979/80 crop year, 1000 breeding populations, comprising both early and advanced generations from the rust resistance, high yield, and earliness projects, were supplied to breeders in 13 countries.

ICRISAT COOPERATIVE TRIAL. This year, the Groundnut Program evaluated breeding material in different environments in India. A 7x7 simple lattice trial, consisting of 47 F_5 breeding lines and 2 standard varieties, was carried out at six locations in the 1979 rainy season. The results obtained (Table 1) indicate a very strong cultivar x location interaction. The breeding line (NC Ac 2953 x X14-4-B-19-B) F2-P1-B1-B1 was the highest yielding at both Junagadh and Dharwar.

Hybridization Program

During 1979/80 we carried out over 56 000 pollinations, in the field as well as in screenhouses, and completed a total of 288 crosses. Breeding for insect resistance was also started. Emphasis in our hybridization program was shifted towards crossing among the ICRISAT-derived lines coming from the Program's various projects.

Breeding for Leaf Spot Resistance

We began this project with the object of utilizing leaf spot resistant tetraploid progenies resulting from interspecific hybridization to transfer the resistance to high-yielding susceptible cultivated varieties. Recently more intensive searches within the cultivated groundnut have shown some usable sources of resistance or tolerance to leaf

Table 1. Summary of the results of the 7 x 7 simple lattice yield trial of groundnut over six locations in India (rainy season, 1979).

	ICRISAT (irrigated)	ICRISAT (rainfed)	Junagadh (rainfed)	Dharwar (rainfed)	Khargone (rainfed)	Jaipur (one irrigation)
Range of yield (kg/ha)	316-1242	158-933	488-1605	425-1932	139-1389	844-2222
No. of entries yielding more than Robut 33-1	4	1	16	37	5	43
No. of entries yielding more than J 11	12	24	9	15	5	46
Yield of Robut 33-1 (kg/ha)	976	641	1204	703	972	844
Yield of J 11 (kg/ha)	794	414	1265	1172	944	866

spot fungi (see Pathology section of this report). Many of the germplasm lines earlier selected for rust resistance (e. g. , PI 259747, EC 76446 [292], NC AC 17133[RF]) have also shown resistance to late leaf spot at ICRISAT Center. Several rust-resistant selections made at ICRISAT from FESR material (USDA, Puerto Rico) are also resistant to late leaf spot (Table 2). A few rosette-resistant cultivars, such as RMP 91 and RMP 12, have also some resistance to late leaf spot. For resistance to early leaf spot, NC 3033 is being utilized in the breeding program. Rust populations are also now being screened for leaf spot resistance. We have

Table 2. Rust and late leaf spot reactions of some FESR selections of groundnut in field screening trials(1978-80) at ICRISAT Center.

Selection	Mean disease score[a] Rust	Leaf spot
FESR 5-P2-B1-B1-B1	2.0	3.0
FESR 5-P17-B1-B1-B1	2.0	3.0
FESR 7-P13-B1-B1-B1	2.0	3.0
FESR 9-P3-B1-B1-B1	2.0	3.0
FESR 9-P4-B1-B1-B1	2.0	4.3
FESR 9-P7-B1-B1-B1	2.7	3.3
FESR 9-P7-B2-B1-B1	2.7	4.3
FESR 9-P8-B2-B1-B1	2.0	3.0
FESR 9-P12-B1-B1-B1	2.0	2.7
FESR 11-P11-B2-B1-B1	2.3	2.7
FESR 12-P4-B1-B1-B1	2.0	2.0
FESR 12-P5-B1-B1-B1	2.0	2.7
FESR 12-P6-B1-B1-B1	2.7	3.7
FESR 12-P14-B1-B1-B1	2.0	3.3
FESR 13-P12-B1-B1-B1	2.0	2.7
TMV-2 (check)	9.0	9.0

a. Mean score of three seasons on 1-9 scale, where 1 = no disease, and 9 = 50-100% foliage destroyed.

identified and are advancing 149 leaf spot resistant selections, mostly Involving PI 259747 as one of the parents.

Breeding for Resistance to Rust

Several new sources of rust resistance (PI 405132, PI 407454, DHT 200, and FESR selections) were included in our crossing program. During the postrainy season (Nov-Apr for groundnut) of 1979/80, 163 plant selections and 3036 bulk selections were made from F_2 to F_5 generations in the field. Several of the high-yielding plants, though susceptible to rust, were also selected and bulked with the expectation that they might segregate into resistant types in later generations (resistance to rust is recessive), or else they will be utilized in further hybridization.

FESR YIELD TRIAL. During the 1978/79 postrainy season when rust was not a problem as in previous postrainy seasons, 316 FESR selections (ICRISAT Annual Report 1977/78, 1978/79) with highly resistant and resistant reactions to rust were evaluated for yield potential along with one resistant (NC Ac 17090) and two susceptible (J 11 and Robut 33-1) checks. The rust-resistant cultivar NC Ac 17090 gave the highest yield (2720 kg/ha). Cultivars J 11 and Robut 33-1 yielded 966 and 1122 kg/ha, respectively. Of the FESR selections, 104 selections yielded more than Robut 33-1; FESR 3-P5-B1-B2-B1 yielded the highest (2198 kg/ha). Most of the high-yielding selections came from FESR lines 3, 5, 7, 8, 10, 11, and 14. During the rainy season of 1979 when rust was present in epiphytotic proportions, the same trial was repeated in a systematic design under rainfed, low fertility, and non-protected conditions. The selection FESR 8-P12-B1-B1-B1 significantly outyielded NC Ac 17090, J11, andRobut 33-1 (Table 3). Two selections yielded significantly more than Robut 33-1, and 41 selections were found superior to J 11. Selections FESR 3-P2-B1-BI-BI, FESR 3-P17-B1-B1-B1, and FESR 13-P14-B1-B2-B1 were among the top 20 highest yielders in both seasons.

Table 3. Performance of some FESR selections of groundnut under low-fertility and rainfed conditions at ICRISAT Center (rainy season, 1979).

Selections	Yield (kg/ha)
FESR 8-P12-B1-B1-B1	1301
FESR 5-P20-B1-B2-B1	1173
FESR 8-P9-B1-B1-B1	1131
FESR 9-P5-B1-B1-B1	1044
FESR 8-P11-B1-B2-B1	1008
FESR 8-P13-B1-B2-B1	990
FESR 5-P19-B1-B2-B1	979
FESR 8-P3-B1-B2-B1	921
NC Ac 17090[a]	899
Robut 33-1[b]	817
J 11[b]	559
SE ±	81.9
CV (%)	34.3

a. Rust-resistant check.
b. Susceptible check.

Promising selections were also made in the FESR material for jassid and thrips resistance.

Breeding for Earliness

Under rainfed conditions in the SAT, where growing seasons can be very short or unreliable, short-season groundnut cultivars would be very useful. During this year, our hybridization program included L. No. 95 A, a weakly dormant Spanish cultivar. In the 1979/80 postrainy season several individual plant and bulk selections were made from crosses with this cultivar. The details are given in Table 4.

During the 1979/80 postrainy season, selections from 14 crosses matured in 102 days, i. e., the same time as the early-maturing parent, Chico (Table 5).

Table 4. Details of the selections made in the Groundnut Program's earliness breeding project at ICRISAT Center (postrainy season, 1979/80).

Generation	No. of pedigrees	No. of selections: Single plant IR[a]	Bulk selections B1: IR	Bulk selections B1: NIR[b]
F_2	22	117		
F_3	28	12	51	
F_5	109	13	145	203
F_6	54	1	368	30
F_7	6		11	

a. IR = Selections made under irrigated conditions.
b. NIR = Selections earlier made under nonirrigated conditions.

Table 5. Groundnut crosses that produced selections maturing in 102 days at ICRISAT Center (postrainy season, 1979/80).

F_4 generation

Argentine x Chico
2-5 x Chico
28-206 x Chico
SM 5 x Robut 33-1
Tifspan x Robut 33-1
2-5 x Robut 33-1
Virginia 72-R x Robut 33-1

F_5 generation

JH 89 x Chico
JH 171 x Chico
Dh 3-20 x Chico
Dh 3-20 x Robut 33-1
NC Ac 2748 x Chico
TMV-7 x Chico
Virginia 72-R x Chico

We selected several high-yielding plants from the following crosses of early-maturing lines and will evaluate them for yield potential during the 1980 rainy season:

F_4 Generation
X40-X-X-3-B x Chico; TMV 10 x Chico; Robut 33-1 x Comet; 28-206 x Chico; 53-68 x Chico; TG 17 x Robut 33-1; Shulamit x Robut 33-1; Spancross x Robut 33-1; 2-5 x Robut 33-1; Robut 33-1 x Ah 8254.

F_5 Generation
Kadiri 71-1 x Chico; TMV 7 x Robut 33-1; SM 5 x Robut 33-1; JH 89 x Robut 33-1; Dh 3-20 x Robut 33-1; Argentine x Robut 33-1; NC Ac 1107 x Robut 33-1; Ah 65 x Robut 33-1; M 13 x Robut 33-1; JH 335 x Chico; Florigiant x Chico; Shulamit x Chico.

Breeding for High Yield and Quality

The purpose of this project is to generate base material with high yield potential for disease resistance programs and for areas of the world where diseases are not prevalent, or where protective measures are routinely taken. Table 6 shows the number of selections made from the 1979/80 postrainy season harvest.

We also grew 39 F_1 crosses in the field during this season. Highly promising selections were made in several crosses (Table 7).

During the 1979 rainy season, 544 F_5 bulks from this project were evaluated in a systematic design in two environments (low fertility, rainfed; and high fertility, irrigated). Under rainfed conditions, 15 bulks significantly outyielded the standard check Robut 33-1 (490 kg/ha). The highest yielding bulk was (Virginia 72-R x 2-5) F2-B1-P1-B1 (800 kg/ha). Under irrigated conditions 40 bulks outyielded Robut 33-1 (1643 kg/ha). (TG 3 x MGS 9) F2-P3-B1-B1 gave the highest yield (2235 kg/ha). Nine entries out of the top 40 bulks tested were common for both sets of conditions.

During the 1979/80 postrainy season, the number of entries was reduced to 512. The trial was an 8x8x8 cubic lattice design superimposed with a systematic design. Besides evaluation of the breeding material, another objective was to compare the efficacy of these two designs in evaluating large numbers of entries. Results from the cubic lattice analysis obtained are as follows:

Four bulks significantly outyielded Robut 33-1 (2949 kg/ha) and J 11 (2915 kg/ha). These four bulks are:

These four bulks are:	Kg/ha
(Robut 33-1 x NC Ac 2821) F2-B3-B1-B2-B1	3827
(Robut 33-1 x NC Ac 2698) F2-B2-B1-B1-B1	3686
(Dh 3-20 x NC Ac 2608) F2-B3-B1-B1-B1	3598
(2-5 x NC Ac 741) F2-B4-B1-B1-B1	3576

An additional 68 bulks were not significantly different from Robut 33-1.

It is likely that Robut 33-1 arose from a natural cross, and when first grown at ICRISAT in 1977 it showed considerable variation. We conducted a yield trial consisting of progenies of several plant selections made from the cultivar Robut 33-1 during the rainy season of 1979 and postrainy season of 1979/80. During the 1979 rainy season, although six selections yielded more than Robut 33-1, they were not significantly different. In the postrainy season eight selections significantly outyielded Robut 33-1 (Table 8). The shelling percentage also improved in the postrainy season.

Table 6. Details of selections made in the Groundnut Program's high yield and quality breeding project at ICRISAT Center (postrainy season, 1979/80).

Generation	No. of pedigrees	No. of selections Plant	Bulk
F_2	18	2	29
F_3	90		129
F_4	152		329
F_5	45		94
F_6	35		101

Table 7. High-yielding groundnut selections at ICRISAT Center (postrainy season 1979/80).

F_4 generation

NC Ac 529 x Shulamit
NC Fla 14 x TG 1
Ah 6279 x Spancross
Florigiant x SM 5
GAUG 1 x NC Ac 310
Starr x NC Ac 1107
Tifspan x SM 5
Virginia 72-R x NC Ac 1107
X14-4-B-19-B x SM 5

F_5 generation

Ah 8254 x JH 62
G 37 x Spanhoma
Faizpur 1-5 x NC Ac 316
NC Ac 63 x TG 17
148-7-4-3- 12-B x Manfredi
NC Ac 2750 x Ah 8189
NC Ac 316 x NC Ac 310
USA 20 x TMV 10

Table 8. Natural hybrid trial of groundnut (postrainy season, 1979/80).

Selections from Robut 33-1	Type[a]	Days to maturity	Yield (kg/ha)	Shelling (%)
11-7-B1-B1-B1	VB, SB, IB	119	2680	77
21-11-B1-B1-B1	SB	119	2683	66
10-3-B1-B1-B1	SB	119	2653	76
7-6-B1-B1-B1	VB, IB	119	2650	70
13-6-B1-B1-B1	VB, SB, IB	119	2628	71
12-10-B1-B1-B1	VB, IB	119	2620	75
50-1-B1-B1-B1	VB	119	2527	71
24-16-B1-B1-B1	SB	119	2488	72
Robut 33-1 (parent)	VB	119	2013	70
SE ±			137.6	
CV(%)			12.0	

a. VB = Virginia Bunch, SB = Spanish Bunch, IB = Irregular Branching,

Breeding for Pest Resistance

A breeding program for resistance to jassids and thrips, which cause economic damage to groundnuts in many parts of the world, commenced in the 1979 postrainy season. Resistant cultivars NC Ac 2214 and NC Ac 2232 were involved in crosses with diverse and elite varieties such as Florunner, Gangapuri, Robut 33-1, JL 24, ManiPintar, Argentine, Tifspan, TMV 4, and M 13. We will make further crosses with NC Ac 2214 and NC Ac 2232 and other resistant cultivars as they are identified.

Adaptation of Cultivars to Vertisols

A set of 500 cultivars was planted in Vertisols to screen for groundnut genotypes that will withstand iron chlorosis in the postrainy season. However, we could not obtain reliable results from this experiment, as there was no uniform expression of chlorosis. Moreover, the symptoms of chlorosis disappeared as soon as the field was irrigated. The pH of the soil was between 8. 0 and 9.0, and that of the irrigation water was 7.3.

Basic Studies

GENETICS OF NONNODULATION. Segregation for nodulation in the crosses NC 17 x PI 259747 and NC Ac 2731 x PI 259747 in the F_2 generation and in F_3 progeny rows indicated that a pair of independent duplicate genes control nodulation.

Diallel Studies

Two full sets of diallel crosses (10x10 and 15x15) involving diverse parents were evaluated for heterosis and combining ability for 15 characters measured at seedling, flowering, and harvest phases. The genetic divergence among Spanish and Valencia parents was substantial enough to suggest the utility of Spanish x Spanish, Spanish x Valencia, and Valencia x Valencia crosses. Parental divergence could explain to a good extent the frequency and magnitude of the realized heterosis. Parents of the diallels were classified as High (H) or Low (L) on the basis of their general combining ability over the 15 characters. H x L crosses were found to contain the highest frequency of heterotic crosses.

Cytogenetics

Collections

During the year we received 52 accessions of section *Rhizomatosae* as cuttings and a few species from other sections as seed. We multiplied this material and observed its performance under conditions prevailing at ICRISAT Center.

Cytogenetic Analysis

Wild species and their hybrids were analyzed cytologically to increase our understanding of the genus *Arachis,* and to improve the efficiency of their utilization. Those species known to cross with *A. hypogaea* were given priority for cytological studies.

Our subprogram completed a detailed karyotype analysis of the 12 available taxa in section *Araohis.* We distinguished the chromosomes by length, position of the centromere (measured by the ratio of the long arm to the short arm), and the presence and position of the secondary constriction, which is the region of the chromosome associated with the nucleolus, distal to which is a region termed the satellite. Chromosomes were ranked in decreasing order of length, and species were grouped by Mahalanobis' D^2 analysis of arm ratio; this was confirmed by cluster analysis.

In addition to *A. hypogaea,* section *Araohis* contains one other tetraploid, *A. montioola* and several diploid species. A chromosome with a secondary constriction and a small satellite was identified as chromosome 3 in *A. villosa, A. oorrentina, A. ohaooense,* and *Arachis* sp "10038." A chromosome with a secondary constriction and a large satellite was seen in both *A. batizocoi* and *A.duranensis* as chromosome 2, in *Araohis* sp "HLK 410" as chromosome 6, and in *A. cardenasii* as chromosome 9. Chromosomes with secondary constrictions had only been reported previously in *A. batizoooi.*The small pair of chromosomes in *A. oardenasii* is larger than in the remaining species but smaller than the smallest chromosomes of *A. batizocoi. A. monticola* and *A. hypogaea* are close karyomorphologically, though *A. monticola* has two pairs of chromosomes with secondary constrictions, whereas *A. hypogaea* has only one. The chromosome with a secondary constriction in *A. cardenasii* resembles one of those of *A. montioola* and that of *A. hypogaea.*

Mahalanobis' D^2 analysis, and canonical analysis of the diploid taxa, resulted in the definition of two distinct clusters. *A. batizocoi* is the only species in one of these clusters; there are eight taxa in the other cluster, which can be further subdivided (Fig. 1). *A. cardenasii,* though furthest

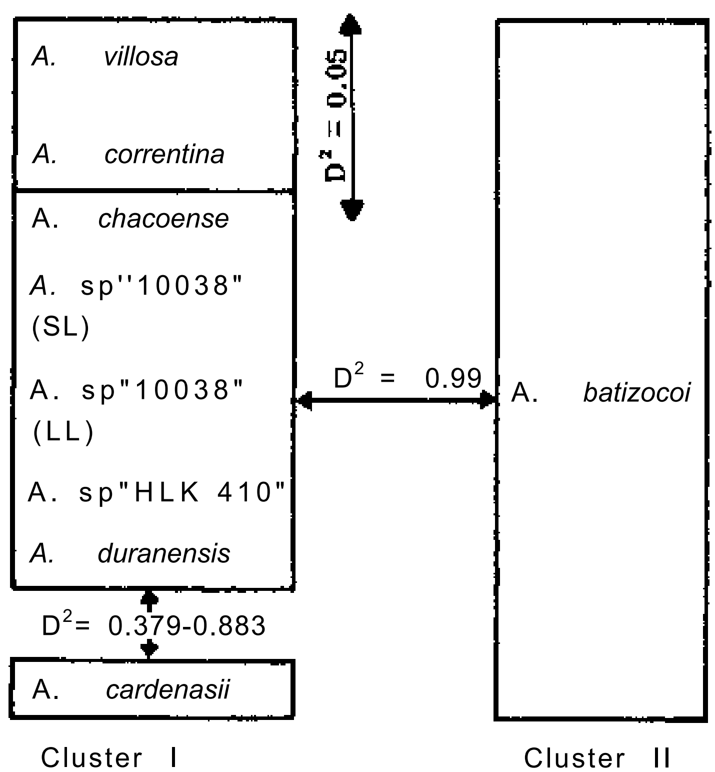


Figure 1. Cluster diagram of section* Arachis *species based on Mahalanobis' D^2 values.

from the other taxa, does not form a separate cluster as defined by the criteria of the analysis performed.

A. *batizocoi* had previously been recognized as distinct from other species studied and was suggested as the donor of the B genome to A. *hypogaea.* Our results indicate that the other species can be distinguished karyomorphologically and that these A-genome species can be subdivided; we can now predict more accurately the fertility of hybrids and the best means of incorporation of desirable genes from these species into *A. hypogaea.*

Hybridization

The seven available diploid species in section *Arachis* were crossed in 34 of the 42 possible cross combinations, as the first stage in producing tetraploid amphiploids to be crossed with *A. hypogaea.* By this route, we intend to produce hybrids combining desirable characters from two wild species.

All crosses attempted produced pods; crossability ranged from 0. 5 to 82 pods per 100 pollinations (Table 9). Although closely related species usually crossed more successfully, there were exceptions, e.g., *A. batizocoi* x *A. villosa;* and reciprocal crosses often differed markedly.

Colchicine Treatment

Some seeds from these crosses were treated with colchicine to double the chromosome number. The apical bud of a young seedling was wrapped in cotton wool, which was then soaked in a 0.125%, 0.25%, or 0.4% aqueous colchicine solution for up to 6 hr. Treatments were repeated on consecutive days up to a maximum of 3 days. The most effective concentration of colchicine was 0.25%; 73% of the treated seedlings survived, and 48% of the survivors were tetraploid (Table 10). This technique was more successful than that of treating lateral branches.The tetraploids produced will be crossed with *A. hypogaea.*

Table 9. Number of pollinations, number of pods, and percentage of crossability among diploid species of section Arachis.

Male parent / Female parent	*A. batizocoi*			*A. villosa*			*A. correntina*			*A. chacoense*			*Arachis* sp "HLK 410"			*Arachis* sp "10038"			*A. duranensis*		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
A. batizocoi				104	38	37				88	13	15	121	66	55				152	5	3
A. villosa	215	9	4				221	1	0.5	76	8	11	169	1	0.6	85	6	7	215	15	7
A. correntina	136	18	13	68	7	10				162	14	9	220	15	7	74	6	8	105	2	2
A. chacoense																					
Arachis sp "HLK 410"	29	2	7	99	41	41	104	36	35	115	66	51				83	19	23	49	5	10
Arachis sp "10038"	118	24	20	99	3	3	63	26	41	111	45	41	160	84	53				126	57	45
A. duranensis	74	6	8	172	27	16	67	5	7	114	93	82	58	11	19	159	43	27			

a = number of pollinations performed; b = number of pods obtained; c = number of pods per 100 pollinations.

Table 10. Colchicine treatment of diploid interspecific hybrids of Arachis.

Hybrid	Number of seedlings Treated	Survived	Tetraploid
A. batizocoi **x** *A. villosa*	6	5	2
A. batizocoi **x** *A. duranensis*	5	5	1
A. batizocoi **x** *A. chacoense*	10	5	4
A. duranensis **x** *A. ohaooense*	5	4	2
A. correntina **x** *A. villosa*	5	3	1
A. correntina **x** (*A. chacoense* **x** *A. cardenasii*)	3	3	1
Arachis **sp "HLK 410" x** (*A. chacoense* **x** *A. cardenasii*)	3	2	2

Tetraploid plants were also produced by colchicine treatment of seedlings of three wild diploid species, *A. batizocoi, Arachis* sp "HLK410," and *A. villosa* (Table 11). The autotetraploids had larger pollen (Table 12), and pollen fertility and plant fertility were reduced. Seeds were harvested from autotetraploid *A. batizoooi* and seedlings were established.

Table 11. Colchicine treatment of diploid species of Arachis.

Species	Number of seedlings Treated	Survived	Tetraploid
A. batizocoi	10	8	3
Arachis sp **"HLK-410"**	10	7	2
A. villosa	10	8	1

Hexaploids and Backcross Progenies

Selections for disease resistance, productivity, and earliness were made from hexaploids, first backcross generation (pentaploids), and second and third backcross generations (with chromosome numbers less than pentaploid). Progenies from natural selfing of backcross plants that will produce plants with a range of chromosome numbers and those from second and later backcrosses producing near tetraploid plants were also included. We also received seed from back-

Table 12. Pollen size (μm) in diploid and autotetraploid wild species of Arachis.

Species	Diploid Range	Diploid Mean	Autotetraploid Range	Autotetraploid Mean
A. batizocoi	35 - 43	39.3	40 - 55	46.5
Arachis **sp "HLK-410"**	33 -40	35.3	35 - 55	44.1
A. villosa	33 - 40	36.3	40 - 53	45.2

crosses done at Reading University under the project funded by U. K. Overseas Development Administration. We screened for disease resistance in the field in the rainy season, using the infector-row technique.

Selected plants were backcrossed with a range of *A. hypogaea* cultivars. These included the original parent, early-maturing Spanish and Runner cultivars adapted to Indian or African conditions, and high-yielding cultivars from the USA. We selected 83 backcrosses (BC) for further backcrossing, and harvested 259 BC2 pods, 192 BC3pods, and 11 BC4 pods (Table 13).

Chromosome counts of 96 hexaploid lines showed that most had remained stable at the 60-chromosome hexaploid level (Table 14). A total of 14 progenies had chromosome numbers less than, but close to, 60.

Interspecific Hybrids from the USA

Material received from North Carolina State University was derived from the following crosses: *A. hypogaea* x *A. cardenasii, A. hypogaea* x *A.batizocoi, A.batizocoi* x *Avaehis* sp "10038," *A. hypogaea* x (*A. batizoeoi* x *Avaehis* sp "10038"), *(A.batizocoi* x *Avaehis* sp "10038") x *A. hypogaea,* and *A. hypogaea* x *A. duranensis.* These were of interest because they incorporated wild species with known or potential disease resistance.

Priorities assigned to this material were therefore to screen for disease resistance, observe for other potential desirable characters, and check chromosome numbers to monitor cytogenetical stability in wild species hybrids.

We received this material through quarantine as single-plant harvests. It was sown in the 1979 rainy season in a 7x7 lattice design, with an infector row after every four test rows. Habit, flowering dates, and pegging dates were recorded. The earliest progenies flowered 39 days after sowing, and the latest after 90 days. Early-flowering (39

Table 13. Selections and backcrosses between hexaploids and A. hypogaea.

Cross	BC_2			BC_3			BC_4		
	No. of selections from BC_1	No. of polli-nations	No. of pods	No. of selections from BC_2	No. of polli-nations	No. of pods	No. of selections from BC_3	No. of polli-nations	No. of pods
A. hypogaea x *A. cardenasii*	14	478	55						
A. hypogaea x *A. chacoense*	23	1063	109	28	1954	192	3	160	11
A. hypogaea x *Arachis* sp "HLK 410"	15	260	95						

Table 14. Meiotic analysis of chromosome number and association in interspecific hexaploid progenies of groundnut.

Cross combinations	No. of progenies analyzed	Mean chromosomal association/cell I	II	III	IV	V-VI	No. of progenies with 2n=60
A. hypogaea X *A. cardenasii*	35	7.24	20.64	1.37	1. 60	0. 15	29
A. hypogaea X *A. chacoense*	44	6.97	21.01	1.42	1.42	0.10	39
A. hypogaea X *Arachis* "HLK 410"	17	8.45	19.14	1.34	1.60	0.26	14

days) progenies occurred in all four cross combinations.

Selections were made on the basis of earliness and number of pods per plant, and both single-plant and bulk selections were made (Fig. 2). A complete assessment of the disease reaction of this material is in process.

We analyzed 85 single-plant progenies cytogenetically and found them to be tetraploid. Approximately one-third of these had regular meiosis, with 20 bivalents. In plants with irregular meiosis many cells showed regular pairing, from 57 to 75% of cells having 20 bivalents (Table 15); the remaining cells had only one or two multivalents.

These results showed that progenies derived from wild species could have potential not only to transfer disease resistance, but also to produce material segregating for a range of characters. The variability of the progenies studied showed that they had not reverted to the *A. hypogaea* parent by losing all the wild species genes; these had been incorporated either as chromosome segments or as whole chromosomes. The stability of some lines and our knowledge of meiosis in hybrids indicate that incorporation as segments is probably the case. The less stable lines, with irregular meiosis, would be less fertile and more variable and would not compete in the early generations with the more stable and fertile progenies that now predominate in this material.

Figure 2. Plant selected from tetraploid progeny of* Arachis hypogaea x A. cardenasii *received from North Carolina State University, USA, 1979/80.

Table 15. Melotic analysis of some progenies from interspecific hybrids (2n= 40) of groundnut

Pedigree of material received	No. of single-plant progenies analyzed	Progenies with irregular meiosis No. (%)	Percent cells with multivalents
A. hypogaea X *A. cardenasii*	62	40 (65)	24.14
A. hypogaea X *A. batizocoi*	10	9 (90)	35.55
A. hypogaea X (*A. batizocoi* X *Arachis* sp "10038")	1	1(100)	42.85
(*A. batizocoi* x *A.* sp"10038") X *A. hypogaea*	12	8 (66)	28.84

Barriers to Hybridization

We began this project in June 1979 to investigate the barriers to intersectional hybridization. The tetraploids of section *Arachis (A. hypogaea* and *A. monticola)* were crossed with some tetraploid species of section *Rhizomatosae*, which are resistant to many pests and diseases.

Fluorescent microscopic comparison of the compatible and incompatible crosses showed that in the former the pollen tubes were smooth with small callose patches distributed evenly along the lengths of the pollen tubes. In the pollinated pistils of incompatible crosses, however, the callose depositions along the pollen tubes were uneven and in larger quantities, indicating irregular and retarded growth of the pollen tubes (Fig. 3). Nevertheless some pollen tubes were observed at the base of styles in incompatible crosses, and pegs were occasionally produced. These pegs usually dried at the tips and degenerated before entering the soil.

We have tried a number of techniques to induce more pegging and pod setting in incompatible crosses. Mentor pollen and mentor pollen leachates applied to stigmas before pollination showed a marginal improvement. A more effective means of overcoming the incompatibility was the treatment of the ovaries with plant growth regulators at specific concentrations. Cotton webs soaked in indole acetic acid, naphthylacetic acid, 2,4-dichlorophenoxyacetic acid, gibberellic acid, kinetin, or benzylamino purine were wrapped around the bases of pollinated flowers. Most treatments,depending on the kind of hormone and the concentration, enhanced the pegging frequency (Fig. 4). Kinetin (10^{-7}molar) and naphthyl-

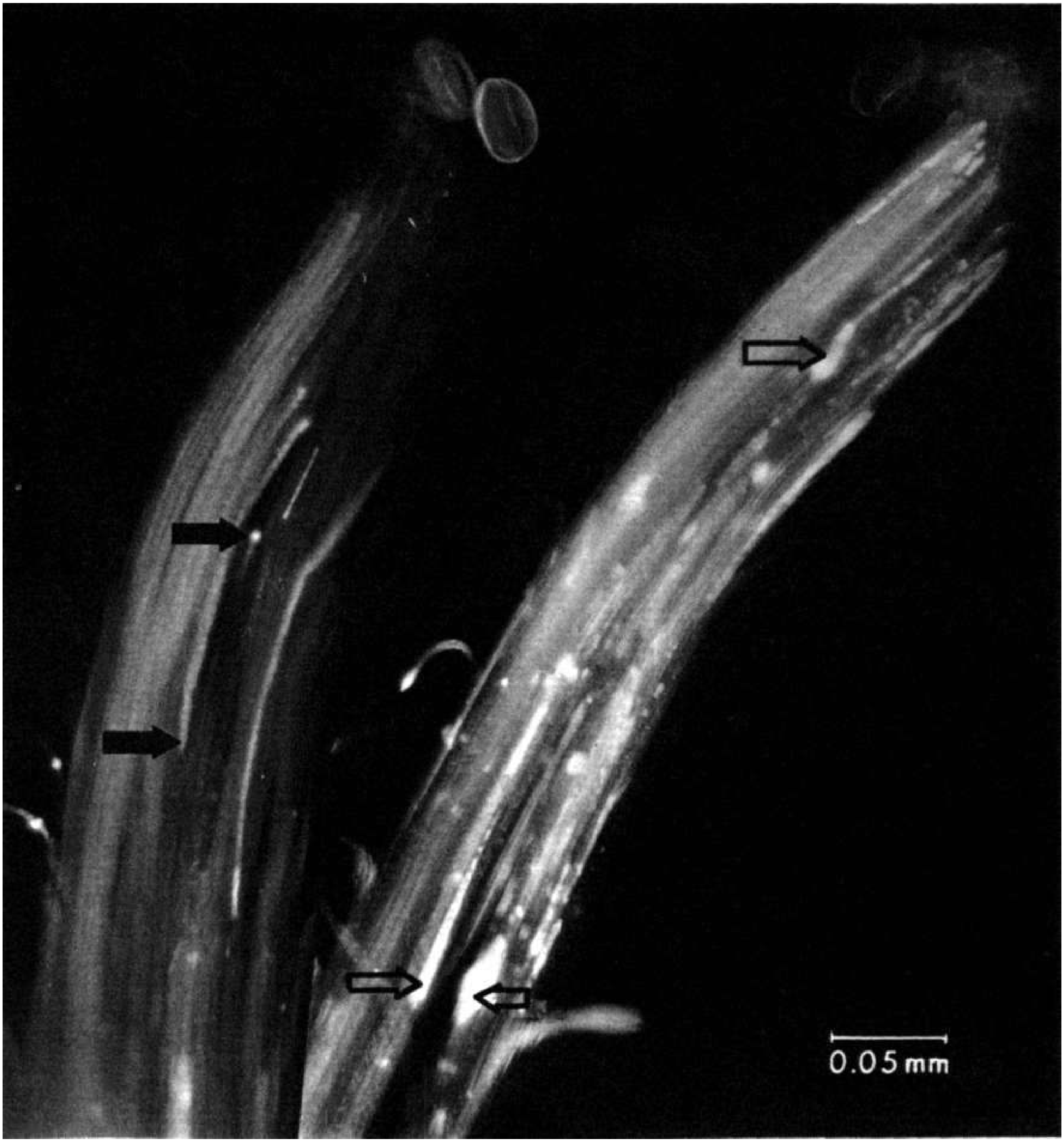


Figure 3. Photomicrographs of groundnut stigmas, with pollen grains, and the upper part of the styles. On the right: section Arachis x *section* Rhizomatosae *cross* (*A.* hypogaeax Arachis *sp "276233"*). *On the left: self-pollinated* A. hypogaea. *Pollen tubes of the compatible cross are of uniform width, with slight callose deposition* (*bold arrows*). *The incompatible cross pollen tubes vary in width, with heavy callose deposition* (*open arrows*).

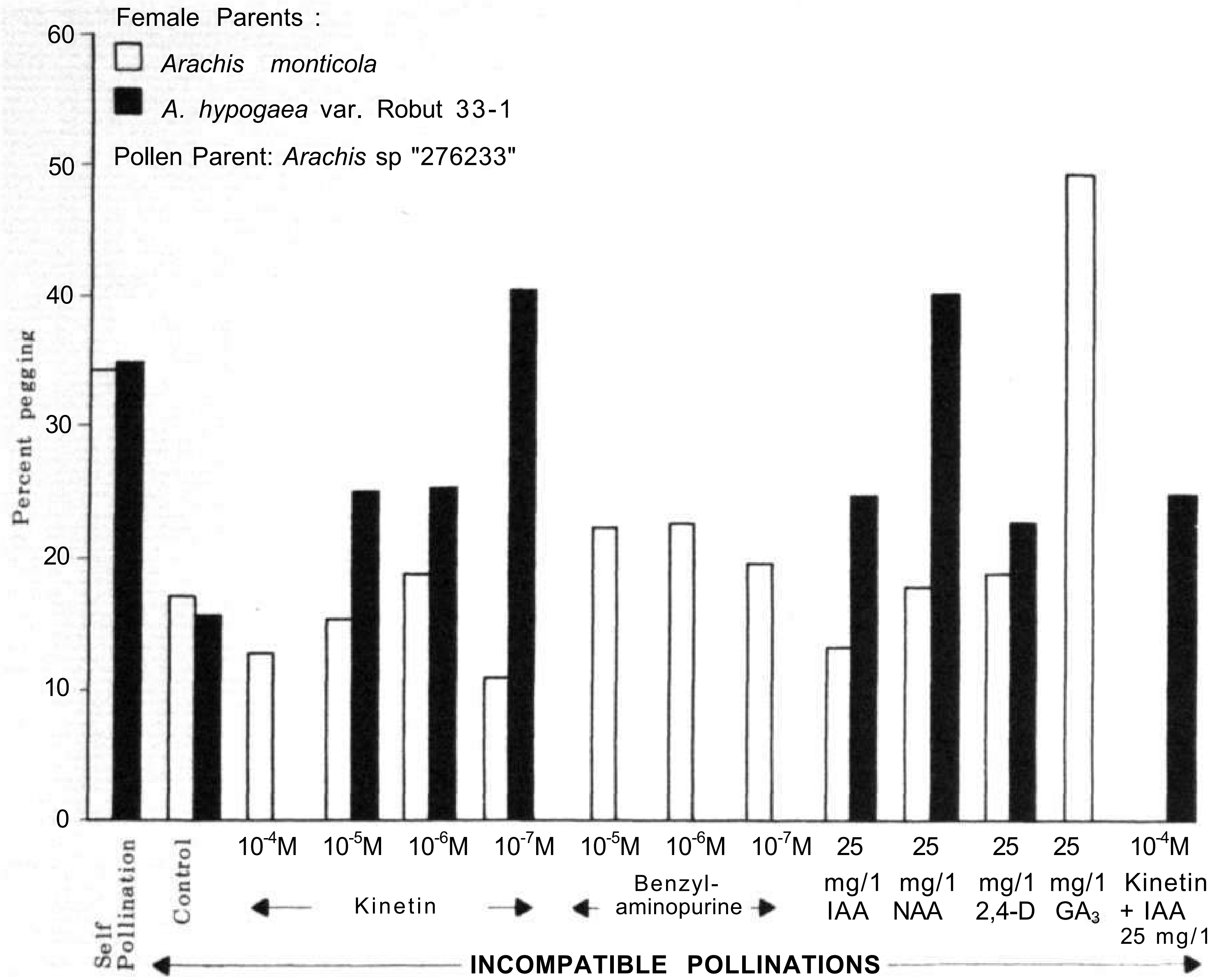


Figure 4. Effect of some plant growth hormones on pegging percentages in section* Arachis x *section* Rhizomatosae *crosses.

acetic acid (25 ppm) increased the pegging percentages substantially over the untreated pollinations. The peg tips from the treated ovaries did not dry; some penetrated the soil and produced pods. Rates of seed maturation within these pods varied; some pods grew to maturity and contained seeds that we have planted. Some pegs began to dry up after the peg tip penetrated the soil and the pod had begun to form. Embryos were dissected out from such pods and cultured aseptically (Fig. 5).

We set up a small tissue culture facility for the application of tissue culture techniques to interspecific hybridization in *Arachis,* and tried a number of media for successful culture of a range of explants *from A. hypogaea* and *A.monticola* toperfect our techniques. Embryos, cotyledons, anthers, leaflets, ovaries, and ovules have been cultured; the responses were variable (Table 16). All tissues were capable of producing healthy callus. Embryoids, shoots, and roots have been obtained from the callus of some of the explants. Murashige and Skoog's medium was found to be better than other media tried and the hormore requirements varied with explants. Plants were

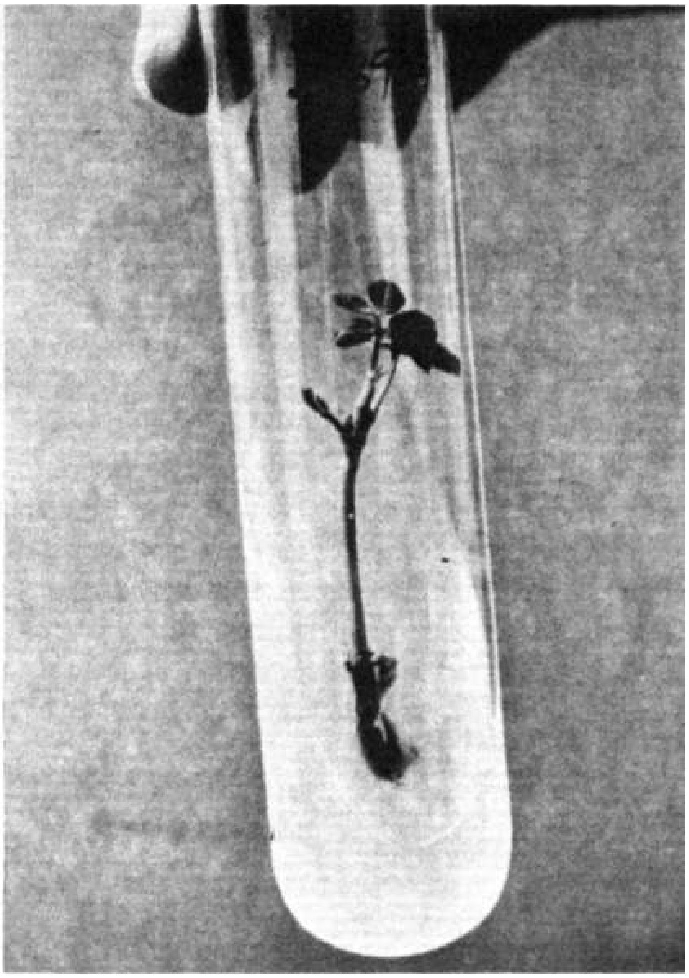


Figure 5. Plantlet grown in culture from immature embryo of **Arachis monticola x Arachis** *sp "276233" at ICRISAT Center, 1979/80.*

Figure 6. **Arachis hypogaea** *plant and flower in aseptic culture at ICRISAT Center, 1979/80.*

obtained from aseptic culture of *cotyledons* (Fig. 6). Some have been successfully established in the soil.

We have successfully cultured mature and immature embryos from both compatible and incompatible crosses. Healthy viable plants and shoots were obtained in culture flasks.

Entomology

Seasonal Variations in Pest Incidence

The different rainfall patterns of 1978 and 1979 offered a useful comparison on the buildup of groundnut pests in relation to the weather at ICRISAT Center. In 1978 the rainfall was above normal and well distributed from June to October, while in 1979 the rains were scanty during the growing season but were heavy before planting and during the harvest period.

In the 1978 rainy season the major pests were thrips (*Scirtothrips dorsalis* and *Frarikliniella schultzei*) and jassids (*Empoasca kerri*).In 1979 jassid populations were negligible, but the leaf miner (*Aproaerema modicella;* syn., *Stomopteryx subsecivella*) and in some fields *Caliothrips indics* became serious pests.

In the postrainy season (Nov-Apr for groundnuts) of 1978/79 the thrips population was higher but the leaf miner was a minor pest, in contrast with the same season of 1979/80 when thrips populations were lower but leaf miner infestation was very high. A possible reason for the leaf miner outbreak was the high residual population from the preceding rainy season (Fig. 7).

Tomato spotted wilt virus (TSWV), which is transmitted by *F. schultzei* and causes bud necrosis disease (BND), reached different infection levels in unprotected plots at ICRISAT Center in the 2 years. In 1978 the levels of infected plants were 60-70% in the rainy and 50-55% in the postrainy season, while in 1979 the levels were 90-100% and 20-30%, respectively. The lower level of BND incidence in the 1979/80 postrainy season was apparently due to lower populations of the vector.

Surveys

Our field trips to parts of Andhra Pradesh, India, in February revealed serious pest and disease problems. Of the 60 fields visited, 30 had high levels of pest infestation and 6 had serious viral diseases. The major pests were thrips (*F.schultzei, S. dorsalis*), tobacco caterpillar (*Spodoptera litura*), and leaf miner (*A. modicella*). In a few fields

Table* 16. *Responses of explants of* Arachis *upon aseptic cultures.

Explants	Media used with and without modifications[a]	Responses
Anthers	MS, KM, M, W B5	Haploid callus and callus from somatic tissues
Cotyledons	MS	Callus, roots, shoots, embryoids, and plants
Embryos[b]	MS, W, K	Shoots, plants
Flower buds	MS (suspension culture)	Embryoids
Gynophores	MS, ZZ	Callus and geotropism
Leaflet segments	MS, W, M, PCL-2 B5	Callus; roots, and occasionally shootlike structures. Embryogenic initials
Ovaries (unpollinated and pollinated)	MS, W, B5, ZZ	Callus; occasionally root/shootlike structures
Ovules	MS, M, SH	Callus; embryogenesis up to cotyledonary stage in one culture.

a. B-5,Gamborg et al..;K, Knop; KM, Kao and Michayluk; M. Martin; MS, Murashige and Skoog; PCL-2, Phillips and Collins; SH, Stewart and Hsu; W, White; ZZ, Ziv and Zamsky.
b. From mature and immature seeds from compatible and incompatible crosses.

Heliothis armigera, E. kerri, Aphis craccivora, and pod-scarifying termites were important. Stored pods suffered extensive damage from *Corcyra cephalonica* and *Elasmolomus eovdidus* (syn., *Aphanus sordidus*). The latter has become a serious problem in the Kadiri area of Andhra Pradesh.

Insecticide use was common on irrigated groundnut in Andhra Pradesh; about 50% of

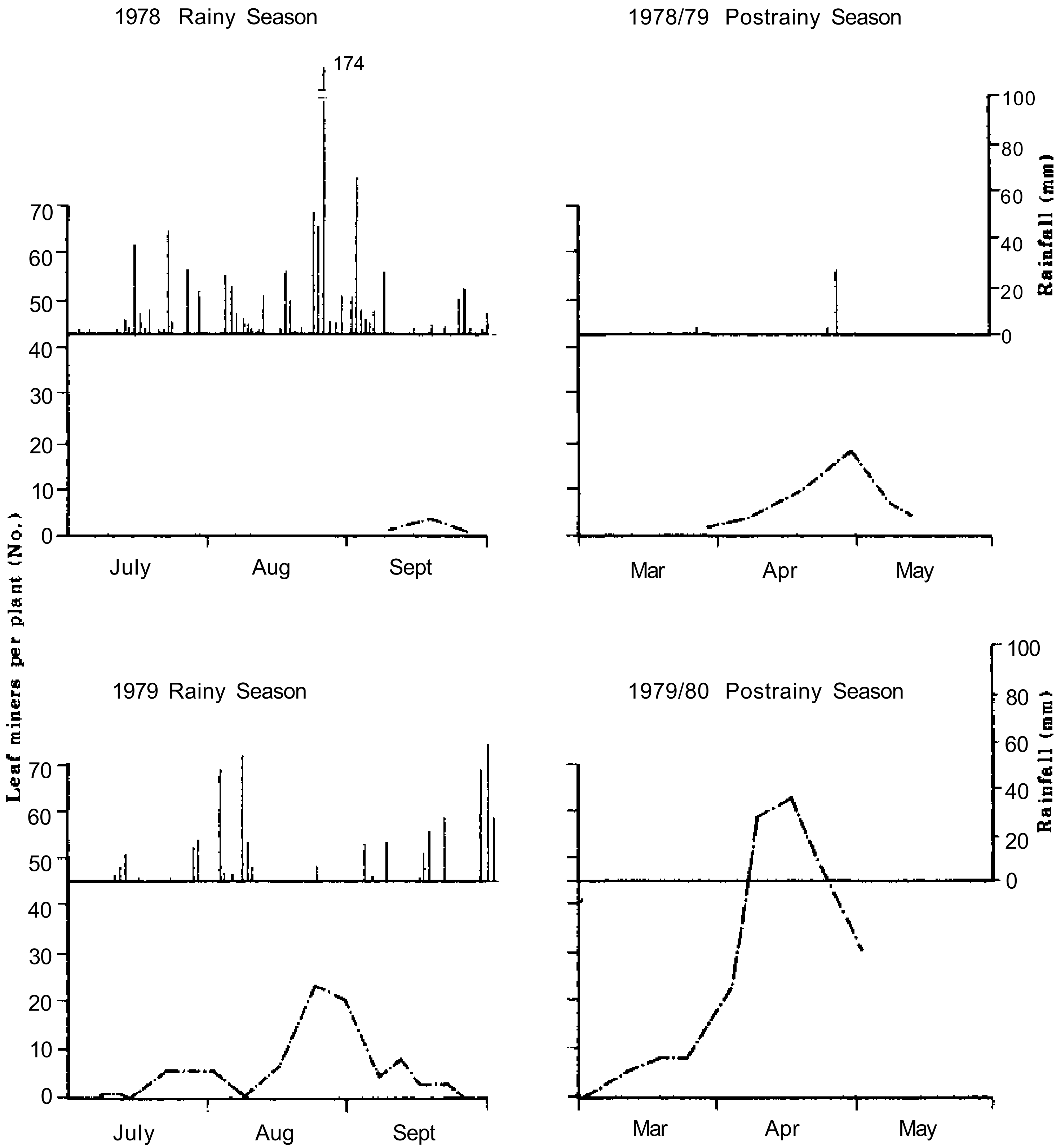


Figure 7. Leaf miner **(Aproaerema modicella;** ***infestation on groundnut at ICRISAT Center in above-average (1978) and below-average (1979) rainfall years.***

the farmers made one or more applications. Most farmers gave two applications, and dusts were more commonly used than sprays. BHC, quinalphos, parathion, and carbaryl were popular as dusts, and malathion and dimethoate as sprays.

Management of Bud Necrosis Disease Vector

The field spread of bud necrosis disease at ICRISAT Center was associated mainly with *F. sohultzei,* which has a wide host range. This thrips is mainly a flower feeder but also feeds on the foliage. Over 40 species of crop and weed plants belonging to the families Papilionaceae, Compositae, and Solanaceae have been identified as hosts. Some of them are hosts of the virus also, but the role of individual host-plant species as sources of the virus is not known.

We observed that during the 1979 summer months (mid-Apr to mid-June) at ICRISAT Center the population of the vector thrips was reduced to a low level, and they were mainly observed in flowers of crop and weed plants. During July the thrips were found breeding on crops such as green and black gram in neighboring farmers' fields and on weeds such as *Cassia tora, Ageratum conyzoides,* and *Tribulus tvitious* at ICRISAT Center. All these except *T. triticus* were highly susceptible to the virus. The young pods of green gram harbored large numbers of thrips adults and nymphs, and many pods had a high virus titer.

Monitoring of thrips in the groundnut crop at ICRISAT Center during 1979 revealed that migrations occurred throughout the season, with mass migrations in August. The populations declined to a low level in September and October, and mass migrations occurred again in December and early part of January (Fig. 8). Spread of the disease was mainly associated with the immigrant thrips.

Yield losses from the disease depended on the crop age and plant population per unit area. Severe yield losses occurred if the crop became infected during the seedling and flowering stages. Late infections in the pod-filling stages did not re.duce yields to any great extent. It was possible to reduce yield losses by adjusting the sowing dates to avoid the peak migration of the vector. Some farmers in the Nuzvid area in Krishna district (Andhra Pradesh) followed this practice. The difference in disease incidence was striking in two adjacent fields in this area. One farmer had sown in December and 80% of his plants were infected, and the other had sown in the 3rd week of January and had only 20% disease incidence.

Plots with closely-spaced rows and full stands had less disease than widely spaced plots with poor stands. At ICRISAT, infestation of thrips on individual plants in dense and sparse stands revealed substantial differences. In a crop with a density of about 50 plants/m^2, an average of 1.0 adult thrips per plant was observed, compared to 2. 2 in sparse stands with a density of 8 plants/m^2 .

The effectiveness of dense planting in reducing the disease incidence was also observed in farmers' fields. In the Krishna district of Andhra Pradesh the disease incidence in a dense (plant density 30 plants/m^2) crop was 5%, compared to 30% in adjoining fields with low plant density.

At ICRISAT a combination of early sowing and dense planting substantially reduced yield losses. The disease incidence during critical periods was 10% against 72% in a late and wide-spaced crop.

Yellow Spot Disease

This disease, first noticed by ICRISAT scientists in 1978, is prevalent in many parts of Andhra Pradesh and is marked by yellow spots on the leaves (Fig. 9) and necrotic areas on the petiole. The symptoms could be confused with jassid injury or with leaf spots caused by fungi. The causal virus is transmitted by *S.dorsalis* but not by *F. sohultzei* or *C. indious.* Our research this year has also shown that *Thrips tabaci* is not a vector and that, once infective, the

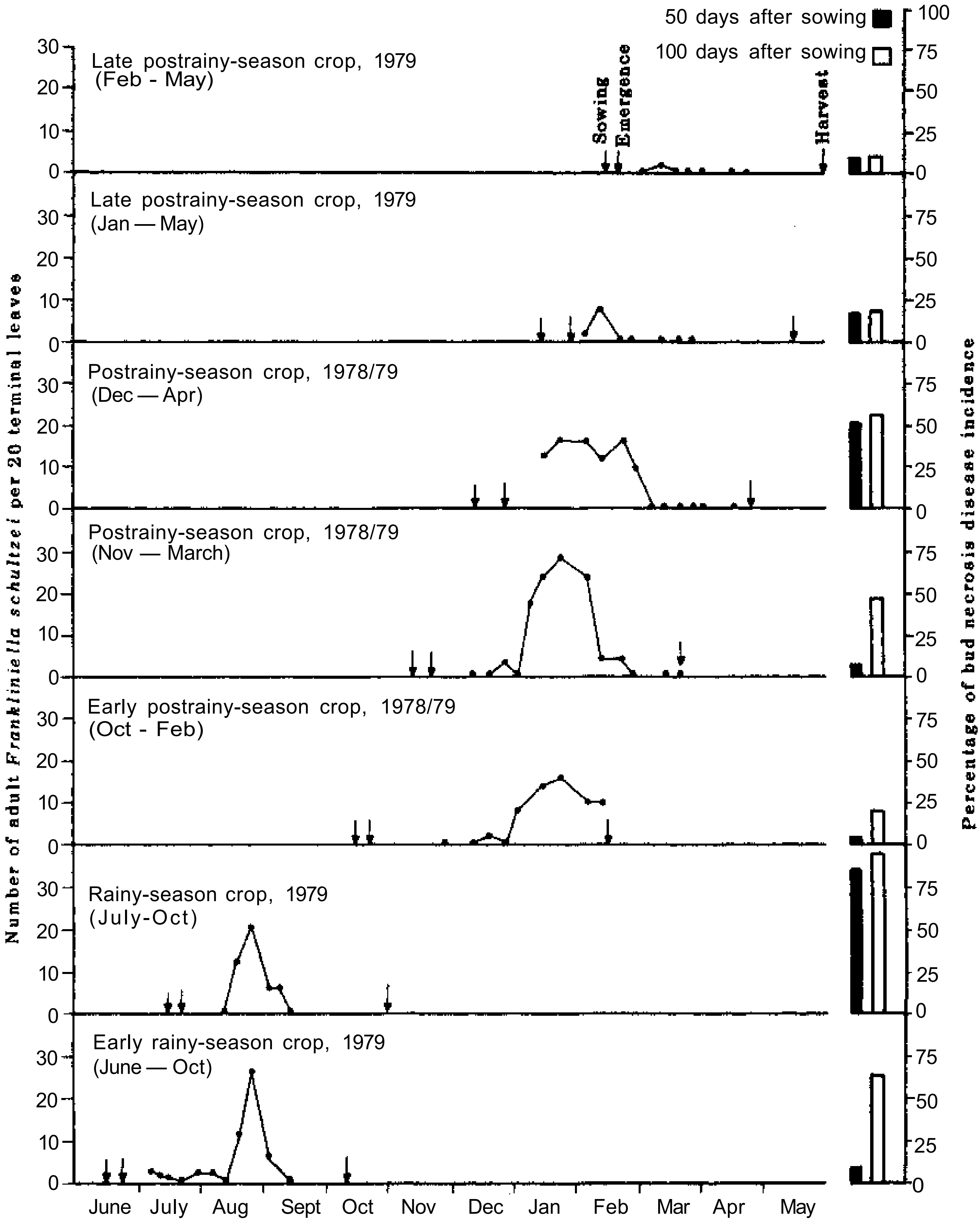


Figure 8. **Frankliniella schultzei** *populations on groundnuts sown on different dates and the percentage of bud necrosis disease incidence at 50 and 100 days after sowing at ICRISAT Center.*

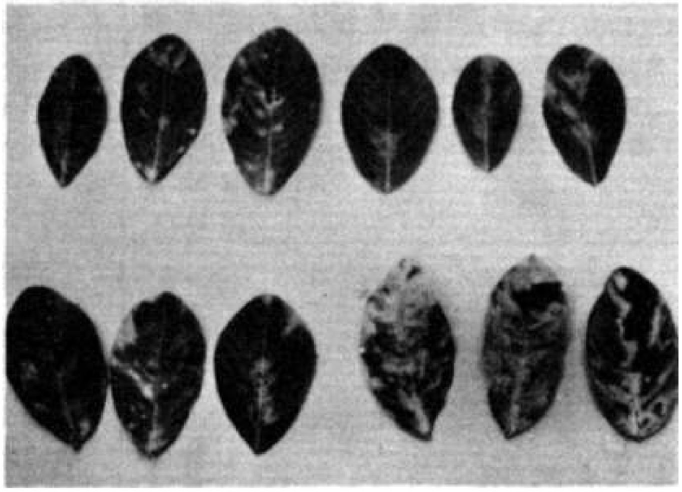


***Figure* 9. *Range of yellow spot symptoms in groundnut (cv TMV-2) caused by a virus that is transmitted by* Scirtothrips dorsalis.**

adults of *S. dorsalis* could inoculate as many as 11 plants at a serial 1-day transfer.

Host-Plant Resistance

THRIPS. The germplasm lines that were found promising against *F. sohultzei* in the 1978 rainy season at ICRISAT Center showed low thrips injury during subsequent postrainy and rainy seasons. The promising accessions are Nc Ac 2214, 2232, 2242, 2243 (runner habit), and NC Ac 2462, 2575, and 2460 (spreading bunch growth habit). A few additional lines have shown promise and are being further evaluated. Among the wild relatives of the groundnut, *A. chacoense* appears to have a high level of resistance to thrips (Tables 17 and 18).

JASSIDS. The major species of jassid occurring at ICRISAT is *E. kerri*. We have confirmed the low susceptibility of some germplasm lines to this pest (Table 19). One such line, NC Ac 343, which has shown moderate jassid injury both at ICRISAT and in the USA, is a good yielder and has been used extensively in crosses in the USA and at ICRISAT. It also has tolerance to pod damage by *Diabrotioa undecimpunctata* subsp *howardi* in the USA, and to pod-scarifying termites (*Micro termes* sp?) at ICRISAT.

Table 17. Susceptibility of* Arachis *species to damage by* Frankliniella schultzei *in fields at ICRISAT Center, 1979/80.

Arachis sp	Thrips injury score[a]
A. chacoense	2
Arachis sp "10596"	4
A. chacoense x *A. cardenasii*	4
A. correntina	4
A. glabrata	7
A. duranensis	7
A. hypogaea (cv TMV-2)	9
A. hypogaea (cv Robut 33-1)	9
A. hypogaea (cv M 13)	9

a. Injury rating scale: 1-9, in which 1 = no injury and 9 = leaf distortion.

Table 18. Fecundity of* Frankliniella schultzei *on different* Arachis *species, ICRISAT Center, 1979/80.

Species	No. of nymphs obtained from leaves exposed to 10 females for 24 hr.
A. chacoense	0
A. glabrata	0
A. dupanensis	4
A. hypogaea (cv TMV-2)	44

TERMITES. We developed techniques for screening against pod-scarifying termites: the pods of many cultivars are left in the ground well after maturity in a pesticide-free Alfisol plot with a high level of termite infestation; or alternatively, the mature pods are buried in the ground for about a month. They are then scored for scarifica-

Table 19. Susceptibility of germplasm lines to Empoasca kerri *at ICRISAT Center in 1979/80.*

Cultivar	Growth habit	Average no. of jassid nymphs[a]	Range[b]	Susceptibility[c]
NC Ac 2214	Runner	2	0-5	R
NC Ac 2232		4	2-6	R
NC Ac 2243		7	3-13	R
NC Ac 2240		4	1-8	R
NC Ac 2242		6	4-10	R
NC Ac 343		13	9-20	MR
M 13		14	8-43	MR
NC Ac 9975		26	17-41	S
NC Ac 2462	Spreading bunch	14	10-19	MR
NC Ac 2477		14	10-17	MR
Robut 33-1		24	11-41	S
NC Ac 2663	Erect bunch	18	12-25	MR
NC Ac 2888		17	9-20	MR
NC Ac 406		14	5-19	MR
NC Ac 489		16	11-18	MR
TMV-2		33	14-61	S

a. Total number of nymphs per 10 plants; average for 4 replications.
b. Number of nymphs per 10 plants.
c. R = resistant, MR = moderately resistant, S = susceptible.

tion. Preliminary screening has shown obvious differences between cultivars. Cultivar NC Ac 2243 has shown great promise.

LEAF MINER. Our preliminary observations in April on leaflet damage by the groundnut leaf miner A. *modicella* revealed that a few FESR lines were less susceptible than the local commercial cultivars TMV-2 and Robut 33-1.

Pathology

Virus Diseases

BUD NECROSIS DISEASE. This disease, caused by the tomato spotted wilt virus (TSWV), occurs In most groundnut-growing areas of India, with incidence ranging from 5 to 80%. In the 1979 rainy season the disease caused severe damage to groundnuts in many places.

ICRISAT research in the 1978/79 postrainy season indicated a relationship between plant population and disease incidence. In further investigations, cultivar TMV-2 was sown in a replicated field trial on 10 July in the 1979 rainy season and on 10 December 1979 in the 1979/80 postrainy season in various combinations of three between-row and two within-row spacings. We recorded plants with bud necrosis disease. From the data shown in Table 20 and Figure 10 it is clear that incidence of this disease was lower at high plant populations (close spacings) than at low populations (wide spacings), and that it was more severe in the

Table 20. Effects of plant spacing on incidence of bud necrosis disease on groundnuts of cultivar TMV-2 at ICRISAT Center.

Plant spacing (cm)		Incidence of bud necrosis (%)	
Between rows	Within rows	1979 rainy season	1979/80 postrainy season
37.5	5	48.7	7.3
37.5	15	74.1	16.1
75/0	5	52.5	9.2
75.0	15	91.0	18.0
150.0	5	56.2	10.7
150.0	15	94.0	20.7
SE ±			
Between-row spacing		0.77	0.31
Within-row spacing		0.83	0.17

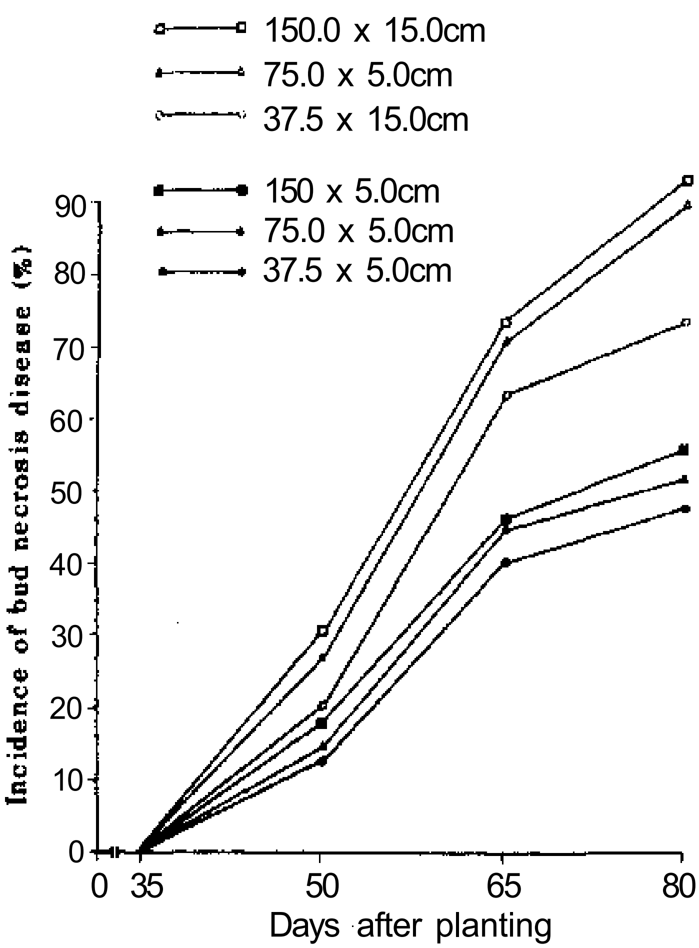


Figure 10. Mean percentage of plants with bud necrosis disease for six different plant spacings at various times after planting (ICRISAT Center, rainy season 1979).

rainy than in the postrainy season.

In other replicated field trials sown on 9 July in the 1979 rainy season and on 10 December 1979 in the 1979/80 postrainy season, we screened several cultivars and breeding lines for possible resistance to bud necrosis disease. In both trials the plant spacing was 75 cm between rows and 15 cm within rows. Results are given in Table 21. Although cultivar MH 2 had significantly lower disease incidence than all other entries in the 1979 rainy-season trial, in the postrainy-season trial only susceptible cultivars TMV-2 and NC Ac 1107 had higher disease incidence.

A few plants of ten wild *Arachis* spp were grown in the field in the 1979 rainy season. No plants of five species *(A. chacoense, A. correntina, A.glabrata, A. pusilla, Arachis* sp PI 262848) showed symptoms of bud necrosis disease, while one or more plants of the other five species were infected. More tests are planned to verify these results.

PEANUT CLUMP VIRUS (PCV). Clump disease has now been recorded in Punjab, Gujarat, and Andhra Pradesh states of India. It caused significant damage to the crop in

Table 21. Mean percentage incidence of bud necrosis disease in several cuitivars and breeding lines under natural field disease conditions at ICRISAT Center.

Cultivars/lines	Incidence of bud necrosis (%) 1979 rainy season	1979/80 postrainy season
TMV-2	96.9	26.0
Pol 2	92.4	
NC Ac 2372	91.4	
NC Ac 1107	90.7	7.8
FESR 9-P12-B1	82.6	5.2
NC Ac 2575	78.3	5.4
FESR 3-P14	74.8	
NC Ac 17090	73.0	
Robut 33-1	65.1	
MH 2	21.3	6.1
SE ±	7.24	2.27

some areas. Trials at Ludhiana (Punjab State) and Talod (Gujarat State) showed that soil applications of Nemagon (25 liters/ha) or Temik (3 kg a. i. /ha) or Carbofuran(6kg a. i. /ha) could greatly reduce disease incidence and increase crop yields. Screeningfor resistance has been carried out at Ludhiana in collaboration with the Oilseeds Breeding Section of Punjab Agricultural University. Nearly 150 germplasm lines were tested and all were found to be susceptible. PCV was recovered from several common weeds growing in clump-infested soils.

We identified *Nicotiana* hybrid (*N. glutinosa* x *N.clevelandii*) as a suitable host on which to maintain the virus for purification and developed a satisfactory purification method. The purified virus retained about 80% of the infectivity of crude plant extracts and had no detectable impurities. The ultraviolet absorption spectrum of the purified virus indicated that the virus contained approximately 5% RNA.

PEANUT MOTTLE VIRUS (PMV). Employing our previously described field inoculation technique (ICRISAT Annual Report 1978/79), we screened 250 germplasm lines for yield reduction from PMV and for percentage of seed transmission of the virus. All lines were susceptible. Losses in yield ranged from 5 to 30%. We tested approximately 1000 seeds of each line and demonstrated seed transmission for all but three lines, with levels ranging from 0.1 to 3%. The three lines [PI 259747, EC 76446(292), NC Ac 1826) that showed no seed transmission are being retested.

We have produced in rabbits an antiserum for PMV with a titer of 1/256, as determined by the precipitin ring test.

COWPEA MILD MOTTLE VIRUS (CMMV). This virus has now been isolated from groundnuts from two more Indian States — Uttar Pradesh and Maharashtra. Although widely distributed, the disease has been found only at low incidence (<1%).

We have developed a virus purification method, using soybean. The purified virus retained high specific infectivity and had no detectable impurities. Electron microscopy showed the virus particles to be filamentous rods about 650 nm long and 13 nm diameter. We determined molecular weights of viral protein and nucleic acid, using polyacrylamide gel electrophoresis. The virus contained a single polypeptide of molecular weight 33 000 daltons and a nucleic acid species of molecular weight 2.60×10^6 daltons.

PEANUT GREEN MOSAIC VIRUS (PGMV). Peanut green mosaic disease (Fig. 11) was first observed in Andhra Pradesh State, India, in 1970, and material was maintained by virologists of the Sri Venkateswara University, Tirupati. In a collaborative study with ICRISAT, the causal virus has been identified as a member of the potato virus Y group on the basis of electron microscopy (Fig. 12), aphid transmission, and chemical characteristics. Virus particles are flexuous rods about 750 nm long. The virus contains a single polypeptide of molecular weight 34 500 daltons and a nucleic acid species of molecular weight 3. 25 x 10^6 daltons. When analyzed in an analytical ultracentrifuge using Schleiren optics, the virus sediments as a single component with a sedimentation coefficient of 171 S. We produced an antiserum with a titer of 1/512, as determined by the precipitin ring test. The virus does not appear to be closely related to PMV, which is also classified within the potato virus Y group.

Figure 11. Symptoms of peanut green mosaic virus (PGMV).

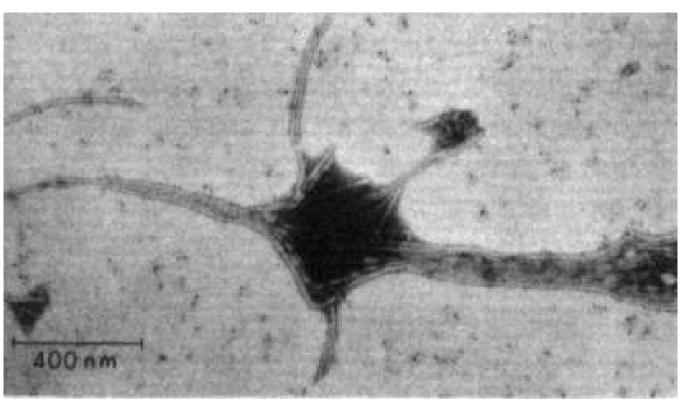


Figure 12. Particles of peanut green mosaic virus (PGMV) identified on an electron microscope at ICRISAT Center, 1979/80.

Foliar Diseases Caused by Fungi

The leaf spots caused by *Cercospora arachidicola* and *Cercosporidium. personatum* (Fig. 13) are the most important diseases of groundnut on a worldwide basis. Rust of groundnut, caused by the fungus *Puccinia arachidis* (Fig. 14), has become a worldwide problem since 1969.

YIELD LOSSES FROM RUST AND LEAF SPOTS. Rust and leaf spots attacks normally occur together and can cause severe damage to groundnut crops. Information is readily available on yield losses from the combined attack, but the proportion of loss due to each disease is less well documented.

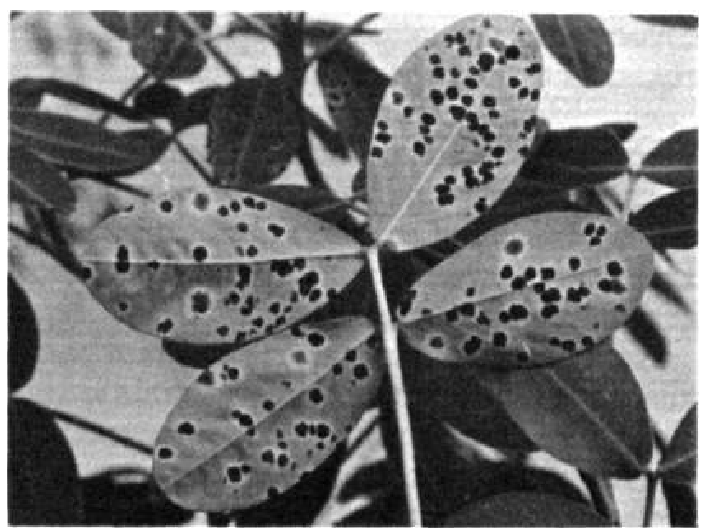


***Figure 13. Leaf spots caused by* Cercospora arachidicola *and* Cercosporidium personatum.**

In the 1979 rainy season we attempted to estimate yield losses by applying fungicides to susceptible and disease-resistant cultivars - Daconil to control rust and leaf spots, Bavistin to control only leaf spots, and Calixin to control only rust. Loss estimates are shown in Table 22. Yield losses were less in the resistant than in the susceptible cultivars. In the no-fungicide check treatment, some of the resistant cultivars outyielded the two established Indian cultivars.

Figure 14. Groundnut rust caused by **Puccinia arachidis.**

FIELD SCREENING FOR RESISTANCE TO RUST AND LEAF SPOT. The foliar-disease-resistant cultivars identified at ICRISAT, plus 22 USDA entries obtained from Dr. R. O. Hammons, Tifton, Georgia, USA, were tested in the infector-row system during the 1979 rainy and 1979/80 postrainy seasons. In the rainy season, the entries were tested under natural disease pressure in the field. In the postrainy season we inoculated the infector rows with

Table 22. Yield loss assessments of foliar-diseases-resistant and susceptible cultivars at ICRISAT Center, 1979 rainy season.

Cultivars	Disease scores[a] Rust	Disease scores[a] Leaf spots	Pod yields (kg/ha), and estimated percentages of potential pod yield losses caused by: Rust and leaf spots	Rust	Leaf spots	Pod yields (kg/ha) with both diseases controlled
TMV-2[b]	9	9	1122[c] (46)[d]	1339 (36)	1500 (28)	2078
Robut 33-1[b]	9	9	1455 (70)	3534 (27)	3010 (38)	4817
NC Ac 17090	2	5	2389 (29)	2922 (14)	2789 (17)	3378
NC Ac 17135	4	5	1991 (33)	2201 (26)	2164 (27)	2982
EC 76446 (292)	3	4	1661 (23)	1839 (15)	1883 (13)	2161
PI 259747	3	4	1266 (37)	1811 (10)	1650 (18)	2017

a. Scored on a 9-point field scale, where 1 = no disease, and 9 = 50 to 100% foliage destroyed.
b. Susceptible check cultivars.
c. Pod yields (kg/ha).
d. Estimated percentage of potential pod yield loss.

uredospore suspensions in tap water and used overhead irrigation to maintain high humidity in the field to ensure good disease development. No inoculations were made with leaf spot pathogens, but there was good late leaf spot development from natural inoculum. We scored each entry both for rust and late leaf spot (*C. personatum*), and entries that showed good resistance are listed in Table 23; scores for two susceptible cultivars are included for comparison.

All ICRISAT foliar-disease-resistant lines continued to perform well. Most of the USDA entries showed good resistance to rust at ICRISAT in both seasons, and some of them also showed good resistance to late leaf spot.

Fifteen individual plant selections made

Table 23. Rust and late leaf spot* (Cercosporidium personatum) *reactions of some groundnut genotypes in field screening trials at ICRISAT Center, 1979 rainy and 1979/80 postrainy seasons.

Genotype	Mean disease scores[a] Rust	Mean disease scores[a] Late leaf spot
NC Ac 17090	2.0	5.0
PI 414332	2.0	ND
PI 341879, 393646, 405132	2.5	ND
NC Ac 17133-RF, EC 76446(292), PI 259747, PI 350680	3.0	3.5
PI 390593, 381622, 393643, 407454, 315608, 215696, 393641, 314817, 393517, 414331, 393527-B	3.0	ND
NC Ac 17127, 927	3.5	4.0
PI390595, 393531	3.5	ND
NC Ac 17130, 17129, 17132, 17135, 17124	4.0	4.5
PI 298115	4.0	6.5
PI 393526	4.0	ND
PI 393516	4.5	ND
NC Ac 17142	5.0	4.5
Krap St 16	5.0	4.0
NC Ac 15989	8.5	4.5
NC Ac 17502	5.5	4.5
RMP 91	8.0	4.5
RMP 12	8.0	5.0
TMV-2[b]	9.0	9.0
Robut 33-1[b]	9.0	9.0

a. Scored on a 9-point field scale, where 1 = no disease, and 9 = 50 to 100% foliage destroyed.
b. Standard susceptible cultivars.
ND = No data, test not run.

from FESR breeding lines in the 1978 rainy season were further testedin the 1979 rainy and 1979/80 postrainy seasons and were found to be good sources of resistance to both rust and leaf spots (Table 2 of Groundnut Breeding section). These lines originated from a natural hybrid selected for resistance to rust in Puerto Rico by USDA scientists.

GLASSHOUSE SCREENING. Cultivars with field resistance to *C. personatium* were further tested for resistance in glasshouse screening trials. We carried out two concurrent experiments in which 30-day- and 50-day-old plants were inoculated. Disease development was studied at 4 weeks and 6 weeks after inoculation by evaluating the percentage of defoliation, percentage of leaf area damaged, lesion numbers, lesion sizes, and sporulation. Good correlations were found between field and glasshouse tests with respect to defoliation, lesion size, and sporulation index. The resistant cultivars showed considerably less defoliation, sparse sporulation, and reduced lesion size (Fig. 15).

SOURCES OF MULTIPLE DISEASE RESISTANCE. The genotypes EC 76446(292), NC Ac 17133-RF, PI 259747 (Fig. 16), PI 350680, NC Ac 927, NC Ac 17127, and some FESR selections were found to be good sources of resistance to both rust and leaf spot at ICRISAT. Cultivars PI 259747 and PI 350680 are resistant to C. *personation* and scab (*Sphaceloma arachidis)* in Brazil (Filho, A. S., and Moraes, S. A. 1977. Revista Agric[Piracicola] 52:39), but susceptible to *C. arachidicola*. They were, however, reported to be resistant to *C. arachidicola* in the USA (Sowell, G., Smith, D. H., and Hammons, R.O. 1976. Plant Dis. Rep. 60:94). Cultivars RMP 91 and RMP 12, which are moderately resistant to leaf spot at ICRISAT, are resistant to rosette in West Africa (Dhery, M., and Gillier, P. 1971. Oleagineux 26:243).

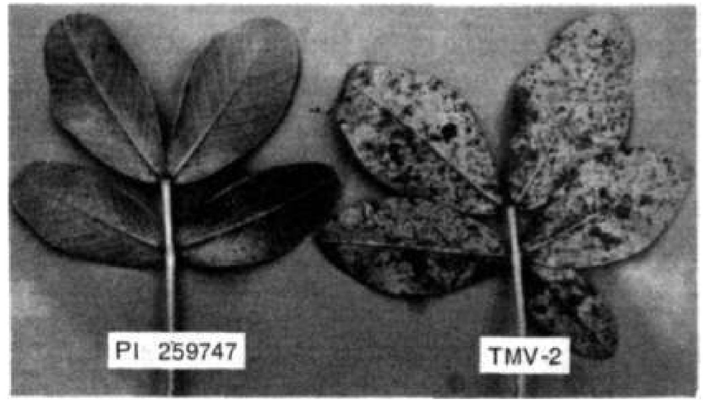


Figure 16. Groundnut cultivar PI 259747 has resistance to both rust and late leaf spot.

NATURE OF RESISTANCE TO RUST AND LEAF SPOTS. In our studies of components of resistance to rust in *Arachis hypo-*

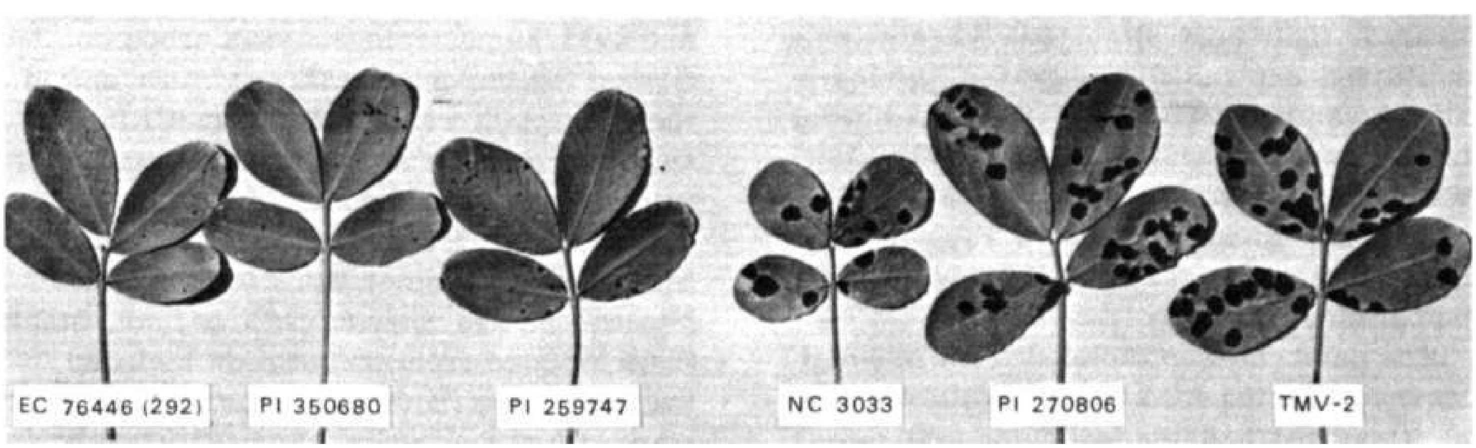


Figure 15. Groundnut cultivars resistant and susceptible to late leaf spot.

gaea genotypes and in some wild *Arachis* spp, neither size nor frequency of stomata was correlated with resistance. The infection frequency was lower in resistant than in susceptible genotypes and the incubation period was longer. Irrespective of whether genotypes were immune, resistant, or susceptible, uredospores germinated on the leaflet surface and germ-tubes entered the leaflet via stomata. In immune genotypes the germ-tubes died without further development. Differences in resistance were manifested by differences in rate and degree of development of the mycelium in the substomatal cavities and in invasion of leaf tissues.

With leaf spots, as with rust, germination of spores and entry into the leaflet via stomata did not appear to be in any way inhibited in resistant *Arachis hypogaea* genotypes. Resistance was again manifested in the postentry phase.

OTHER FOLIAR DISEASES. In the course of routine disease surveys a new type of leaf disease, incited by *Alternaria alternata,* was observed in the 1977/78 postrainy season in some parts of Andhra Pradesh and subsequently in the 1978/79 and 1979/80 postrainy seasons. The disease was also observed in parts of Karnataka and Tamil Nadu States. Considerable damage was caused to foliage. The disease first appeared as small chlorotic water-soaked lesions, which spread over the surface of the leaf. The round to irregular-shaped lesions became necrotic and brown. As they increased in area, their central portions became pale and dried out and disintegrated, giving a shot-hole effect. Veins and veinlets adjacent to the lesions became necrotic (Fig. 17). When many lesions were present, they coalesced, giving the leaf a ragged and blighted appearance. Lesions were not found on petioles or stems.

The pathogen was isolated from infected leaves collected from several different localities, and isolates are being maintained at ICRISAT.

***Figure 17. Leaf spot and vernal necrosis caused by* Alternaria alternata.**

Soilborne Diseases

SEED AND SEEDLING DISEASES. Sick plots for germplasm screening are being developed by continuous cultivation of groundnuts with incorporation into the soil of all crop debris. Meanwhile, we have screened a limited number of lines in the field for resistance to *Aspergillus, niger* and to *A. flavus* by applying inoculum of the fungi to the seeds at planting. From this preliminary work we found that the cultivars J 11, U-4-47-7, and U-2-1-26 showed resistance to collar rot disease incited by *A. niger,* and cultivars J 11 and Florunner showed resistance to "aflaroot" disease incited by toxigenic strains of *A. flavus.*

POD ROT. Investigations of large numbers of rotted pods from the 1979 rainy-season and 1979/80 postrainy-season crops confirmed the importance of *Fusarium.* spp in the pod-rot-disease complex at ICRISAT Center. *Fusarium solani* and *F. oxysporum* were the most common invaders, being present in 65-100% of rotted pods examined. Slightly less common were *Macrophomina phaseolina* and *Rhizoctonia solani.* Other fungi isolated from rotted pods included *Fusarium acuminatum, F. fusaroides, F. equiseti, Gliooladium roseum, Triohoderma viride,Aspergillus niger,* and *A. flavus.*

Since screening germplasm for resistance to pod rot started in the 1978/79 postrainy season, we have checked some 2000 lines. Entries that showed less than 10% of rotted pods were retained for advanced screening, and those that have performed consistently well over three growing seasons are listed in Table 24. Pod rot levels for two commonly grown cultivars, TMV-2 and Robut 33-1, are included in the table for comparison.

THE AFLATOXIN PROBLEM. Using a modification of an already described method (Mixon, A. C., and Rogers, K. M. 1973.

Table 24. Germplasm entries that had less than 70% of rotted pods over three seasons at ICRISAT Center.

Entries			Percentage pod rot		
ICG No.	Cultivar/line	Type[a]	Postrainy seasons 1978/79	Postrainy seasons 1979/80	Rainy season 1979
1740	AK-10-24	Sp.	9.4[b]	6.6	5.1
2031	Ah 3533	Sp.	9.2	7.7	5.7
2288	NC Ac 841	Sp.	6.3	2.8	6.3
2303	NC Ac 648	Sp.	6.7	7.4	5.6
3316	EC 27446	Sp.	6.2	7.1	4.6
3331	Exotic 3-5	Sp.	8.6	6.6	5.0
3336	Exotic 6	Sp.	8.1	4.8	8.4
3388	KG 61-240	Sp.	8.9	9.2	6.3
3424	NG 387	Sp.	9.5	7.1	4.5
3469	Sir of Bizapur	Sp.	6.3	4.2	6.6
4589	Exotic 2	Sp.	4.6	6.5	6.5
4590	Florigiant	Sp.	9.9	4.1	6.3
4593	GFA Spanish	Sp.	6.8	5.7	5.6
1326	J 11	Sp.	6.1	7.4	7.2
4528	U 1-2-1	V.B.	9.6	8.4	6.3
4799	Ah 7207	V.B.	9.1	7.7	4.1
635	Ah 6715	V.B.	7.0	8.4	6.0
7838	MG 10	V.B.	8.1	8.5	9.6
2601	C 501	V.B.	8.3	5.7	5.7
4790	Krap Strain 16	Val.	9.6	7.0	6.0
4601	Var 27	Val.	6.0	6.7	7.3
Commonly grown cultivars:					
221	TMV-2	Sp.	20.4	12.1	13.5
799	Robut 33-1	V.B.	24.6	21.2	19.8

a. Sp = Spanish, V.B. = Virginia Bunch, Val. = Valencia.
b. Means of three replications.

Agron. J. 65:560-562), we screened a number of cultivars and breeding lines for dry seed resistance to colonization by the *toxigenic Aspergillus flavus.* Our screening method and associated aflatoxin analysis methods have been detailed in a separate paper (Mehan, V. K. , and McDonald, D. 1980. ICRISAT Groundnut Improvement Program, Occasional Paper 2). Essentially, seeds are surface-sterilized, hydrated to approximately 20% moisture content, surface-inoculated with a suspension of conidia *of A. flavus* , and incubated at 25°C for 8 days. Seeds are then examined, and the percentage with sporulating colonies of *A. flavus* are recorded. Lines with fewer than 15% of seeds colonized are regarded as resistant, those with 16-30%) colonized as moderately resistant, those with 31-50% colonized as susceptible, and those with over 50% colonized as highly susceptible. Table 25 shows the results of our screenings of several lines and cultivars, including two lines reported resistant in the USA by Mixon and Rogers that were also resistant in the ICRISAT tests. In addition, the commercially grown cultivar J 11 was also found to be resistant (Fig. 18).

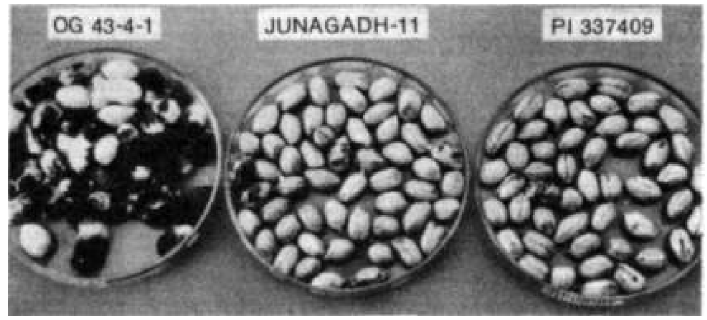


Figure 18. Cultivars J 11 and PI 337409 showing resistance to seed colonization by* Aspergillus flavus, *as compared with the susceptible cultivar OG 43-4-1.

Microbiology

Nitrogen Fixation

RESPONSE TO INOCULATION. We reported in our last year's Annual Report (p 159) a significant increase in seed yield when

Table 25. Seed resistance to colonization by* Aspergillus flavus *in tests at ICRISAT Center in 1979/80.

Cultivars/lines	Mean percentages of seeds colonized by *A. flavus* Test 1	Test 2	Test 3
PI 337409[a]		8.3	8.0
PI 337394F[a]		9.1	7.2
J 11	14.8	11.9	10.3
Asiriya Mwitunde	27.3		
TMV-2		39.4	28.4
PI 259747		32. 1	29. 7
Samrala	32.3		
EC 76446(292)	45.9	30.3	33.7
Florunner	32.8		
US 26	63.1		
OG 43-4-1	93.2	97.5	94.1
LSD (0. 05)	5.90	3.07	1.27

a. Lines reported resistant in USA.

cultivar Robut 33-1 was inoculated with *Rhizobium* strain NC 92. During the 1979 rainy season we again obtained an increase in yield, this time of 25%, by inoculating Robut 33-1 with strain NC 92.

The effect of inoculation on pod yield of other cultivar/*Rhizobium* combinations was not significant (Table 26). During the 1979/80 postrainy season (Nov-Apr for groundnut), Robut 33-1 did not respond to inoculation. We are now examining the interaction between site and *Rhizobium* strain and its effect on groundnut yield.

INTERCROPPING. Experiments in the 1979 rainy season on a maize/groundnut intercrop and in the 1979/80 postrainy season on sorghum/groundnut confirmed our earlier observation (ICRISAT Annual Report 1978/79, p 158) that nodulation and nitrogen fixation is generally adversely affected when groundnut is intercropped.

Nodulation and nitrogen fixation of groundnut at 70 days after planting was affected by intercropping with maize where maize received nitrogen fertilizer. When no nitrogen was added to the maize and its growth was poor, intercropping did not affect the groundnut nodule weight and nitrogenase activity (Table 27). The inhibition of nitrogen fixation increased as more fertilizer nitrogen was added. Intercropping had more effect on nodule weight and nitrogenase activity than on nodule number since most nodules were formed before the cereal had grown much.

The decrease in nitrogenase activity in intercropped groundnut could be due to (a) the inhibition of nodulation by the nitrogen fertilizer added to the cereal crop, as fertilizer nitrogen reduces nodulation and nitrogen fixation or (b) the reduction of light available to the groundnut in the intercrop, as more nitrogen fertilizer is added to the cereal and its foliar development increases. The second hypothesis is supported by the groundnut/sorghum experiment in which the amount of shading of groundnut by the sorghum was varied by removing alternate leaves from the sorghum plants. The nitrogen-fixing activity of groundnut declined as the amount of shading by the sorghum intercrop increased (Table 28).

SEASONAL VARIATION IN NITROGEN FIXATION. We earlier observed differences in the seasonal pattern of nitrogen fixation for the cultivars Kadiri 71-1 and MH 2 during the postrainy season (ICRISAT Annual Report 1978/79, pp 157-58). During the 1979 rainy season the pattern was sim-

Table 26. Response of groundnut yield to* Rhizobium *inoculation in the 1979 rainy season at ICRISAT Center.

Rhizobium strain	Cultivar (kg/ha pod yield)		
	Kadiri 71-1	Robut 33-1	Ah 8189
5a/70	363	796	422
IC 6006	478	789	291
NC. 43.3	460	960	474
NC.7.2	447	946	417
NC.92	571	1157	478
Control	497	866	473

SE ± for cultivar means 24.3
SE ± for strain means 32.5
CV (%) 20.5

ilar, except that nodulation and nitrogen fixation started earlier, probably because cold weather at the start of the postrainy season had delayed nodulation. There was less nodule development in the rainy season, and nitrogen-fixing activity reached a maxi-

Table 27. Modulation and nitrogen fixation by groundnut intercropped with maize, 70 days after planting in the 1979 rainy season at ICRISAT Center.

Treatment	Nodule number/ plant	Nitrogenase activity (μ mol C_2H_4/plant per hr)	Light reaching groundnut canopy (%)[a]
Sole groundnut	171	21.3	100
Intercropped groundnut, nitrogen added to maize (kg/ha)			
0	165	20.1	67
50	160	9.4	54
100	150	7.0	43
150	134	3.5	46
SE ±	15	1.9	
CV(%)	19.7	30.3	

a. Mean of spot readings on sampling date.

Table 28. Nitrogenase activity of groundnut sole cropped and intercropped with sorghum in the 1980 postrainy season at ICRISAT Center.

	Nitrogenase activity (μ mol C_2H_4/plant per hr)[a]			
Cultivars	Sole groundnut	Intercrop[b]	Intercrop	SE ±
Chico	15.2	11.8	6.8	3.79
TMV-2	18.1	12.6	8.3	
Robut 33-1	21.5	15.9	12.2	
MK 374	25.8	23.6	12.2	
MH 2	15.4	7.9	9.1	
Gangapuri	15.7	10.6	6.5	
SE ±	4.17			
CV = 42%				

a. Plants were harvested 70 days after planting. Sorghum in the intercrops was fertilized with 62 kgN/ha.
b. Alternate leaves of sorghum were removed to increase available light for groundnut.
c. Groundnut and sorghum were planted in a ratio of 2 rows: 1 row in the intercrop.

mum at 50 days after planting, and then declined rapidly, probably because of severe foliar disease attack (Figs. 19 and 20).

NONNODULATING GROUNDNUT. We have now observed nonnodulating segregants in the F_2 generations of 11 more crosses, for a total of 13 crosses seen with this trait at ICRISAT Center (Table 29). Sterile, nonnodulating plants were also observed in the F7 generation of some of the FESR lines. Nonnodulating lines selected from the three crosses previously reported (ICRISAT Annual Report 1978/79, p 158) have been advanced to the F5 generation.

So far crosses generating nonnodulating segregants include either PI 259747, NC Ac 17090, NC Ac 17142, or EC 76446 (292) as one of the parents. These genotypes are all rather primitive South American landraces and would be classified as Valencia types belonging to *Arachis hypogaea* subsp *fastigiata* var *fastigiata*. So far none of the modern Valencia cultivars, cultivated in many countries, have given nonnodulating segregants when used in hybridization programs.

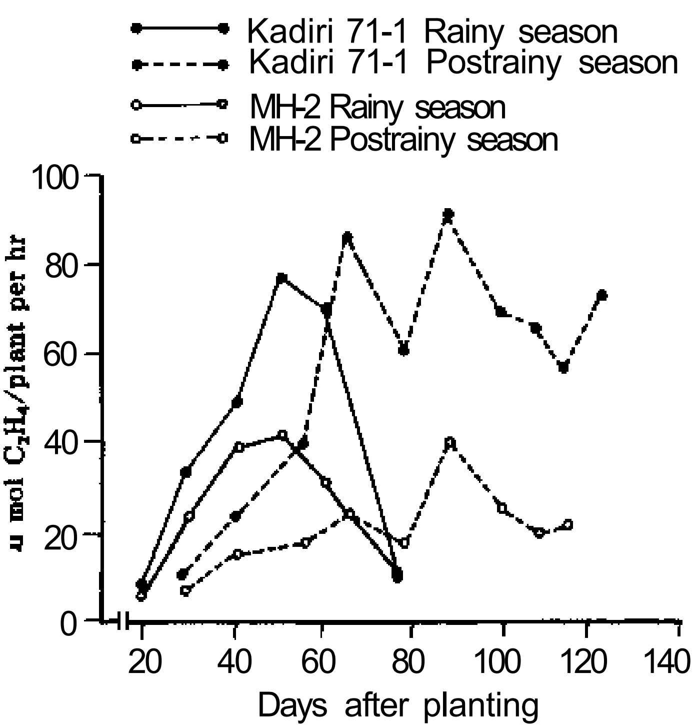


Figure 19. Nitrogenase activity of Kadiri 71-1 and MH-2 during 1978/79 postrainy and 1979 rainy seasons at ICRISAT Center.

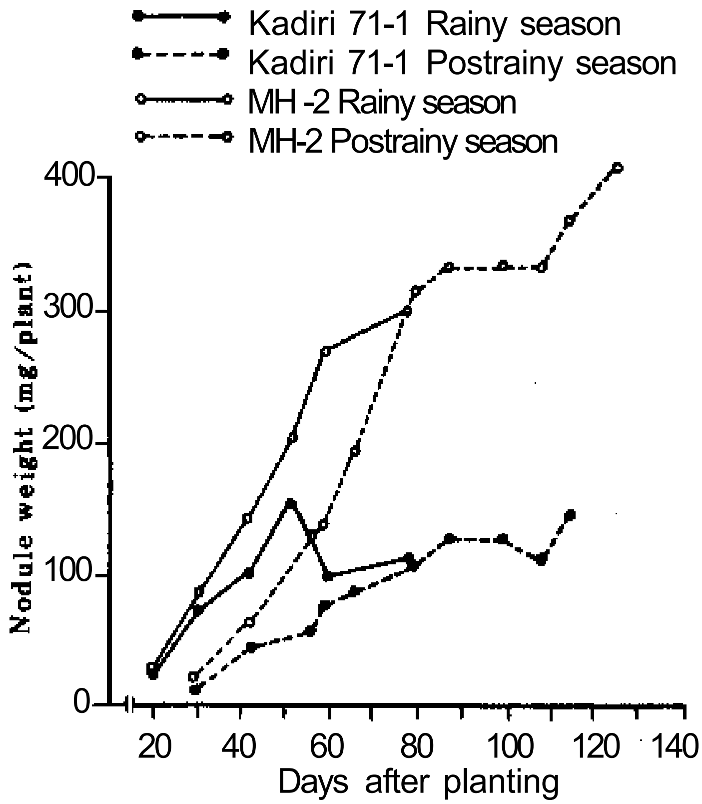


Figure 20. Nodulation of Kadiri 71-1 and MH-2 during 1978/79 postrainy and 1979 rainy seasons at ICRISAT Center.

NITROGEN TRANSPORT COMPOUNDS. When the stems are cut off groundnut plants, xylem sap exudes from the root stump. This sap contains nitrogenous compounds being exported from the root system to the tops of the plant. It includes nitrate taken up from the soil through the root system, as well as reduced nitrogen compounds such as amino acids and amides (20-30% of the total soluble nitrogen in the sap). Less than 5% of the nitrogen is allantoin, which is the form in which nitrogen is transported from the nodules to the tops of soybean and pigeonpea plants. The nitrogen transport compounds of groundnut contain a large unidentified component. The amount of allantoin exuded in the xylem sap follows a diurnal periodicity that is similar, but not identical, to that of nitrogenase activity. The amount declines a great deal during night time.

Table 29. Crosses In which nonnodulating groundnut progenies were observed at ICRISAT Center.

1. Shantung Ku No. 203 x NC Ac 17142
2. NC Ac 2731 x NC Ac 17090
3. NC Ac 2731 x EC 76446 (292)
4. NC Ac 2768 x NC Ac 17090
5. NC 17 x NC Ac 17090

6. Shantung Ku No. 203 x NC Ac 17090
7. Shantung Ku No. 203 x EC 76446 (292)
8. Shantung Ku No. 203 x PI 259747
9. NC 17 x EC 76446 (292)
10. NC Fla 14 x NC Ac 17090

11. RS 114 x NC Ac 17090
12. NC 17 x PI 259747
13. NC Ac 2731 x PI 259747

The amount of nitrate in the sap increases and the amount of amide and amino acid nitrogen decreases with the amount of nitrate in the rooting medium, so that with 100 ppm NO_3-N, the sap contains 11.4% of the total nitrogen as nitrate.

Looking Ahead

BREEDING. Our emphasis on breeding for stable disease resistance, high yield, and earliness will continue, with testing under both high and low input conditions. Advanced material will be entered in national and international testing systems, but we will continue to supply early generation segregating material to cooperators.

CYTOGENETICS. Advanced material that is cytogenetically stable and at or near the tetraploid level will be transferred to the breeding program. More of the wild species will be tested for disease and pest resistance and utilized in the interspecific breeding program. We will Intensify research on overcoming the existing barriers that prevent us from utilizing certain useful wild *Arachis* species in the breeding program.

PHYSIOLOGY. Recruitment of the senior scientists for this program is under way, and a research program will commence shortly.

ENTOMOLOGY. Increased emphasis will be placed on screening the germplasm and breeding material for resistance to thrips, jassids, aphids, termites, and the leaf miner. For those pests that cannot be controlled by host-plant resistance, we will emphasize integrated control methods.

PATHOLOGY. The search for additional sources of stable resistance to the major pathogens, both fungal and viral, will continue to be a major objective. Now that several viruses have been precisely characterized, and antisera have been produced, screening of material for resistance to these will be intensified. More emphasis will be placed on searching for alternative sources of resistance to dry seed invasion and aflatoxin production by *Aspergillus flavus.* We will further investigate the complex of root and pod fungi.

MICROBIOLOGY. Priority will continue to be given to the development of suitable inoculants that will successfully compete with the native rhizobia and to the development of simple inoculant application techniques. We will continue to work with the breeders in developing cultivars with an increased ability to fix nitrogen.

Publications

Journal Articles

Ghanekar, A. M. 1980. Research on bud necrosis disease of groundnut at ICRISAT. Indian Phytopathology 33:155.(Abstract.)

Nevill, D.J. 1979. An investigation of the disease reaction to *Cercosporidium personatum* in *Arachis hypogaea.* Tropical Grain Legume Bulletin 15:18-22.

Nevill, D.J., and Evans, A.M. 1980. The effect of host development on the field assessment of disease resistance to *Cercospora* leaf spots in groundnuts (*Arachis hypogaea* L.). Journal of Agricultural Science (Cambridge) 94:229-237.

Subrahmanyam, P., Gibbons, R.W., Nigam, S.N., and Rao, V.R. 1980. Screening methods and further sources of resistance to peanut rust. Peanut Science 7(1):10-12.

Subrahmanyam, P., McDonald, D., Nigam, S. N., and Gibbons, R.W. 1980. Identification of multiple disease resistance in groundnut. Indian Phytopathology 33(1):151.

Conference Papers

Amin, P.W., and McDonald, D. 1980. Termites as pests of groundnuts. *In* Proceedings of the Symposium on Soil Biology and Ecology, 18-20 April 1979, Bangalore, Karnataka State, India.

Amin, P. W., and Reddy, D. V. R. 1979. Biology of *Soirtothrips dorsalis* Hood and *Frankliniella sohultzei* (Trybom), the respective vectors of yellow spot and bud necrosis diseases of groundnut (*Arachis hypogaea* L.). Presented at the First Symposium on the Insect Vector Biology, Indian National Science Academy, 22-24 Nov 1979, Madras, India.(Abstract.)

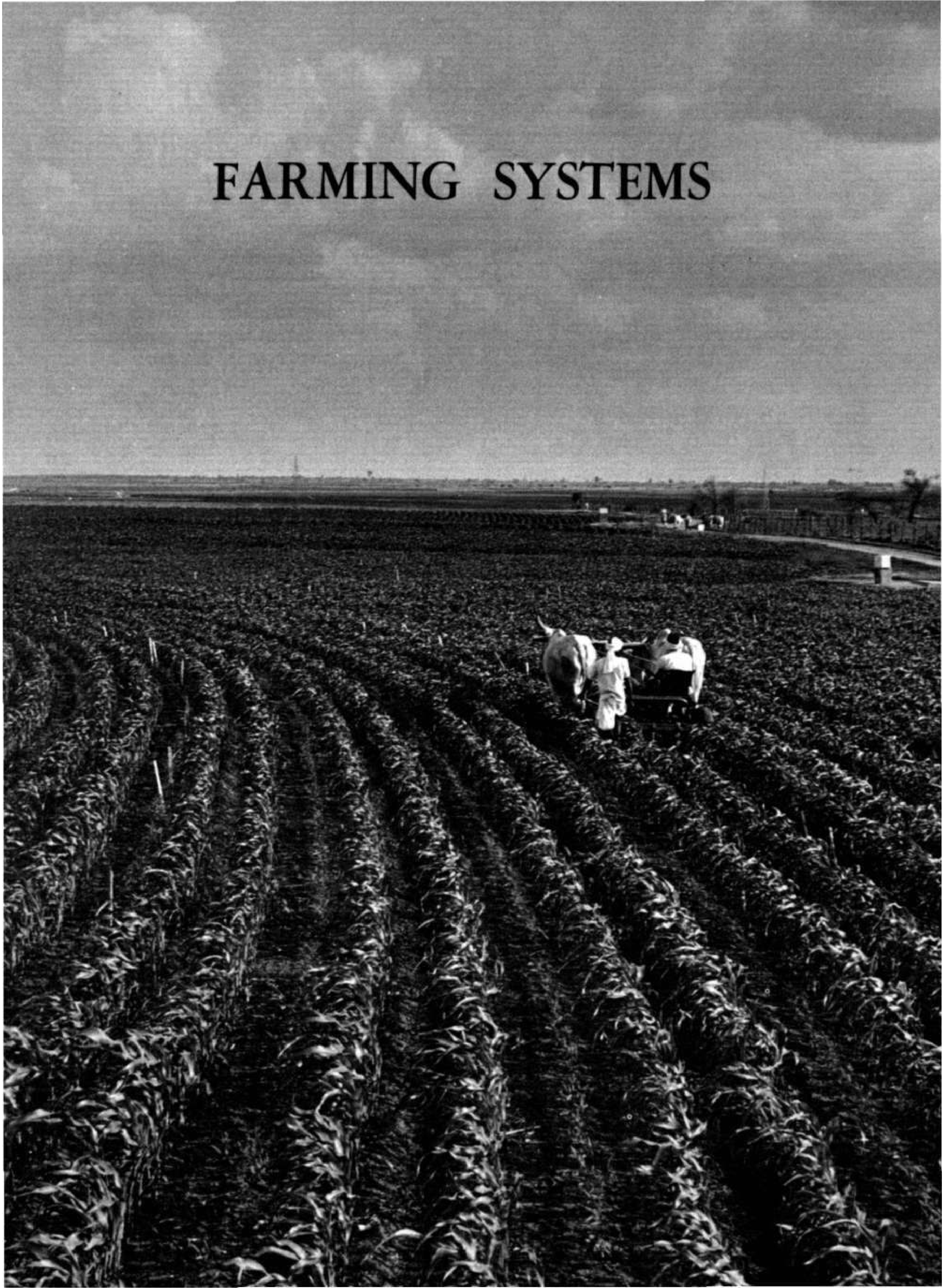
Iizuka, N., Reddy, D. V. R., and Ghanekar, A. M. 1979. Identification of some viral diseases of groundnut in India. Presented at the Legumes in the Tropics Symposium, 13-17 Nov, Malaysia.

Reed, W., Reddy, K. V. S., Lateef, S.S., Amin, P.W., and Davies, J. C. 1980. Contribution of ICRISAT to studies on plant resistance to insect attack. Presented to the Scientific Working Group on the Use of Naturally Occurring Plant Products in Pest and Disease Control 12-15 May, Nairobi, Kenya.

Singh, A. K., Moss, J. P., and Sastri, D. C. 1980. Utilization of wild relatives in genetic improvement of *Arachis hypogaea;* I. Techniques. Page 15 *in* Abstracts of All India Seminar on Current Methodological Approaches in Cytogenetics, 22-24 Mar, Centre of Special Assistance in Cytogenetics, Patna University, Patna, India.

Sastri, D. C., Nalini, M. S., and Moss, J. P. 1980. *Araohis* ovary and ovule culture in vitro. Number J6 (p 57) *in* Abstracts of Symposium on Plant Tissue Culture, Genetic Manipulation and Somatic Hybridization of Plant Cells, 27-29 Feb., Bhabha Atomic Research Center, Trombay, India.

FARMING SYSTEMS



Contents

FARMING SYSTEMS

The goal of the Farming Systems Research Program (FSRP) at ICRISAT is consistently higher agricultural production in the seasonally dry tropics, especially for small farmers of limited means. Because the applicability of food production technology varies with the agroclimatic region, our research efforts focus on the development of principles, concepts, and methodologies that are transferable and have broad application. Therefore the FSRP 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 establish basic principles that describe these processes.
- develop production practices and systerns of farming that will result in improved, stable food production by optimum utilization of the SAT's natural resources.
- determine regional research priorities by execution of simulation and modeling studies based on climatic, soil, and cropping systems data.

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 often require interdisciplinary investigations with several subprograms in ICRISAT and with 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 (see Economics Program section of this Annual Report).

Agroclimatology

The principal objective of agroclimatology research at ICRISAT is to increase our understanding of climatic environments of crops in the SAT in order to provide a basis for improving agricultural production in this region. The main research efforts are in (1) collection and interpretation of climatological data for the SAT regions of the world and their classification in agronomically relevant terms, and (2) microclimatological and crop weather modeling studies to evaluate the effects of the production factors singly or in combination.

Meteorological Observations in 1979/80

An agrometeorological observatory is located at ICRISAT Center where data on rainfall, evaporation, air and soil temperatures, relative humidity, wind, sunshine hours, and global solar and net radiation are collected. Detailed information is available in Agroclimatology Report of Work, 1979/80, Farming Systems Research Program, ICRISAT.

Rainfall Characteristics of West Africa

Our agroclimatic survey of the West African region (Senegal, Mali, Upper Volta, Niger, and Chad) covered a total area of about 4.2 million km^2 between 7° and 15°N, and 17°W and 24°E.

In the pursuit of these efforts we published A Handbook on the Rainfall Climatology of West Africa (Virmani et al. 1980; listed in "Publications"). Data on mean monthly rainfall, potential evapotranspiration, and dependable rainfall for over 280 locations are included in the handbook.

Maps showing mean annual rainfall and mean annual potential evapotranspiration (PE) have been prepared for the West African area including Senegal, Gambia, Mali, Upper Volta, Niger, and Chad. As depicted in Figure 1, the annual rainfall decreases as one moves away from about 10°N to the 20th parallel.

Mean annual PE over West Africa (Fig. 2) follows the general pattern of the distribution of rainfall. The values of PE are low in the higher rainfall areas and increase nearer the Sahel. The exception is observed in areas adjacent to the Atlantic Ocean where, due to the pressure of a large body of water, the PE values are more or less uniform on land, particularly over Senegal.

Microclimatological Studies

Experiments are being conducted to quantify the interception and disposition of solar energy and water by the leaf and soil surfaces.

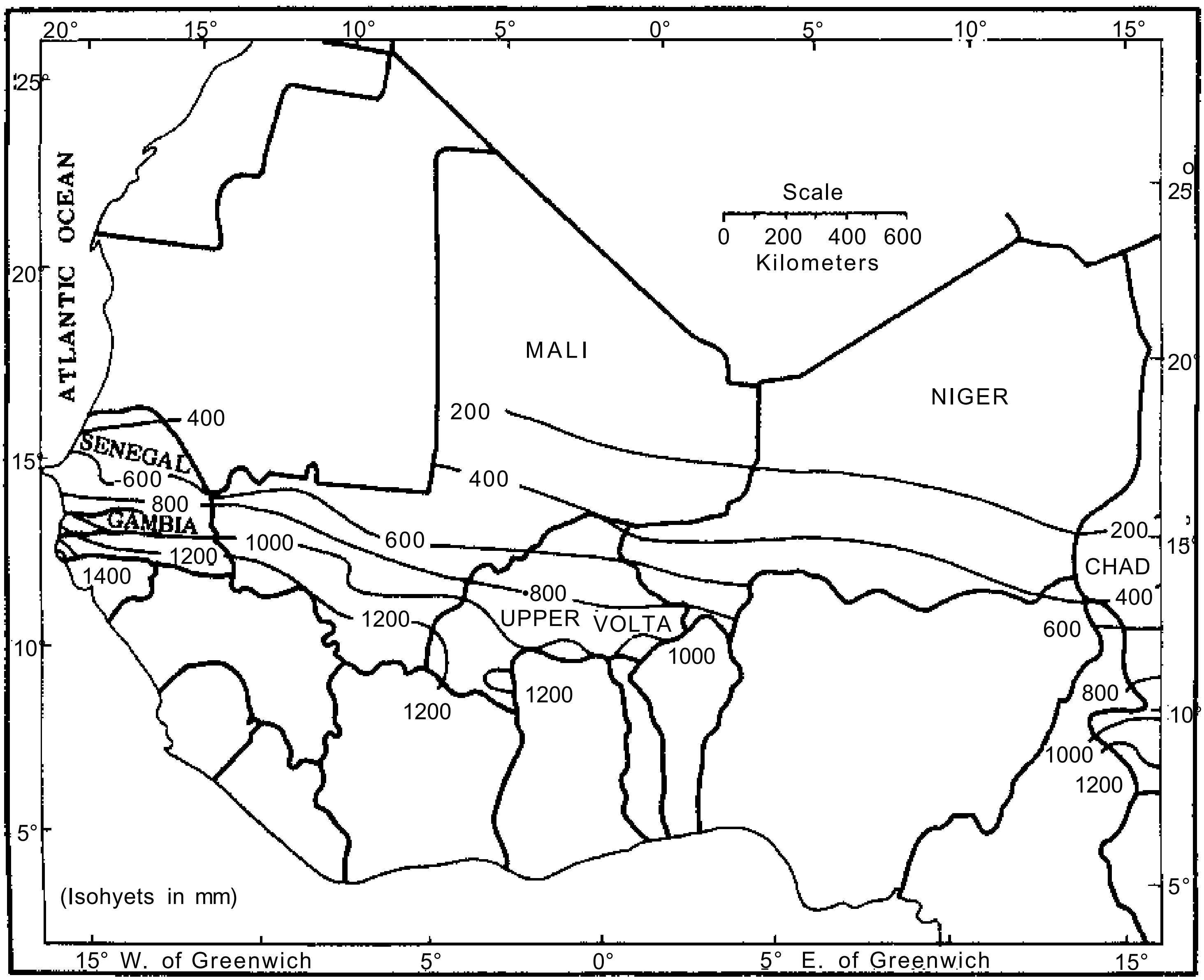


Figure 1. Mean annual rainfall over West Africa.

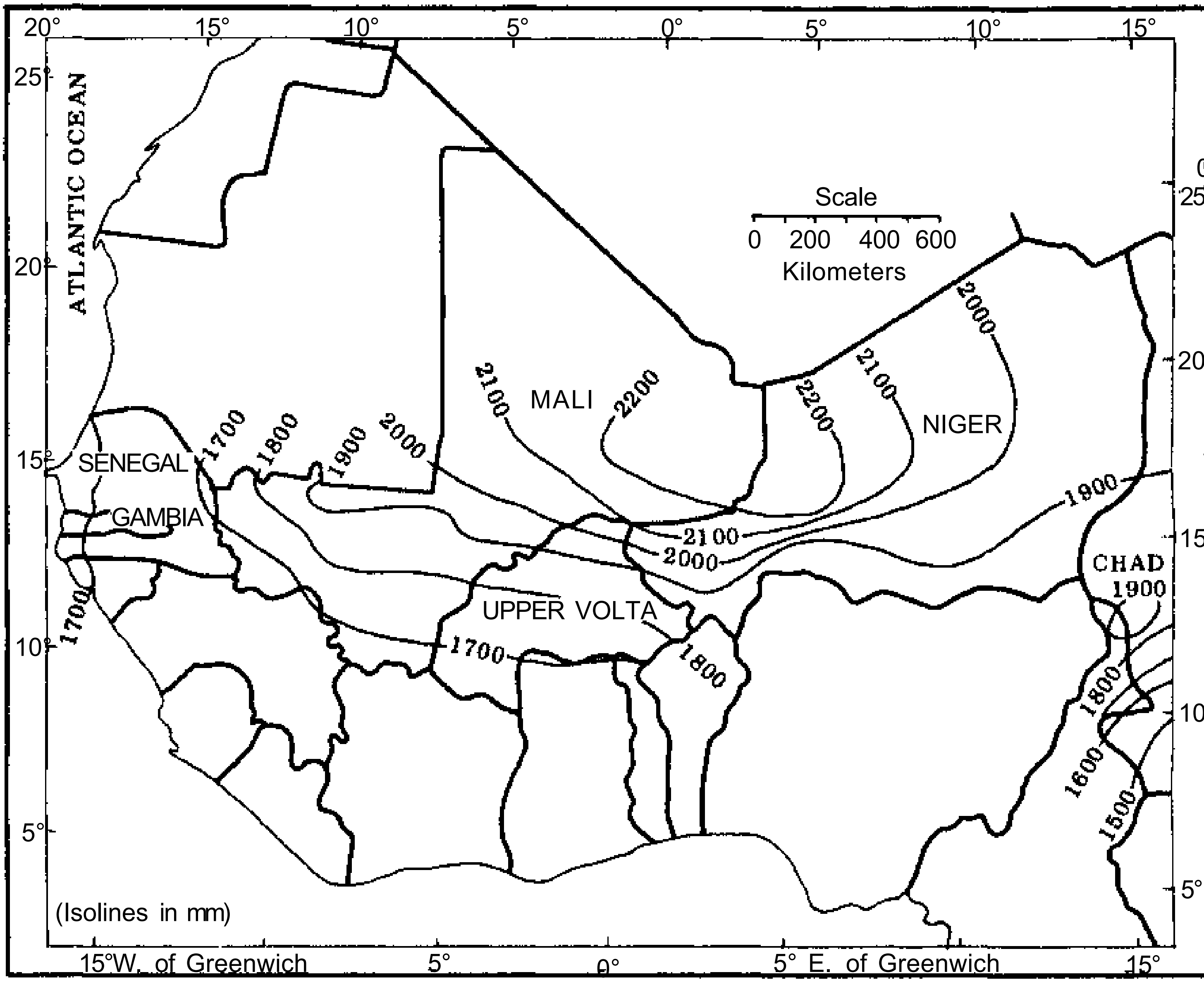


Figure 2. Mean annual potential evapotranspiration over West Africa.

Interception of Photosynthetic Photon Flux Density (PPFD)

Studies on the efficiency of conversion of intercepted PPFD and dry-matter production in maize/pigeonpea, maize, and pigeonpea crops grown in 1978/79 on a deep Vertisol with about 250-mm available water storage capacity showed that growth efficiency for maize/pigeonpeas was 7.3%, followed by maize with 5.3%, and sole pigeonpea with 1. 8% (Sivakumar and Virmani 1980; listed in "Publications"). Growth efficiency was calculated from the slope of the regression relationship between cumulative intercepted PPFD and dry matter and the calorific value of the crop,

A study was also conducted on the relationship between cumulative intercepted PPFD and dry matter produced for sorghum hybrids CSH-6 and CSH-1 grown on an Alfisol during the 1979 rainy season (Fig. 3). On a seasonal basis per unit of intercepted PPFD, CSH-6 was superior to CSH-1 in production of dry matter.

CSH-6 showed a growth efficiency of 4.9%, while for CSH-1 it was 4.1%. CSH-6 had slightly better canopy growth, reflected by

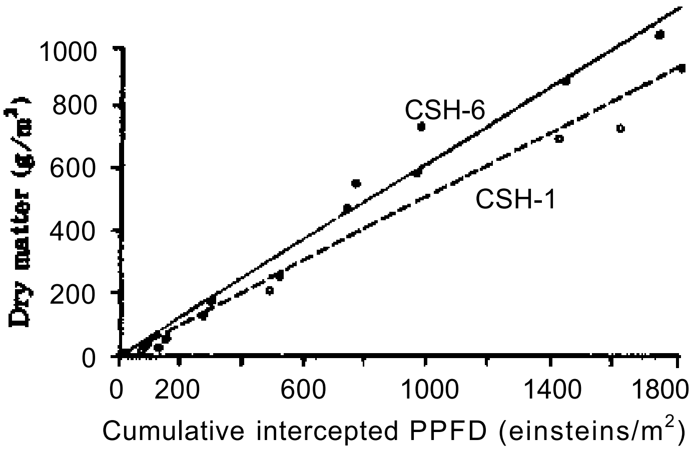


Figure* 3. *Relationship between cumulative intercepted PPFD and dry matter produced for two sorghum hybrids grown on an Alfisol during the 1979 rainy season at ICRISAT Center.

higher leaf area index and dry-matter production, resulting in the marginal difference in growth efficiency.

In a study to quantify the response of sorghum hybrid CSH-6 grown on two soil types during the 1979 rainy season, calculated growth efficiency of CSH-6 was 5.9% on a Vertisol and 4.9% on an Alfisol.

Row Crop Microclimate of Sorghum

Experiments on the row crop microclimate of sorghum were conducted during the rainy and postrainy seasons of 1979/80 on a medium-deep Vertisol. The treatments in the 1979 rainy season consisted of five row spacings (30, 60, 90, 120, and 150 cm) at a constant population of 170 000 plants/ha for sorghum hybrid CSH-6. The experiment was repeated during the postrainy season with sorghum hybrid CSH-8-R sown in a split-plot design with two moisture treatments (irrigation and no irrigation) in the main plots and the same five spacing treatments in the subplots. Irrigations of approximately 60 mm were given to the crop at 50, 69, and 90 days after sowing (DAS).

RAINY-SEASON SORGHUM STUDY. The extinction coefficients of the crop, calculated (using the Beer's law approach) from the measured data of PPFD transmission, decreased with increasing row space: 0.85 at 30, 0. 57 at 60, 0.43 at 90, 0.36 at 120, and 0.27 at 150-cm row spacing.

Soil temperature at 10-cm depth, monitored on a continuous basis from 23 to 84 DAS in four treatments, was higher under the wider rows.

Reflected radiation was higher in the 30- and 60-cm rows than in the 90- and 150-cm rows on the first 2 days of measurement. On 11 August (45 DAS) the albedo over the narrow rows was 6% more than that over the wide rows.

POSTRAINY-SEASON SORGHUM STUDY. Seasonal changes in total dry matter under different treatments are shown in Figure 4. Wide rows outyielded the narrow rows in both irrigated and nonirrigated sorghum, but total dry matter was higher in irrigated than in nonirrigated sorghum in all row spacings.

Final grain yields of sorghum in the 30, 60, 90, 120, and 150-cm row spacingswere 974, 1402, 1622, 1734, and 2076 kg/ha in the nonirrigated sorghum and 1990, 1968, 2288, 2360, and 2854 kg/ha, respectively, in the irrigated sorghum. These data suggest that because sorghum in the narrow rows had moisture available to it in the top layers of the soil early in the growing season, it developed shallow roots that put it at a disadvantage in a prolonged dry spell. In the wide rows because of evaporation of moisture from the soil surface early in the growing season, the root system may have penetrated deeper, enabling the crop to extract moisture from deeper layers in the later stages and survive prolonged spells of late-season stress.

Row Crop Microclimate of Groundnut

During the rainy seasons of 1978 and 1979, groundnut variety Robut 33-1 was sown to

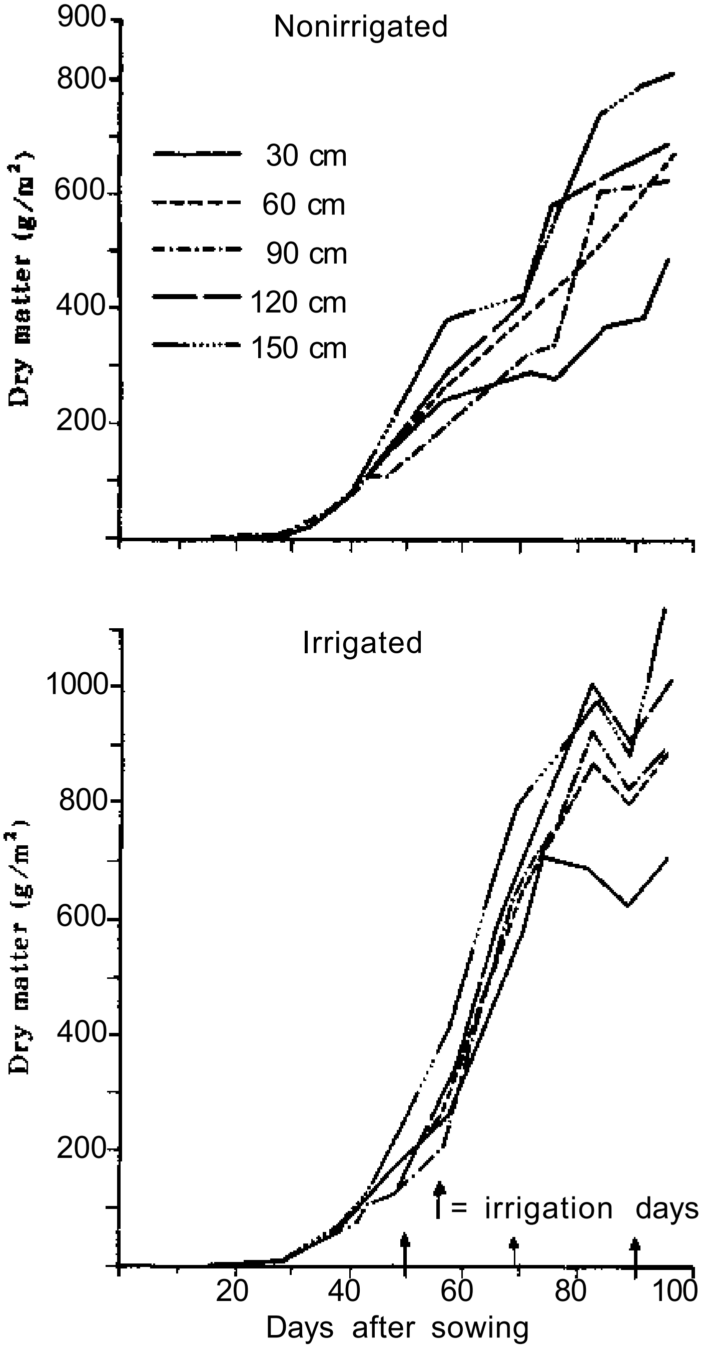


Figure 4. Seasonal changes in the dry-matter production of irrigated and nonirrigated postrainy-season sorghum in five row spacings at ICRISAT Center, 1979/80.

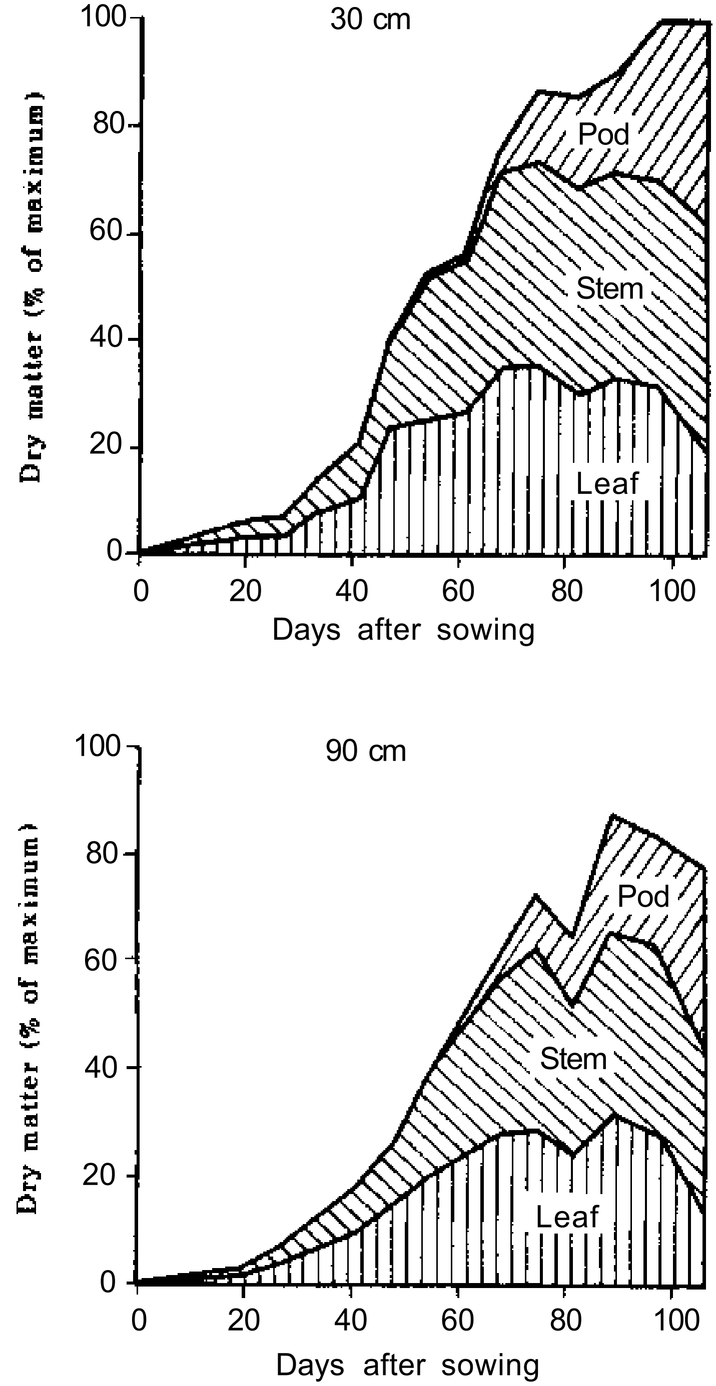


Figure 5. Seasonal changes in the dry-matter production of groundnut grown during the rainy season in two spacings at ICRISAT Center in 1979.

two spacings on medium-deep Alfisols in a randomized block design with three replications.

Total dry-matter produced in 30-cm rows was 338 g/m^2, whereas groundnut in 90-cm rows produced 283 g/m^2. Both treatments produced similar biomass accumulation in the leaf component (Fig. 5), but their stem and pod fractions differed. Maximum soil temperature at 10-cm depth was always higher in the wide-row crop.

Diurnal variation in the incoming solar radiation, net radiation, and reflected radiation above the groundnut crop for the two

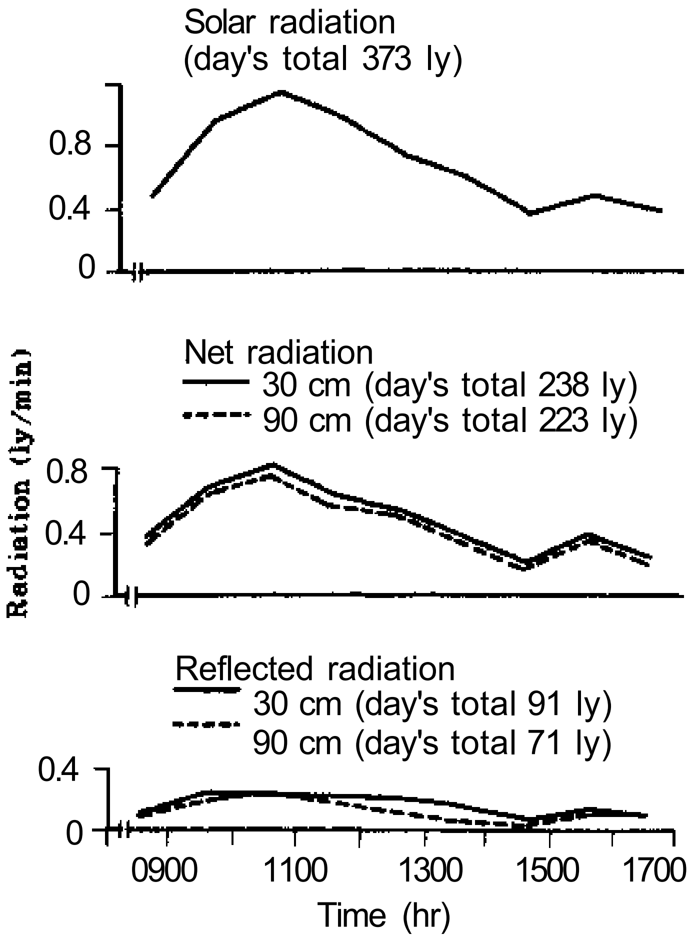


Figure* 6. *Diurnal variation in the incoming solar radiation, net radiation, and reflected solar radiation on 17 August 1979 over groundnut sown in two spacings at ICRISAT Center.

treatments is shown in Figure 6. Integrated over the measurement period, the difference in the net radiation between the two treatments was about 15 langleys (ly), indicating higher transpiration in the narrow-row groundnut. Because of better canopy spread and higher leaf area index, the crop in the narrow rows reflected more incoming solar radiation. Integrated over the measurement period, narrow-row groundnut reflected 91 ly, whereas wide-row groundnut reflected only 71 ly.

Using the data of radiation fluxes collected throughout the season, it is possible to calculate the parameter heating coefficient as defined by Monteith and Szeicz (1961, Quarterly Journal of Royal Meteorological Society 87:159-170) from the empirical relationship between net radiation and solar radiation and the basic energy balance equation. The heating coefficient in the narrow-row groundnut was 0.025, whereas in the wide rows it was 0.071. The heating coefficient is larger in the wide rows because of greater exposure of the soil surface for absorption of radiation and subsequent emission.

Moisture Stress Effects on Chickpea

In an experiment to check moisture stress effects on canopy-air temperature differentials, chickpea cv Annigeri was sown on 26 October 1979 in 30-cm rows in a randomized block design with three replications, each containing three plots. One plot was given no irrigation (I_0), the second plot received two irrigations (I_1), and the third plot received four irrigations (I_2).

Seasonal changes in the canopy-air temperature differentials during the 1979/80 growing season are shown in Figure 7. Treatment I_0, which was under continuous moisture stress starting from 60 DAS (25 December), showed a rapid increase in the leaf-air temperature differential. Both I_1 and I_2 treatments received irrigations on 39 and 70 DAS, and the I_2 treatment received additional irrigations 53 and 81 DAS. Both I_1 and I_2 showed negative temperature differentials throughout the growing season, with the I_2 treatment lower, as would be expected.

Figure 8 shows that the canopy-air temperature differentials are negative when the available soil water is above 100 mm.

Stress degree days (SDD) are defined as the summation over the measurement period of the leaf-air temperature differential. SDD during the period from 34 to 112 DAS were 111 for the I_0, -385 for the I_1, and -503 for the I_2 treatment. The corresponding yields are 1710, 2455, and 2544 kg/ha. These data show that the canopy-air temperature differential measured between 1300 and 1400 hr could be used as an effective indicator of water stress effects in chickpea.

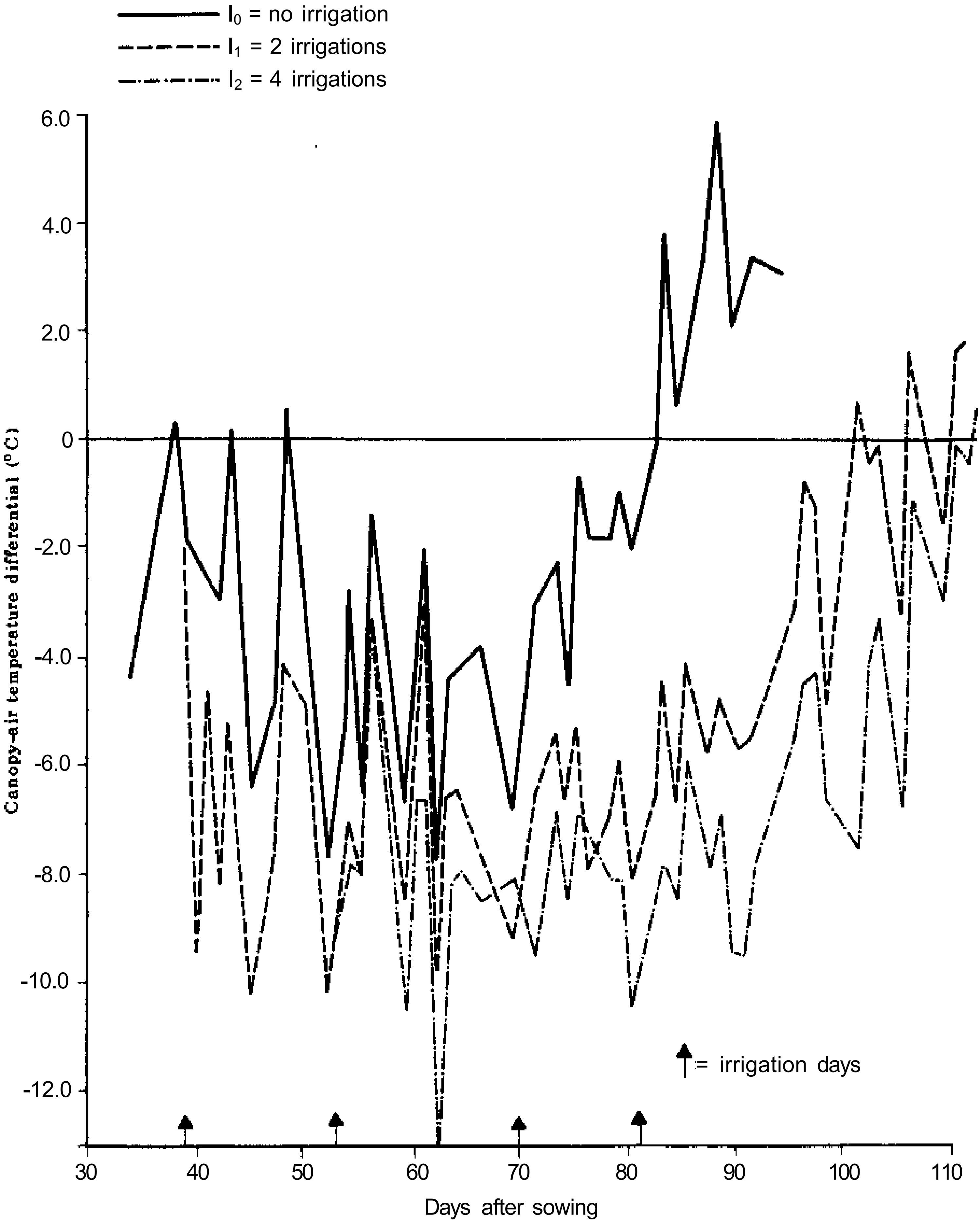


Figure 7. Seasonal changes in the leaf-air temperature differential of chickpea grown during the 1979/80 postrainy season under three moisture regimes at ICRISAT Center.

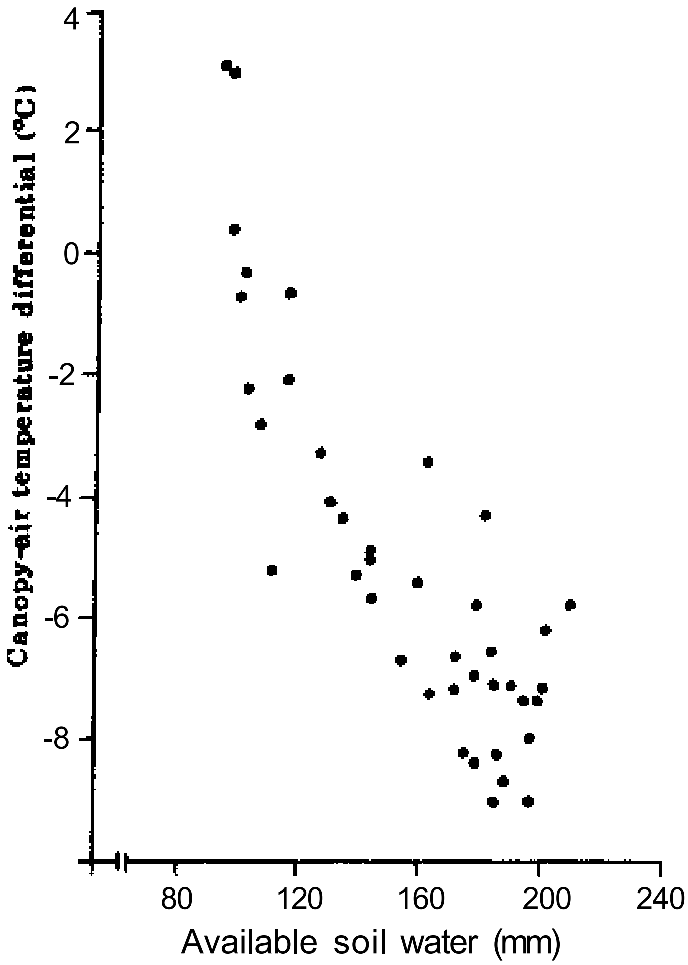


***Figure* 8. *Relationship between leaf-air temperature differential and available soil water for chickpea* (*data pooled from different treatments at ICRISAT Center*).**

Crop Weather Modeling: SORGF

A sorghum simulation model, SORGF, developed by Arkin et al. (1976, Trans. Amer. Soc. Agric. Eng. 19:622-630) was computerized at ICRISAT. This model calculates the daily growth and development of an average grain sorghum plant in a field stand by considering the physical and physiological processes of light interception, photosynthesis, respiration, and water use, which are independently computed and used as submodels. Grain yields per unit area are estimated by taking into account the plant population at harvest. The details of the submodels used are discussed by Huda and Virmani (1980; listed-in "Publications").

To check the applicability of this model to the SAT environment, experiments were initiated in the 1979 rainy season at ICRISAT in collaboration with several institutions in the SAT. The minimum data required to run this model are collected from seven locations in India, but an extensive data set is collected from ICRISAT Center and from a few of the cooperating centers to improve the model. Simulation results are discussed by Huda et al. in Agroclimatology Progress Report-4 (1980, p 79).

Simulation of sorghum yields using the SORGF model showed that modifications in the model were necessary. Preliminary modifications were made in the model based on a limited data set; the revised version of SORGF is called SORGF-1. The correlation coefficients between observed and simulated grain yields and total dry matter are given in Table 1. The observed and simulated yield components and phenological events for CSH-6 grown in deep Vertisols at ICRISAT are plotted in Figure 9 to give an example of the model's performance. The results indicated that the partitioning of dry matter into different organs should be further examined. The observed days from emergence to flag leaf and anthesis were very close to the simulated values.

Further improvements in the model are needed. A thorough examination of the data collected from multilocation collaborative trials is under way to bring about revisions in the model. Emphasis will be given to incorporation of the critical soil moisture value for calculation of emergence, to reckoning the daily soil water balance, to the use of water stress factors for computing leaf growth and development, and to partitioning of dry matter into different plant organs.

Environmental Physics

The main focus in this subprogram continues to be on interdisciplinary studies of soil-plant-water relations. Scientists from Agroclimatology, Cereal Physiology, Pulse

Table 1. Correlation coefficients between observed and simulated grain yields and total dry matter for different locations.

Parameter	No. of observations	Coefficient between observed and simulated data SORGF	SORGF-1
		ICRISAT Center	
Grain yields	16	0. 53	0. 80
Total dry matter	16	0.29	0.60
		Pooled data from ICRISAT and cooperating centers	
Grain yields	29	0. 52	0.50
Total dry matter	29	0.18	0.38

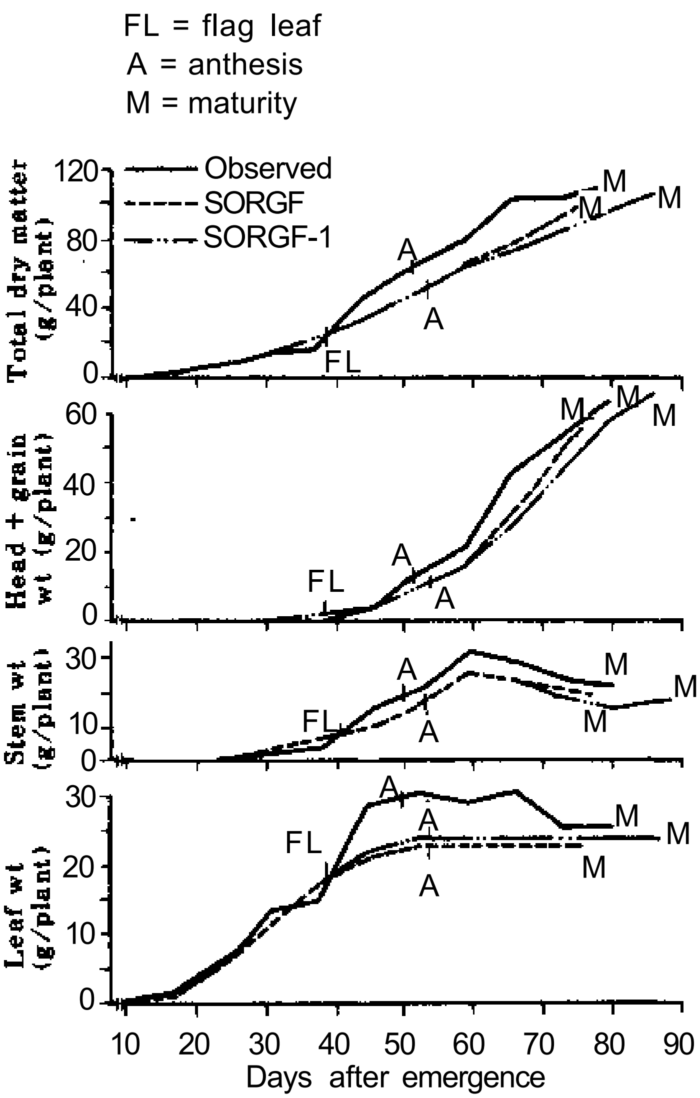


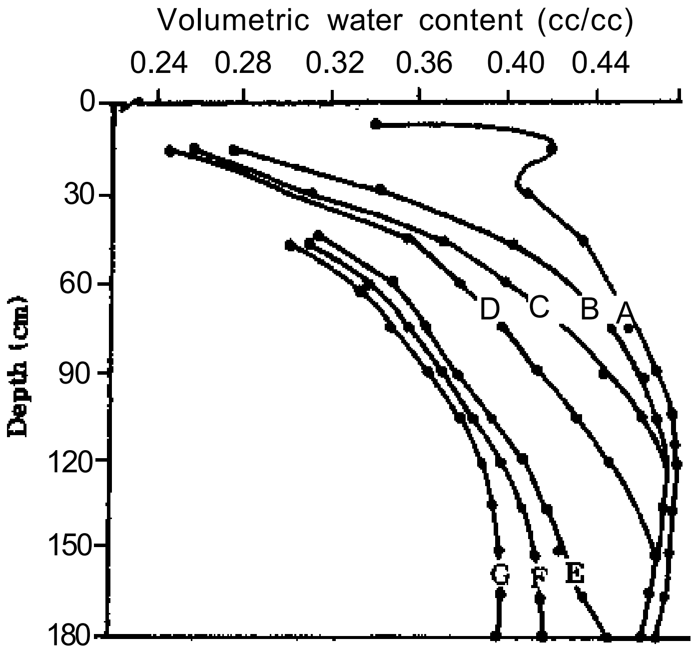
Figure 9. Observed and simulated yield components and phonological events of sorghum hybrid CSH-6 in a deep Vertisol at ICRISAT Center during the 1979 rainy season.

Physiology, Farm Power and Equipment, and Environmental Physics subprograms collaborated in a series of field experiments designed to produce congruent data sets of the physical and physiological performance of the soil-crop-atmosphere system.

Profile Water Use by Sorghum on a Deep Vertisol

Sorghum (CSH-8) was planted on 14 October (postrainy season) on a deep Vertisol. Three moisture regimes were imposed on the crop: regime I_0, no irrigation; I_1, one 80-mm irrigation on 22 November (39 DAS); and I_2, two irrigations of about 86-mm each on 22 November (39 DAS) and on 19 December (66 DAS). At sowing time the 187-cm profile contained 200 mm of available water. The progressive depletion of profile moisture under rainfed sorghum is shown in Figure 10. The seasonal changes in the available water fraction for the three treatments are plotted in Figure 11.

The total loss by evaporation for the season for all three treatments was small and constituted less than 3% of the seasonal open-pan evaporation (E_O) and less than 5% of seasonal transpiration. When the crop was small it transpired at about one-third the open pan rate. At about 40 DAS when the rainfed sorghum was well established, the



	DAS	ASW
A. 23 Oct	9	220
B. 17 Nov	34	177
C. 27 Nov	44	163
D. 7 Dec	54	145
E. 28 Dec	75	101
F. 19 Jan	96	82
G. 30 Jan	107	66

DAS = Days after sowing

ASW = Total available water in 187-cm profile

Figure 10. Soil-moisture profiles under rainfed sorghum (treatment I_0) on a deep Vertisol during the 1979/80 postrainy season at ICRISAT Center.

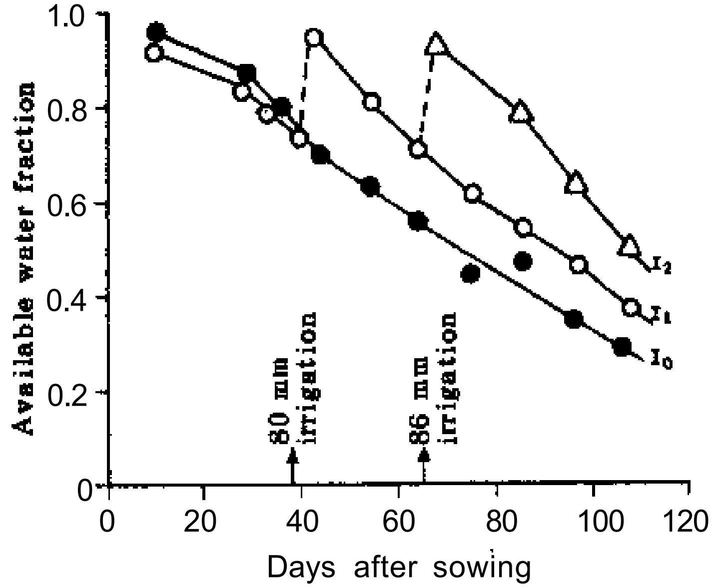


Figure 11. Seasonal changes in the available water fraction for sorghum under different water regimes in deep Vertisol during the 1979/80 postrainy season at ICRISAT Center.

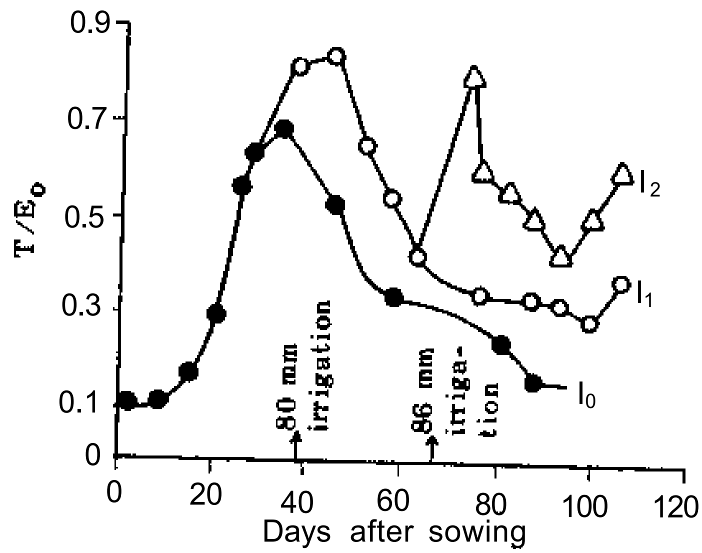


Figure 12. Seasonal changes in the transpiration /open-pan evaporation (T/E_O) ratios of sorghum under different moisture regimes on a deep Vertisol during the 1979/80 postrainy season at ICRISAT Center.

profile was still well charged with water and the crop transpired at about one-half the open pan rate. Following the two irrigations, transpiration rose to about 80% of E_0.

On a seasonal basis the crop transpired 30, 50, and 60% of the E_O in the I_0, I_1, and I_2 treatments, respectively. Water loss during the season increased from 163 mm to 216 mm by one irrigation of 80 mm at 39 DAS and from 216 mm to 274 mm by an additional irrigation of 86 mm at *66* DAS. Thus about two-thirds of the water applied in each irrigation was used by the crop. Transpiration rates were determined as the slopes of the cumulative water-use curve; the corresponding T/E_O ratios are plotted in Figure 12.

The grain yields were 2740, 2500, and 3130 kg/ha, and water-use efficiencies were 16.8, 11.6, and 11.4 kg/ha of grain per mm of water transpired for treatments I_0, I_1, and I_2.

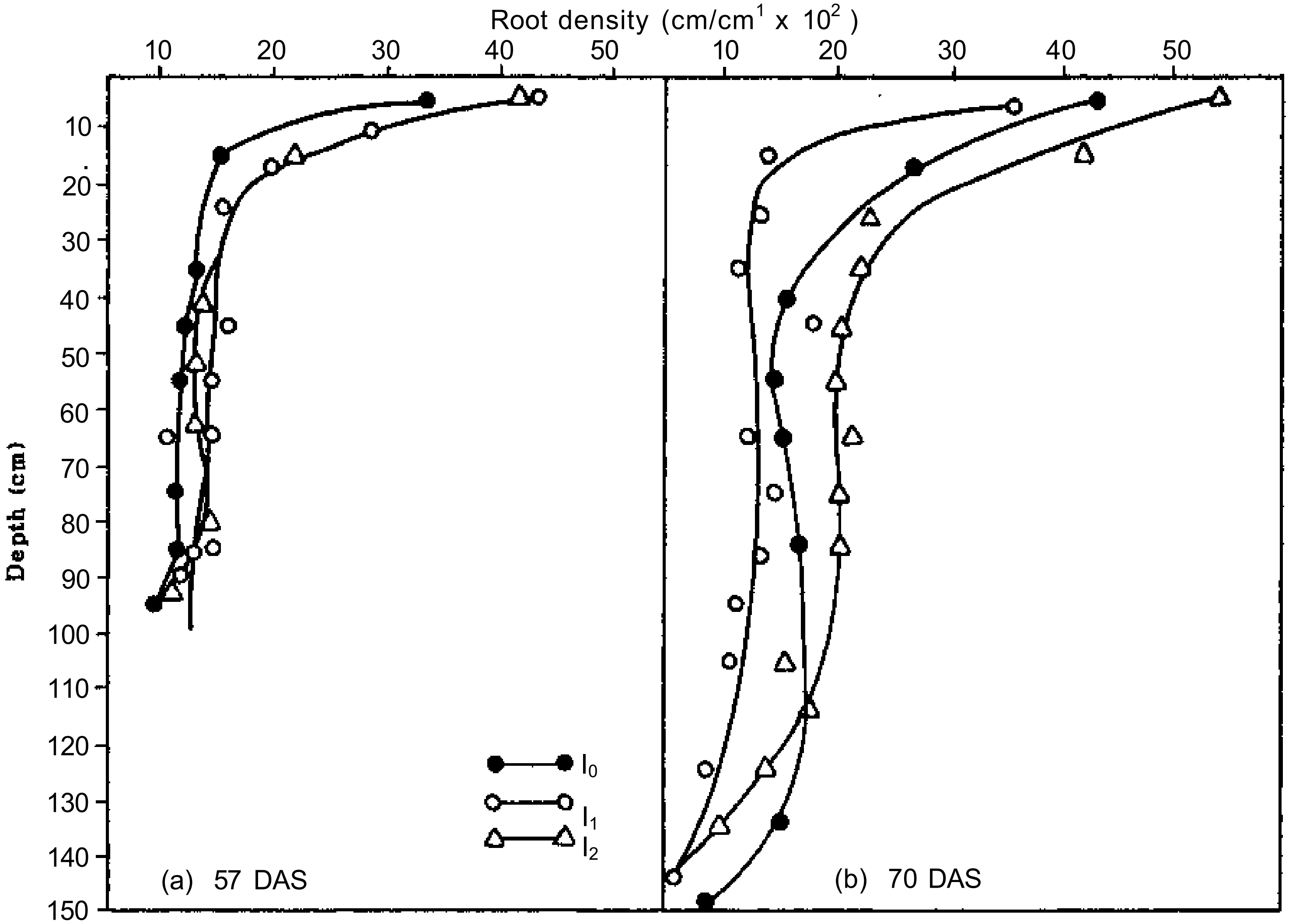


Figure 13. Effects of irrigation on root density profiles of sorghum on a deep Vertisol at ICRISAT Center in the 1979/80 postrainy season.

Time and depth moisture profiles and root density profiles (Fig. 13) were used to calculate the daily extraction rates per unit length of root in each soil layer. The relations between extraction rates and the available water fraction (AWF) in the two layers are shown in Figure 14. When the soil was fully charged, most depletion occurred in the surface 50-cm layer; depletion from the deeper layer was lower, reflecting the root distribution profile.

When the evapotranspiration (ET) from the entire 187-cm profile was plotted against the AWF of the whole profile, a linear reduction of ET with AWF from 1.0 to 0.3 was observed. The scatter in the points was somewhat reduced when the depletion was normalized by dividing the observed losses by corresponding open pan values (Fig. 15).

Plant Stand Establishment on Alfisols

Poor or uneven plant stand is one of the major causes of the low crop yields in the SAT. At shallow soil depths the physical environment changes rapidly with time and depth, and unfavorable physical conditions will suppress or prevent normal germina-

Preliminary studies were conducted to evaluate techniques for measuring some of the edaphic factors, such as bulk density, water absorption rates of seeds, crust strength, and soil water at shallow depths.

WATER ABSORPTION BY SEEDS. To determine the effect of soil moisture and bulk density on water absorption by seeds, a 2-

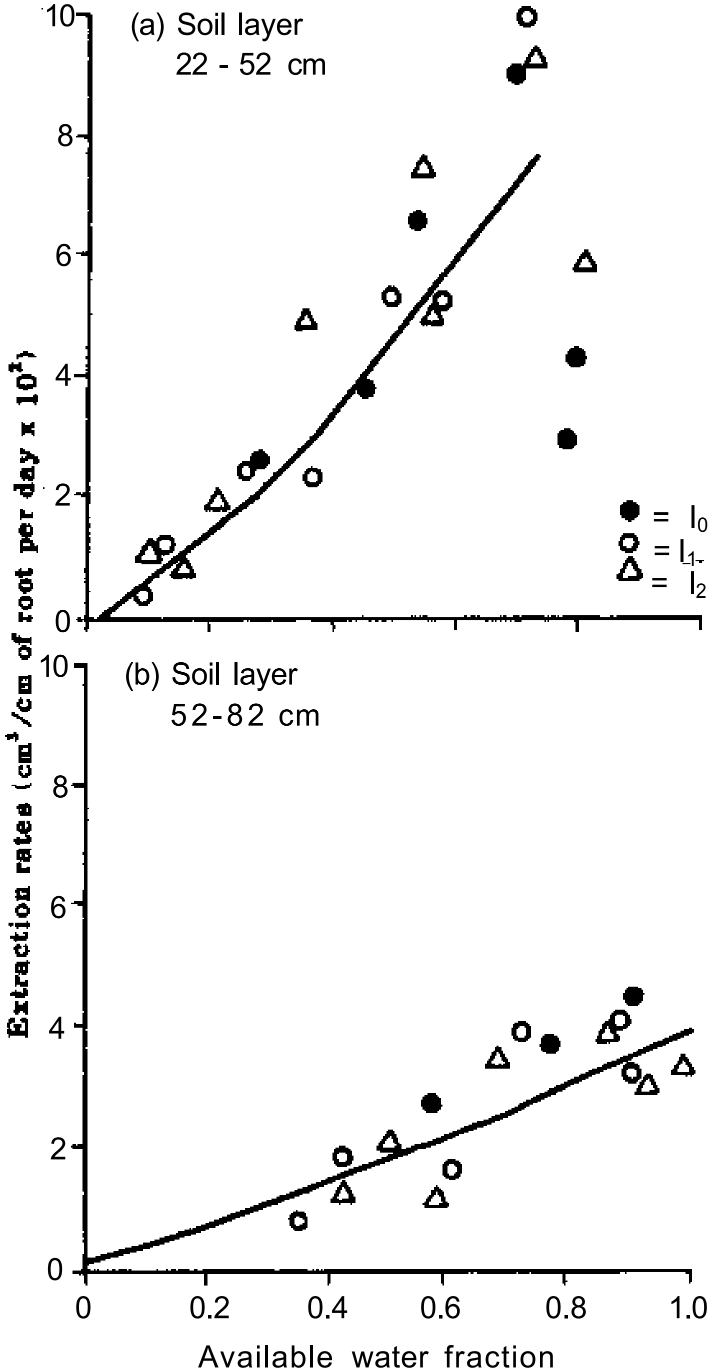


Figure 14. Effects of available water fraction on root extraction rates by rainfed and irrigated sorghum from two layers of a deep Vertisol in the 1979/80 postrainy season at ICRISAT Center.

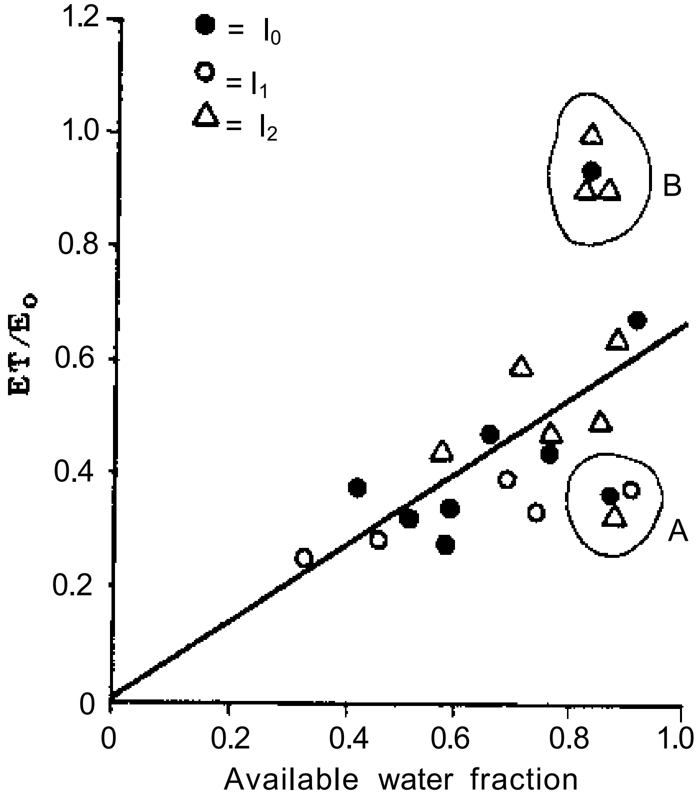


Figure 15. Effect of available water fraction of a 187-cm Vertisol profile on the evapotranspiration/open-pan evaporation (ET/E_O) ratio of rainfed and irrigated sorghum. (Divergent points A refer to extraction rates early in the season when depletion rates were low; those marked B were at times when drainage may have occurred, causing an overestimation of the amount of water extracted by the crop.)

cm layer of soil premoistened to 4.9, 6. 8, and 8.9 g of water/100 g of soil was packed at high (1.8 g/cm^3) and low (1.0 g/cm^3) bulk densities in 8-cm diameter cans. Twenty sorghum seeds were placed in each can in a circular pattern 1 cm away from the walls and covered with the same soil. The cans were kept at a constant temperature of 23 ± 1°C. After 4,8,18,30, and 48 hr the seeds from five cans for each treatment (150 total cans) were removed from the soil, washed under a gentle stream of water, dried with a blotting paper, weighed, dried at 60°C for 48 hr, and reweighed. The amount of water absorbed per 100 g of dry seed above the initial seed moisture was 11.3%.

Table 2 shows the rates of water uptake as a function of soil water and bulk density. Water absorption declined for the first 18-30 hr and then reversed. The time of the reversal seems to be the end of imbibition and start of radicle growth.

Table 2. Rates of water absorption by sorghum seeds as a function of soil water and bulk density.

	Rates of water absorption g/100 g per hr				
Period after	Soil water (g/100 g)			Bulk density (g/cm^3)	
sowing (hr)	4.9	6.8	8.9	1.0	1.8
0-4	4.6	5.6	5.6	5.0	5.4
4-8	1.4	1.0	0.9	1.1	1.1
8-18	0.5	0.4	0.4	0.5	0.4
18-30	0.1	0.6	0.6	0.4	0.4
30-48	1.4	2.4	3.3	2.5	2.2

These observations indicate that at 4. 9% moisture treatment, soil moisture was limiting, whereas above 6. 8% the absorption capacity of the seeds limited water uptake. Initially, high bulk density increased the amount and rate of water absorption, probably because of better seed-soil contact. But with the start of radicle growth 18 hr after sowing, the lower bulk density treatments were better, probably because of more rapid growth of the radicle as it encountered less soil resistance. However, these are preliminary observations and need verification from data on radicle elongation at different bulk densities.

EFFECTS OF CRUST STRENGTH ON SEEDLING EMERGENCE. We initiated cooperative field experiments to study the effects of crust strength on radicle and plumule lengths and percent seedling emergence of postrainy-season sorghum with the Farm Power and Equipment and Sorghum Physiology subprograms. A tractor-mounted planter with a 20-mm chisel furrow-opener was used with the required type of covering wheels. CSH-5 sorghum was planted at a 5-cm depth in moist soil at 14 seeds/m. To induce a crust, water was applied by a tractor-mounted sprayer 2 DAS.

The crusted and uncrusted treatments showed no differences in moisture distribution and rates of water uptake at different depths 6-9 DAS, indicating that water applied at the surface to induce crusting evaporated before moisture sampling.

Data on emergence, and plumule and radicle length for the crusted and uncrusted main plots are shown in Figures 16 and 17. Sorghum radicle lengths for the crust and

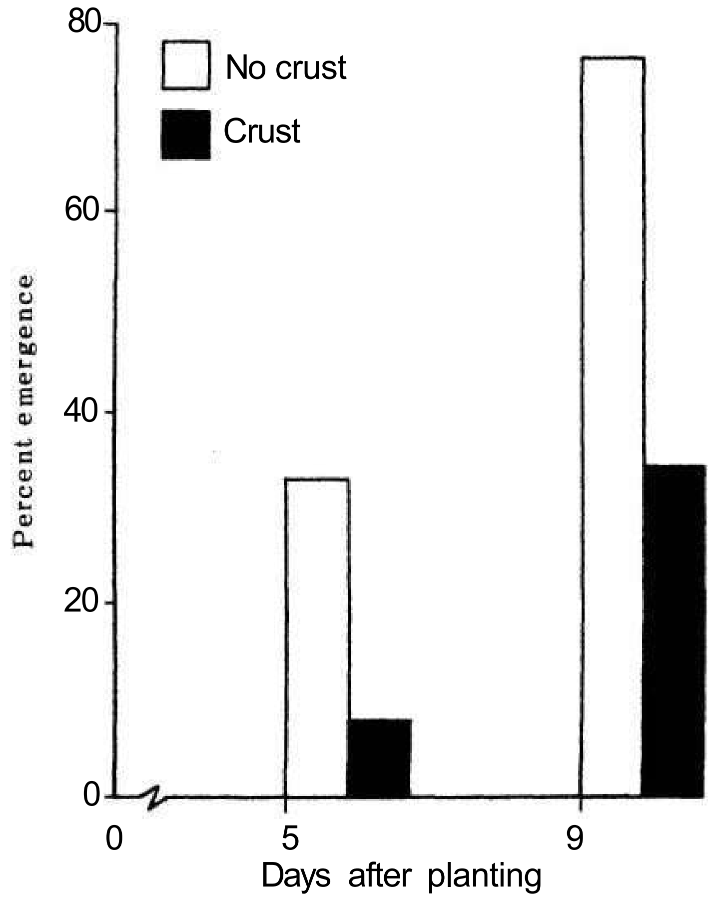


Figure 16. Percent emergence of sorghum seedlings under crust and no crust treatments following planting.

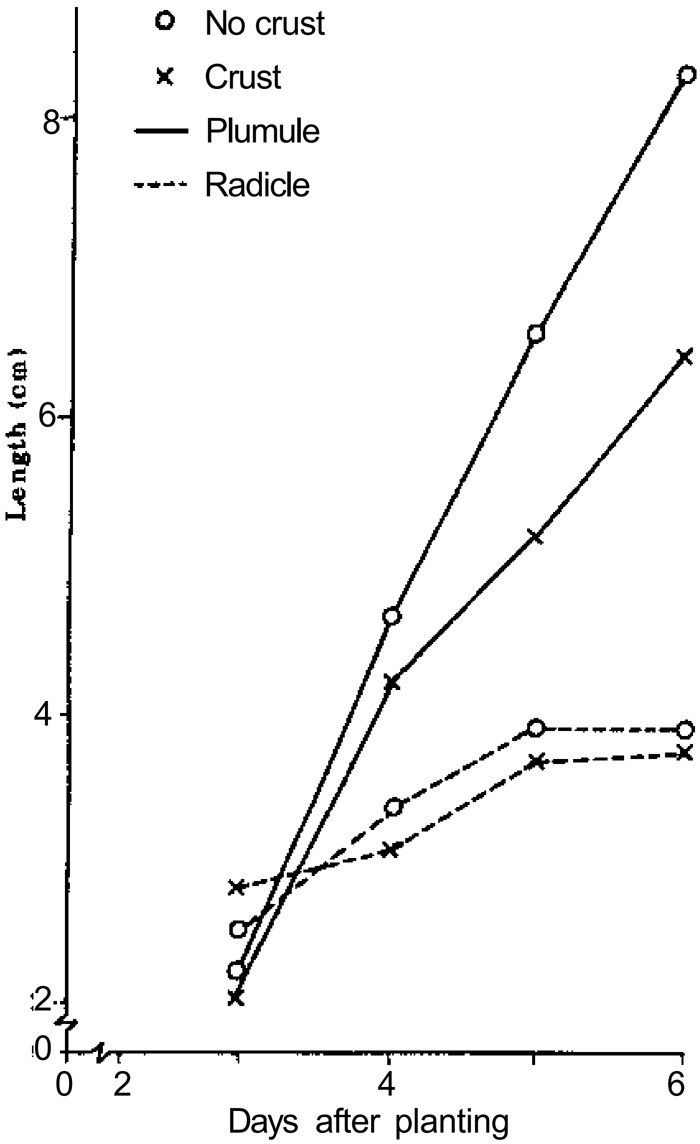


Figure 17. Changes in plumule and radicle lengths of sorghum seedlings under crust and no-crust treatments following planting.

no-crust treatments were not different. Plumule lengths were similar until the start of emergence, when the soil crust reduced the rate of plumule elongation. Crusting also reduced the percent emergence at both 5 and 9 DAS.

Pocket as well as cone types of penetrometers showed that crust strengths (kg/ cm^2) were always higher where water had been sprayed over the row after planting. The penetrometer results indicate that the lower plumule length and percent emergence were consequences of the crust since there were no differences in soil moisture in the 0-5 cm layer. These observations indicate the possibility of separating the effect of crust strength from the soil moisture effect because the small amount of water sprayed evaporates quickly without causing any soil moisture changes in the seed-zone.

Soil Fertility and Chemistry

In the SAT the present low fertility of most soils is likely to become even more pronounced because of increasing cropping intensities and introduction of new cultivars with higher yield potential and higher nutrient requirements. Therefore research in Soil Fertility and Chemistry subprograms has been directed towards the correction of nutrient deficiencies in SAT agriculture. Nitrogen and phosphorus, usually the most limiting nutrients, have been given the main emphasis in recent continuing research, which has focused on the effects of fertilizer on intercropped cereal/legume mixtures. Although we have given some results in earlier reports, it is appropriate at this stage to review the major results obtained in this work over the past few years.

Nitrogen

SORGHUM/PIGEONPEA INTERCROPS. Experiments on the effects of intercropping sorghum with pigeonpea have now been conducted over three successive rainy seasons on deep Vertisols to assess the response of the sorghum to nitrogen fertilizer, and to determine whether the population of sorghum influenced its response to nitrogen. A similar experiment was established on an Alfisol in 1979/80.

On Vertisols, intercropped sorghum responded to fertilizer nitrogen applications in a manner similar to sole sorghum in each of the three markedly different seasons, but the intercrop was always less responsive than the sole crop (Fig. 18). The magnitudes of the responses and the optimum rates of nitrogen applications differed markedly between seasons, apparently as a result of the markedly different seasonal moisture conditions. In 1979, a lower-than-average rainfall season with two severe midseason droughts, the maximum increase in yield of sole sorghum resulting from N fertilization was 1600 kg/ha at 40 kg N/ha; but in the average and high rainfall years of 1977 and 1978 maximum responses of 3200 and 3700 kg grain/ha were observed at 80 and 120 kg applied N/ha.

Sorghum population densities from 60 000 to 180 000 plants/ha had little detectable effect on sorghum grain yield on the Vertisols. But on the Alfisol in 1979, sorghum yield was depressed by both increases in the rate of nitrogen fertilizer above 40 kg

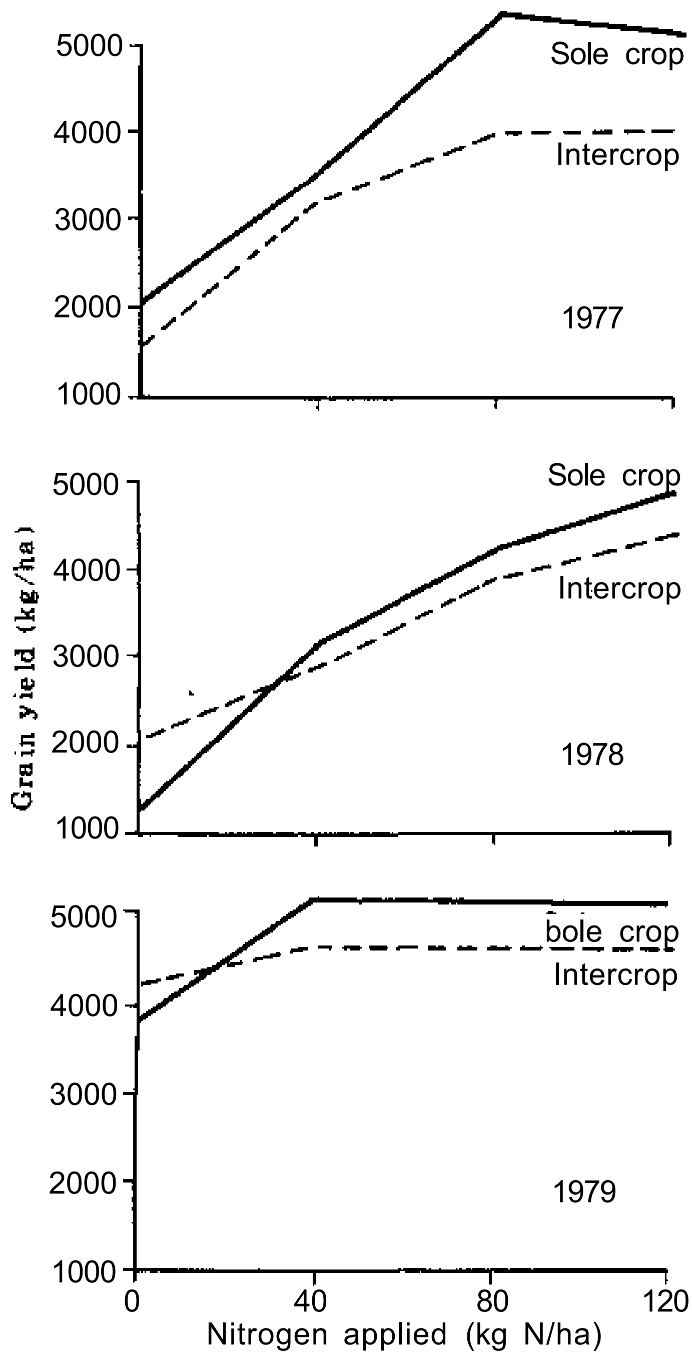


Figure 18. Response of sole and intercropped rainy-season sorghum to nitrogen on Vertisols at ICRISAT Center, 1977-79.

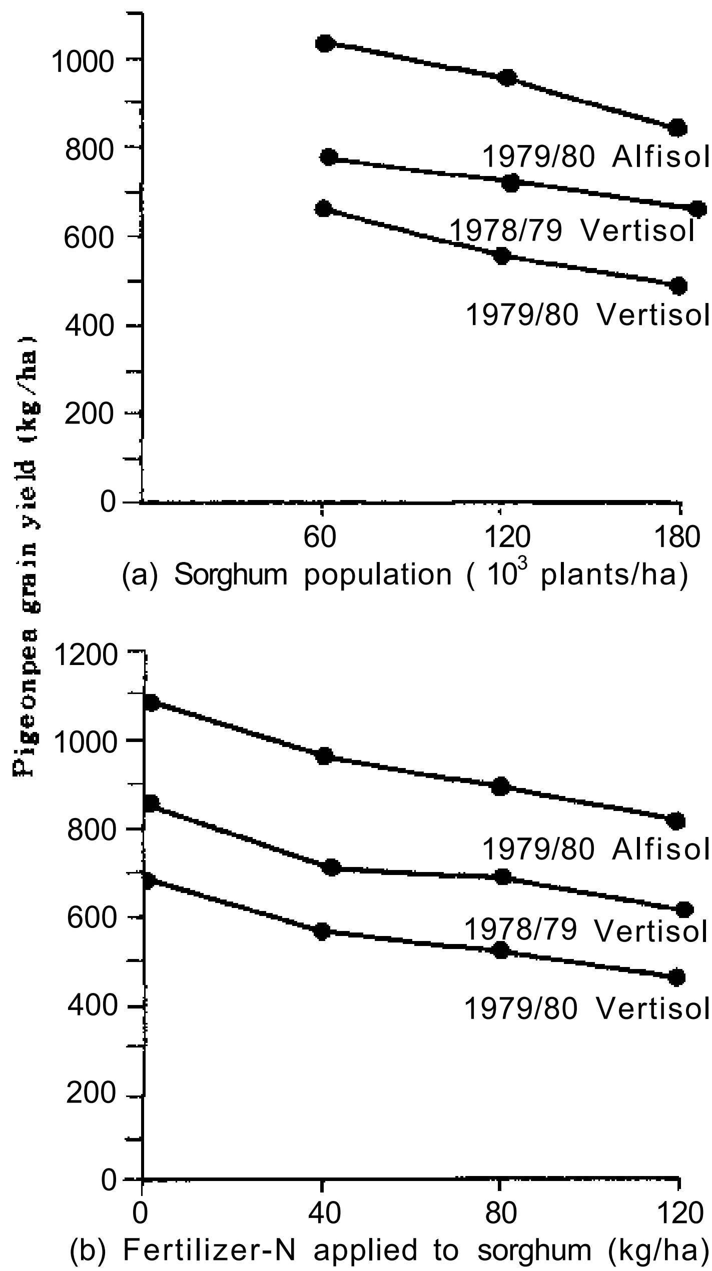


Figure 19. Effect of (a) sorghum population and (b) fertilizer nitrogen applied on the yield of pigeonpea grain in sorghum/pigeonpea intercrops at ICRISAT Center, 1978-80.

N/ha and increases in population density; also there was a significant (negative) interaction between nitrogen and population. These effects were no doubt due to promotion of vegetative growth early in the season with a consequent higher consumption of soil water, thus causing a greater moisture stress on plants during later droughty periods.

In common with the results of other intercropping studies, responses of sorghum grain yield to nitrogen on the Vertisols were generally affected only to a small extent by intercropping with pigeonpea. However, yields of the companion pigeonpea crop were usually depressed by increasing populations of the sorghum intercrop and increasing nitrogen fertilization rates to the sorghum (Fig. 19). The decreased yields may be attributed to various competition mechanisms, especially limitations on the amount of soil water left in the soil profile after the sorghum crop has matured.

The overall effect of a slightly lower response to nitrogen fertilizer of sorghum when intercropped, and depression in growth of pigeonpea when this is intercropped (and nitrogen fertilizer is applied to the sorghum), was that the biological advantage of intercropping decreases with an increase in the rate of nitrogen fertilizer applied. The overall efficiency of the intercrop, as expressed by the land equivalent ratio (LER), was quite good (1.60) when no nitrogen fertilizer was applied, but diminished rapidly with the first increment of nitrogen (40 kg/ha) and then slowly thereafter with further nitrogen increments (Fig. 20).

MILLET/GROUNDNUT INTERCROPS. Our experiments with millet/groundnut intercrops on Alfisols in the 3 years (1978-80) showed that millet responded to nitrogen applications. Millet yields per meter length of row were higher from intercropping than from sole cropping (Table 3), but the

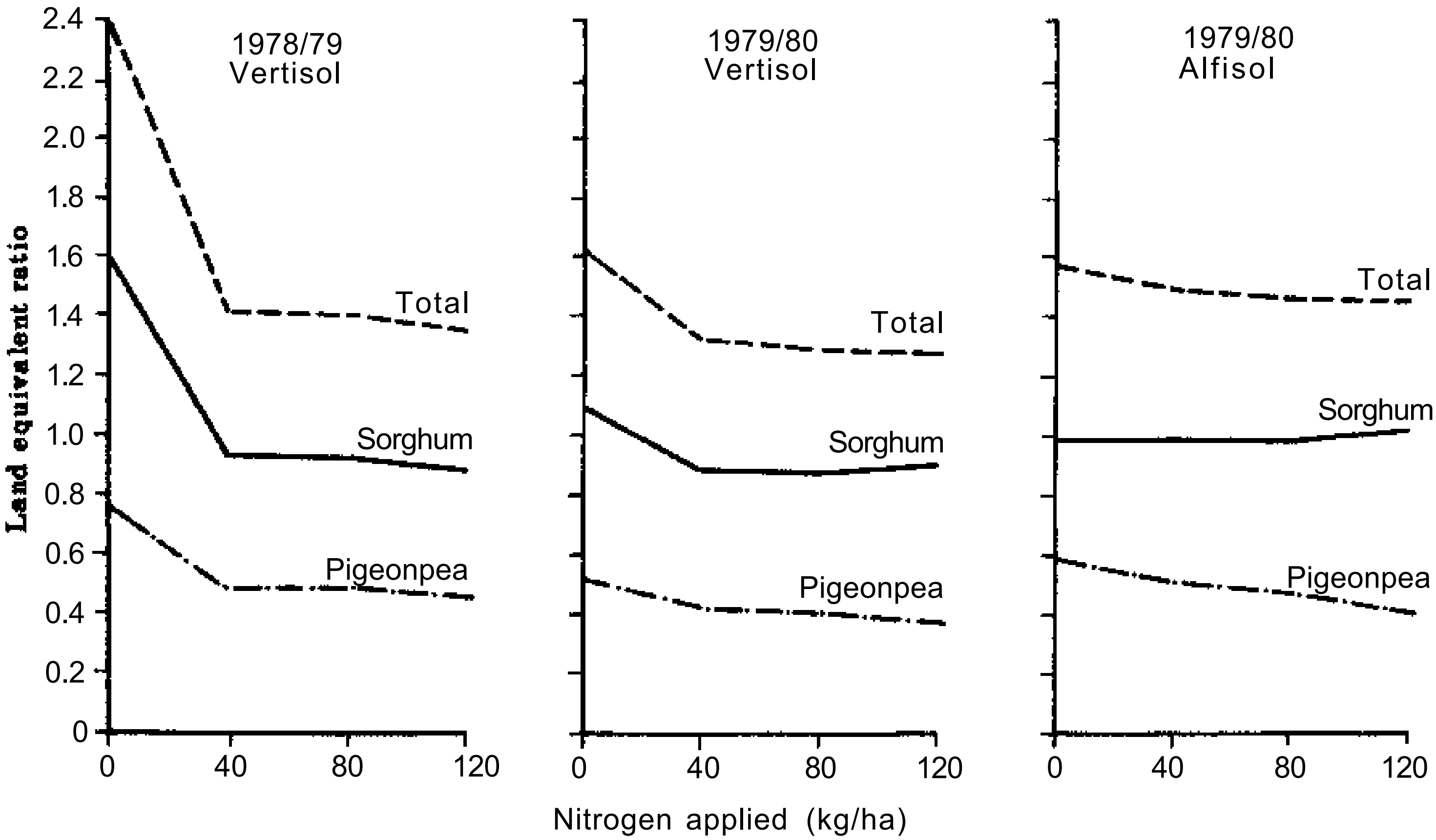


Figure 20. Effect of nitrogen fertilization on the land equivalent ratios in sorghum/pigeonpea Intercrops at ICRISAT Center, 1978-80.

groundnut yield in the intercrop was depressed by nitrogen application to the millet. The overall biological advantage of millet/groundnut intercropping was much less than with sorghum/pigeonpea intercropping; the decline in LER with increasing rates of nitrogen fertilizer was such that, on the basis of these two seasons' data, there appeared to be little advantage of intercropping millet and groundnut if nitrogen fertilizer were used (Fig. 21).

Table 3. Grain yield of millet in sole and intercrop on Alfisols as affected by nitrogen fertilization at ICRISAT Center, 1979 and 1980.

N applied[a] (g/m of row)	Millet grain yield (g/m of row)[b]		
	Sole millet	1M:2G	1M:3G
0	50.1	108.6	113.6
1.42	73.5	141.1	125.3
2.84	86. 0	141.1	139.4

a. Amounts applied equivalent to 0, 40, and 80 kg N/ha for sole millet.

b. Intercrops were 1 row of millet intercropped with either 2 rows of groundnut (1M:2G) or 3 rows of groundnut (1M:3G).

AVAILABLE NITROGEN IN SOIL. Many methods are used to assess the nitrogen-supplying status of soils, and one frequently used in India is measurement of the amount of ammonium-N distillable from the soil during digestion with alkaline potassium permanganate. Evaluations have shown that, although this method is widely used in India for upland as well as lowland (paddy rice) soils, consistently better results have been achieved for lowland soils. One possible reason is that the method might not be capable of measuring one of the most useful forms of nitrogen for plant growth—nitrate—which is found in appreciable amounts only in upland soils and not in water-saturated paddy soils. This hypothesis was shown to be correct by use of a modification that ensured that the nitrate present was reduced to ammonium (by Devarda's alloy), and so included in the measurement; Table 4 indi-

Table 4. Comparison of the standard and modified alkaline permanganate methods for assessing the available contents of soils of differing nitrate-N contents.

Soil order	Available N (ppm) Standard method	Available N (ppm) Modified method	Difference (ppm)	Nitrate-N content of soil (ppm)	Apparent recovery of nitrate-N (%)
Alfisol	63	112	49	50	98
	73	83	10	11	91
	177	202	25	26	96
Vertisol	64	77	13	15	87
	67	79	12	12	100
	77	90	13	14	93
	81	90	9	9	100
	85	124	39	41	95
	85	138	53	53	100
	114	151	37	40	93
Mean	89	115	26	27	95

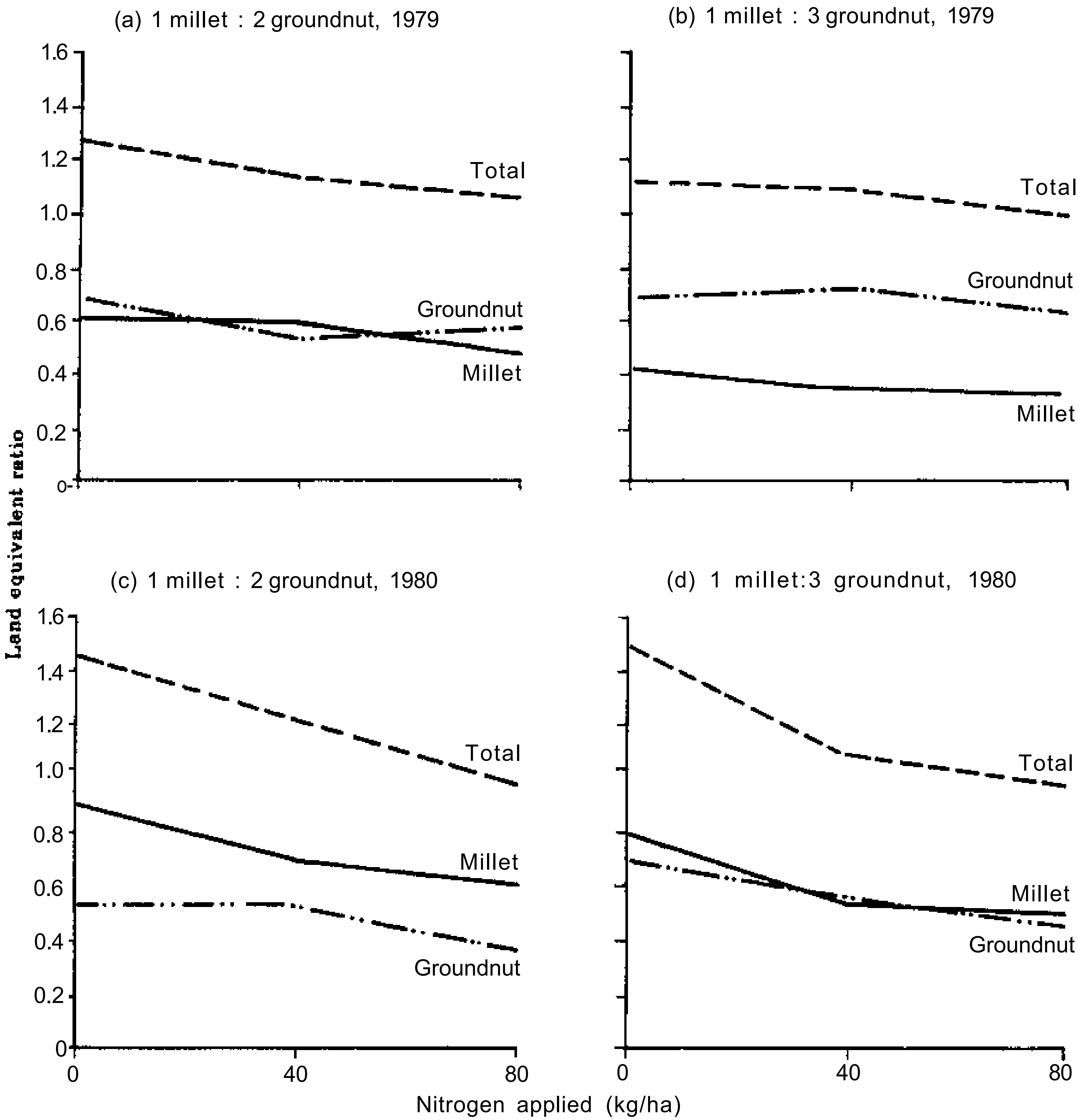


Figure 21. Effect of nitrogen fertilization on land equivalent ratios In millet/groundnut intercrops at ICRISAT Center, 1979 and 1980.

cates that nitrate-N is not measured by the standard method but it is by the modified method. Further confirmation was obtained by other tests involving the determination of the recovery of nitrate-N added to the digestion chamber both with and without soil.

Phosphorus

LONG-TERM ROTATION EXPERIMENTS. In 1976, we began a long-term experiment whose major objective was to compare the efficiencies of rock phosphate and the more costly but mainly water-soluble single superphosphate as sources of phosphorus. A key feature of the experiment has been the experimental design, which provides a rotation of crops to minimize the buildup of diseases that can occur with monoculture. To allow examination of the response of each crop in each year, two series of replicated plots were established so that, for example, in 1976 one series was planted to sorghum and the other to millet/pigeonpea intercrop. On each plot a simple 2-year rotation was established, so that sole sorghum could be grown one year and a millet/pigeonpea intercrop the next.

On this slightly acidic Alfisol(pH 6.0-6.5), superphosphate has been clearly superior to rock phosphate during the first 4-year cycle of the experiment. Only small, nonsignificant increases in yield resulted from rock phosphate applications, whereas superphosphate on average caused an increase of more than 100% in the grain production of sorghum and millet (Fig. 22). The order of response to water-soluble phosphorus was: sorghum > millet > pigeonpea. Sorghum required application rates of 10 kg water-soluble P/ha to achieve a response in excess of 90% of the maximum, but its response to only 5 kg P/ha was 68% of the maximum response. The responses of sorghum (Fig. 23) and millet were fairly consistent from year to year.

The responses of the individual crops indicate a much higher efficiency of plant response per unit of phosphorus applied than is commonly reported. The average response over the 4-year period to the first 5 kg water-soluble phosphorus was 165, 75, and 15 kg of sorghum, millet, and pigeonpea for each kg phosphorus applied.

Treating rock phosphate with various amendments did not result in any substantial change in its availability to plants. The concurrent addition of farmyard manure (FYM) increased yields, but this may be attributed to the effect of FYM alone in pro-

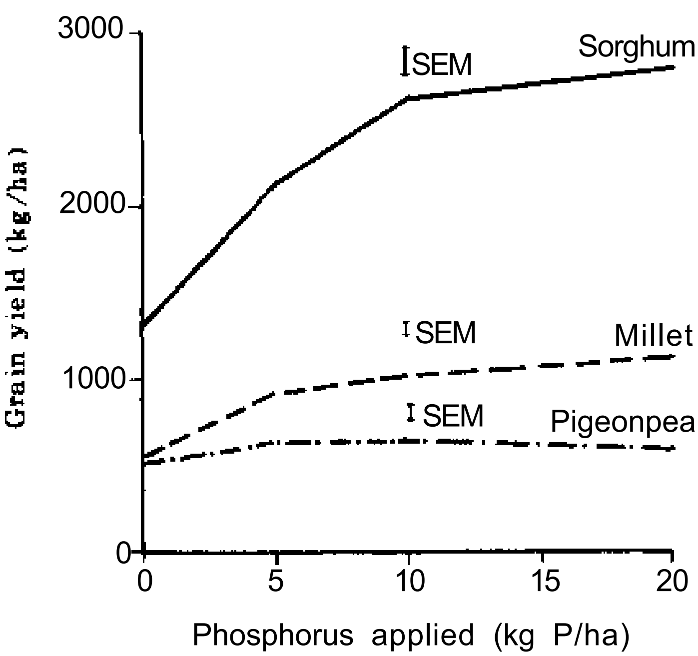


Figure 22. Effect of phosphorus applied as single superphosphate on the grain yield of sorghum, millet, and pigeonpea on Alfisols at ICRISAT Center, 7976-79.

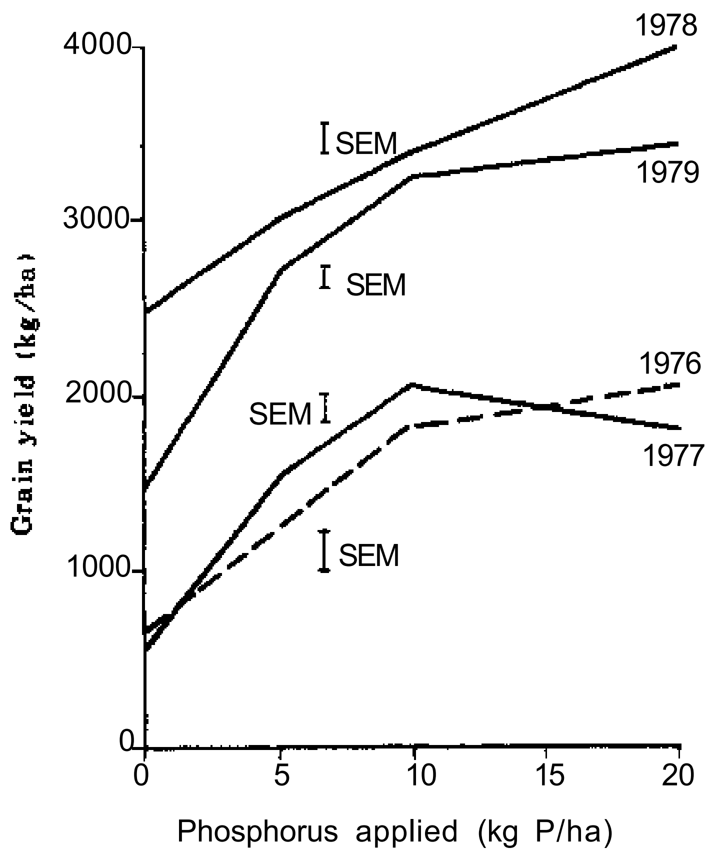


Figure 23. Seasonal variation in the response of sorghum to single superphosphate at ICRISAT Center, 1976-79.

viding both phosphorus and nitrogen by mineralization; the yield of produce and the uptake of both phosphorus and nitrogen were similar on the FYM + 80 kg rock phosphate/ ha and the FYM-only treatments. Similarly, adding sulphur or 5 kg P/ha as water-soluble phosphate with rock phosphate did not cause any substantial increase in yield over those resulting from sole applications of rock phosphate or 5 kg P/ha water-soluble phosphate.

There are very few experiments in SAT India in which the long-term effects of phosphorus fertilization on dryland crops have been examined. This experiment will therefore be continued for a further 4-year cycle to measure the buildup of phosphorus in the soil, as well as to obtain additional information on the stability of the responses to phosphorus.

RESPONSE OF PIGEONPEA TO PHOSPHORUS. Pigeonpea is usually much less responsive than sorghum to applications of phosphorus; in fact, no appreciable responses have been obtained on Vertisols or Alfisols at ICRISAT. Various hypotheses have been put forth to account for this phenomenon; these have involved suggestions that the deep tap-root system enables the plant to obtain phosphorus from deeper layers in the profile, that the surface soil is dry for much of the growth period of pigeonpea so that there is little possibility for absorption of fertilizer, and that the plant is especially efficient at absorbing phosphorus from low-fertility soils.

A preliminary experiment during the 1979/80 postrainy season indicated that responses might not have been obtained previously partly because of placement of phosphorus only in the surface soil. The pigeonpea crop absorbed fertilizer phosphorus only when this was placed at a depth of 30 cm, not at 5 cm; this behavior (Table 5) presumably reflects the deep rooting system of pigeonpea. In this same experiment, the uptake of fertilizer phosphorus by the plant was not improved by regular moistening of the zone of fertilizer application, thus we were not able to confirm the previous hypothesis that phosphorus uptake would be restricted by dry soil conditions. However, the crop in this experiment was sown particularly late; further testing is needed at normal sowing times in both the postrainy season and the rainy season.

Pot studies showed that, in addition to its deep rooting habit, pigeonpea was much more efficient than sorghum at absorbing phosphorus from a soil that was partially deficient in this nutrient (Table 6).

Table 5. Effects of method and depth of phosphorus application on yield of late-sown postrainy-season pigeonpea at ICRISAT Center, 1979.

P applied (kg/ha)	Placement		Grain yield (kg/ha)	Nutrient uptake (kg/ha)	
	Depth (cm)	Method		P	N
0	0	0	188	1.1	13.9
20	5	Band	180	1.1	12.7
20	5	Spot	176	1.1	12.5
20	30	Spot	320	2.3	20.3
LSD (0.05)			58	0.4	3.0

Table 6. Effect of addition of phosphorus on growth[a] of sorghum and pigeonpea on a phosphorus-deficient Alfisol, pot experiment at ICRISAT Center, 1980.

	No added P	P added (20 ppm)	LSD (0. 05)
Dry-matter production (g/pot)			
Sorghum	0.9	3.5	0.3
Pigeonpea	2.5	2.2	0.5
P uptake (g/pot)			
Sorghum	0.6	3.7	0.3
Pigeonpea	3.4	4.4	0.7

a. Forty days after emergence.

Long-Term Potassium Experiment

On light-textured soils, which commonly contain only limited reserves of potassium in slowly available forms, this nutrient may become limiting where herbage is continually removed because most of a crop's potassium is located in its vegetative parts. Knowledge is lacking on the soil's ability to supply potassium under the exploitive system in much of India in which both straw and grain are removed from the fields. In 1978 we therefore began a long-term experiment to examine the effect of continuous cropping on depletion of both readily and slowly available potassium in an Alfisol.

Experimental treatments consist of rotation of sorghum/pigeonpea one year and millet/groundnut the next, with various application rates of potassium with other fertilizer inputs so that vegetative growth and thus removal of potassium are maximized. The effects of removal of straw versus straw incorporation, and of the addition of FYM are also being tested. Although this experiment is located on an area of Alfisol where seven successive crops had been grown before the experiment began, onset of potassium deficiency has not yet been detected.

Land and Water Management

Major areas of land and water management research are:

- Cooperative studies with national programs on the effects of present techniques on the moisture environments for crop growth and the long-term productivity of the resource base.
- A search for more effective, alternative means for in situ soil and water conservation and better use of the total available water resources.
- Operational-scale research at research centers and on farms aimed at improved resource utilization and technology integration.

Within the next 10 years this subprogram, as part of the FSRP, expects to be primarily involved in helping to achieve two major targets:

- Adoption of watershed-based improved farming systems by farmers in the assured rainfall areas on deep Vertisols.
- Development of runoff collection and storage methods suitable to different agroclimatic conditions and of guidelines for optimizing the utilization of available water resources.

The "watershed-based" resource development approach consists of three basic components: (1) control and management of rain where it falls—i. e., on the cultivated land; (2) controlled and safe removal of excess water; and (3) where feasible, the development and use of supplemental water to back up rainfed agriculture.

Management on Vertisols

The performance of two land treatments, flat-on-grade and broadbed-and-furrow

(BBF), was evaluated in field-size plots for the fourth consecutive year. A detailed observation of time requirement for primary tillage, planting, and intercultivation operations shewed (Fig. 24) that semi-permanent BBF treatment results in considerable saving of time and cost of cultivation over flat-on-grade. Differences in time requirements may be due to several reasons:

- In the BBF treatment only the bed zone is actually tilled during the land preparation phase.
- Operations are speeded up because furrows guide animals and the wheeled tool carrier.
- There is less compaction in the bed zone.
- In the flat-on-grade treatment 2-3 harrowing operations were executed using the traditional blade harrow.

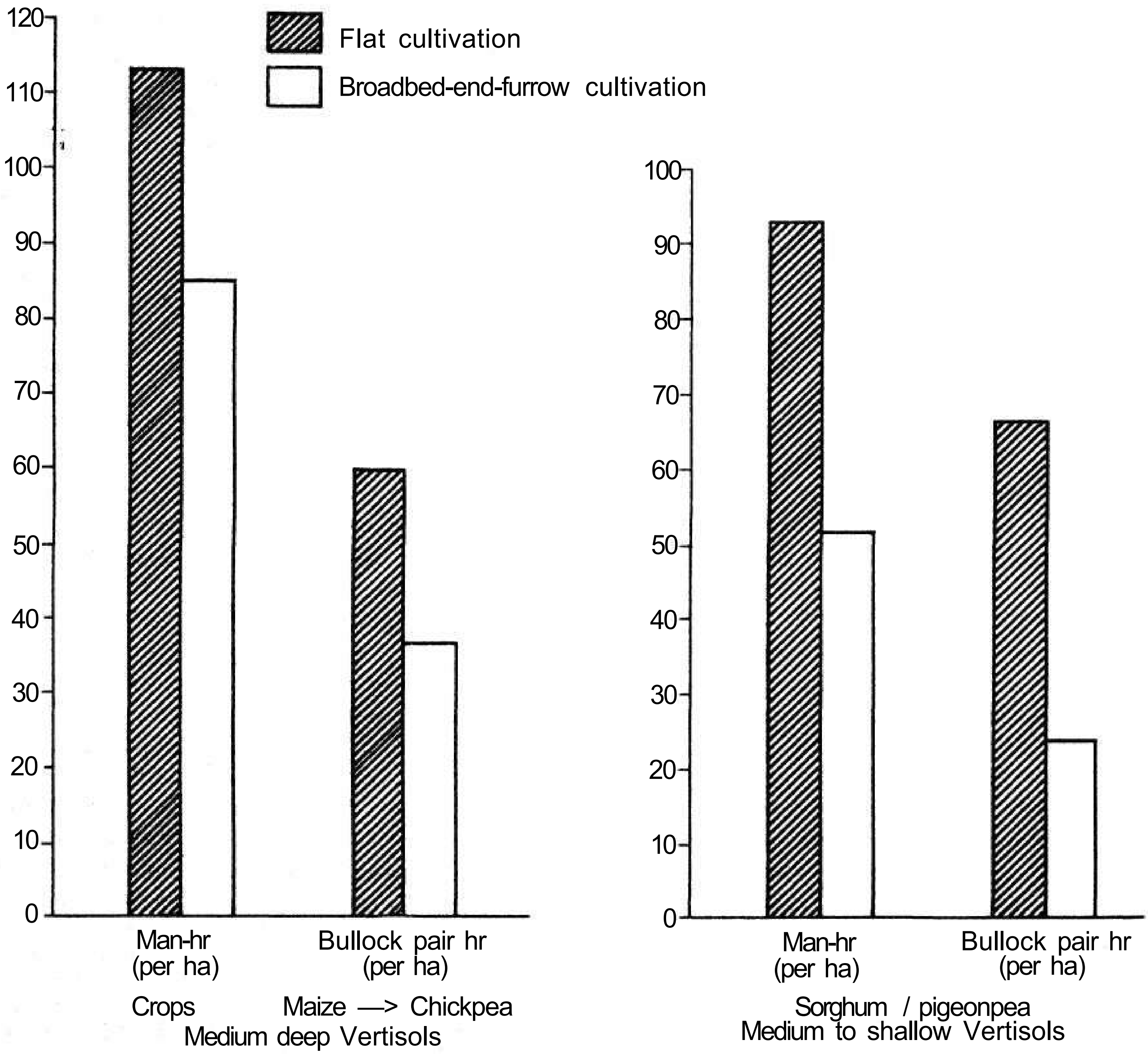


Figure 24. Time required for primary tillage, planting, and intercultivation operations in alternative land treatments.

The rainy season this year was marked by three severe dry spells. Almost all the runoff-producing storms were received after the crop canopy was fully developed. Runoff and soil loss values were similar and relatively low in both treatments.

On broadbeds it was possible to plant chickpea in the moist zone in a receding moisture situation; this was difficult to do in flat cultivated plots because of high penetration resistance. However, due to about 80-mm rain in the first week of November, plant stands were similar in both treatments.

The furrows of the BBF system were effectively used to apply supplemental water to the chickpea crop on half of a replicate on 12 December when soil was beginning to crack. Irrigation of the flat plot (divided in 6-m-wide borders) required 760 m^3/ha water compared to only 626 m^3/ha required for broadbed plots— a saving of about 20% water. In addition there was no expenditure for constructing border levees on the BBF treatment. The crop yields under the two land treatments were similar this year.

Management Systems on Alfisols

The major problem encountered on Alfisols with the standard BBF cultivation is increased runoff. Flat-cultivated fields have greater depression storage than the BBF system, whose smooth furrows drain the field fast with little chance for additional infiltration.

One option to obtain increased infiltration on Alfisols could be to create a higher level of surface detention and/or depression storage by engineering or tillage practices. Data collected under artificial-rain conditions from 3-m^2 plots show that additional depression reduced runoff during storms not exceeding about 20 mm. During the past 7 years, an average of about 50% of the rainfall for June and July and about 35% of the August and September precipitation was received in such storms.

In field-scale observations during the 1979 rainy season, we compared three surface configurations: the standard bed-and-furrow, (B); the "wave-type" bed-and-furrow, (C); and (D) a surface configuration similar to C, with additional small furrows at the shoulder of the bed to increase depression storage capacity (Fig. 25). Configuration D did not reduce runoff as expected, as the depth was limited in order to avoid mechanical damage to the crop.

In one location, runoff was measured for eight storms (Table 7). Runoff from the standard beds (B) was generally greater than from the wave types (C and D). To explain the differences a multiple linear regression equation was developed (Fig. 26), which shows that the intensity of a rainstorm affects runoff more than the quantity of precipitation. (However, higher depression storage and surface detention, partly based on rough and stable surface aggregation, could act as a buffer and would cause rainfall quantity to be a more important factor in runoff.) It is also shown that the runoff from the standard BBF is less than from the wave type during rainstorms with a low Z-value, but more during those with a high Z-value. This may be explained by the greater depression storage of the standard broadbeds, which has a relative large influence during small storms, while during high rainfall events (quantity and intensity) with more substantial runoff, the shape of the furrow begins to have more influence, reducing flow velocity and inducing additional infiltration in the wave type.

SOIL LOSS. Five runoff-producing storms occurred within a period of 1 week at the end of the rainy season. In this set of data, rainfall and rainfall intensity presumably are the two independent variables influencing soil loss. Linear regression taking the mean soil loss of all plots as the dependent variable gives the equation indicated in Figure 27.

The S-shape of the broken line connecting the actual observations suggests a threshold value for increased soil loss at higher runoff events. Values for soil-loss

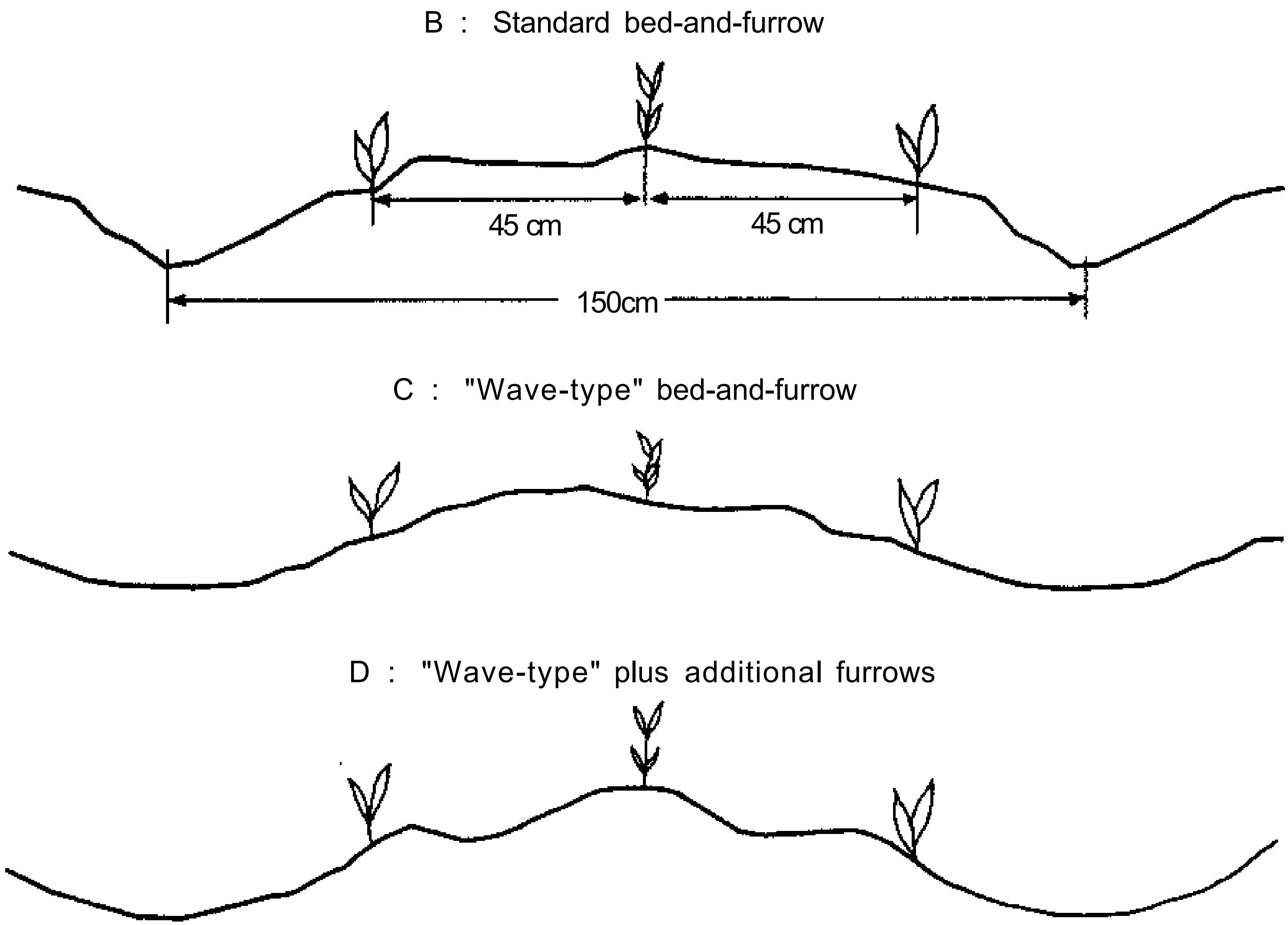


Figure 25. Cross sections of three different shapes of beds, measured 6 weeks after sowing of a sorghum/pigeonpea intercrop at ICRISAT Center.

Table 7. Runoff (mm) from two surface configurations on Alfisols at ICRISAT Center in 1979.

Storm number :	2	5	8	9	13	14	17	18
Date :	28/7	28/8	11/9	14/9	25/9	26/9	1/10	5/11
Rainfall (mm)	36	24	22	32	10	17	17	30
WMI (mm/hr)	32	36	24	25	18	8	20	41
Runoff B (mm)	9	4.2	7	8.8	1.8	2.2	2	7.5
C/D (mm)	7.7	3.9	6.8	8.5	2.0	2.6	2	6.1
Ratio B vs C/D	1.18	1. 08	1.03	1.04	0.9	0.85	1	1.23

WMI = Weighted mean rainfall intensity.
B = Narrow furrows (mean of n =5).
C/D = Wide furrows (mean of n = 8).

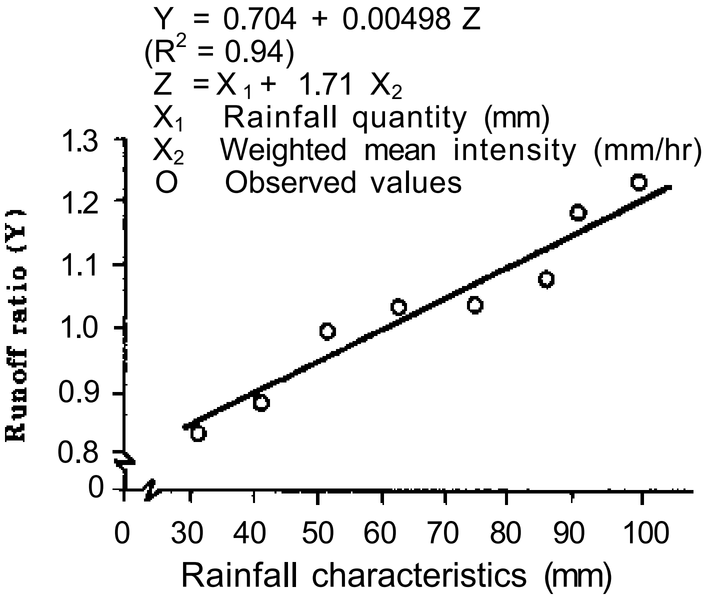


Figure 26. Multiple linear regression of runoff ratio between treatments B and C/D (Y) versus rainfall characteristics (X_1 and X_2).

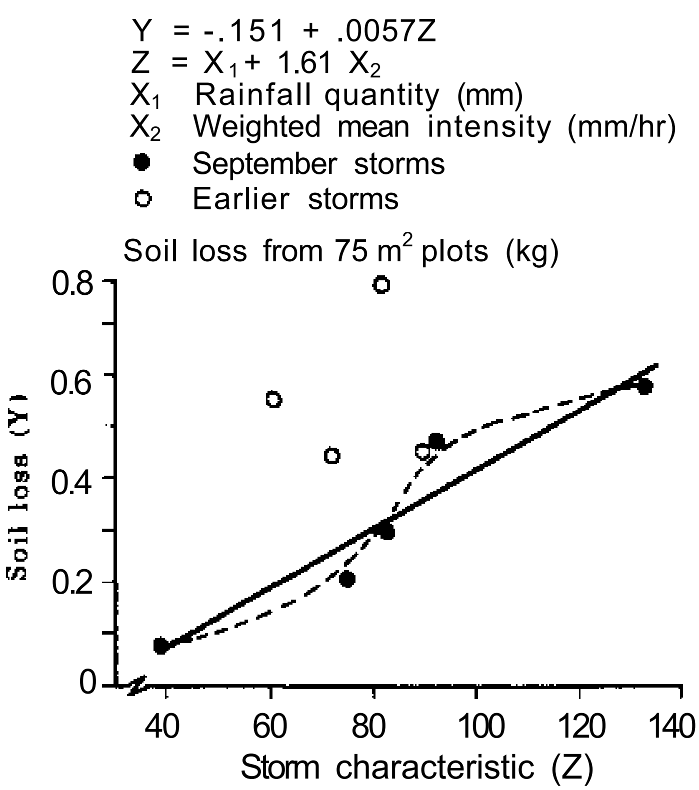


Figure 27. Mean soil loss (n -20) versus storm characteristics for five consecutive storms, compared to earlier storms at ICRISAT Center in the 1979 rainy season.

of all earlier storms were higher, irrespective of the rainfall amount or intensity,

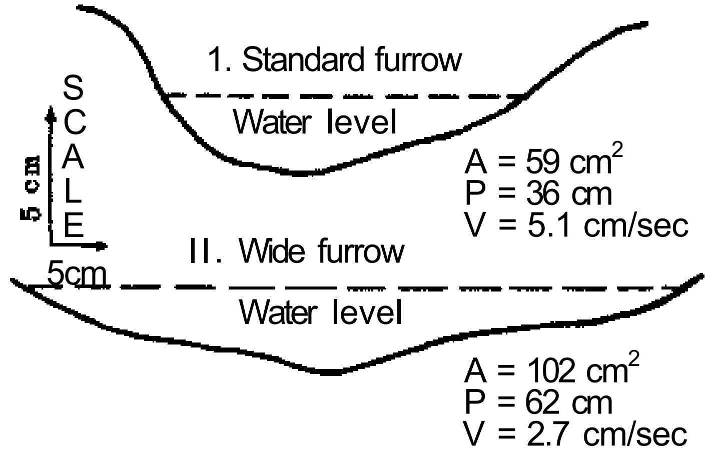


Figure 28. Characteristics of two types of furrow during flow of 17 l/sec.

since crop cover development was low at those stages.

HYDRAULIC PROPERTIES OF VARIOUS FURROW SHAPES. To measure the differences in hydraulic properties of narrow and wide furrows, known and constant discharges were released at the top of 50-m-long furrows and the outflow at the lower end and the wetted cross section at intervals were monitored. An illustration of the difference in the flow pattern is given in Figure 28.

Flow velocities for the wide furrow were distinctly lower than the values for the narrow furrows, especially with higher discharges. Flow velocities did not exceed 0.1 m/sec at the highest discharge of 53 liters/min (equivalent to runoff of 42 mm/hr). However, with the present soil-loss figures ranging from 1 to 1.5 tonnes/ha per year, it would be unwise to accept much higher velocities than this.

Agricultural Hydrology

Runoff

During the 1979 rainy season we monitored runoff on 9 watersheds on Alfisols and 11 on Vertisols. Two big storms on 27 and 28 September significantly affected the annual runoff on most watersheds. These were the only storms that produced runoff on four watersheds (the contour-bunded Alfisol watershed, the deep Vertisol watershed under broadbed system with field bunds, the shallow Vertisol watershed, and the Alfisol watershed with natural vegetation). On Alfisols the watersheds under the broadbed system at 0.8% slope produced an average runoff of 93 mm, or 14% of the seasonal rainfall; while only 55 mm of runoff was recorded from flat cultivation. A low seasonal runoff of only 25 mm was observed from the contour-bunded Alfisol watershed.

On deep Vertisols the rainy-season fallow flat-cultivated system yielded the largest runoff, 202 mm. On similar soils the cropped watersheds under the broadbed system had an average runoff of 55 mm. On shallow Vertisol watersheds extremely low runoff was recorded.

Duncan's multiple range test was used to determine the effects of different land and water management treatments on runoff, soil loss, and peak runoff rate. This test was done on the daily data collected over the past 5 years from the various deep Vertisol watersheds (Table 8).

RUNOFF SAMPLER. The automatic sampler developed by us in 1977/78 was initially

Table 8. Effects of different land and water management systems on runoff, peak runoff rate, and soil loss in deep Vertisols at ICRISAT Center (1975-80).

	Broadbed system at 0.6% slope with field bunds	Broadbed system at 0.4% slope	Broadbed system at 0.6% slope	Flat-on-grade 0.6% slope	Rainy-season fallow, flat cultivation
Runoff amount for small storms Mean (mm)	0.6d	0.94cd	2.0c	4.62b	11.21a
Runoff amount for medium storms Mean (mm)	16.9c	17.6c	22.7c	31.9b	59.7a
Runoff amount for big storms Mean (mm)	138cd	130.3d	172bc	193b	228.2a
Peak runoff rate for medium and big storms Mean (liters/sec per ha)	21c	24c	34.2b	40.8b	85.4a
Soil loss for medium and big storms Mean (kg/ha)	177b	187b	312b	432b	1245a

Values with the same letter not significantly different ($P \leq 0.05$), Duncan's multiple range test.

* Small storms, runoff amount up to 10mm; medium storms, above 10mm and up to 30mm; big storms, above 30mm.

tested for 2 years in field situations; its general working performance has been quite good. Intensive laboratory testing has shown the general efficiency of this sampler to be in the range of 85 to 95%. The catching efficiencies were as high as 96% for clay particles and as low as 50% for coarse particles. In the sand, silt, and clay portions of the eroded soil particles, the average efficiency of the sampler was found to be nearly 90% for the Vertisols and *86%* for Alfisols.

Hydrologic Modeling and Simulation

RUNMOD TESTING. The parametric simulation model RUNMOD, developed to predict runoff from small agricultural watersheds, was tested using data for 1974,1975, and 1976. After several minor modifications to enable it to deliver the required output, RUNMOD was further verified using recent data from the rainy-season cropped Vertisol watershed under improved management and from the traditional-technology rainy-season-fallow watershed (Table 9). This served three purposes:

- It pinpointed changes to be made in the program to improve output precision.
- Greater confidence was gained in the effectiveness and accuracy of the model.
- It was confirmed that the model will apply for fallow conditions as well as it does for cropped conditions, provided the necessary changes in input data are made.

PROCESS-BASED HYDROLOGIC MODEL. We are developing a mathematical model to obtain separate descriptions of various natural physical processes occurring on watersheds during the rainfall-runoff process. This model will not only be useful for predicting hydrologic events but can also serve as a means to obtain an improved understanding of factors governing hydrologic processes. The present model has three main subroutines: infiltration, soil moisture accounting, and overland flow; and four functions: interception, soil surface condition, surface treatment, and interflow. The work on overland flow and soil moisture accounting and on interflow and surface treatment is almost completed.

Water Lifting and Application Methods

USE OF SOLAR ENERGY TO LIFT WATER. A sun pump was evaluated for its usefulness

Table 9. Summary of RUNMOD performance using data from rainy-season Vertisols at ICRISAT Center from 1974 to 1978.

Treatment	Year	Measured runoff (mm)	Computed runoff (mm)	R^2	Mass balance
Cropped— improved management	1974	114	112	0.970	0.016
	1975	156	155	0.998	0.008
	1976	71	70	0.947	0.020
	1977	0	0		
	1978	270	305	0.985	0.129
Fallow— traditional management	1974	210	204	0.974	0.030
	1975	249	280	0.984	0.124
	1976	209	189	0.956	0.089
	1977	52	50	0.880	0.029
	1978	409	413	0.989	0.010

in pumping water in ICRISAT farm conditions. The motor and pump assembly along with the solar-cell array was tested at a well at ICRISAT from January till June. Since then the testing has been intermittent due to cloudy weather and rains.

Notwithstanding frequent repairs, snags in the pump suction continued. Since the discharge rates of the present pump were generally low and since several difficulties were encountered in its operation, use of an alternative pump was explored. Accordingly, we have obtained a German model that can be tested with the present solar-cell array.

HYDRAULIC PROPERTIES OF TWO IRRIGATION METHODS. In another study, the advance and infiltration characteristics of irrigation on 150-cm broadbeds and 75-cm narrow-ridges were determined for an Alfisol location. We also studied the application efficiency, distribution uniformity, and wetting pattern in the two systems. The distribution uniformity was nearly the same for four different inflow rates in the narrow-ridge system, while it decreased with increase of inflow rate in the broadbed system. The wetting pattern was more uniform in the narrow-ridge system than in the broadbed system. However, the broadbed system was satisfactory if only two rows of crops (each row located near either side furrow) were grown.

Farm Power and Equipment

Our subprogram continues to work towards development of a complete machinery system appropriate to the SAT farmer. Such a system would allow the farmer to capitalize on his resources when using the new farming practices being developed by ICRISAT and would at the same time reduce much of his drudgery.

Animal Power

All machines require some source of power, and the Farming Systems Research Program aims to increase the efficiency of the animal power prevalent in many parts of the SAT.

Bullocks are the main source of animal power in countries such as India, Pakistan, and Bangladesh, as well as being important in many other SAT countries. A thorough knowledge is required of how fast and steadily they move under different conditions of draft, climate, and length of operating time in order to design any bullock-operated equipment, because this determines limitations on the size of machinery.

To investigate how bullocks perform in terms of speed, horsepower developed, and work output as a function of body size, draft, duration of work, and climate, we selected four pairs of Hallikar bullocks of different sizes. The average individual body weights were: pair 1, 370; pair 2, 390; pair 3, 435; and pair 4, 550 kg.

The bullocks were tested by pulling fixed loads on a sled behind a wheeled tool carrier on a smooth road (Fig. 29) to ensure repeatability of the trials. This scheme was replicated three times in each of three climatic periods; March (cool: 20-30°C), May (hot: 30-35°C), and July (warm, humid: 30°C).

In preliminary tests to determine appropriate load level limitations for the main work capacity experiment, we found that the maximum loads (kg of pull) that the bullocks could pull for 6 hr in the cool season were 120 kg for the smallest pair and 150 kg for the largest pair. Since they could not pull as much during the hot season, we used lower maximum loads of 110 kg for the three smaller pairs and 140 kg for the largest pair in our final tests. The minimum load tested was 50 kg because this is generally the minimum load encountered in field operations. The resulting load scheme for the tests is shown in Table 10.

In the following paragraphs on the main

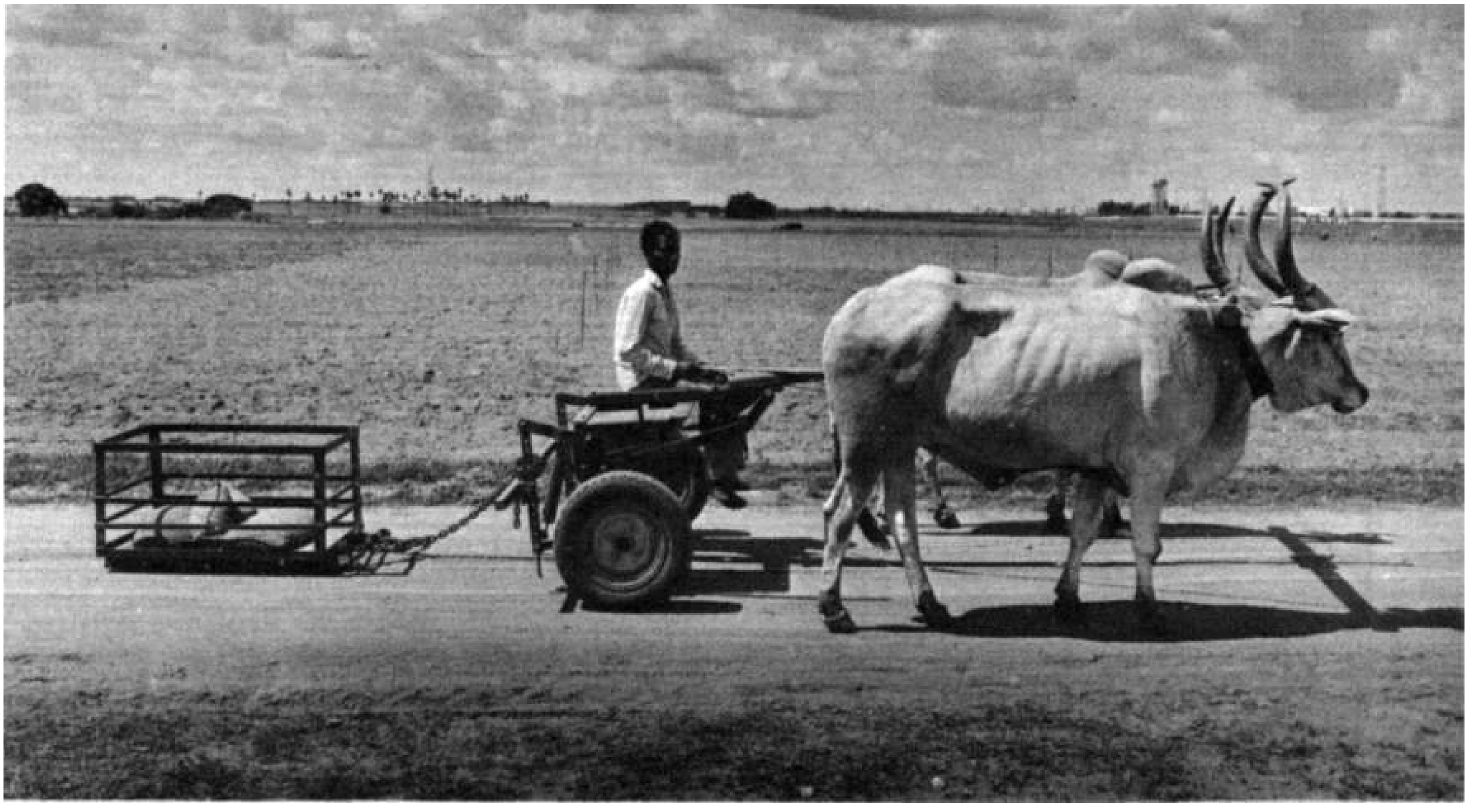


Figure 29. Measuring the pull and power output from a pair of bullocks at ICRISAT Center in 1979.

Table 10. Load levels at which bullocks were tested in 1979 work capacity experiment at ICRISAT Center.

Bullocks	Avg wt (kg)	Load 1 (kg)	Load 2 (kg)	Load 3 (kg)	Load 4 (kg)	Load 5 (kg)
Pair 1	370	50	80	95	110	
Pair 2	390	50	80	95	110	
Pair 3	435	50	80	95	110	
Pair 4	550	50	80		110	140

work capacity experiment all figures are averaged from all load levels, seasons, and animals.

The speed and power of the bullocks declined linearly over time, with the larger animals walking slightly faster. Their initial speed and power were 3.4 km/hr and 1.1 hp, which reduced to 2. 6 km/hr and 0.8 hp in 6 hr. The respiration rate increased rapidly while the pulse rate increased slowly during the initial hours of work; both showed a tendency to reach a steady state in 6 hr of work.

While the speed of the bullocks decreased with an increase in draft (horizontal component of pull), their power and work output increased (Fig. 30). When the draft increased from 49 to 107 kg, i.e., an increase of about 120%, the decrease in speed was about 12%.

The bullocks were able to work for 5. 9, 5. 7, and 5. 5 hr under drafts of 49, 78, and 107 kg, respectively. Their respiration rate was not affected by draft increases until the drafts went above 75 kg. While the bullocks developed more power at higher loads, the

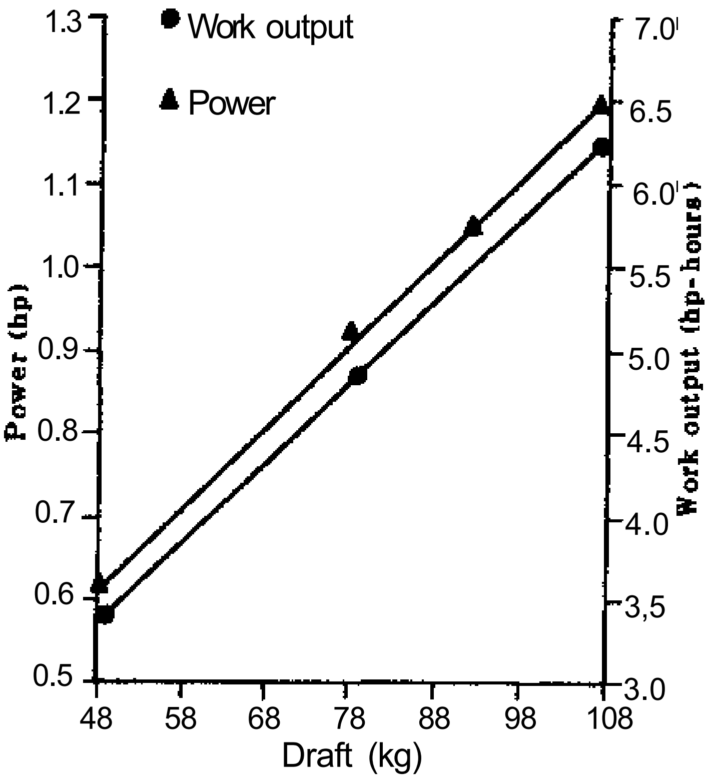


Figure 30. Average power and work output versus draft of four bullock pairs in 1979 work-capacity experiment at ICRISAT Center.

limiting factor in obtaining more power and work output from bullocks appears to be these animals' capacity to withstand the increased physiological stresses at higher levels of draft. Changes in draft, however, did not seem to affect the pulse rate of the bullocks.

Soil Management

The effects of primary and secondary tillage on the growth and yield of sorghum and on weed growth were studied on an Alfisol on a permanent bed-and-furrow system. Four primary tillage methods in decreasing order of the amount of soil tilled were tried (Fig. 31).

Four combinations of between-row mechanical cultivation and hand weeding, plus a weed-free treatment, were imposed on each of the primary tillage treatments.

Primary tillage was done after premonsoon rainfall sufficiently increased the soil moisture content. Generally the soil was less compact under center rows than under side rows; also soil strength was reduced with increased levels of previously executed primary tillage. Though the split/strip plow method required three separate passes, it controlled weeds much more efficiently than the other methods, which also required more time for seedbed preparation. A sorghum plant population of 175 000/ha was our target when planting 300 000 seeds/ha. Maximum plant stands, occurring 5 days after planting, were significantly lower with the shallow cultivation method but generally declined with all methods in the 2-week dry period that followed. The decline significantly correlated with the amount of weeds (average 110 kg dry matter/ha) present in this phase. The amount of weeds was not significantly different among primary tillage methods.

Weed management improved yields independently from primary tillage systems. Within-row hand weeding was absolutely necessary to maintain adequate stands and to obtain high yields (Fig. 32).

Yields were significantly higher with increased levels of primary tillage. The split/strip plow treatment ranked first by 340-640 kg/ha grain more than the other methods at an overall yield level of 2130 kg/ha.

Yield advantages seem to be associated with improved soil structure but perhaps also with improved infiltration and water movement characteristics due to tillage.

Harvesting

This year we initiated investigations to determine the optimum moisture content for harvesting of sorghum and millets. Samples of millet (BJ-104) and sorghum (CSH-6) were harvested, threshed, the moisture content was determined, and the yield was calculated at both the actual moisture content and a moisture content of 12%, which is the desired level for storage purposes.

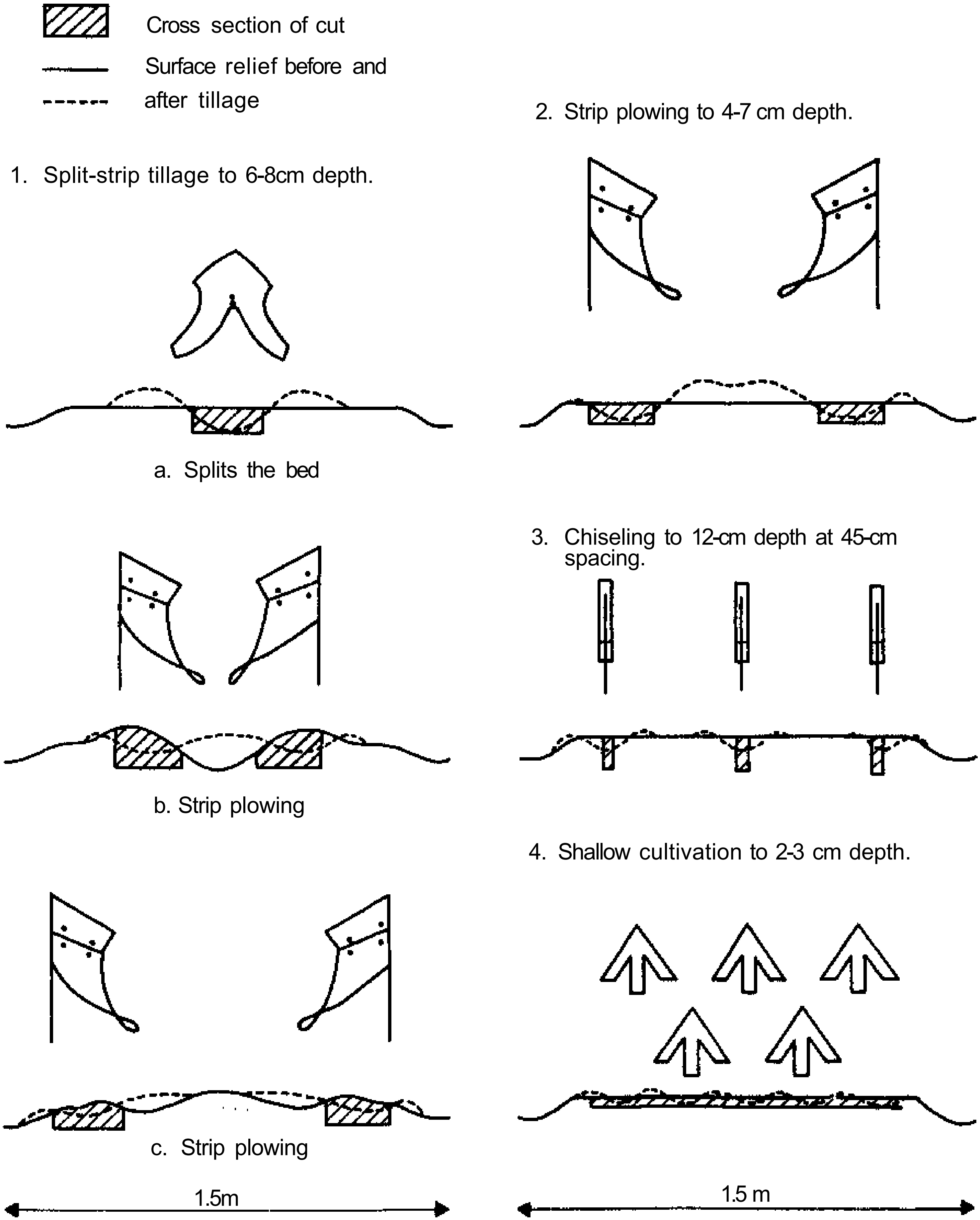
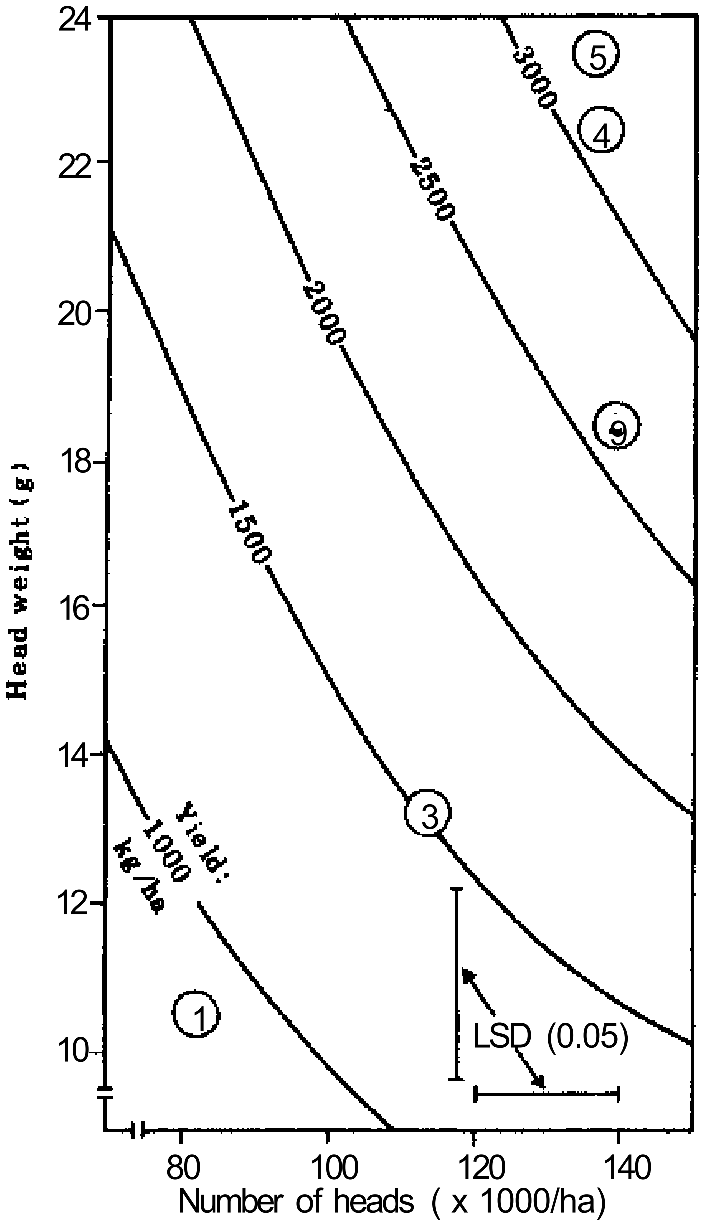


Figure 31. Four primary tillage methods compared on a 1.5-m (center-to-center) wide bed-and-furrow system.



1 No weeding
2 IC, HW
3 IC, IC
4 IC, IC+HWI, HW
5 Weed-free
IC Between-row cultivation
HW Handweeding
HWI Within-row handweeding

Figure 32. Effect of weed management treatments on crop.yield components at ICRISAT Center 1979/80.

In millet the optimum harvesting period was from the 26th to the 35th day after flowering (Fig. 33). After this, the yield decreased due to bird damage and shattering of the standing crop.

Similar results were also obtained for sorghum. Maximum yield was attained when the crop was harvested at a moisture content of 22-24%, giving an optimum duration of harvest of about 8-10 days.

Threshing

The latest model axial flow thresher with a cleaning mechanism was obtained from the International Rice Research Institute (IRRI) for evaluation in threshing pearl millet and sorghum. This machine is of particular interest because it has fewer moving parts, fewer adjustment requirements, and less vibration than other available designs and lends itself well to simple manufacturing techniques easily carried out in small manufacturing plants.

This model, like earlier models from IRRI, performed well when threshing rice but required a different cylinder and concave design for threshing sorghum and millet. Results of our various modifications are presented in Table 11. When tested with 13 sorghum varieties, the capacity of the modified thresher ranged from 630 to 890 kg/hr with an average of 715 kg/hr, which is a satisfactory performance for a thresher using a 10 hp engine.

Machinery Design and Fabrication

WHEELED TOOL CARRIERS. One of our long-time aims has been to develop a multipurpose animal-drawn wheeled tool carrier for use on small SAT farms, and most of our efforts in this direction in past years have been directed at testing and adapting a French model, the Tropicultor (ICRISAT Annual Report 1978/79, p 195), which is now being manufactured commercially in India.

In 1979 we began collaboration to develop an alternative to the Tropicultor with the National Institute of Agricultural Engineering (NIAE), U.K., who are designing and

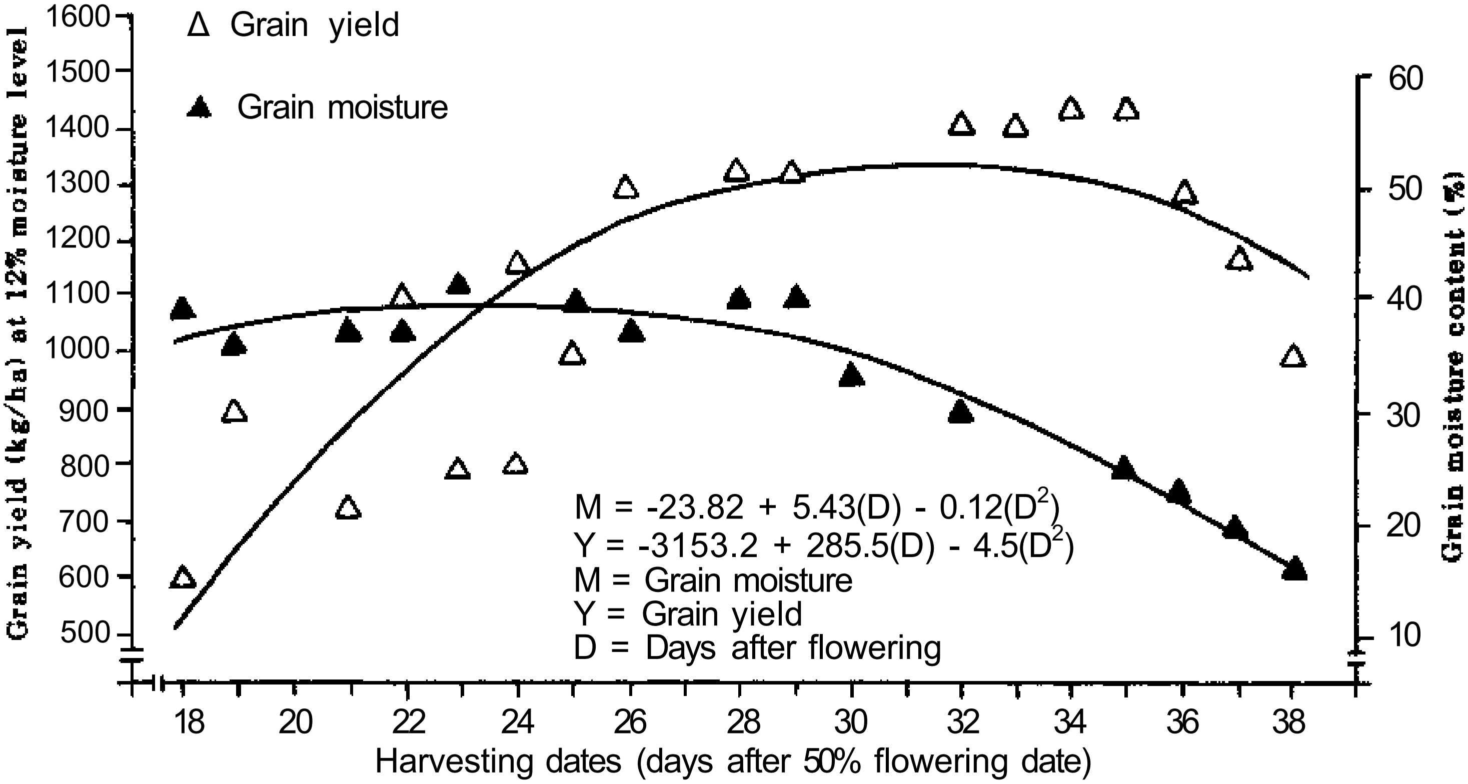


Figure 33. Harvesting studies of millet at ICRISAT Center, 1979/80.

Table 11. Test results for threshing sorghum cultivar CSH-6 with IRRI axial flow thresher using various modifications.

Cylinder[a]	Concave	Threshing (%)	Separation loss (%)	Capacity threshed grain output (kg/tar)
Pegs full length	Original[b]	36	2.5	430
4 rows of flaps (last 2/3 length) + pegs	Original	48	4.8	520
4 rows of flaps (last 2/3 length) + pegs	Original with perforated sheet	82	25.0	600
4 rows of flaps (first 2/3 length) + 4 rows flaps (first 1/3 length)	Modified[c]	88	25.0	640
4 rows of flaps (first 1/3 length) + pegs	Modified	87	25.0	625
4 rows of flaps (first 1/3 length) + pegs	Modified	80	5.0	725
8 rows of flaps (first 1/3 length)	Modified	87	5.0	780

a. Peripheral speed 780 m/min.
b. Bar concave designed for rice threshing at IRRI.
c. Different grades of perforated sheets with rubber strips.

providing the prototypes that we field-test. This year we have made significant progress on this model, which will offer another choice in wheeled tool carrier design to the SAT small farmer.

The NIAE tool carrier has been designed for use with implements for all tillage, seedbed preparation, fertilizer application, planting, and weeding operations on flat, ridge, or bed systems. It is also usable as a cart.

To minimize the cost, we have standardized the track width at 150 cm, which is suitable for many cropping systems and row spacings on flat, ridged, and bed cultivations. A toolbar of 40 x 40-mm square steel section has been adopted in order to standardize it with other tool carriers. This ensures the interchange ability of implements among different machines, since there is a common system of attaching them to the tool carriers.

The working depth of implements is adjusted by using a vertical threaded rod between the axle of each wheel and the frame. In this way the frame and attached implements can be moved up or down in relation to the wheels.

An over-center lifting mechanism locks itself both when the implements are raised and when lowered in the working position. The lifting lever moves through an arc of about 200° to give a 20-cm lift to the toolbar.

To facilitate manufacturing of the NIAE tool carrier, most of the components involve simple fabrication limited to cutting, welding, and drilling processes. The threaded rod used for depth adjustment is a standard truck jack screw. In order to minimize the cost, a secondhand car-axle assembly and used tires are fitted.

PLANTER. The FSRP has been doing most of its planting with unit planters having an inclined meteringplate that is driven through a chain and sprocket drive from the press wheel. The metering mechanism is generally satisfactory, but wheel slippage and wet soil sticking to the wheel are major problems that affect the uniformity of seed dropping. Also when three or four planters are used at a time, their weight makes it difficult to lift the toolbar. In order to reduce these problems, we have made the following modifications: The planters are being mounted on the chassis of both the Tropicultor and the NIAE tool carrier, with only the furrow openers and press wheels remaining on the toolbar. By using a common drive shaft for all the planters it has been possible to eliminate the problems arising from contact between the wheel surface and soil and to maintain metering uniformity between the planter units. Power to the drive shaft is obtained from one of the pneumatic tires through friction contact with a small rubber-lined wheel. The small drive wheel disengages from the tire when the furrow openers are raised at turns or in the transport position.

FERTILIZER DRILL. In our continued search for more effective machinery, we have undertaken a new approach to metering dry chemical fertilizers. This is based on the oscillatory principle shown in Figure 34.

The hopper is filled with dry fertilizer, which flows down to the concave, filling the chamber in the process. During operation the concave oscillates about its center. The construction is such that, while the concave is moving away from the central position in either direction, the raker strip pushes the fertilizer outward, causing fertilizer to spill over the edges of the concave. During the return stroke of the concave the cavity created by the raker strip is filled by fresh fertilizer from the hopper by gravity flow. In each cycle the fertilizer is dropped once from the front edge and once from the rear edge. The rate of fertilizer application can be varied by changing the angular displacement of the concave and/or the frequency of oscillation. Figure 35 shows a prototype of the four-row fertilizer drill developed on this principle mounted on the NIAE tool carrier.

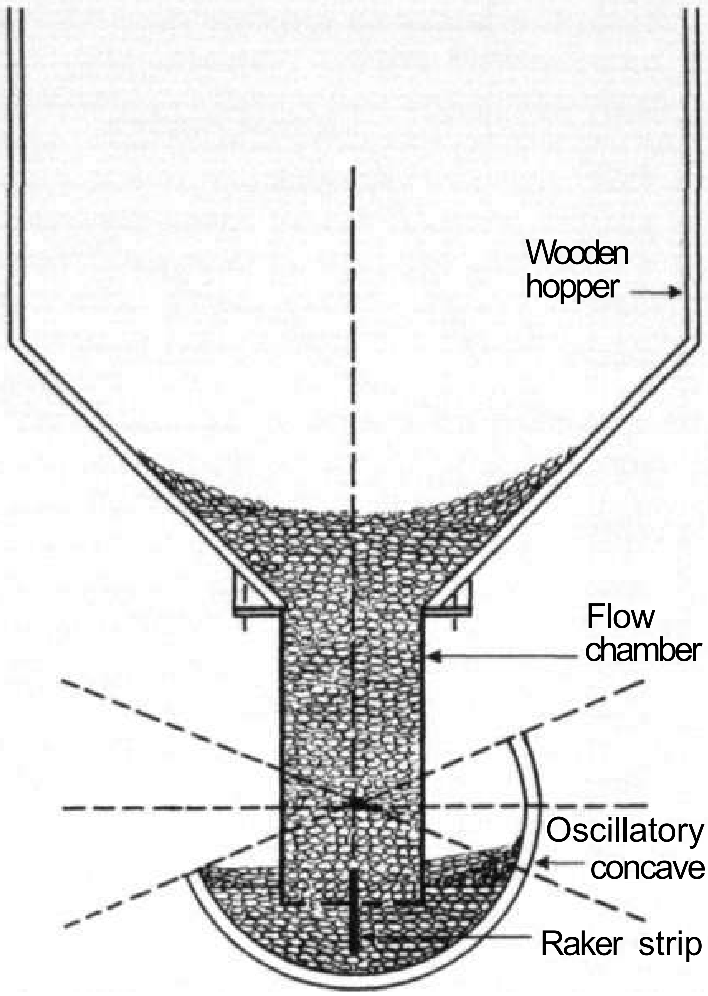


Figure 34. Metering mechanism of oscillatory fertilizer drill.

After limited testing in the laboratory, the prototype was mounted on a Tropicultor for field trials with diammonium phosphate (DAP). The test was conducted over a distance of 20 m covered five times for each adjustment of the application rate. Five positions for the cam were arbitrarily chosen to obtain five different application rates. During the test run the output for each row was collected and weighed.

Results of this test showed no large variations between the replications and also within the rows for any setting. In most cases the variability was within 10% of the mean figure, which appears to be a quite acceptable value. Two major factors appeared to be critical in obtaining this performance: First, the fertilizer must be dry

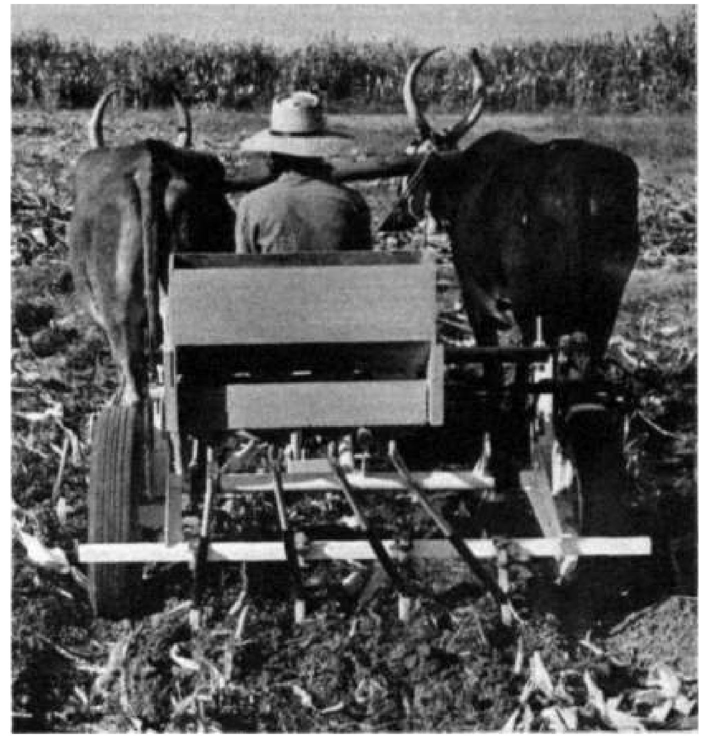


Figure 35. Four-row oscillating fertilizer drill mounted on NIAE wheeled tool carrier.

and screened to remove grains bigger than 6 mm before filling the hopper. These bigger grains or lumps tend to block the chamber, causing interruptions in the downflow of fertilizer. The second factor is the manufacturing accuracy in the position of the raker strip with respect to the concave. The gap under the raker strip should be uniform all along the length of the concave. The displacement of the concave about the raker strip in either direction should also be equal to ensure uniform droppings at both edges.

Cropping Systems

Again this year we emphasized intercropping because of its special importance to the poorer farmers of the SAT. Our research has continued to be based on crop physiological work to seek an understanding of how intercropping advantages are achieved, and we have further examined the major agronomic areas of plant population, genotypes, and yield stability. Throughout our work, more emphasis has been given to the low-fertility and/or low-moisture conditions typical of the farmer's environment.

On the Vertisols, we continued to evaluate the relative advantages of sequential, relay, and intercropping systems and developed a promising three-crop system. Last year's initial studies on extended systems for Alfisols were further developed this year.

Physiological Studies in Intercropping

Sorghum/Pigeonpea

On Vertisols, previous experiments in sorghum/pigeonpea sown at the beginning of the rainy season in a 2 sorghum:l pigeonpea row arrangement highlighted the poor light interception of the intercropped pigeonpea after sorghum harvest. This was improved in 1978/79 in a 1:1 row arrangement, but it produced no beneficial effects on pigeonpea seed yield. We examined this row arrangement again this year on both Vertisols and Alfisols. Each crop in intercropping was grown at the same population as its sole crop (180 000 plants/ha for sorghum and 50 000 plants/ha for pigeonpea), and row spacing was 45 cm. A basal phosphate dressing (48 kg P_2O_5/ha) was applied to both crops and a nitrogen top dressing (80 kg N/ha) was applied to the sorghum. On the Alfisols a light irrigation was given in order to facilitate timely thinning and fertilizer application.

On the Vertisol, sole sorghum growth was good and there was little sign of drought stress despite low rainfall during the early part of the season; final grain yield was 4121 kg/ha. Sorghum growth was not affected by intercropping with pigeonpea in the 2 sorghum:1 pigeonpea row arrangement (Fig. 36) and final grain yield (3904 kg/ha) was only 5% less than that of sole sorghum. The intercropped pigeonpea was severely depressed by this good sorghum growth and at the time of sorghum harvest its dry-matter

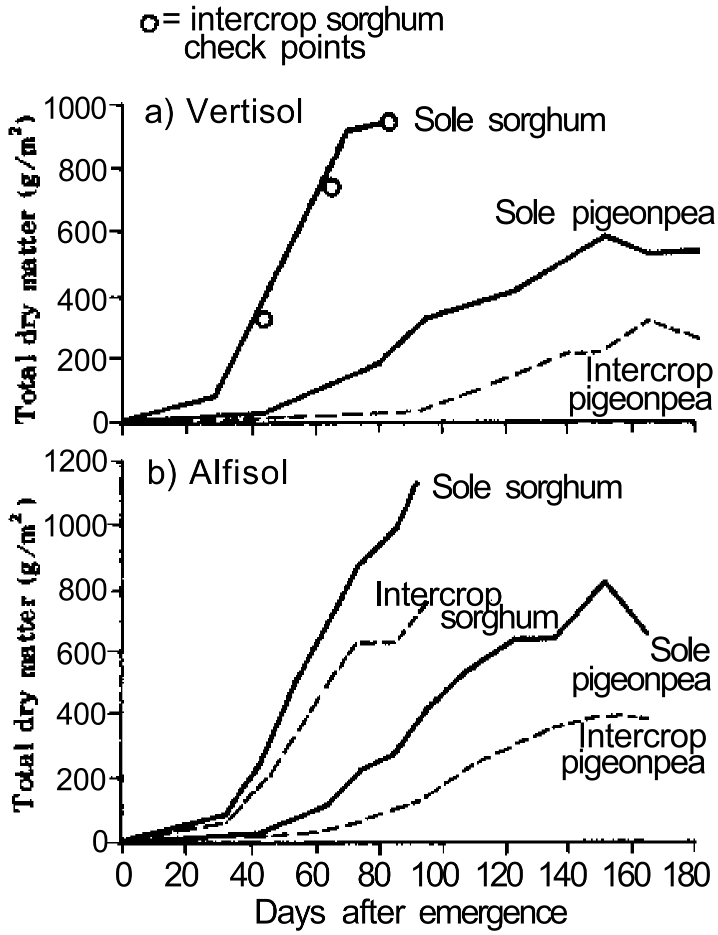


Figure 36. Total dry-matter accumulation patterns of sorghum and pigeonpea in sole and intercrop systems at ICRISAT Center, 1979/80.

yield was less than 10% of the sole pigeonpea dry-matter yield. Final seed yield (875 kg/ha) was equivalent to 54% of the sole crop yield, an appreciably lower proportion than in previous years.

On the Alfisol, sole sorghum showed symptoms of severe moisture stress during the early part of the season, but final dry-matter production (Fig. 36) was higher than on the Vertisol because of a more extended period of growth; grain yield was also higher at 5017 kg/ha. In the 2 sorghum:1 pigeonpea intercrop, sorghum growth was depressed (Fig. 36) and final grain yield (3595 kg/ha) was 28% less than the sole crop. Thus under the greater moisture stress conditions of the Alfisol the intercropped sorghum was less able to maintain its yield, either because the 2:1 row arrangement did not give a sufficiently uniform distribution of plants or, more probably, because the pigeonpea became more competitive under these conditions. The intercropped pigeonpea suffered much less competition from the sorghum than it did on the Vertisol; its dry-matter yield at sorghum harvest was equivalent to 35% of the sole crop (Fig. 36) and its final seed yield (1348 kg/ha) was 71% of the sole crop.

This comparison of growth on the Vertisol and Alfisol illustrates that environmental conditions can have marked effects on the competitive balance and final yield proportions of sorghum and pigeonpea in intercropping. On the Vertisol, where conditions favored sorghum, the yield proportions were 95% sorghum and 54% pigeonpea; on the Alfisol, where conditions favored the pigeonpea, they were 72% sorghum and 71% pigeonpea. The total land equivalent ratios (LER) of 1.49 on the Vertisol and 1.43 on the Alfisol were little different, however, illustrating how the competitive adjustments between the crops have an important stabilizing effect on overall yields.

Changing from a 2:1 to a 1:1 row arrangement had no effect on sorghum yield on the Vertisol, but the pigeonpea yield was increased from 54% to 67% of the sole crop, resulting in an increased total LER of 1.61. On the Alfisol, the intercropped sorghum yield was further reduced from 72% to only 60% of the sole crop and the pigeonpea yield showed only a moderate increase from 71% to 76%, resulting in a decreased total LER of 1.36. Summarizing these and the previous year's results, it appears that under conditions where sorghum growth is very good and the pigeonpea very suppressed, changing to a 1:1 row arrangement may produce some overall benefit by giving a greater pigeonpea contribution without reducing sorghum yield. Conversely, where sorghum growth is poor and pigeonpea growth relatively better, changing to a 1:1 row arrangement is likely to give an undesirable decrease in sorghum yield but little extra pigeonpea yield.

Pearl Millet/Groundnut

GROWTH STUDIES. A first growth study of a 1 row millet:3 rows groundnut situation in the 1978 rainy season (June-Sept) showed a yield advantage over sole crops of 26%, which was attributed largely to an improvement in light use efficiency. But the fertility level was high and it was a very wet season, so since then we have concentrated on examining how yield advantages are affected when below-ground resources are more limiting. In the 1979 rainy season a growth study examined the effect of 0 and 80 kg/ha of nitrogen (0-N and 80-N) applied to the millet in both a 1:3 and a 1:1 row arrangement. Within-row spacing for each crop was the same in sole cropping and intercropping (millet 15 cm, groundnut 10 cm) and row width was 30 cm.

At 80-N in the 1:3 row arrangement (Fig. 37a), results were very similar to those of 1978/79. Dry-matter accumulation of intercropped millet was almost twice that expected from its 25% sown proportion (i. e., yield per plant in intercropping was approximately double that in sole cropping), while that of groundnut was similar to its expected 75% (i. e., yield per plant was similar in intercropping and sole cropping). The final yield advantage for dry matter was 29% and for grain yield 21%. At 0-N, millet yields were much lower, but the intercrop millet yield at the 1:3 row arrangement was again about twice that expected; intercropped groundnut yield was slightly more than expected, however, presumably because of the reduced millet competition, so final overall advantages were rather greater at 42% for dry matter and 32% for grain yield (Fig. 37b).

At the 1:1 row arrangement at both nitrogen levels (Fig. 37c and d) Intercrop millet produced about 75% of the sole crop compared with the expected 50% (i. e., there was a 50% increase in yield per plant). Intercropped groundnut again gave greater yields at 0-N, resulting in greater yield advantages both for dry matter (47%) and grain

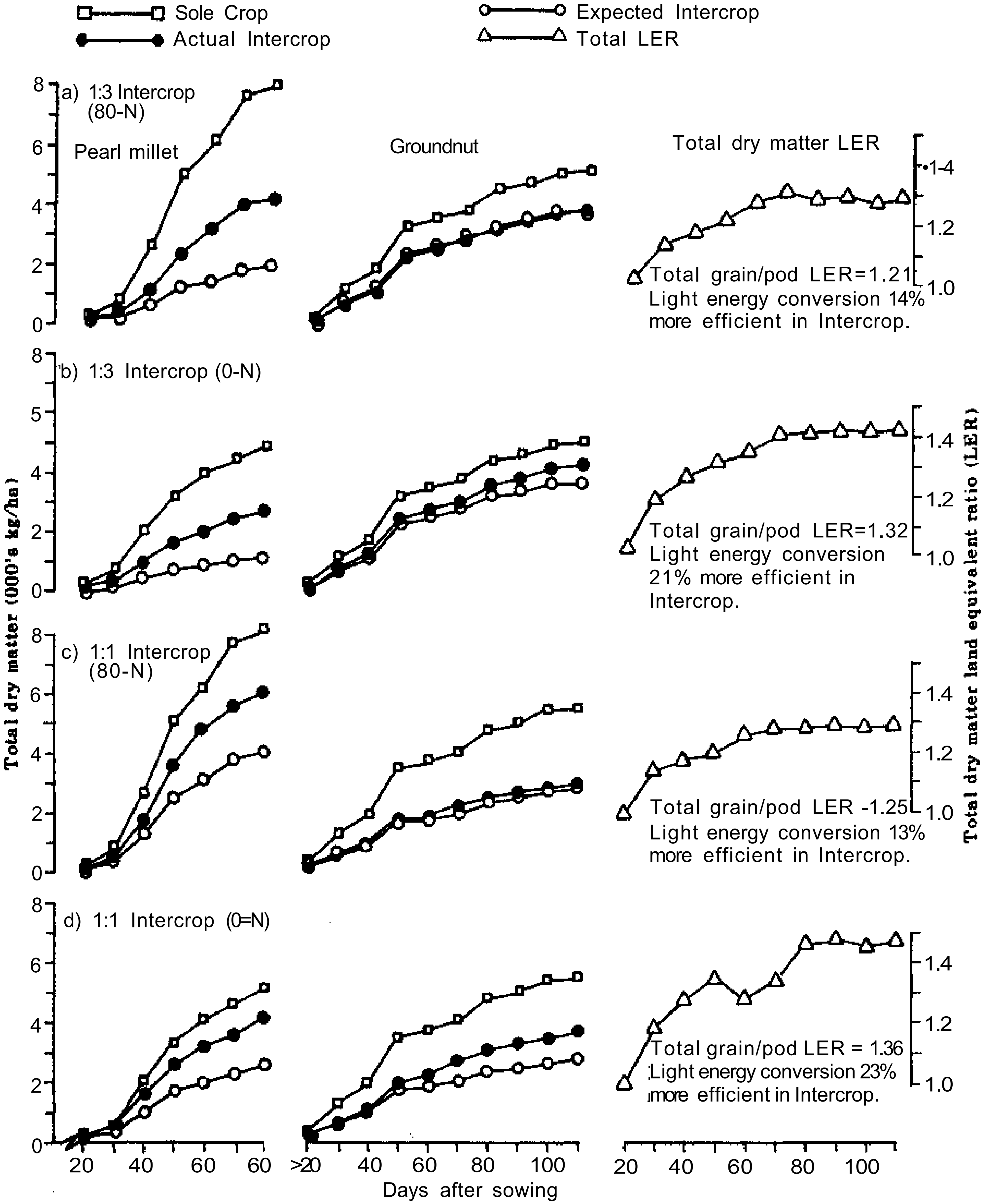


Figure 37. Total dry-matter accumulation and land equivalent ratios in pearl millet/ groundnut intercropping and in sole cropping at two nitrogen levels, ICRISAT Center, 1979/80.

yield (37%) than at 80-N (29% and 25%, respectively).

Unlike the previous year's experiment, little more than half the dry-matter yield advantages could be attributed to improved light use efficiency (Fig. 37). Moisture was more limiting this year, suggesting that the light factor may be less important in this combination when below-ground factors are more limiting.

The higher relative advantage of intercropping at 0-N for both row arrangements has an interesting parallel with last year's moisture studies in which greater relative advantages were also obtained under "stress." These findings have particular importance for the farmer trying to grow his crops in a low-fertility and/or low-moisture situation. In these nitrogen studies the gross monetary advantages of intercropping were greater at 0-N, despite the lower millet yields; at the 1:3 row arrangement, these were Rs. 1705/ha for the 0-N and Rs. 1200/ha for 80-N, whereas at the 1:1 row arrangement they were Rs. 1656/ha and Rs.1216/ha, respectively (Rs. 8 = $1 U.S.). These differences would be even greater, of course, if the costs of applied nitrogen were deducted.

Underground partitioning: The relative importance of above- and below-ground resources in the millet/groundnut combination was examined by installing underground partitions between the crops. Trenches 30-cm wide, 1-m deep and 20-m long were dug out where millet rows were to be sown and polythene partitions were positioned down the sides of the trenches before refilling. The whole experimental site was then well watered prior to sowing to ensure proper settling of the trenches. Basal phosphate (50 kg P_2O_5/ha) was applied to all plots and nitrogen was top dressed to both sole and intercropped millet at the same rate per row (equivalent to 80 kg/ha for the sole crop). The row arrangement was again 1 millet: 3 groundnut with 30 cm between rows.

The normal intercrop (i.e., not dug out) gave a competitive balance similar to previous experiments and produced a yield advantage of 22%. A dug-out check with no partitions gave similar yields and a yield advantage of 21%, indicating that digging out per se had little effect. The partitioned intercrop gave a yield advantage of 19% — not significantly different from the control or dug-out intercrop. This appears to support the earlier suggestion that, when below-ground factors are less limiting, yield advantages in this millet/groundnut intercrop are determined largely by above-ground interactions. These studies are potentially important for further yield improvement (e. g., by genotype selection) because they help to indicate the extent to which improvement is more likely to be brought about by above-ground interactions between canopies or below-ground interactions between root systems. The partitioning technique looks very promising, so we will continue these studies, but with particular emphasis on low-fertility and/or low-moisture conditions.

Plant Population Studies in Intercropping

The systematic design used last year to examine plant population effects in sorghum/pigeonpea on the Vertisols was tried on the Alfisols this year; four populations of sorghum were examined in combination with seven systematically arranged populations of pigeonpea. Like this year's growth study on Alfisols, the sorghum yield was considerably lower in intercropping than in sole cropping and the intercropped pigeonpea yield was relatively high. Maximum intercropped sorghum yield (80% of the 5035 kg/ha sole crop) was achieved at 180 000 plants/ha (equivalent to the recommended sole crop optimum) but, like last year, this was not significantly greater than yields at lower populations. The intercropped pigeonpea yield again responded to populations well above its recommended sole crop optimum of 40 000 plants/ha, a fitted response giving the optimum population at approximately 81 000 plants/ha with a maximum yield of 1031 kg/ha (70% of the sole crop).

This systematic design has been especially useful in making efficient use of land area; 73% of the experimental site was harvest area compared with the 47% that would have been possible for a conventional design occupying the same total area but examining only four pigeonpea populations. All our population data on sorghum/pigeonpea (14 experiments) have now been pooled in a single fitted response that indicates that at twice the sole crop optimum population the average intercropped pigeonpea yield is approximately 15% higher than at the sole crop optimum population. This is a relatively small response, but on average it will give additional gross monetary returns of about Rs. 300-400/ha for an extra seed cost of only Rs. 15-20/ha.

Last year's Vertisol experiment examining row arrangements in sorghum/pigeonpea on the 150-cm broadbeds was repeated and earlier findings were confirmed. The normal 2:1 row arrangement with the single pigeonpea row in the middle of the bed gave 91% sorghum yield and 49% pigeonpea yield. Sowing two rows of pigeonpea, either inside or outside the two sorghum rows, increased pigeonpea yield to an average of 62% of the sole crop, but this was partly offset by less sorghum (84%). This still gives a small monetary advantage of about Rs.300/ha, but these systems would be acceptable in practice only if the farmer was prepared to make a small sacrifice in sorghum yield to gain the extra pigeonpea.

We further examined population and spatial arrangement effects in millet/groundnut this year. The study confirmed that, due to decreased yields per row of both millet and groundnut, arrangements with double rows of millet were inferior to those with single rows, whatever the number of intervening rows of groundnut (Fig. 38); this aspect of the study is now concluded.

In contrast to last year, millet population in intercropping had little effect on millet yield, though high populations did slightly reduce groundnut yields. There is a need to examine lower millet populations in the future. At the 1:1 row arrangement, the groundnut yield per row was slightly less than in sole cropping, and it showed a slight tendency to increase as the millet rows were widened to the 1:2 or 1:3 arrangements. Millet yield per row was much greater in the 1:1 row arrangement than in sole cropping and it increased still further as the millet rows were widened to the 1:2 or 1:3 row arrangement; however, this increased yield per row was not sufficient to offset the decreasing proportion of millet, and thus overall yield advantages gradually decreased from the 1:1 to the 1:5 row arrangement (Fig. 38). This combination has again shown very consistent yield advantages across the different populations and row arrangements, though the latter factor especially has produced marked

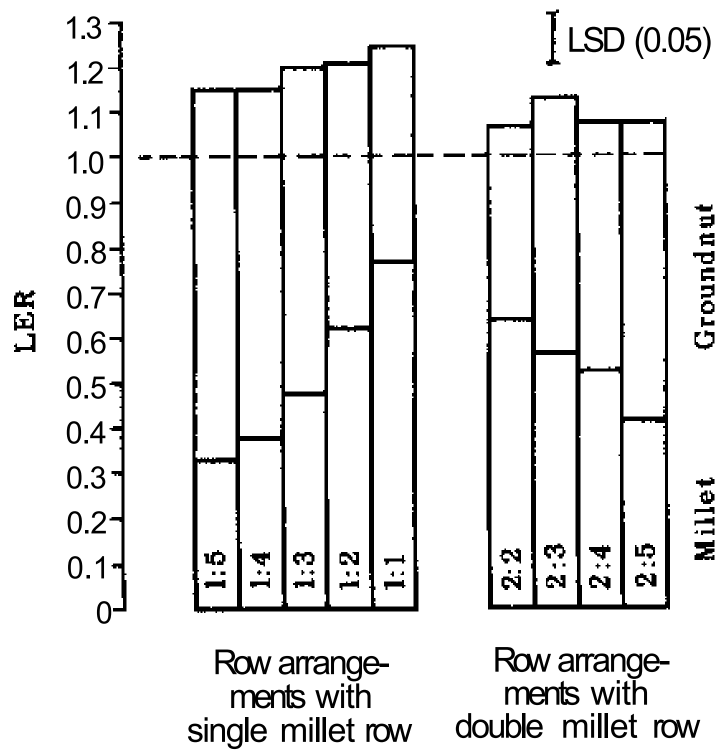


Figure 38. Effect of different row arrangements on LERs in millet/groundnut intercropping at ICRISAT Center, 1979/80.

changes in the proportions of the crops (Fig. 38).

Genotypes for Intercropping

CEREAL/PIGEONPEA. The agronomic evaluation of pigeonpea genotypes for intercropping with cereals continued in collaboration with pigeonpea breeders: 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 in 45-cm rows. Intercropped pigeonpea yields ranged from 32% to 79% of sole crop yields, which was similar in level and range to the first season in 1977 but much lower than the consistently high yields in the very favorable pigeonpea season of 1978. These data again indicate that, especially in seasons less favorable for pigeonpea growth, there may be a need to identify genotypes specifically suited to intercropping. This was particularly apparent this season because of (1) a significant genotype x cropping-system interaction, (2) a nonsignificant rank correlation between the systems, and (3) only 42% of the variation in intercrop yield being attributable to variation in sole crop yield. As examples of how the performance of individual genotypes differed between the systems, ICP-1-6 ranked fourth in sole cropping (1330 kg/ha), but only ninth in intercropping (730 kg/ha) with a fairly low LER (0.55). In contrast, ICP-6982-6 ranked just below ICP-1-6 in sole cropping (1307 kg/ha) but it ranked first in intercropping (988 kg/ha) with a high LER (0.72).

The efficiency of using sole crop selection to identify intercropping performance is illustrated in Table 12 for all 3 years of this work. At a 20% selection pressure, an average of only 50% of the best intercropping genotypes were identified; at a low selection pressure of 33%, the efficiency was still only 76%. These data emphasize that relying on sole crop selection can have only limited success. There must be at least some evaluation in the intercropping situation itself, perhaps in the later stage of selection. Such evaluation is relatively easy with this crop combination because a cereal can simply be added between normally spaced rows of pigeonpea. Evaluation of genotypes for intercropping on the Alfisols also started this season, and results will be presented in due course.

Studies to determine the best genotype combinations of sorghum/pigeonpea or mil-

Table 12. Results of selection in medium-maturity pigeonpeas at 20% and 33% levels in sole crop and sorghum intercrop at ICRISAT Center in three crop years.

Year	No. of test lines	20% Selection: No. of lines selected	20% Selection: No. of lines common	33% Selection: No. of lines selected	33% Selection: No. of lines common
1977/78	17	3	2	6	5
1978/79	19	4	3	6	5
1979/80	16	3	0	5	3
Totals	52	10	5	17	13
Efficiency of sole crop selection		50%		76%	

let/pigeonpea for intercropping on the Alfisols continued. Sole millet yields were higher this year, whereas sorghum yields were about the same as last year except that the season proved too dry for the late E-35-1, which yielded only 266 kg/ha. The late pigeonpea PS-41 yielded less than the three earlier-maturing genotypes, though yield was still good at 1021 kg/ha. Intercropping trends were similar to last year, though cereal yields were more depressed (except for CS-3541 sorghum and IVS-A75 millet). Pigeonpea yields were again high with the millets, a little lower with the early and/or short sorghums, but low with the late and tall E-35-1 sorghum.

The mean LERs and monetary returns for both years are given in Figure 39. Of the sorghum/pigeonpea combinations, the highest total LERs were given by CS-3541/PS-41 and CSH-6/PS-41, but the latter gave the highest monetary returns because of the higher yield potential of the CSH-6. Total LERs were rather lower when the CSH-6 sorghum was combined with either ICP-1-6 or PM-1 pigeonpea, but monetary returns were still quite good because of higher pigeonpea yield potential. In view of the lower yields of the late PS-41 pigeonpea in this present dry year, the medium maturity ICP-1-6 may be more reliable for these Alfisol conditions.

With pigeonpea genotypes PS-41, ICP-1-6, or HY-2, the IVS-A75 millet gave monetary returns equal to the best sorghum combinations, despite a lower yield potential; this was partly because of the higher value for millet grain, but mainly because this genotype gave a high intercrop yield and was sufficiently early to allow a high pigeonpea contribution.

MILLET/GROUNDNUT. Genotype studies in millet/groundnut intercropping in the rainy season were extended this year to include a Vertisol situation. Millet genotypes were BK-560, WC-C75, and GAM-73-K77 on both soil types; groundnut genotypes were MH-2, TMV-2, Robut 33-1, and M-13 on the Vertisol, with the additional genotypes Chico and MK-374 on the Alfisol. All combinations were grown in a row arrangement of 1 millet: 3 groundnut.

On the Alfisol, intercropped millet yields were about twice the expected 25% of the sole crop (as in previous experiments), but on the Vertisol they were almost three times the expected, giving much higher total LERs (1.20 to 1. 80) than on the Alfisol (1.00-1.40). There was little difference between millet genotypes on any given soil type, though a slightly poorer performance of GAM-73-K77 on the Vertisol and BK-560 on the Alfisol was reflected in slightly poorer overall intercrop performance. There was little differential effect of millet genotype on groundnut, but the range of millet genotypes clearly needs to be widened in these studies. Groundnut genotypes differed considerably; the late-maturing spreading types gave the best intercrop performance, and this was reflected in high overall intercrop performance. These studies confirm the earlier indication of little interaction between specific genotypes of each crop, so in future studies we will try to screen a greater number of genotypes of each crop against a standard genotype of the other crop.

A summer (Jan-Apr) experiment examined the better intercropping performance of the late-maturing, spreading groundnuts to determine how much this could be attributed to the longer period for compensation after cereal harvest. The genotype Gangapuri had to be substituted for M-13, but the other five groundnut genotypes given above were included. They were grown with CSH-8R sorghum that was removed at 70, 90, and 110 days. Al sorghum: 2 groundnut row arrangement was used to provide a fairly high level of competition for the groundnut, but a lower level of competition was included by removing alternate pairs of sorghum leaves. Sorghum was used instead of millet to give a sufficiently long period of competition; the removal and defoliation techniques were used to avoid the

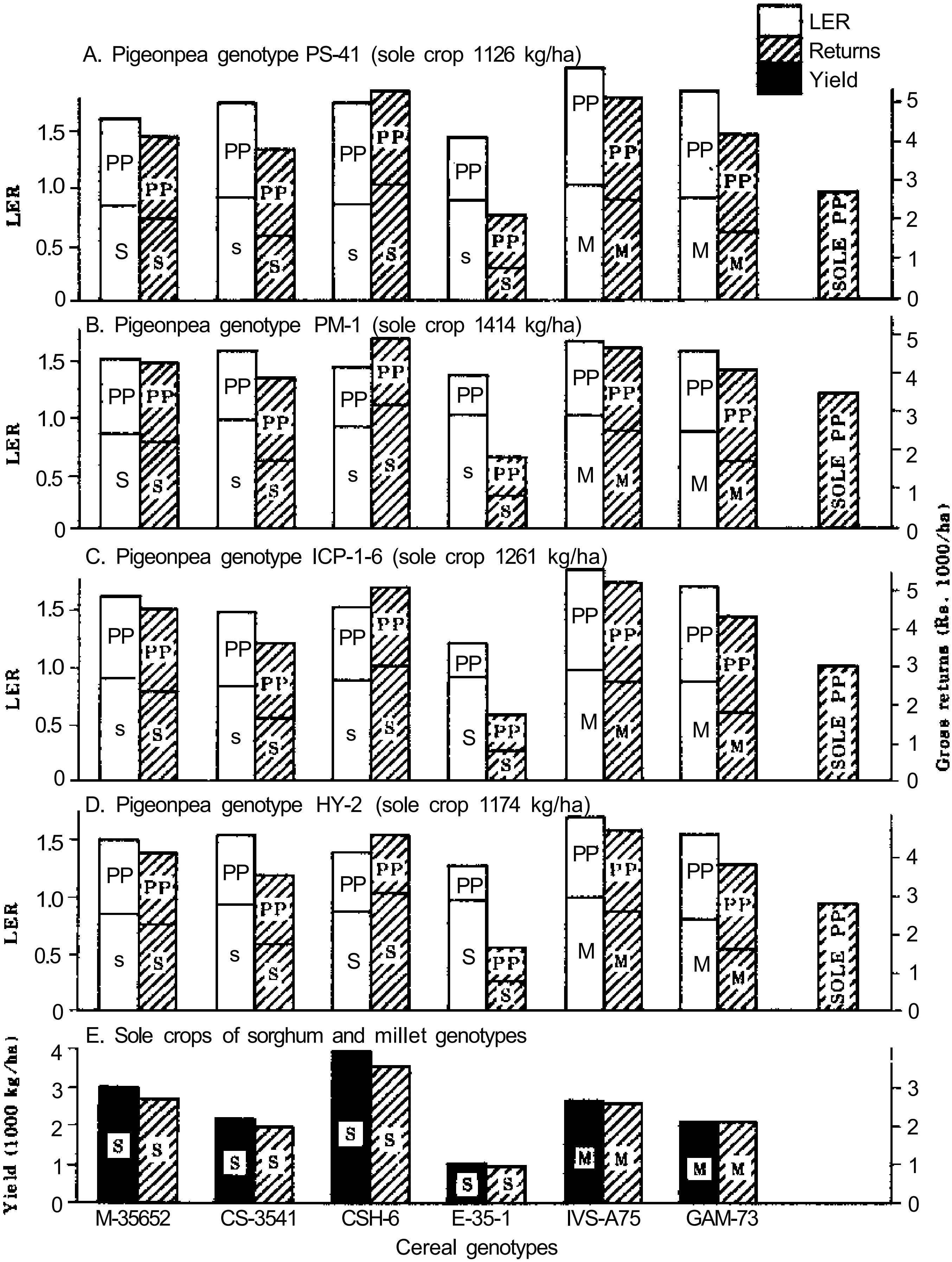


Figure 39. LER advantage and monetary returns of pigeonpea (PP) genotypes intercropped with different sorghum (S) and millet (M) genotypes (mean of 1978 and 1979), ICRISAT Center

confounding of other factors that occurs when different durations or intensities of cereal competition are imposed by using different cereal genotypes.

The groundnut LERs are shown in Figure 40 against the proportion of their growing period in which they were subjected to cereal competition. LERs were mostly lower than the expected 0.66, reflecting the good sorghum growth (sole crop 4830 kg/ha). Differences between genotypes were small, but the LER intercept values (indicating groundnut performance if cereal competition was experienced for the whole of the growing period) tended to be higher for the later genotypes (TMV-2, R-33-1, MK-374). This suggests that the generally better performance of these genotypes in intercropping may not be entirely dependent on a period of compensation after cereal harvest.

The regression lines also give a very

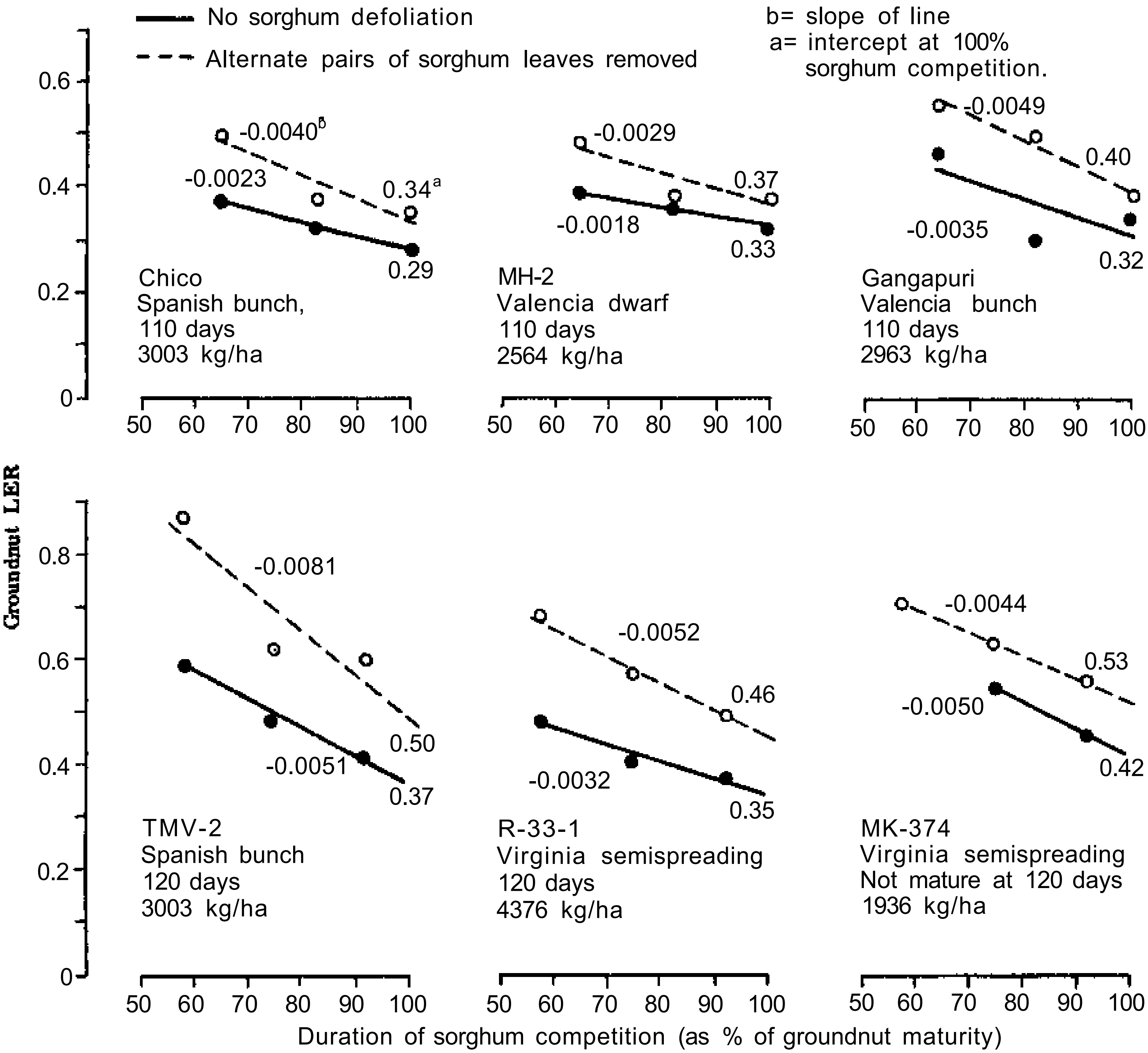


Figure 40. Effects of duration and intensity of sorghum competition on the relative yields of six groundnut genotypes (ICRISAT Center, summer season 1980).

useful indication of the increased groundnut yield that can be achieved by reducing the period or intensity of cereal competition; lor example, the average slope (0.004) of the regression lines of the three later genotypes under the normal level of competition indicates that if the duration of cereal competition were reduced by the equivalent of 25% of the groundnut growing period, the groundnut LER would be increased by 0.10.

SORGHUM/MILLET. A more detailed study of the sorghum/millet combination was made this year. All combinations of three sorghum genotypes x three millet genotypes were grown during the rainy season both on a Vertisol and an Alfisol, though the latter location had to be abandoned because of severe shoot fly attack. Intercropping effects were similar at two different nitrogen levels and yield advantages were very low (maximum 13%). Sorghum was usually the dominant crop, giving higher LERs than the millet, but the performance of each crop increased with increase in its height relative to the other (Fig. 41). This effect was greater for millet yield, with the result that the overall intercrop performance was highest where millet was taller than the sorghum and it decreased as millet became the relatively shorter component.

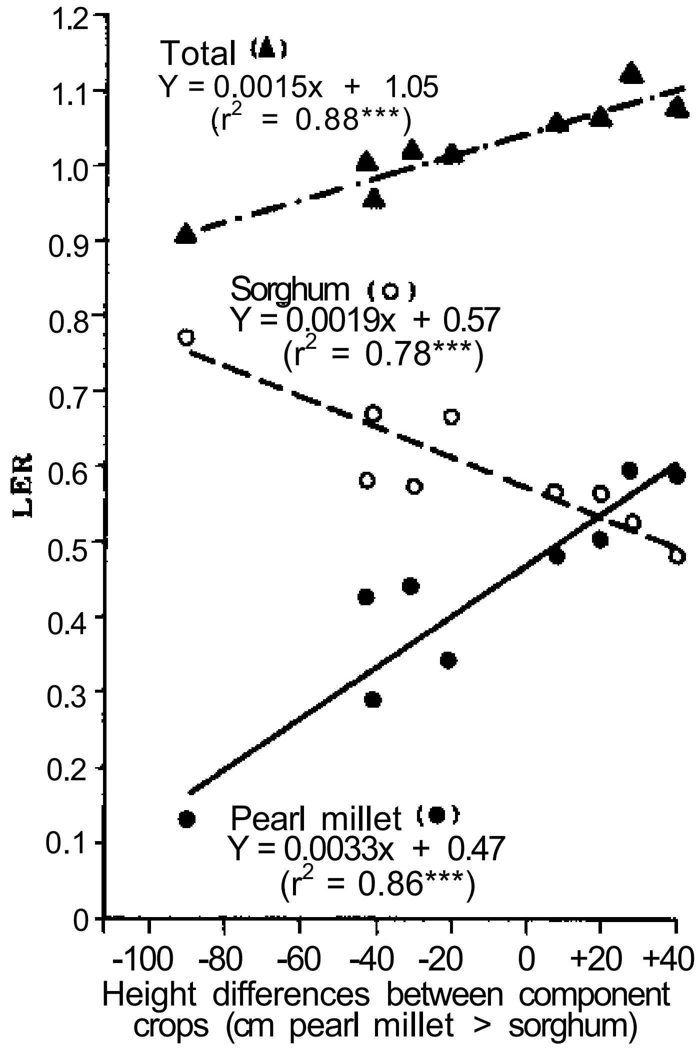


Figure 41. Effects of height differences between pearl millet and sorghum genotypes in intercropping on total and component crop LERs (Vertisol, ICRISAT Center, rainy season 1979).

Moisture Regime and Intercropping Advantages

Previous experiments indicated the possibility that intercropping gave a greater relative yield advantage under moisture stress than under no such stress. During the 1979 summer season we explored a much greater range of moisture regimes by establishing plots at different distances from a "line-source" of sprinklers. All crops were established with uniform overall irrigations totaling 120 mm. Starting at 42 days after sowing, line-source irrigations were given at 10-day intervals, except that every third irrigation was a uniform one across the treatments. The water applied at a given distance from the line source varied with wind direction and speed, so the actual water applied at the different plot positions was collected and measured.

The sole *crops* of sorghum and groundnut showed marked reductions in total dry matter with increased moisture stress; even bigger reductions in reproductive yields occurred because of decreased harvest index. Sole millet showed rather less reduction , and the grain yield pattern was similar to that for total dry matter because of little change in harvest index.

Curvilinear regressions of sole and intercrop yields against the amount of water applied were computed, with proportions of the variation accounted for by regressions ranging from 70% to 83% for sorghum, 48% to 79% for millet, and 89% to 95% for groundnut. LER values were calculated from these fitted curves (Fig. 42). With maximum water applied (and no evidence of any severe stress throughout the season) the millet/groundnut treatments gave overall advantages ranging from 18% to 34%, agreeing with earlier experiments. With increasing stress, advantages increased to very high peak values and then declined sharply; this pattern was determined almost entirely by changes in groundnut LERs. Under conditions of stress, intercropped groundnut yields exceeded sole crop yields, a possible explanation being that millet produced a beneficial shading effect that reduced water loss. This suggestion is supported by the larger effects at the closer row spacings of millet.

Sorghum/groundnut showed a similar pattern of yield advantages, with especially high values from the 1:2 row arrangement under conditions of severe stress; in this combination the changes in total yield advantages reflected changes in both crop components. Sorghum/millet also showed a similar pattern of yield advantages, but in this combination the millet showed little change in LER and total LER patterns were a close reflection of sorghum LERs.

These results provide very good support for the earlier indications of greater relative advantages of intercropping under conditions of moisture stress, a finding that has particularly important implications for the farmer operating in the drought-prone areas of the SAT. It is worth noting, however, that the lower relative advantages under favorable moisture conditions can be higher in absolute terms because of higher yield levels; for instance, in the 1 millet:3 groundnut treatment the maximum 44% advantage under stress was worth Rs.368/ha extra gross returns, whereas the 18% advantage at no stress was worth Rs. 1167/ha. But the very large relative advantages under the stress conditions of this experiment resulted in most absolute advantages also being greater under stress; for instance, in the 1 sorghum : 2 groundnut the maximum advantage under stress was worth Rs. 990/ha compared with Rs. 737/ha under no stress. These very large intercropping advantages achieved this year clearly need to be examined further; the line-source technique will be continued.

Yield Stability in Intercropping

Last year we established from data of a large number of experiments that sorghum/pigeonpea intercropping gave much greater stability than sole crops. Studies to provide data for other combinations were extended this year, and experiments were conducted on five Vertisol and four Alfisol sites, including sprayed and unsprayed situations for both soil types. Information on stability will be presented when sufficient data have been collected. This season the mean LERs for Alfisols and Vertisols, respectively, were: sorghum/pigeonpea 1.29 and 1.55, millet/groundnut 1.17 and 1.31, sorghum/millet 1.14 and 1.13, and groundnut/pigeonpea 1.67 and 1.70. The groundnut/pigeonpea combination proved particularly interesting, giving 83% of a sole groundnut yield and 86% of a sole pigeonpea yield, averaged over both soil types.

Cropping Systems for Deep Vertisols

Growing a maize crop instead of the traditional fallow land treatment during the rainy season again had no effect on postrainy-season crops of sorghum or chickpea, but a 25% yield reduction was recorded in the postrainy-season pigeonpea crop this year. All three postrainy-season crops again showed some evidence of slightly lower yields after rainy-season sorghum. Post-

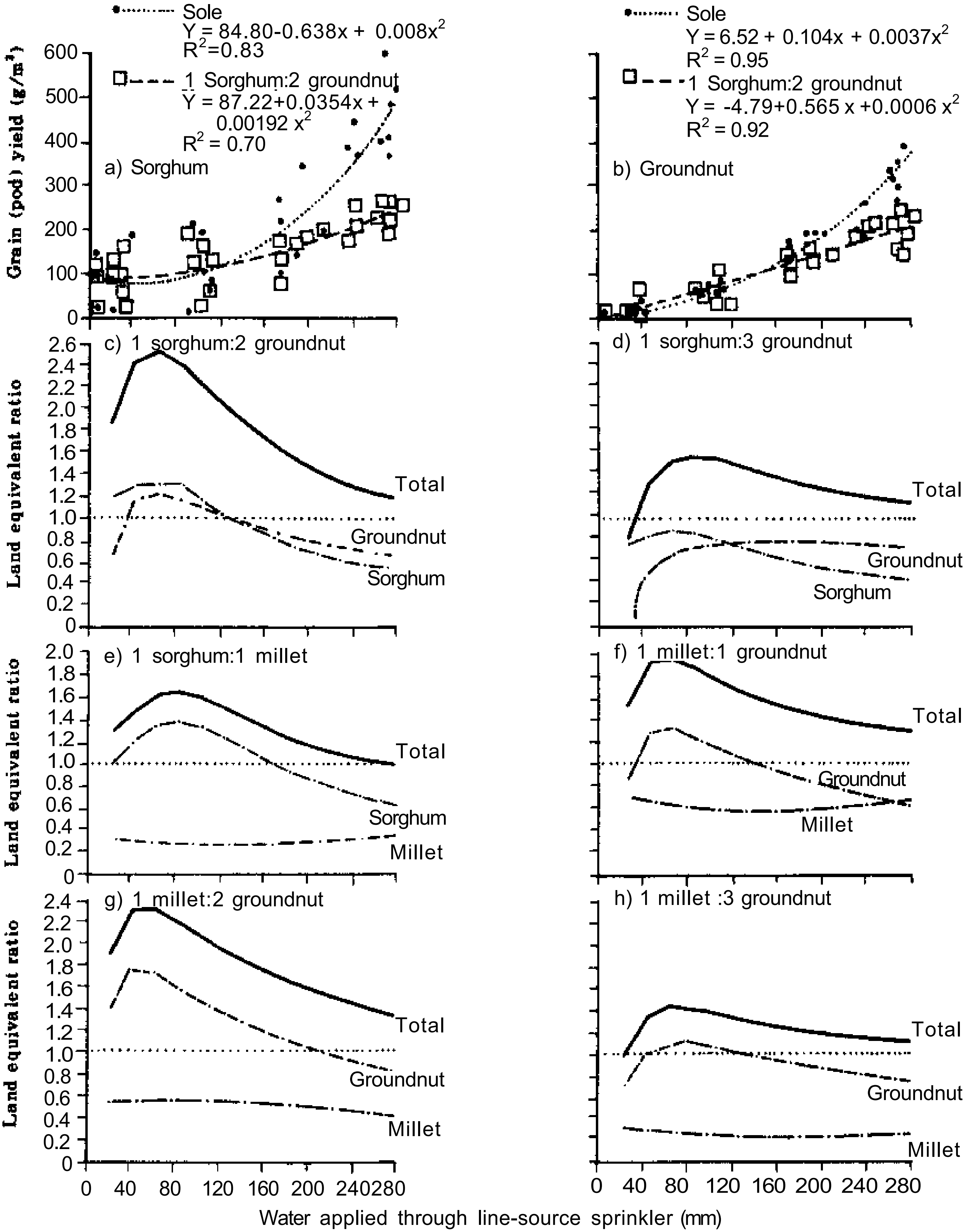


Figure 42. Effect of moisture regime on relative yield advantages of different inter-cropping treatments at ICRISAT Center, 1979 summer season; (a) and (b) examples of fitted yield responses, (c) to (h) LER of different treatments.

rainy season pigeonpea and sorghum were better as relay crops (sown 12 Sept, before harvest of the first crop on 30 Sept) than as sequential crops (sown 1 Oct, immediately after harvest of the first crop), but chickpea was markedly better as a sequential crop.

Sequential cropping was directly compared with maize/pigeonpea or sorghum/pigeonpea intercropping within the same experiment this year, and the best sequential systems of maize-chickpea and sorghum-chickpea averaged 12% higher gross returns than intercropping (Fig. 43). These small plot experiments do not of course reflect the farmer's difficulties in establishing the second crop at the end of the rains when the upper soil layers may be dry, and at a time when his labor demand is high because of the harvesting of his rainy-season crops. A potentially more flexible three-crop system was tried where chickpea was sown after harvest of the maize in a maize/pigeonpea intercrop. This added 528 kg/ha of chickpea (worth Rs. 1346/ha) without reducing the yield of pigeonpea, and the whole system gave 15% greater gross returns than the best sequential crop system (Fig. 43). This could be a system where the farmer sows the chickpea crop only in years that have good moisture supply for establishment and subsequent growth; in the drier years when a chickpea crop is not possible, the farmer still has the assurance of the intercropped pigeonpea.

A sorghum ratoon system gave quite a good low-cost second crop equivalent to 50% of the first crop, but this did not compare very favorably with the other two crop systems in terms of gross monetary returns (Fig. 43). A sorghum allowed to ratoon in a sorghum/pigeonpea intercrop system gave

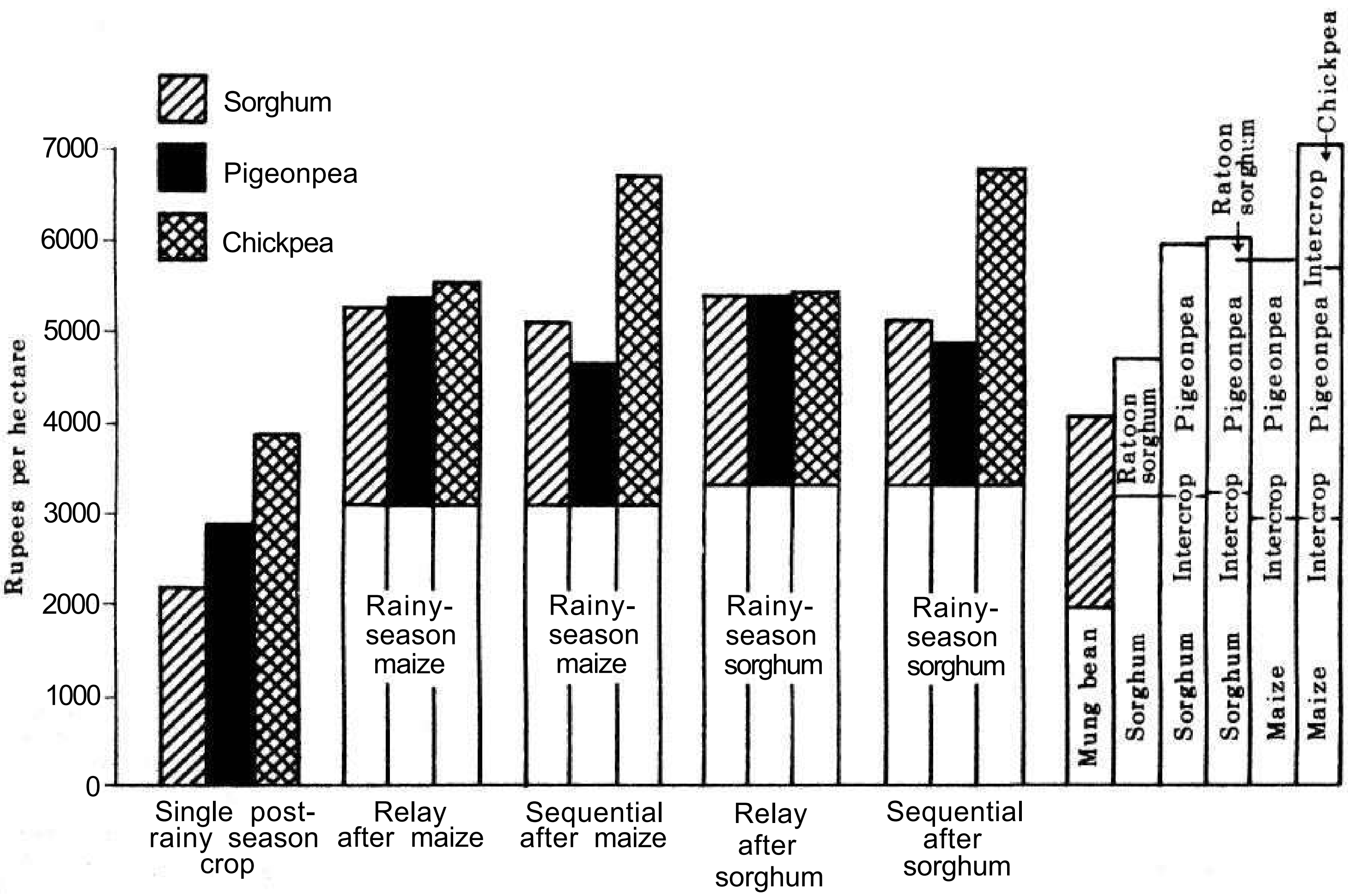


Figure 43. Gross monetary values of different cropping systems on deep Vertlsols at ICRISAT Center (1979/80).

only a very small ratoon yield (262 kg/ha). An early mung bean crop followed by sorghum gave poorer gross returns than any other two-crop system, but this may be a useful system for situations where there is insufficient moisture for two full-season crops.

Cropping Systems for Alfisols

Some of the promising systems of 1978/79 were reexamined this year. Groundnut/pigeonpea intercropping was tried for the first time and gave the highest gross returns (Rs.4297/ha) of all systems. Growing an early mung bean crop before the traditionally late-sown castor again proved worthwhile, the relay castor system (Rs.4090/ha) being better than the sequential system (Rs.3625/ha) because of less depression in castor yield. Growing mung bean before pearl millet or *Eleusine* millet was not worthwhile because of big depressions in the cereal yields. Sorghum/pigeonpea intercropping (Rs. 3673/ha) and millet/groundnut intercropping (Rs. 3371/ha) were again good —better than any sole crop system tried. A drought-resistant crop of horse gram or cowpea gave useful additional returns when relay cropped after pearl millet (Rs. 547/ha and Rs. 713/ha, respectively) but was less promising after the slightly later sorghum or groundnut.

Cropping Entomology

Surveys

Surveys of arthropod endoparasites of major insect pest species received increased attention this year. Over 120 endoparasite species were reared from pests on crops at ICRISAT Center and from farmers' fields in Andhra Pradesh. In general, hymenopterans were predominant and were most effective in controlling pests, particularly in the early stages of pest development and early in the crop season. Dipterans were dominant late in the season and were less effective than hymenopterans since dipterans usually killed the pests either in the larval or in the prepupal and pupal phase, after they had caused appreciable damage. We consolidated a list of arthropod endoparasites based on our surveys in Andhra Pradesh (Progress report 3 of Cropping Entomology).

The importance of weeds harboring *Heliothis armigera* and its natural enemies between and within crop seasons was further investigated. Grazing areas uncultivated for at least 15 years in Alfisols, 40-50 km northwest of ICRISAT Center, harbored high larval populations of *Heliothis* (up to 74/100 plants) on a common rainy-season weed, *Acanthospermum hispidum* (weed density, up to 18 plants/m^2). Over 92% of *Heliothis* larvae were parasitized by a mermithid parasite, *Ovomerims albicans.* A spiny weed, *Carthamus oxyacantha,* thriving in thousands of hectares in northern India near Hanumangarh (30°N and 74°E), harbored low larval populations (3/100 plants) in early May when temperatures were high (42-45°C) and relative humidity low (16-30%).

On sorghum, maize, pearl millet, cowpea, mung bean, tomato, and cotton, eggs of *Heliothis* were highly parasitized, but not on chickpea and pigeonpea. Lack of egg parasitization on these two grain legumes led to high larval numbers and heavy yield loss. A high density of glandular hair with sticky tips was implicated in the failure of eggparasitization in chickpea: adults of *Trichogramma* sp were found trapped in the sticky exudates on chickpea leaves.

An important Ichneumonid parasite of *Heliothis* larvae on sorghum in August-October was later recovered from its larvae on chickpea, safflower, tomato, peas, onion, and linseed during November-March, but rarely from larvae on pigeonpea. In surveys in Maharashtra, the proportion of *H. armigera* moths recovered from total Heliothidinae on safflower was higher in intercrop (25%) than in sole crop (9.5%) fields. A reverse trend was observed in *H. peltigera* moths (75% in intercrop compared to 90.5% in sole crop fields). More larvae on safflower wereparasitized by hymenopterans (mainly *Eriborus argenteopilosus* than by dipterans (mainly *Carcelia* sp). By contrast, *Campoletis chlorideae* was the main hymenopteran parasite on this crop in parts of Andhra Pradesh.

Insect Trap Studies

We published a report on light trap studies at ICRISAT Center and the trap design for local fabrication (Progress report 2 of Cropping Entomology), Trap studies have now been initiated in Tamil Nadu, Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Haryana, and Rajasthan. A very high population of moths of the cereal stem borer *Chilo partellus* at ICRISAT Center was recorded during 1979/80- some 14 599 moths trapped as opposed to 2420 in 1978/79, 2350 in 1977/78, and 2012 moths in the 1976/77 season. Females, however, constituted over 81% of the total catch in every season.

In Vertisol watersheds during 1977-80, of the lepidopteran legume borers, *Adisura marginalia* and *Maruca testulalis* were trapped in highest proportions in September-November, whereas during December-February others such as *H. armigera, A. stigrmtica* and *Etiella zinckenella* were predominantly trapped. Cereal pests *C. partellus, Mythimna loreyi,* and *M. separata,* and cotton pests *Dysdercus* sp, *Earias insulana, E. vittella,* and *Spodoptera litura* were trapped in very high proportions from September through November. *S. exigua,* however, was trapped in highest proportions in March through May, and subsequently its numbers declined.

Within the *He Heliothis* complex, *H. armigera* was most numerous, and more males were caught of all species. *H. armigera* moths trapped during 1977-80 were sexed and females were dissected to assess the fertility status (Fig. 44) and spermatophore index on this noctuid in the region. Of approximately 15 000 moths trapped annually, less than 47% were females and the majority were virgins, particularly during December. Mated females usually had only one spermatophore,but a few had none or up to five spermatophores. Over 30% moths were trapped in December and only 1% in May-July.

Four-week moving means for *H. armigera* recorded at ICRISAT Center (Patancheru, 18°N and 78°E) and at Hissar substation (29°N and 76°E) during 1979/80 showed three peaks of moth activity at both locations (Fig. 45). Information on peaks of *Heliothis* from traps and from egg and larval counts in the fields over several seasons at ICRISAT Center has enabled us to gain valuable insight into best dates for screening, escaping damage, pest and damage levels, timing of control measures, and parasitization on crops.

The synthetic pheromone of *H. armigera* was tested in cooperation with the Tropical Products Institute (UK). Catches were much lower than those obtained on the light traps. Higher concentrations of synthetic pheromone and/or virgin females attracted only a few male moths. In January, sticky traps baited with virgin females of *H. peltigera* caught a few *H. armigera.* males along with males of *H. peltigera.* No *H. peltigera* males were ever caught in traps baited with *H. armigera* females.

Studies on Intercropped Sorghum/Pigeonpea

A replicated trial was sown in the rainy season at four locations each on both Vertisols and Alfisols on low-fertility areas at ICRISAT Center. Sole plots of sorghum (CSH-6) and pigeonpea (ICP-1) and sorghum/pigeonpea intercropped at full and at half stands were used. Intercrops at full and half stands were also sown at two Vertisol locations in an adjoining village. Distribution patterns and levels of pest damage were studied and insect numbers, levels of parasitism, and yield losses were measured and compared with the data obtained from a few farmers' fields in a village in district Medak (Choutkur,45 km NW) and one in Rangareddy (Tan-

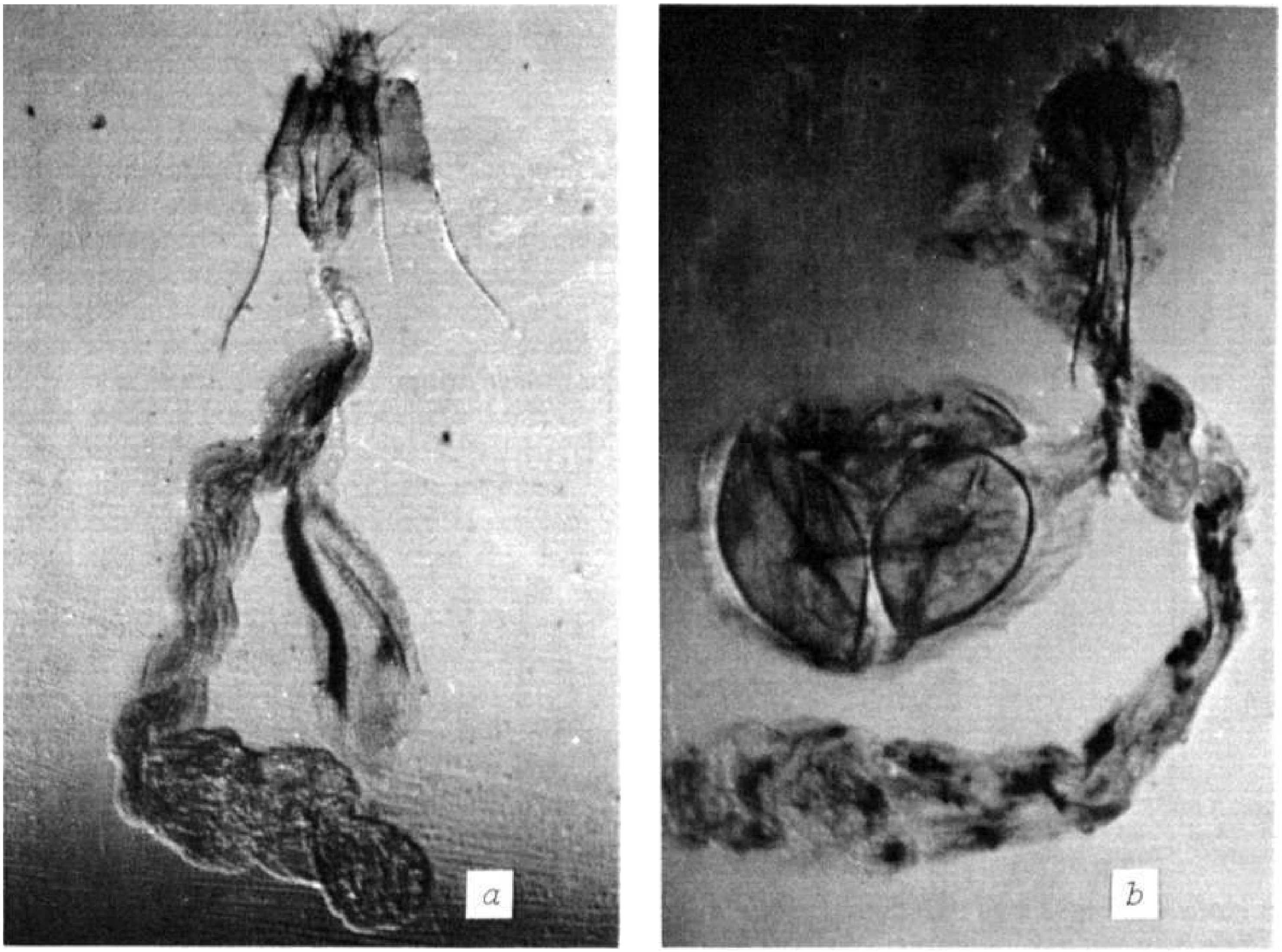


***Figure 44. Female genitalia of* Heliothis armigera (*Hb*): (*a*) *virgin, and* (*b*) *mated* (*with three spermatophores*).**

door, 80 km SW) in Andhra Pradesh.

SORGHUM. The pest and parasite study in sorghum showed that over 50% of the population of some early-season pest species, including earhead worm *(H. armigera),* is naturally controlled by parasites. *Chilo* damage counts in intercropped sorghum fields revealed that less than 8% of the cropped area had more than 10 deadhearts/100 plants. This suggests the possibility of using a "spot" insecticidal treatment of initial damage foci instead of an overall spray. This would also help reduce the chance of disturbing the early-season natural pest/parasitoid level.

The levels of pests attacking sorghum at the seedling or the earhead stages and their parasitoid/predator complexes were similar on sole and intercropped sorghum at the same plant densities. Between the intercropped treatments, there was a tendency for increased pest incidence in the plots with the half plant stand. Pest incidence was higher at ICRISAT Center than at the village sites.

At ICRISAT Center, the levels of shoot fly *(Atherigona soccata)* and armyworm *(M. separata)* attack and percent earheads infested with earhead bugs *(Calocoris angustatus)* were significantly higher ($P < 0.05$) on Alfisols than on Vertisols. A slight delay in germination and a slow initial growth rate were important factors encouraging shoot fly

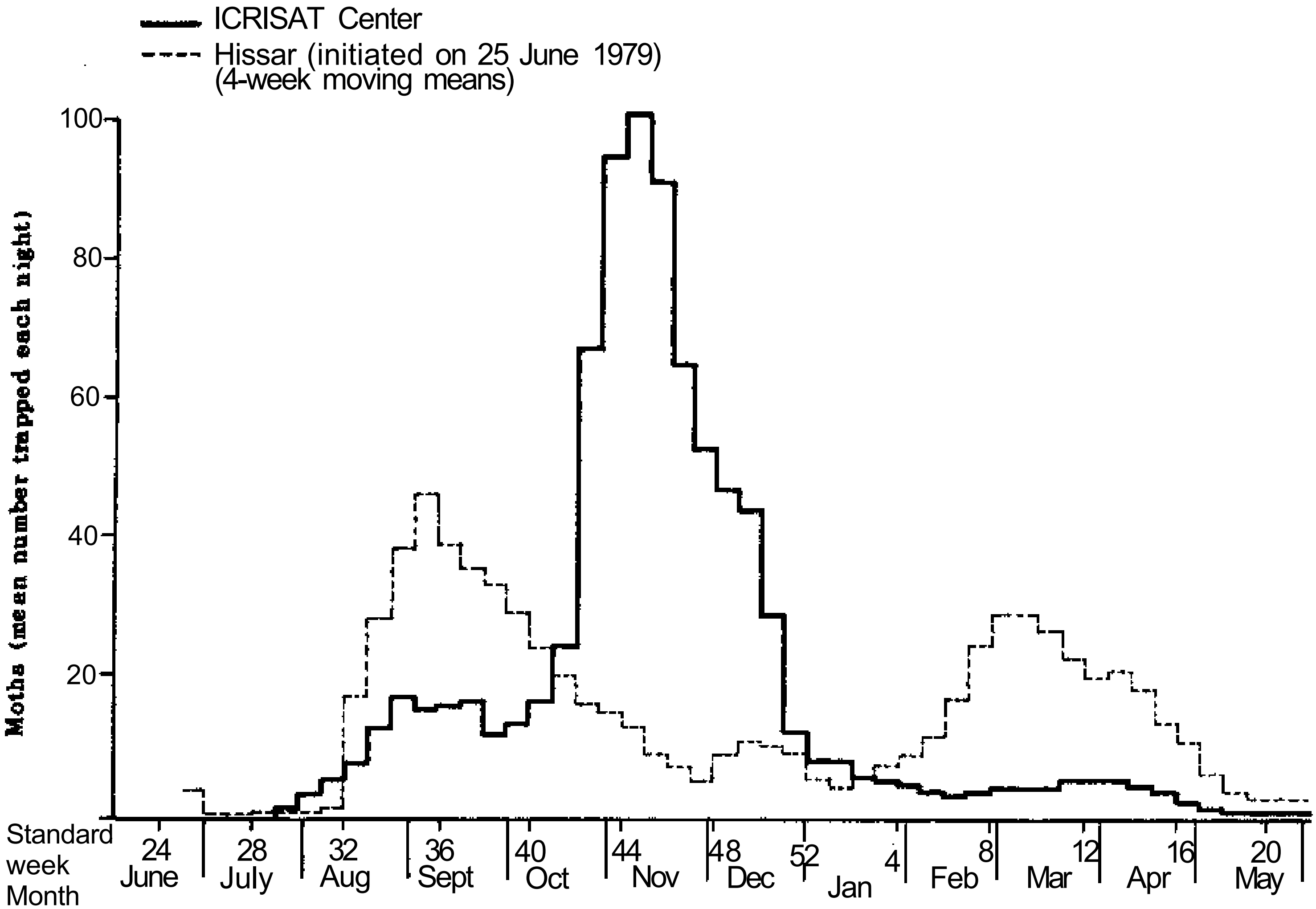


Figure 45. Light trap catches of **Heliothis armigera** *(Hb.) at ICRISAT Center and Hissar, 1979/80.*

attack on sorghum on low-fertility Alfisols. As a result of high aphid (*Rhopalosiphum maidis*) number per plant, incidence of the common coccinellid predator, *Menochilus sexmaculatus,* was significantly higher ($P < 0.01$) on Alfisols —149 as opposed to 21/100 plants on Vertisols.

Oviposition by *E. armigera* was heavier on Alfisols (90 compared to 34 eggs/10 earheads on Vertisols) and similar trends in egg parasitization levels by *Trichogramma* sp were observed (52% compared to 29%). However, the larval population/100 earheads at peak activity was significantly higher on Vertisols (78, as opposed to 17 larvae on Alfisols; n = 12 each). The incidence of an important hymenopteran parasite reached a maximum of only seven in the current season compared with 90, 58, and 38 cocoons/100 earheads in 1978, 1977, and 1976, respectively. Another parasite, *Microchelonus curvimaculatus,* was more common and was recovered from up to 32% larvae sampled. Similar trends with lower numbers were obtained in the village sites sampled and surveyed. Dipteran parasites of *Heliothis* were recovered only on Vertisols.

PIGEONPEA. The number of eggs and larvae of *H. armigera* on pigeonpea and of moths trapped in light traps at ICRISAT Center were significantly higher on Vertisols than on Alfisols. Peak oviposition occurred in early November at the Center, in the adjoining village sites, and in the farmers' fields in the Medak and Rangareddy districts. This period was also favored in

1977 and 1978, irrespective of lunar phase. The oviposition and the subsequent larval increase were higher at Choutkur than at ICRISAT Center and Tandoor.

At ICRISAT Center, oviposition and subsequent larval population/100 terminals at peak activity was significantly higher ($P < 0.05$) and percentage of yield loss was greater on intercropped than on sole-crop plots (Table 13). Losses in yield due to insect pests were determined by using the actual weights of damaged and undamaged pods and seeds and calculating the potential yields had all pods been undamaged. However, since the actual yield from sole-cropped pigeonpea was higher than from intercropped plots, the actual grain weight loss was greater in the sole crop. Slight yield advantages from intercropping in low-fertility situations, particularly at low plant stands, were obtained (see LER in Table 13).

In this entomological work we noted higher incidence of complete and partial sterility mosaic disease in intercropped plots than in a sole-cropped pigeonpea plot at a Vertisol unsprayed location (Table 14). Within the intercrops, the disease incidence was higher at low plant densities of pigeonpea.

Confirmatory data obtained at ICRISAT Center and in all the village sites surveyed showed that the parasite complex that develops on *Heliothis* in association with sorghum gives only slight advantage to the associated pigeonpea crop, because the parasites do not subsequently transfer in appreciable number to *Heliothis* on pigeonpea. Egg parasitization on pigeonpea was low (less than 1%) in contrast to the situation on sorghum (up to 85%). Hymenopteran parasites were common on sorghum and dipterans on pigeonpea. Overall larval parasitism levels were higher at ICRISAT Center (up to 67%) than in the farmers' fields (up to 10%), with peaks occurring late in the season. High moth pressure in the winter months in Andhra Pradesh (Fig. 45) further creates a disequilibrium with the local parasite fauna, leading to a rapid increase in larval populations and high grain loss on pigeonpea.

Table 13. Heliothis armigera *at peak activity and loss assessment on pigeonpea (ICP-1) grown as sole crop and intercropped with sorghum (CSH-6), ICRISAT Center, 1979/80.*[a]

Crop system	Population (1000 plants/ha)		Pest (no.)/100 terminals at peak activity		Insect-induced yield loss to pigeonpea		Grain yield (kg/ha)		LER
	Pigeonpea	Sorghum	Eggs	Larvae	(%)[b]	(kg/ha)	Pigeonpea	Sorghum	
Sole crop									
Sorghum		179.3						2313	1.00
Pigeonpea	50.2		97.0	24.1	38.9	280.8	842.7		1.00
Intercrop									
Full stand	50.6	184.9	148.6	28.3	39.4	111.1	369.5	1711	1.17
Half stand	24.8	94.7	141.1	38.3	46.4	116.0	328.6	1872	1.20
SE ±	1.1	5.5	15.3	4.4	5.8	30.6	100.2	258.3	

a. Based on 8 sites; b. Based on analysis of 25 plants; LER = land equivalent ratio.

Table 14. Incidence of sterility mosaic disease in sole and intercropped pigeonpea (ICP-1) with sorghum (CSH-6) in pesticide-free Vertisols, ICRISAT Center, March 1980.

Crop system	Blocks observed[a] (no.)	Percent plants with disease	
		Complete	Partial
Sole crop	336	0.22	13.46
Intercrop			
Full stand	342	2.08	27.00
Half stand	261	3.38	41.16

a. One block = 15 m^2.

This year we also initiated a study on the role of predators in intercrops. Several predatory spider and wasp species were active on sorghum and pigeonpea during the rainy and postrainy seasons. Mud nests of wasps *Delta conoideus* contained up to 26 *Heliothis* larvae per nest in the postrainy season (Fig. 46).

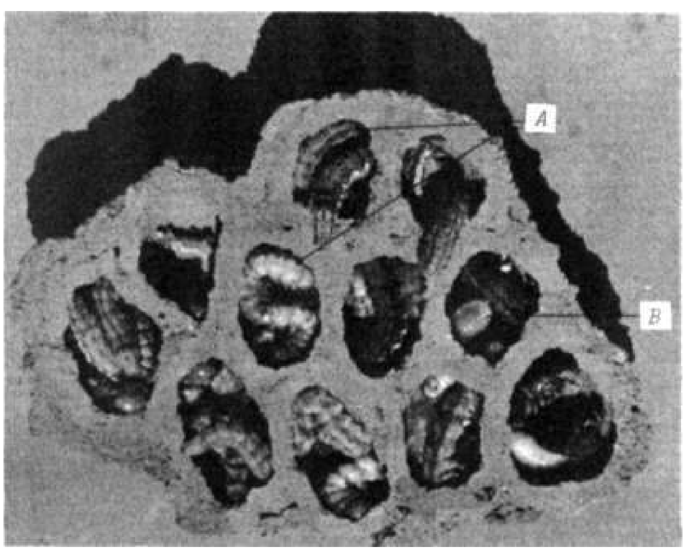


Figure 46. Mud nest of the wasp **Delta conoideus G.** ***Soyka filled with larvae of*** **Heliothis armigera** (***Hb.***) ***in postrainy season 1979/80 at ICRISAT Center. A, cells with*** **Heliothis** ***larvae; B, developing offspring of wasp.***

Agronomy and Weed Science

Steps in Improved Technology

In our research to improve farming systems technology, we have grouped the factors involved in crop production into four important "steps": crop variety, fertilization levels, soil and crop management methods, and supplemental irrigation (where needed). During the past 4 to 5 years, field trials were conducted to determine the contribution from each of these factors to improve the productivity of different cropping systems.

The cropping systems included in the study were rotated to avoid buildup of diseases and insects and to provide information on a range of crops. Large-scale replicated plots were used to facilitate bullock-drawn operations with both improved and local implements and to carry out economic analysis.

The yield values for the treatments on Alfisols and on Vertisols for 1979 are presented in Table 15. Results of the 5 years of experiments are being evaluated and will be presented in next year's Annual Report.

Table 15. Yields (kg/ha) for two intercropping systems under different combinations of production practices at ICRISAT Center in 1979/80.

Treatments VFMI	Sole crop Millet Grain	Millet Fodder	Intercrop Sorghum Grain	Sorghum Fodder	Pigeonpea Grain
- - - -	490	3310		10 500	180
- - + -	800	3870	ND	14 790	20
- + - -	1030	3000		11650	190
- + + -	1120	4080		15 790	10
- - - -	1000	2700	2330	4430	290
+ - + -	1600	2600	2830	4 270	290
+ + - -	2080	2790	3180	4140	420
+ + + -	2530	3160	3820	4 250	270
- + + +	1150	4160	ND	18130	20
+ + + +	2500	2830	4060	5 430	240
SE ±	92	232		686	38

V, variety; F, fertilization; M, soil and crop management; I, irrigation.
- Traditional practice; 4 Improved practice.
ND = No data, trials not harvested.

Weed Science

Weed management research was mainly oriented towards studies to determine the effect of different cultural, biological, and physical factors on crop-weed balance.

SMOTHER CROPPING AND CROP GEOMETRY. In trials conducted to determine the effect of different row widths on crop and weed growth, growing sorghum in wider rows did not reduce the crop yield significantly (Fig. 47), nor did allowing weeds in crop rows and weeding only between the crop rows. Data on weed dry matter indicate that the wider crop rows did not minimize weed infestation, though the competition offered by these weeds to crop growth was not substantial. The same set of treatments with only one hand weeding and with a smother crop between the crop rows resulted in no significant yield differences even up to 90-cm row widths. However, smother crop yields were better in wider rows than in narrower row widths. Weed dry-matter weights also indicated a decreasing trend as the sorghum row widths were increased. The growth and development of cowpea was favored in the wider rows because of less competition offered by sorghum, while the enhanced growth of cowpea could suppress weed growth better In wider rows.

LIGHT/WEED STUDIES. Studies to quantify the growth response of some common SAT weeds to light were continued. *Dactyloctenium aegyptium, Anuranthus viridis, Tridax procumbens,* and *Cyperus rotundus* were the test weed species. Among these four weeds, *Cyperus rotundus* emerged as

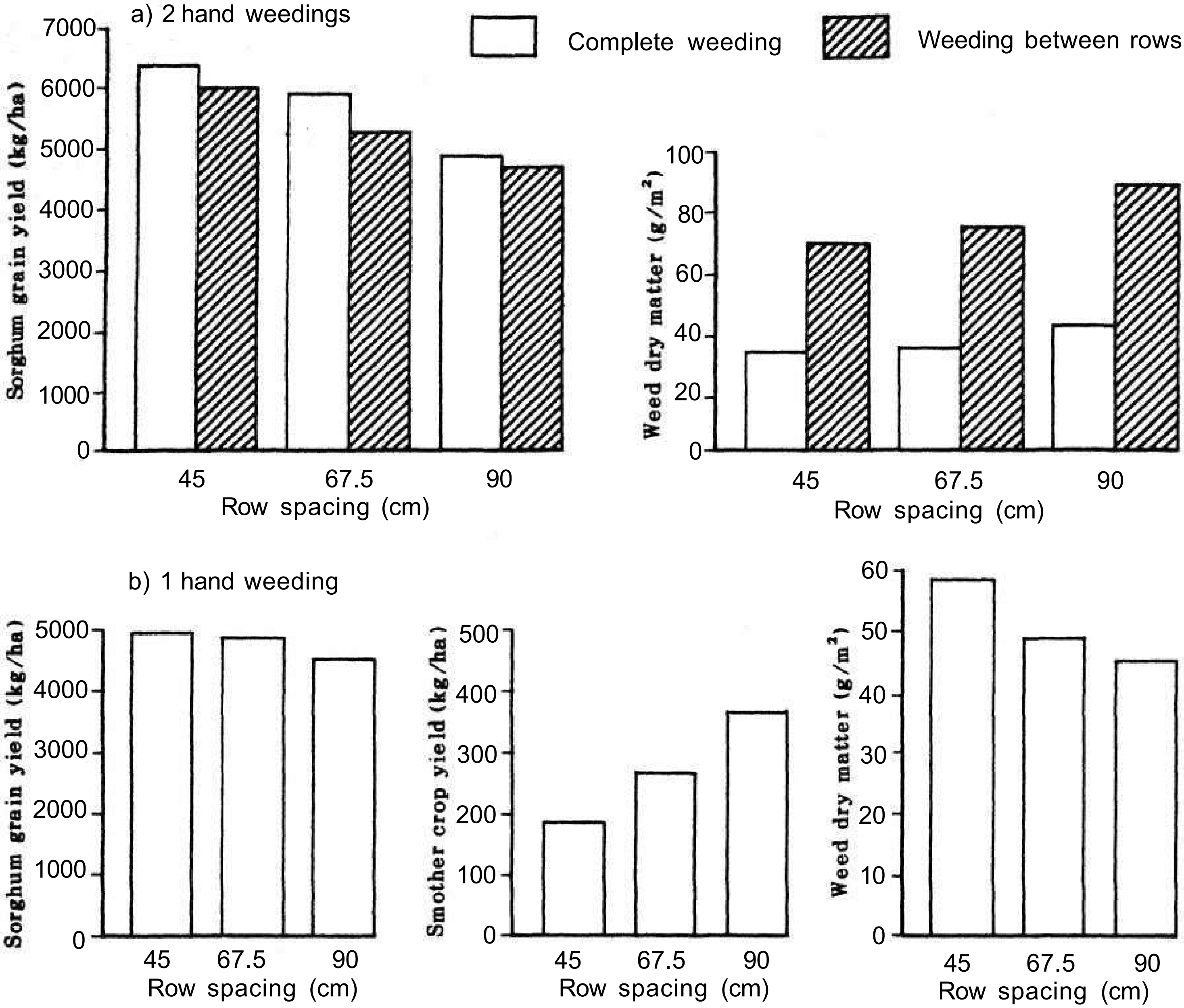


Figure 47. Effect of row spacing® and different weeding systems on crop yields and weed growth on Alfisols at ICRISAT Center, 1979/80.

the weed most sensitive to shading. *Cyperus* grown under bamboo shade frames that transmitted different levels of photosynthetically active radiation (PAH) showed marked reduction in height, leaf-area index (LAI), and dry weights as the available light intensity was reduced (Fig. 48). The correlation coefficient relating percent PAR and dry matter was 0.93, which indicates the shade sensitivity of the weed. Further, a small amount of shading affected the seed production and tuber formation considerably, indicating the potential of shading in reducing the propagation of this perennial weed. This study also confirmed our earlier observation that management practices which helped in establishing good crop canopy early in the season also acted as important components of improved weed management treatments.

WEED DENSITY. As weed density is one of the important biological factors affecting the crop-weed balance, a trial was conducted in deep Vertisols to examine the competitive effect of individual weeds at differ-

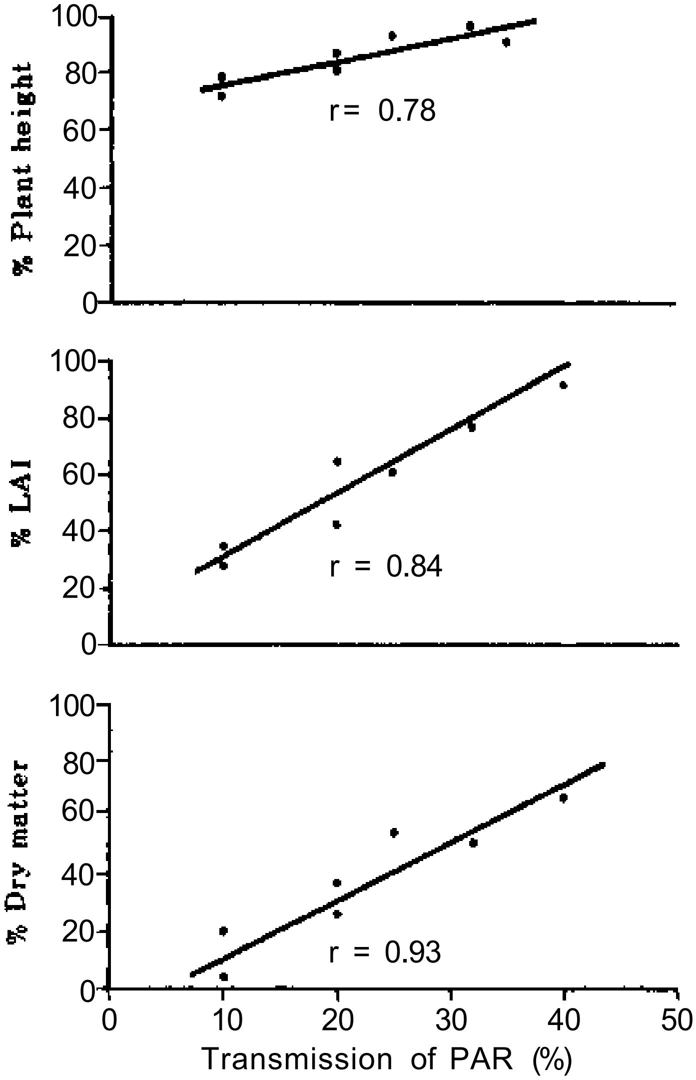


Figure 48. Relationship between light transmission (PAR) and plant height, LAI, and dry matter of Cyperusrotundus *at ICRISAT Center in 1979/80.*

ent densities on the growth and yield of sorghum. The test weed species were *Digitaria ciliaris,* a grass, and *Corchorus olitorius,* a dicot. Increases in weed density adversely affected crop yields (Fig. 49). The effect was more pronounced with *Corchorus* than with *Digitaria* at high density levels. At lower densities (up to 100 plants/m^2), *Digitaria* was more competitive with sorghum than the dicot *Corchorus,* perhaps because its growth habit is similar to that of sorghum. The data on weed dry-matter weights indicate that these increased as the density increased to 200/m^2, but further increases in density did not influence the dry-matter

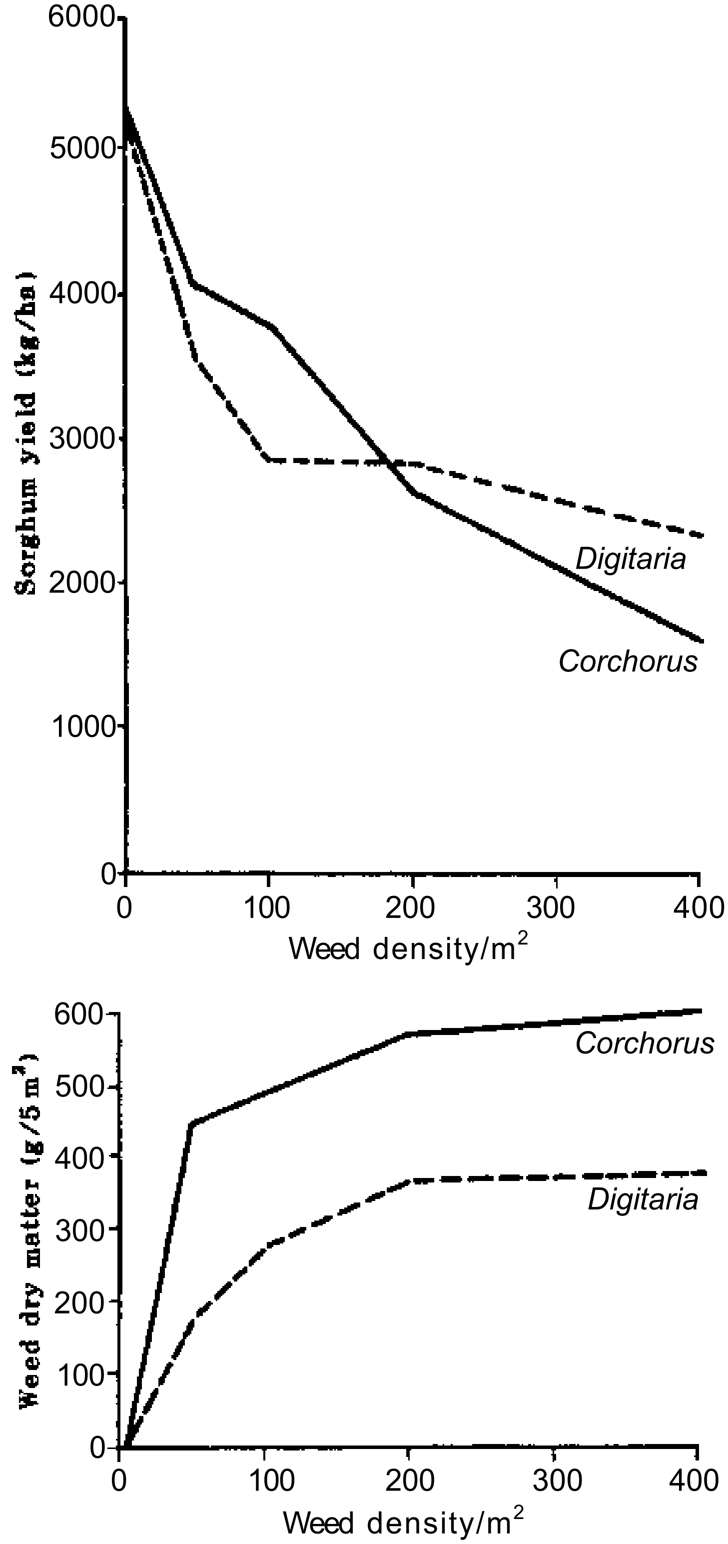


Figure 49. Effect of different densities of weed Corchorus *and* Digitaria *on sorghum yield and weed dry matter on Vertisols at ICRISAT Center in 1979/80.*

weights. This was mainly due to weed-weed competition at high densities, which resulted in poor growth. This observation agrees with sorghum yield data, which show that increasing weed density above $200/m^2$ did not significantly affect sorghum yields further.

WEED MANAGEMENT IN CROPPING SYSTEMS. Weed management treatments evaluated on different cropping systems on an operational scale in the ICRISAT Vertisol watersheds included (1) hand weeding (two hand weedings in the rainy season and one during the postrainy season), (2) herbicide treatment (preemergence herbicide plus one hand weeding in the rainy season and one in the postrainy season), and (3) smother cropping involving cowpea and mung bean. These treatments were compared with weed-free and weedy-check treatments for their efficacy and operational and economical feasibility on the following cropping systems: (a) maize-chickpea sequential cropping, (b) sorghum/pigeonpea intercropping, and (c) sorghum-chickpea sequential cropping. Except weeding, all other agronomic practices were kept uniform. Results are shown in Figure 50.

Evaluation of different weed management treatments on ratoon cropping of sorghum also indicated that the weed management treatments adopted in the rainy season have a profound influence upon weed competition in this crop. The optimum time to weed in ratoon sorghum was found to be 3 and 6 week after ratooning the sorghum.

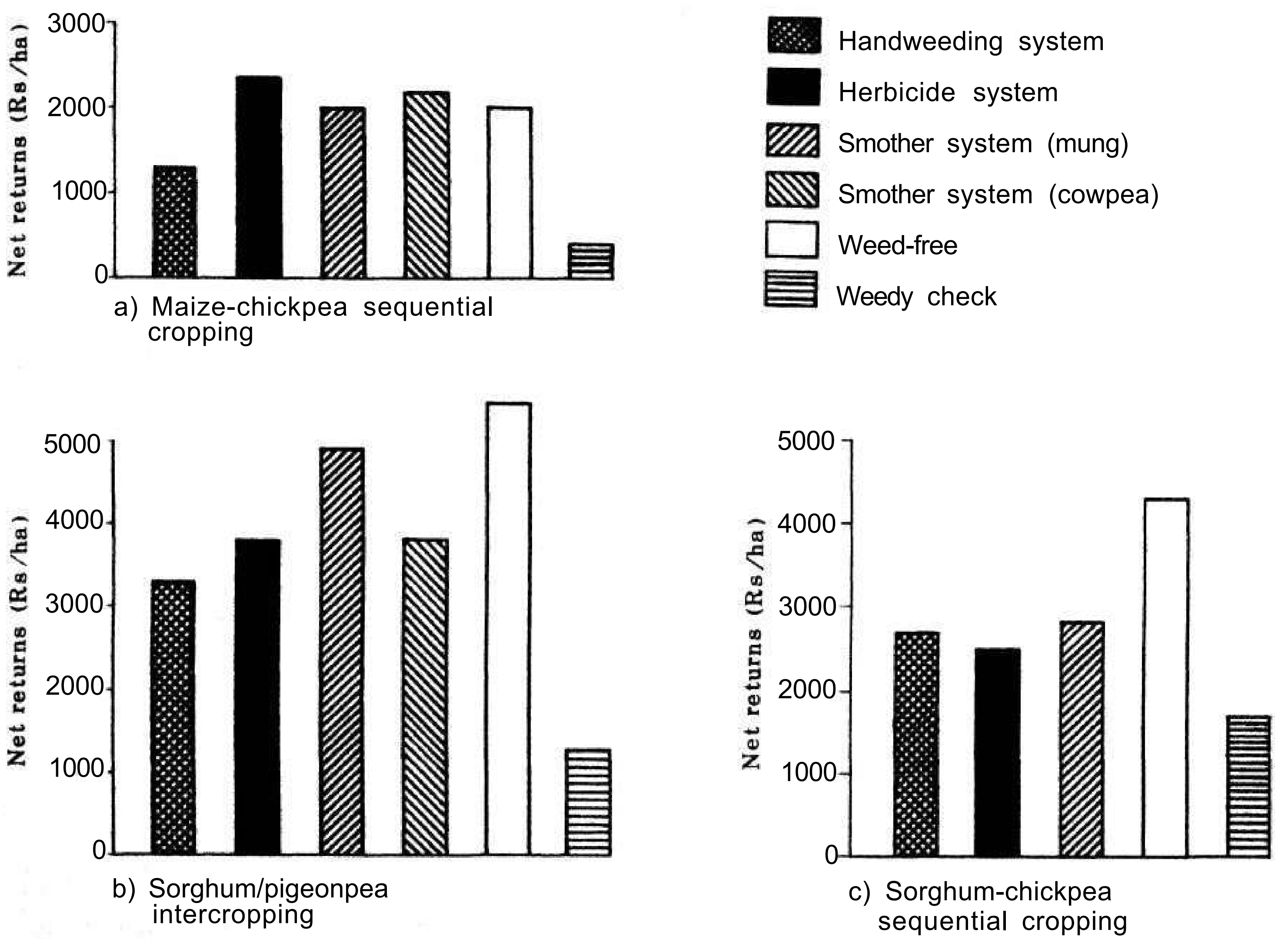


Figure 50. Net returns from different cropping systems as affected by different weed management treatments on Vertisols at ICRISAT Center, 1979/80.

Forage Evaluation

During the year, evaluation of grasses and legumes in the nursery, waterways, and tank bunds and the experiments on fertilization and management of natural vegetation were continued.

Among 25 collections, *Cenchrus ciliaris,* 214, 393, 541, and Pusa Giant performed better than others and yielded more than 16 tonnes/ha green forage. In *Cenchrus setigerus,* 76, 415, and two collections from Jhansi and Pali observed previously, regrowth and performance were good; although it is generally known that this grass is not suitable for Vertisols, these collections appeared promising in nursery evaluation on broadbeds. In *Panicum antidotale* the regrowth in one-third of the 61 collections was satisfactory, but forage production was low.

Among other grass species, *Chloris gayana, Chrysopogon fulvus, Setaria sphacelata, S. porphyvantha,Pennisetum massaicum,* P. *pedicellatum,* Pusa Giant Napier, *Brachiaria mutica,*and *Urochloa mosambicensis* appeared promising in nursery, waterways, and tank bunds. Among legumes, siratro, (*Macroptilium atropurpureum)*., *Desmanthus virgatus*,and *Clitoria ternatea* were better than others.

Six grass-legume mixtures comprising three grasses (*C. ciliaris, C. gayana,* and *Uroohloa mosambicensis)* and two legumes (siratro and *C. ternatea*) were evaluated in both Alfisols and Vertisols. Since repeated harvests were done before flowering, there was no chance of self seeding. Thus the composition of legumes (particularly siratro) was reduced in all the experimental plots. In Alfisols in all six grass-legume mixtures, multicut management was superior to multicut plus grazing, and green forage yields ranged between 11 and 23 tonnes/ha. In Vertisols green forage yields varied in different grass-legume mixtures and ranged from 11 to 25 tonnes/ha. A mixture of *C. gayana* and C. *tematea* yielded maximum forage in both soil types.

We conducted an experiment in Alfisol and Vertisol natural vegetation areas to study effects of two phosphorus levels (0 P and 20 P) with uncut and mulficut management on forage production, botanical composition, and longevity of the native grasses and other species. Application of 20 kg P/ha enhanced dry-matter production in Alfisol and Vertisol natural revegetation areas and also appears to have a specific effect on the species composition: The plots under uncut treatment were dominated by perennial grasses and dicots, whereas those under multicut were dominated by annual grasses and ephemerals.

On-Farm Watershed Research

A cooperative on-farm research project was initiated in 1978 with the All India Coordinated Research Project for Dryland Agriculture, three state agricultural universities, and the ICRISAT Farming Systems Research and Economics Programs in three southern Indian villages. The objectives are:

1. to adapt, test,and measure the performance of prospective land and water management technology on farmers' 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 the adoption of a watershed-based system of resource development and management.

Small-scale on-farm experiments were initiated in 1978 as part of ICRISAT's Village-Level Studies (VLS) to obtain preliminary information on suitable cropping systems and appropriate land and water management techniques. These small replicated experiments showed that higher yields could be achieved with improved soil and crop management. Farmers appreciated the multipurpose tool carrier (Tropicultor) and the importance of precision and uniformity of seed and fertilizer placement which it permitted.

Because of the interest and cooperation shown by farmers in 1978, land and water management on a watershed basis was initiated in 1979. Watersheds of 11.7 ha on Alfisols in Aurepalle village in Andhra Pradesh involving five farmers, 10.8 ha on medium-deep Vertisols in Kanzara village of Maharashtra involving six farmers, and 13.9 ha on deep Vertisols in Shirapur village of Maharashtra involving eight farmers, were developed during the dry season. The farmers were continuously involved in planning the work and participated in development activities. ICRISAT agreed to underwrite the scheme by guaranteeing farmers would achieve at least double their normal profits. We also made provision for advances for material inputs, which were to be recovered provided profits were above the guaranteed levels. Inputs were also made physically available in the villages well prior to the monsoon.

The watershed in Aurepalle was sown to sole crops of sorghum, groundnut, and castor, and an intercrop of pearl millet/pigeonpea early in the rainy season of 1979. Similar activities were initiated on the fields of three farmers in Kanzara, where groundnut, sorghum intercropped with pigeonpea, and cotton mixtures were planted. Shirapur watershed was sown to mung bean, and pearl millet intercropped with pigeonpea, as well as postrainy-season sorghum.

The early part of the rainy season of 1979 was reasonably favorable in terms of the onset of the monsoon. Satisfactory crop stands were established in all three villages. Soon after, however, the rains ceased and crops were subject to very serious moisture stress. Rainy-season crops at Shirapur failed. The crops most adversely affected were sorghum in Kanzara, and castor and pearl millet intercropped with pigeonpea in Aurepalle. However, late-season rains allowed some crop recovery.

In none of the three villages were "record" yields attained. However, the yields obtained with improved technology— improved seed, chemical fertilizers, and better soil and crop management using the tropicultor— were mostly greater than those obtained by traditional farming systems.

An economic analysis of these experiments showed that irrigated groundnut grown on broadbeds and furrows was most profitable (1600 Rs/ha) in Aurepalle. Profits from crops irrigated from a refurbished well in Aurepalle were on average about 50% higher than the profits from traditional technology (Fig. 51). No significant difference in profits was observed between broadbeds and the flat method of cultivation on the watershed area. Though higher yields were obtained under improved watershed technology, profits after deductingprorated development costs and operational and material input costs were almost equal to the profits from traditional technology under nonirrigated conditions. Higher gross returns from the higher yields were discounted by higher cost levels.

On the medium-deep Vertisols of Kanzara village in Maharashtra, similar results were obtained. The profits from improved technology were only 20% higher than from traditional technology. Results from the deep-Vertisol area of Shirapur—traditionally a rainy-season fallow/postrainy-season cropping area—showed that postrainy-season sorghum grown with chemical fertilizers and improved soil and crop management was some 150% more profitable than on the fields under traditional management throughout the village. In Shirapur watershed, rainy-season crops were also grown but, due to the early cessation of rains, the crops failed. This substantially reduced the prof its from the whole system and strongly suggests that one cannot rely on a rainy-season crop in this region, as found by Binswanger et al. (1980).

Farmers expressed their desire to continue the experiment during 1980/81. We

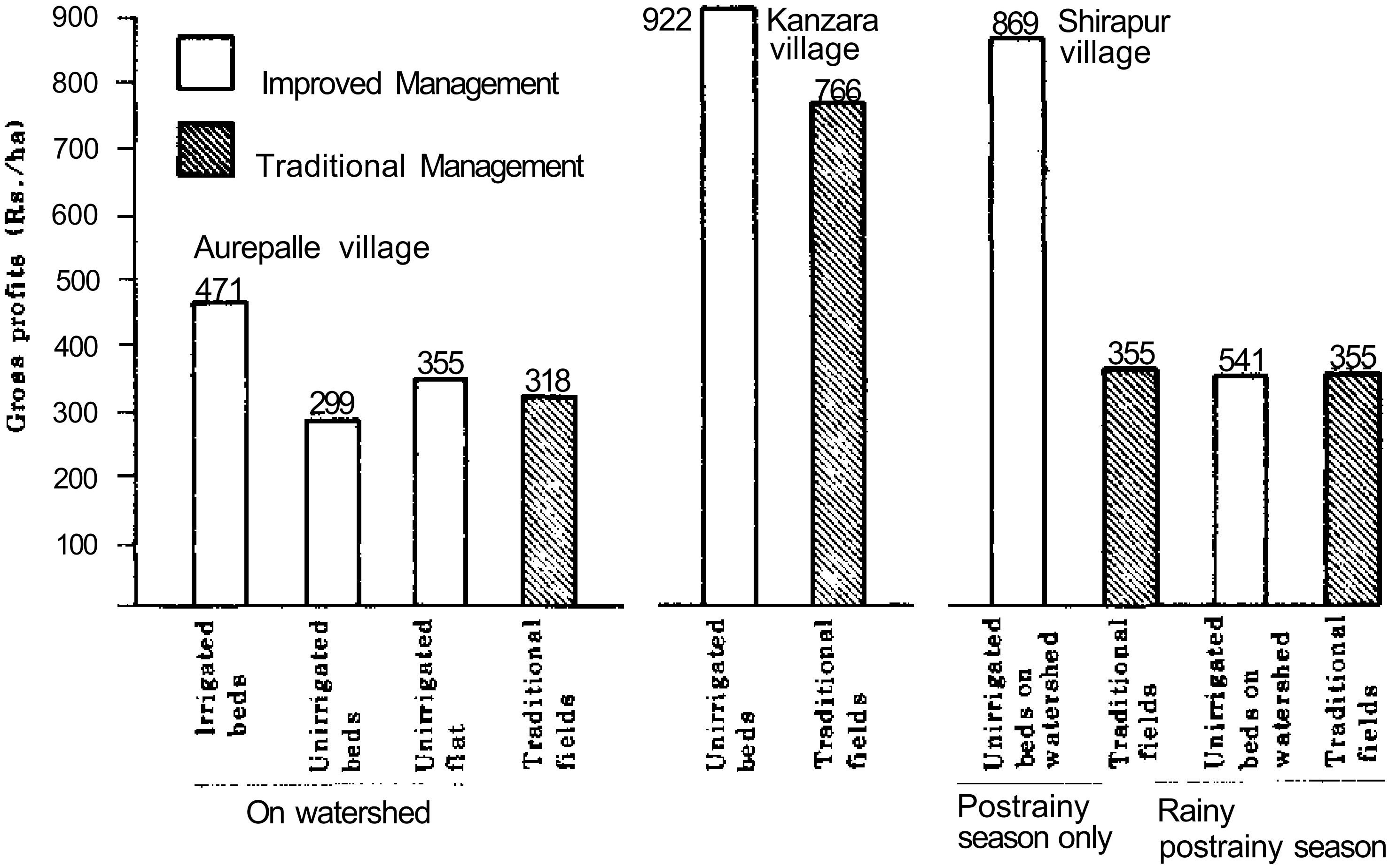


Figure 51. Gross profits from various systems in village on-farm watershed experiments, 1979/80.

will summarize the combined results after the next season and then study the response of farmers to ascertain their interest in adopting the various technology options.

Collaborative Studies

Research results from ICRISAT and Indian national programs such as AICRPDA and the Central Water Conservation Research and Training Institute indicate that improved resource conservation and utilization, along with improved crop production technology, have great potential for generating economically and technically superior farming systems. These encouraging results are being verified through two cooperative research projects with ICAR through AICRPDA, which started in 1977: FS-1—Resource development, conservation, and utilization (with reference to soil and water); and FS-2—Hydrologic studies to improve land and water utilization in small agricultural watersheds in the SAT of India. The cooperating AICRPDA research centers are located at Jhansi, Varanasi, Jodhpur, Rajkot, Udaipur, Ranchi, Indore, Akola, Sholapur, Hayatnagar, Bijapur, Bellary, and Bangalore.

FS-1 studies are conducted in all the cooperating centers, but FS-2 is presently confined to the Bangalore, Hayatnagar, and ICRISAT stations. Early this year the Central Institute for Cotton Research at Nagpur sought ICRISAT's assistance in setting up an FS-1-type of experiment with cotton as the main crop.

The highlights of the results of the two studies reported by AICRPDA and ICRISAT scientists during the annual evaluation meeting held in March 1980 are as follows:

1. The advantages of the graded broadbed-

and-furrow system observed especially on medium-deep and deep Vertisols (soil depth > 45 cm) at the ICRISAT station include:

- Reduces soil erosion
- Provides surface drainage
- Concentrates organic matter and fertilizer in the plant zone
- Reduces soil compaction in the plant zone
- Is suitable to supplemental water application
- Can be laid out on a permanent basis
- Facilitates land preparation during the dry season
- Reduces the power and time requirements of agricultural operations
- Makes possible precise intercultivation work and placement of seeds and fertilizers
- Increases yield and profitability

However, from past data on medium to shallow Vertisols (lately classified as Vertic Inceptisols with soil depth less than 45 cm), it is difficult to conclude that the broadbed-and-furrow system has appreciable yield advantages over the "improved" flat-on-grade system of cultivation. The runoff quantities observed from the bed treatment were generally higher than those from the flat system.

2. On Alfisols, reports from ICRISAT, Hayatnagar, and Bangalore show that the bed system and its specific configuration seem to have no significant impact on runoff and erosion, management costs, or crop yields, compared to the graded flat. The bed system even shows increased runoff if compared to flat cultivated plots. However, the system does not reduce yield and it does provide the land with surface drainage that assures safe disposal of runoff under extreme rainfall conditions.
3. Yield data of FS-1 tended to reveal that raised soil conditions around plants create a better environment for their growth, whether these conditions were created before or after sowing. Efforts directed towards determining how and when raised soil conditions are to be created to promote crop growth should be worthwhile.
4. Information being gathered from the FS-2 studies shows that critical supplemental irrigation on a watershed basis may be highly rewarding in stabilizing the agricultural production in dry lands. The data demonstrate that supplemental irrigation has a good payoff. More concentrated efforts are needed in exploring the feasibility of runoff collection, storage, simple water-lifting devices, and efficient application of limited water at different locations to bring stability to crop production in dry lands.
5. Results from cooperating centers in general show high location specificity.

Looking Ahead

Agroclimatology

We hope to promote wider application in crop planning of existing knowledge on climate evaluation, including presentation of general climatic characteristics of various regions and identification of homoclimes for facilitating technology transfer. Efforts will be made to improve current understanding of the role of the canopy microclimate in crop production processes by employing an automatic data acquisition system. Cooperative multilocation research on crop-weather modeling will be intensified, aided by modifications of available models for adoption in the SAT and by results of research on canopy microclimates. Collaborative research on soil-plant-water relations with the Physiology, Soil Physics, Land and Water Management, and Soil Fertility and Chemistry subprograms will be enlarged to provide quantification of crop response to water and nutrient stress.

Environmental Physics

We will work to determine the degree of profile water depletion at which sorghum, millet, pigeonpea, chickpea, and groundnut experience an agronomically significant reduction in evapotranspiration and dry-matter production rates.

Increased emphasis will be placed on investigating effects of choice of variety, date and rate of sowing, fertilization, weed control methods, intercropping, tillage practices, etc., that may result in alterations of profile moisture utilization by the crops.

Soil Fertility and Chemistry

The behavior of nitrogen in various crop-soil combinations will continue to be given major emphasis; aspects requiring high priority are the efficient use of nitrogen fertilizer and the maximum utilization of biological nitrogen fixation. Our studies on the efficiency of nitrogen fertilizer will be facilitated by the use of ^{15}N to distinguish between fertilizer nitrogen and native soil nitrogen, in collaborative work with the International Fertilizer Development Center.

We will also expand our studies of the phosphorus requirements of crops. There is a need to maximize the efficient use of phosphorus fertilizer; particular attention will be given to assessment of the residual effects of previous phosphorus applications, and to identification of the factors that affect the accuracy of predictive soil tests.

Land and Water Management

FSRP will continue to explore approaches to predicting the suitability and possible adaptation of land and water management systems for a given topography, soil, climate, and cropping pattern, using estimated critical limits of selected soil parameters such as depression storage, aeration, infiltration, and stability indices. A compatible weed control component will also be integrated, and long-term effects of particular systems on a given soil's physical and chemical properties will be included in the investigation.

Considering the mixed and inconsistent research results being obtained on Alfisols, we envisage studies on some additional alternative surface configurations with more attention to crust management.

The relative usefulness of small tanks for supplemental irrigation in various situations will be studied. Present rainfall-runoff models, soil moisture models, and available data will be used in conducting this analytical study, which is expected to provide the probability of receiving given quantities of water during the course of the cropping season and tank failure at varying degrees of seepage losses. In this connection, we will conduct more intensive research on low-cost seepage control methods.

Collaborative studies with ICAR through AICRPDA on resource development, conservation, and utilization will be intensified to test and verify the promising technology of the bed-and-furrow system on medium and deep Vertisols in the assured rainfall and predominantly rainy-season fallow areas.

The parametric runoff prediction model RUNMOD will be further tested with additional data from ICRISAT and from AICRPDA cooperating centers. Other models will be compared with RUNMOD.

Work will be started to develop and validate another simulation model for predicting soil moisture profiles and groundwater recharge in cultivated fields, utilizing soil preparation and crop characteristics. It will be useful in deciding timings of supplemental irrigations, determining movements of different solutes in the soil profile and estimating the groundwater recharge.

Farm Power and Equipment

Feedback from the Indian commercial manufacturers of the Tropicultor and a complementary range of implements indicates the need for some design changes to reduce production costs and to make it more suitable for manufacture by small-scale industries. The low-cost modified bullock cart that we modified last year for use as a wheeled tool carrier has been field tested and is now ready to move into village production and farmer evaluation. Thus we will place considerable emphasis on assisting manufacturers and monitoring farmers' evaluation of machinery.

The machinery under development at ICRISAT is being increasingly tested and evaluated in many SAT countries, resulting in a growing number of requests for training, which we hope to keep pace with.

Modeling for machinery selection will receive increasing attention as a research tool to assist in identifying research priorities more clearly.

Cropping Systems

In intercropping, we will give more emphasis to establishing patterns of competition and possible yield advantages under low moisture and/or low nutrient supply; the very promising "line-source" technique will be developed further. Plant population studies will be confined to the millet/groundnut intercropping combination. The evaluation of medium-maturity pigeonpeas suitable for intercropping will continue, and the number of genotypes examined in millet/groundnut intercropping will be increased. Yield stability studies will continue, and the preliminary disease studies conducted in cooperation with ICRISAT pathologists (not reported here) will be strengthened.

On Vertisols, we will continue the comparison of 2- or 3-crop intercropping with sequential systems and also plan to develop Alfisol systems on a more operational scale.

Entomological work on intercropping will be intensified at sites away from ICRISAT Center, and surveys will examine the natural control agents of *Heliothis armigera.* At ICRISAT Center we will further study the effects of insecticide use and agronomic factors such as plant population on pest/parasite levels and crop losses. Our efforts to establish a light trap grid across India and our cooperative work with the Tropical Products Institute (UK) on synthetic pheromones will continue.

Agronomy and Weed Science

As weed management transects many aspects of farming systems, the necessity to quantify the effects of physical, cultural, and biological factors on crop-weed competition will receive higher priority. We will intensify our monitoring of weed populations as affected by improved systems and traditional systems of farming across different agroclimatic regions of the semi-arid tropics.

Herbicide studies will be concerned with improving the year-round productivity of cropping systems. In the development of alternative weed management systems, we will examine the performance of improved systems on an operational scale, along with varying levels of other production factors on a year-round basis. Studies will be designed to develop improved weed management principles that have wider applicability in the SAT.

Future work may also include long-term experiments to determine the effects of different factors on the crop-weed competition and development and evaluation of different agronomic methods to manipulate these factors to shift the crop-weed balance in favor of crops.

It is hoped that future studies will be oriented in such a way that weed management research will serve as a practical vehicle for producing agronomic research coordination.

Publications

Institute Publications

Binswanger, H. P. , Virmani, S.M.,and Kampen, J. 1980. Farming systems components for selected areas in India: evidence from ICRISAT. ICRISAT Research Bulletin No. 2. Patancheru. A. P., India: ICRISAT. 40pp.

Virmani, S.M., Reddy, S.J., and Bose, M. N. S. 1980. A handbook on the rainfall climatology of West Africa: Data for selected locations. Information Bulletin No. 7. Patancheru, A. P., India: ICRISAT. 52 pp.

Journal Articles

Bhatnagar, V. S., and Davies, J. C. 1978. Factors affecting population of gram pod borer, *Heliothis armigera* (Hubner) at Patancheru (Andhra Pradesh). Bulletin of Entomology 19:52-64.

Rao, M.R., and Willey, R.W. 1980. Preliminary studies on intercropping combinations based on pigeonpea or sorghum. Experimental Agriculture 16:29-39.

Shetty, S.V.R., and Krantz, B.A. 1980. Weed research at ICRISAT. Weed Science 28:451-454.

Sivakumar, M.V.K., and Virmani, S.M. 1980. Growth and resource use of maize, pigeonpea, and maize/pigeonpea in an operational research watershed. Experimental Agriculture 16:377-386.

Conference Papers

Bhatnagar, V. S. 1980. A report on research on *Heliothis* complex at ICRISAT (India), 1974-79. Presented at the All India Workshop on Consolidation of Pest Management Recommendations and Guidelines of Research. Entomological Society of India, 24-26 Apr, University of Udaipur, Udaipur (India).

Huda, A.K.S., and Virmani, S.M. 1980. A systems analysis approach to developing cropping systems in the semi-arid tropics. *In* Proceedings, International Conference of Operations Research in Agriculture and Water Resources, 25-29 Nov 1979, Jerusalem, Israel. Amsterdam, Netherlands; North Holland Publishing Co.

Kampen, J. 1980. Watershed management and technology transfer in the semi-arid tropics. Pages 111-119 *in* Proceedings, International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, ICRISAT, Patancheru, India.

Kampen, J. 1980. Farming systems research and technology for the semi-arid tropics. Pages 39-56 *in* Proceedings, International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, ICRISAT, Patancheru, India.

Kampen, J., and Burford, J.R. 1979. Production systems, soil related constraints, and potentials in semi-arid tropical regions of Asia, Africa, and Latin America. Conference on Priorities for Alleviating Soil Related Constraints to Food Production in the Tropics, 4-8 June, International Rice Research Institute, Los Banos, Philippines.

Kampen, J., and Krishna, J. H. 1979. Rainy season cropping on deep Vertisols in the semi-arid tropics: Effects on hydrology and soil erosion. International Conference on Watershed Management and Land Development in the Tropics, 20-24 Nov, International Institute for Tropical Agriculture, Ibadan, Nigeria.

Krishna, J.H., and Hill, R.W. 1979. Hydrological investigations on small watersheds at ICRISAT. Joint meeting of the American and Canadian Societies of Agricultural Engineers, 24-27 June, Winnipeg, Canada.

Rao, M. R. Ahmed, S., Gunasena, H. P. M., and Adelaida, P. A. 1979. Multilocational evaluation of productivity and stability of some cereal-legume intercropping systems: A review of INPUTS trial III. Final INPUTS Review Meeting, 20-24 Aug, East-West Center, Honolulu, Hawaii, USA.

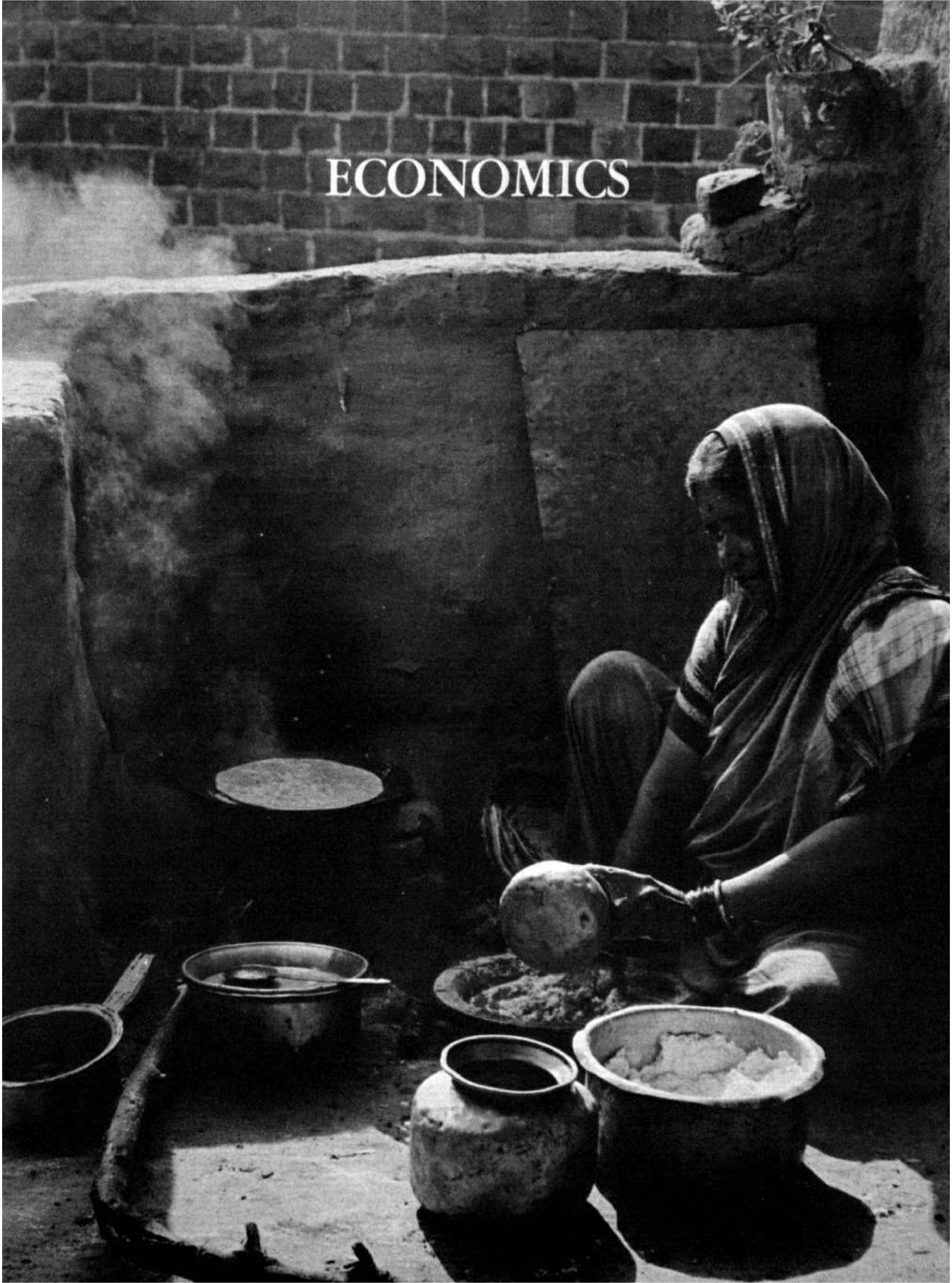
Sahrawat, K. L., Rego, T. J., and Burford, J. R. 1979. Work experience in rainfed farming systems at ICRISAT with special reference to fertilizer use. Pages 19-30 *in* Proceedings, FAI Group Discussion on Fertilizer Use in Drylands, 17-18 Aug 1979. New Delhi, India: Fertilizer Association of India.

Shetty, S.V.R. 1979. Approaches to integrated weed management in maize and sorghum in tropical and subtropical areas. Seventh Asian-Pacific Weed Science Society Conference, 26-30 Nov, Sydney, Australia.

Shetty, S.V.R. 1979. Integrated weed management systems for the semi-arid tropics. Annual Meeting of the Indian Society of Weed Science, 29-31 Jan, Marathwada Agricultural University, Parbhani, Maharashtra, India.

Sivakumar, M.V.K. 1979. Environmental factors affecting plant productivity: Adaptive production systems. Final INPUTS Review Meeting, 20-24 Aug, East-West Center, Honolulu, Hawaii, USA.

Virmani, S.M. 1980. Climatic approach to transfer of farming systems technology in the semi-arid tropics. Pages 93-101 *in* Proceedings, International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, ICRISAT, Patancheru, India.


ECONOMICS

Contents

ECONOMICS

Research in the Economics Program aims to identify socioeconomic and other constraints to agricultural development in the SAT and to evaluate means of alleviating them through technological and institutional changes. In examining the human element in agriculture, we study production and marketing economics and social organization.

Village-Level Studies (VLS)

In early 1980 in collaboration with Gujarat Agricultural University, the VLS were extended to Gujarat to cover an important groundnut- and pearl millet-producing region of SAT India. Village studies were also initiated by the economists appointed to the West African Cooperative Program in late 1979. Details of those West African studies are to be found in the International Cooperation section of this Annual Report. May 1980 marked the fifth birthday of our Indian VLS. It is therefore appropriate to assess the role played by the VLS in research at ICRISAT. This was done by Binswanger and Ryan (1980; listed in "Publications"), whose findings are summarized below.

The VLS were designed initially by ICRISAT's Economics Program in close consultation with physical and biological scientists. An attempt was made to build a general approach using the appropriate methods from many types of applied research. Underlying our approach is the conviction that the SAT village is the best locus for socioeconomic research and for technology adaptation studies. It is only there that real constraints to development have full opportunity to express themselves. Such expression can lead scientists to understand more quickly what changes might be needed in recommended technological and institutional options.

Using background data compiled at the state, district, subdistrict, and village levels, and based on exploratory visits, two typical villages were selected in 1975 in each of three agroclimatic regions of SAT India. This range of regions was needed to allow comparison across agroclimatic zones. Within each village a sample of 10 landless laborers and 30 cultivators in three farm-size classes was randomly selected as a panel to be monitored over a number of years.

An investigator who has a university education in agricultural economics, comes from a rural background, and speaks the local language has been stationed in each village to interview the panel households every 3-4 weeks and to undertake a number of agrobiological investigations. He also acts informally as a participant-observer.

Data on agricultural operations are collected on a plot basis. Information is gathered on labor inputs and time allocation of each household member and bullock pair, and on economic transactions, income, and capital endowment of each household. Intensive anthropological data collection started in 1978. The panel approach allows easy resurvey capability and provides a vehicle for special-purpose studies.

Socioeconomic observation has two main objectives: to monitor and document existing practices in order to help in the assessment of research priorities, and to generate a data bank for a broad range of socioeconomic inquiries. Studies on risk attitudes, cropping patterns, nutrition, weed management, and the labor market are some examples of where the VLS have contributed recommendations for priorities in technology development, helping ICRISAT to formulate a well-grounded research strategy.

The second objective of our socioeconomic work goes beyond technology assessment and development. It encompasses the generation of knowledge useful for socioeconomic policy in the SAT. The VLS have demonstrated their potential to illuminate general policy questions such as adjustment

A Village-Level Studies (VLS) participant with his hybrid sorghum crop grown as part of the VLS on-farm studies in watershed development.

to risk, agricultural tenancy, and farm size and productivity.

Over time the field research and technological adaptation functions of the VLS have attained increasing importance, which is what was intended. From the point of view of technology development and adaptation, the studies have two main functions: first, they serve as the most important (but not the only) data source for specific studies assessing research priorities and prospective technology; second, they provide a locus for a multidisciplinary effort on what may be the most difficult research problem of the semi-arid tropics: generating improved soil-, crop-, and water-management techniques that are adaptable to different agroclimatic, economic, and sociocultural environments. This effort involves farmers, and scientists from national programs and agricultural universities, as well as scientists from ICRISAT. The VLS are our approach to a grass roots or "bottom-up" philosophy of agricultural research and development.

During the first 2 years, the VLS were used by a number of ICRISAT programs for farm-level observations and diagnostic experiments, including studies on the prevalence of pests, diseases, and weeds, and on germination problems in chickpea and nodulation patterns in legumes. In 1977/78, ICRISAT's Farming Systems Research Program initiated studies of existing tank and well irrigation systems in two villages. At about the same time, it became clear that sufficient results on the watershed-based soil and water management systems were available to make it worthwhile to plan field tests of key portions of these systems, in collaboration with farmers and with research scientists in institutions of the Indian Council of Agricultural Research. Such tests in three VLS villages were initiated in the 1978/79 season. They are to be evaluated in 1981 after having been in operation three crop years.

The use of VLS sites in Indiafor ICRISAT's watershed development experiments has illustrated their value in providing background data for such research. For these villages, data on panel households provide a "comparison treatment" for the 3 years before and in every given year of the watershed study. Furthermore, one village in each region is used as a control to measure the hidden impacts of the presence of a substantial research effort in the other villages. Thus we have comparisons both "before and after" and "with and without. "

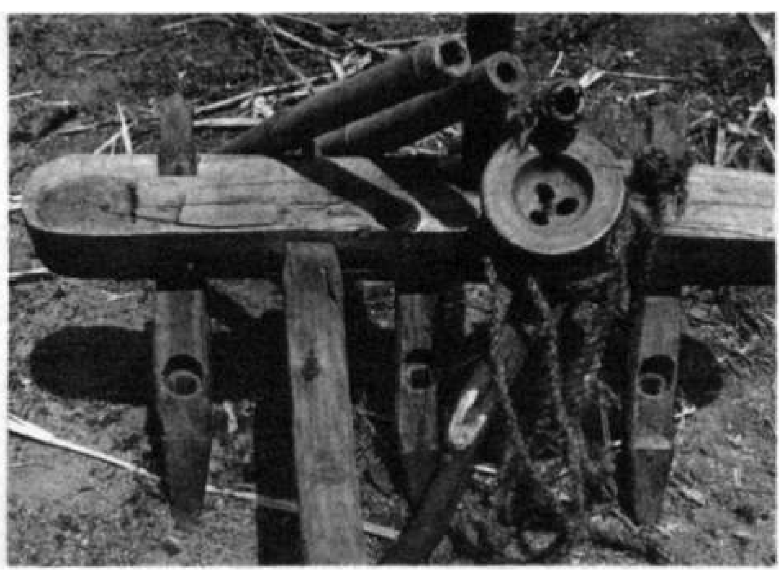
The time-series nature of the VLS offers a unique setting for inquiries that involve social, household, and agroclimatic variation. By combining features of ethnographic research, special-purpose surveys, farm management studies, village studies, and on-farm biological/technical experimentation, they provide flexibility in data collection and a rich and unique data bank. They perform the same function for the socioeconomic researcher that the experiment station or laboratory performs for the physical or biological scientist. By concentrating the analytical capability of a number of socioeconomic researchers inside and outside of ICRISAT on the same data, the VLS also produce complementarities that add to more than the simple sum of the individual results and insights.

Fertilizer Use in Semi-Arid Tropical India

Nearly two-thirds of the cropped area of India falls in the SAT, and only about one-third of this portion has well developed irrigation resources with high fertilizer use. The nonirrigated SAT uses little fertilizer. This vast region, characterized by low output and highly unstable agricultural systems supporting fairly high population densities, poses a great challenge. Research efforts over the past decade have shown that fertilizers can be a force for productivity gains for most dryland crops. Most past studies on fertilizer use in India have focused on irrigated areas and crops. In order to assess possibilities for improvement of semi-arid rainfed agriculture we need to understand what factors determine SAT farmers' decisions to use or not to use fertilizers on nonirrigated fields. This was the focus of an ICRISAT study on fertilizer use in SAT India (Jha 1980 and Jha and Sarin 1980, Economics Program progress reports 11 and 10). Preliminary results from this study were briefly reported in the 1978/79 ICRISAT Annual Report. A more detailed summary of the major conclusions is presented below. Tabular and multivariate regression techniques were used to analyze the following data:

1. District fertilizer consumption data from the Fertilizer Association of India.
2. Data from an Indian Agricultural Statistics Research Institute project to assess a high-yielding variety (HYV) promotion program carried out in 47 districts of India.
3. ICRISAT VLS data for 1975/76, 1976/77, and 1977/78.

Analysis of district-level data showed that the 192 SAT districts of India (those districts receiving between 500-mm and 1500-mm rainfall annually) accounted for nearly 73% of the national consumption of nitrogenous, 75% of phosphatic, and 70% of potassic fertilizers in 1977-79. However, over 62% of total fertilizer (N + P_2O_5 + K_2O) used in the SAT districts was consumed in the 78 "irrigated" districts (those having more than 25% irrigated area), which cover only 35% of the

Especially in assured rainfall areas, Indian SAT farmers use chemical fertilizers on sorghum and pearl millet when high-yielding varieties of these crops are available. Where soil conditions permit, fertilizer can be applied with locally manufactured drills such as the one shown on the left. On the right, the drill is dismantled to show the round distribution cone, the bamboo tubes, and the drill tines.

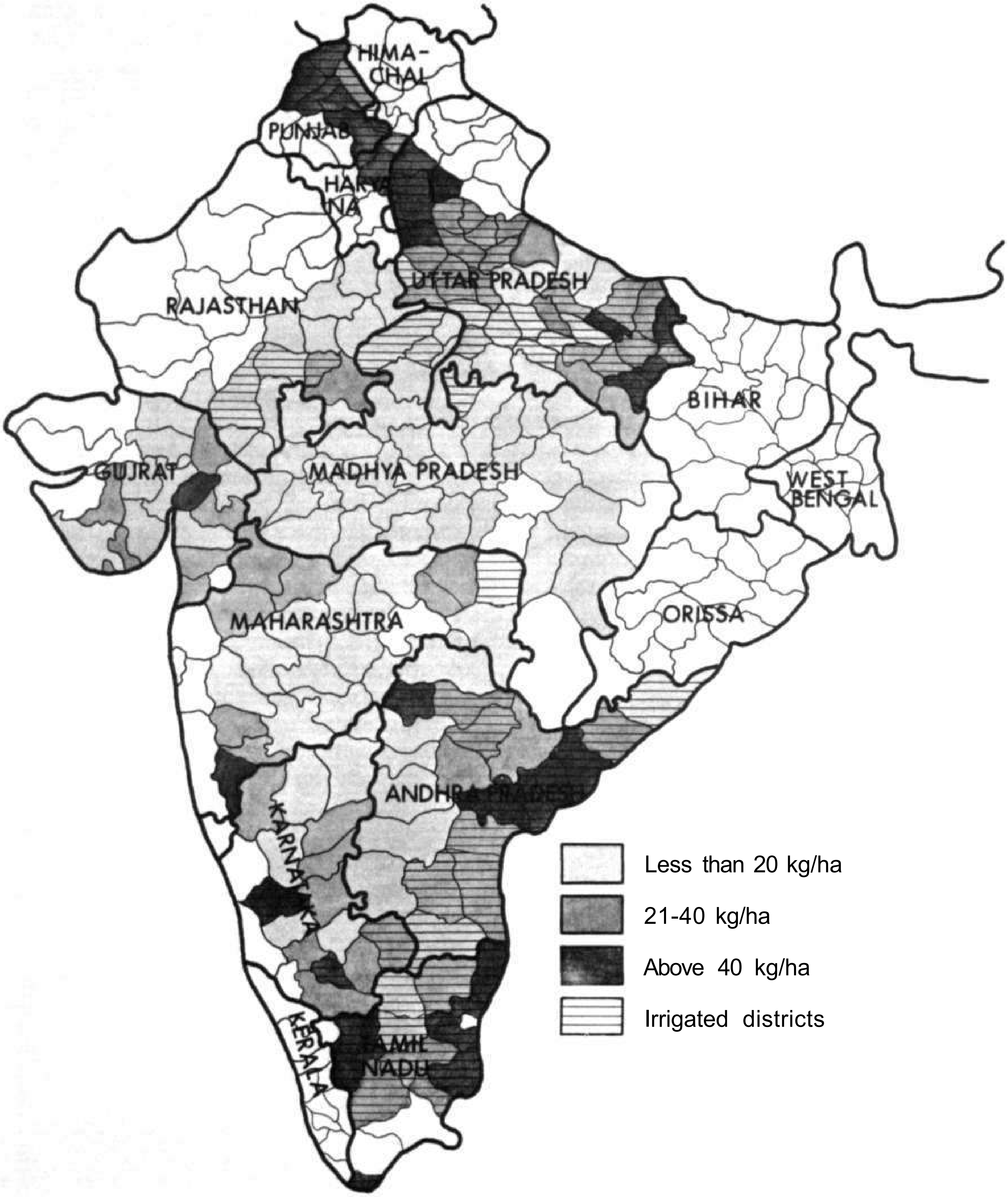


Figure 1. Average level of fertilizer* (N + P_2O_5 + K_2O) *consumption in kilograms per hectare of gross cropped area in semi-arid tropical India, 1976/77.

SAT cropped area. Thus, currently, irrigated lands receive most of the fertilizers used in the Indian SAT (Fig. 1): there is also some use of fertilizer on nonirrigated lands in areas receiving relatively high rainfall. The average level of fertilizer consumption per hectare of cropped land was 57 kg in the "irrigated" and 18 kg in the "nonirrigated" districts. Irrigated farming has provided the main source of growth in fertilizer consumption through the 1960s and 1970s. This trend is likely to continue because there is still considerable potential in irrigated lands in terms of expanding both crop area fertilized and rates of fertilizer application.

As would be expected, profitability of fertilizer application and assurance of response have been the major forces motivating fertilizer use in the Indian SAT. This high profit/low risk circumstance obtains primarily in irrigated areas, and in these areas fertilizer use diffusion has been high. In nonirrigated areas, diffusion has been slow and is characterized by intermittent rather than continuous use.

Our analysis of data on adoption of fertilizers and on extent and rates of fertilization for HYVs of sorghum and pearl millet in India raises doubts about two popularly held beliefs: First, the view that farmers in the SAT do not use fertilizers for low valued, inferior cereals was not supported by data, which showed that in one-third of the sorghum and 43% of the pearl millet districts studied, more than 80% of the farmers growing HYVs of these two crops used fertilizers. Application rates for HYVs of sorghum ranged from 11 to 117 kg/ha of total nutrients ($N+P_2O_5+K_2O$). For HYVs of pearl millet the range was from 8 to 141 kg/ha.

Second, the data contradict the view that nonirrigated pearl millet HYVs receive no fertilizers. In the major pearl millet-producing districts, more than 80% of the fertilizer adopters applied fertilizer to nonirrigated HYVs of pearl millet. The data showed that in more than 75% of the sorghum districts, more than 80% of fertilizer adopters applied fertilizers to nonirrigated sorghum HYVs.

It must be emphasized that our findings make it clear that the adoption of HYVs of these two crops has not been high, and the local varieties, which cover most of the area for these crops, are largely unfertilized. This suggests that it is not the low value of these crops that inhibits adoption of fertilization; *rather, it is look of fertilizer response in the traditional crop varieties and/or their risk under nonirrigated conditions that are responsible for their relatively low levels of fertilization.*

The application rates of fertilizer on SAT Indian farms are given in Table 1. These

Table 1. Fertilizer use on sorghum and on pearl millet hybrids in SAT India 1973-74.

Crop/treatment	N	P_2O_5	K_2O
	(kg/fertilized ha)		
Sorghum			
Nonirrigated	21-40	21-30	11-20
Irrigated	41-60	31-40	11-20
Pearl millet			
Nonirrigated	21-40	<20	<10
Irrigated	41-60	21-30	<10

Source: Indian Agricultural Statistics Research Institute, unpublished data.

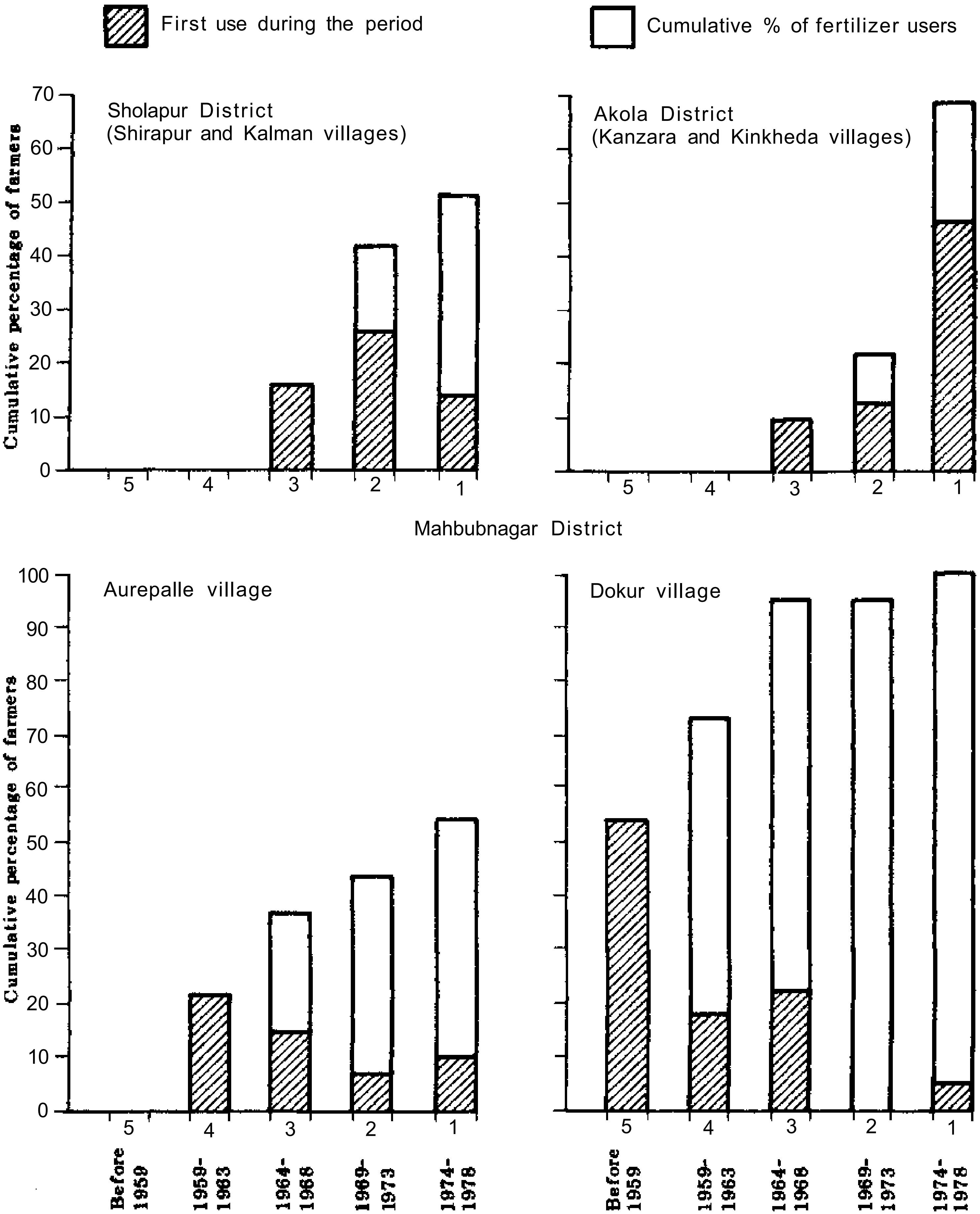


Figure 2. Adoption of fertilizer over time in ICRISAT's VLS villages.

rates were attained within 4-5 years after HYVs were introduced and have remained stable since then.

Results from analysis of ICRISAT's VLS data (Fig. 2) show that adoption of fertilizers was higher and consistent in highly irrigated areas (e. g., Dokur) and in areas where commercial crops were important (Akola District). The average level of fertilizer use was only 2 kg/ha of cropped area in the Sholapur District, an area of quite low and unstable rainfall. The average in Dokur was the highest at 39 kg/ha. Akola's villages used 7 kg/ha and Aurepalle village, 12. A significant fraction of even the irrigated land was not fertilized in these six villages. In Dokur, where over 50% of the cropped area is irrigated, around 30% of this irrigated land went without fertilizers. In other VLS villages the figures were much higher. These facts imply there is considerable scope for future growth in fertilizer use and productivity in the SAT. Mixed crops were not found to be fertilized under low rainfall situations. In relatively high rainfall areas such as Akola, mixed crops were generally fertilized at lower rates than sole crops (Table 2). The extent of area fertilized was higher for mixed crops based on HYVs.

The results suggest some guidelines for agricultural research as well as for development programs relevant for SAT agriculture:

1. Emphasis should be continued on fertilizer responsiveness in crop improvement work.
2. Classification of the SAT is needed to identify areas where stability-oriented

Table 2. Fertilizer use in two SAT Indian villages of ICRISAT's Village-Level Studies, 1975-78.[a]

		% crop area devoted to mixed cropping	% share of mixed crops in total fertilizer used on the crop	Rate of application (kg/fertilized ha) for					
				Sole crop			Mixed crop		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Sorghum	Local	97	65	20 (26)[b]	3 (66)	c (66)	11 (3)	6 (2)	4 (2)
	Hybrid	27	13	30 (64)	16 (35)	10 (35)	19 (25)	0	0
Groundnut		72	57	45 (11)	17 (34)	31 (11)	9 (29)	10 (28)	6 (20)
Cotton	Local	92	68	18 (70)	7 (55)	4 (45)	12 (18)	7 (13)	5 (13)
	Hybrid	39	41	47 (81)	23 (60)	13 (60)	36 (100)	22 (82)	15 (82)

a. Kanzara and Kinkheda villages in Akola District of Maharashtra State. Average rainfall, 817 mm/year; soils are predominantly medium-deep Vertisols.
b. Figures in parentheses indicate percentage of area fertilized.
c. Less than 0.5.

Table 3. Resource adjustments through land tenancy in six Indian villages (1975/76 to 1978/79).[a]

Village of partner in tenancy	Availability of land before and after transaction[b]			
	Per family worker[c]		Per bullock[c]	
	Before (ha)	After (ha)	Before (ha)	After (ha)
Aurepalle				
Landowner	1.1	0.9	2.6	2.1
Tenant	3.1	3.9	3.7	9. 8 (8. 7)[d]
Dokur				
Landowner	0.5	0.2	3.8	1.5
Tenant	0.6	0.8	1.2	1.6
Shirapur				
Landowner	1.7	0.4	30.9	5.8
Tenant	1.0	1.9	4.4	8.2 (7.4)
Kalman				
Landowner	1.7	0.9	18.3	5.5
Tenant	2.2	3.8	3.4	7. 2 (5. 8)
Kanzara				
Landowner	2.6	1.9	9.5	7.2 (5.8)
Tenant	1.5	1.9	3.4	5.1
Kinkheda				
Landowner	3.3	2.1	7.7	5. 0 (4. 5)
Tenant	1.1	1.7	1.9	4.0

Source: Page 21 in Jodha (1979; listed in "Publications"); an extension of previous work by Ryan and Rathore (1978. Factor proportions, factor market development and the development and transfer of technology. Seminar on Economic Problems in Transfer of Technology, 9-10 Nov 1978, Indian Agricultural Research Institute, New Delhi, India).

a. Based on details from 240 sample households and their partners in tenancy transactions in six villages. For Kalman and Kinkheda villages, data relate to first 3 years only.
b. Includes all cases of leased-in and leased-out land by sample respondents existing at the beginning of the field work and taking place during the subsequent 4 years. Land transfers resulting from termination of leases are excluded.
c. Includes details of all landowners and tenants where resource adjustment was the main reason for the tenancy transaction.
d. Figures in parentheses indicate the situation once land kept fallow is excluded from land availability per bullock.

crop improvement research programs would be likely to have the highest payoffs.

3. For pearl millet, improved and fertilizer-responsive varieties for nonirrigated conditions are needed.
4. Crop improvement and management technology for nonirrigated crops should be evaluated at relatively low fertility conditions.
5. Particularly for nitrogenous fertilizers, more information is needed on the most efficient ways to adjust fertilizer use according to changing soil moisture conditions throughout the crop season.

Tenancy, Labor, and Bullock Power

In order to achieve optimum or more full utilization of available resources like family labor or bullocks, farmers try to hire in or rent out such resources. How far this adjustment has been achieved over a 4-year period for farmers in ICRISAT's VLS through leasing of land is revealed by Table 3.

In the case of human labor and land, tenancy did not help equalize the ratios in four of the six villages. On the contrary, it made the labor/land ratios more unequal,except in Kanzara and Kinkheda. An important limitation of Table 3 is that it does not give any weight to irrigated land, which requires a larger input of human and bullock labor. However, irrigated plots were particularly important in only one VLS village, Dokur. There tenants and landowners both tended to have irrigated lands prior to and after tenancy transactions. This implies that tenancy transactions are not entered into primarily to adjust land availability with family labor availability. In view of the availability of employment possibilities on other farms via

Animal draft power is an important factor in food production in the Indian SAT. Here a traditional blade harrow is being used for weeding a field of groundnut.

the daily labor market, this is quite plausible.

Data on the adjustment between bullock availability and land availability through tenancy show different results. Except for Aurepalle, there was a clear trend towards reducing the gap in land availability per bullock between landowner and tenant after the tenancy transaction. Once lands kept fallow were excluded from the land available per bullock, the tendency towards equalization of land/bullock ratios for landowners and tenants was further strengthened. This suggests that tenancy does help in resource adjustment but that it is not the sole means available. Fallowing of land (resorted to mostly by large farmers) is another alternative available in this regard. Furthermore, as long as resources like bullocks and human labor are available for hire in markets, adjustment of resources by means of tenancy is not necessary. Even when there are large gaps in land/labor or land/bullock ratios on farms with varying resource endowments, in actual use the factor ratios tend to be equalized.

The fact that it is primarily the land/bullock ratios that are equalized through the operation of the land tenancy market and not the land/labor ratios suggests that the hired labor market operates more effectively in these villages than the hired bullock markets. This requires more detailed study.

Human Nature and the Design of Agricultural Technology

In the small-watershed development research being carried out at ICRISAT Center (Doherty 1980; listed in "Publications") two of the prospective technological options involve substantial investments: the improved, bullock-drawn wheeled tool carrier, or Tropicultor, and the small ponds for collection of runoff water to be used for supplementary irrigation of upland crops. Particularly from the point of view of the small and marginal farmer, these improvements could be attractive but might also be out of reach. At 1980 prices, the estimated cost of a Tropicultor with attachments (including a seeder and fertilizer drill) was Rs 10 000 ($1.00 = Rs 7.75 in late 1980). Table 4 shows that the average financial condition of small farmers is likely to make such a cost prohibitive.

Similarly in the case of runoff collection ponds there are difficulties. A 70-year simulation suggests that, on Alfisols in a climate similar to Hyderabad's, 8-16 ha might be an optimum catchment size (Ryan, Sarin, and Pereira 1980; listed in "Publications"). Yet Table 5 shows that most south Indian SAT farmers' entire individual holdings are much less than this.

Therefore it has been suggested that small groups of farmers might cooperate in owning and operating ponds for supplementary irrigation and Tropicultors. In the case of ponds, given the data in Table 5, we would expect any such groups to have 5-10 heads of households in SAT India. About the same number might be involved in the use of a single Tropicultor, if we project a range of 10-15 ha for the machine.

In order to assess the likelihood of achieving cooperation in such a group, we carried out a study of anthropological and sociological literature (Doherty 1980), which showed that in many societies, in different cultures, and at different levels of technological sophistication, small groups of around 5-9 members are common units for cooperative action. There is some persuasive social-psychological evidence that suggests this pattern of cooperation might be, at least in part, a constant based on human nature. At the same time, however, our study suggested that when uncoerced and/or unadministered such small groups were evanescent, while larger groups (well in excess of 100 members) seemed more suited to the formulation and enforcement of rules needed for long-term activity. However, large groups would be unlikely to show an interest in group ownership of Tropicultors. Similarly, large groups also would be unlikely to show an interest in administering a network of small ponds for supplementary irrigation when large tanks could satisfy more farmers at less administrative cost.

As a result of this study, we have formulated two hypotheses to be tested: first, farmers would prefer that small-sized sources for supplementary irrigation be privately owned; second, they would prefer individual ownership of Tropicultors.

If these hypotheses were to be borne out in the course of village-level study, there would be clear implications for directions that research might take on these two proposed technologies for the SAT. In the case of the Tropicultor, research would fo-

Table 4. Average financial condition of small farmers[a] in selected areas of SAT southern India, 1976/77 crop season.

Village	Land operated (ha)	Value, owned land (Rs)	Value, gross agricultural output[b] (Rs)	Value, owned implements (Rs)	Value, owned livestock (Rs)	No. of bullock pairs owned
Aurepalle (Andhra Pradesh)	1.36	2331	452	115	1471	0.20
Shirapur (Maharashtra)	1.38	7819	478	416	978	0.22
Kanzara (Maharashtra)	1.25	4256	2040	83	278	0.00

a. Data collected in the VLS of ICRISAT's Economics Program. Small farmers are defined in each case as a random sample of 10 farmers from the lowest of three land-holding strata in each village. Further details are in Jodha, Asokan, and Ryan (1977; Economics Program occasional paper 16).

b. Figures in this column are for the 1975/76 season. The very high value of gross agricultural output shown for small farmers in Kanzara is due in large part to the widespread cultivation of cotton in this village.

Table 5. Owned farmland (hectares) in three villages of SAT southern India, 1975/76 crop season.

	Aurepalle	Shirapur	Kanzara
Mean	5.46	4.31	5.29
Median	2.60	4.05	3.14
Range	0.32-38.58	0.81-9.72	0.81-28.50

cus on reducing its cost and/or on institutionalizing means whereby such a machine might be rented easily and cheaply by farmers. In the case of ponds, researchers might be advised to assess possibilities for land consolidation or for the improvement of existing, larger irrigation tanks, to mention only two options.

Markets for Hired Labor in VLS Villages

During 1979/80 the Economics Program carried out a comparative study in all six southern Indian VLS villages to describe major features of the markets found there for long-term and daily hired labor (Binswanger et al. 1979; listed in "Publications"). The results of this survey have important implications for designingpolicies to improve the economic condition of Indian agricultural laborers and small farmers who depend on wages for a substantial portion of their income.

Both daily and long-term wages were higher, and the subsidiary terms of long-term labor contracts seemed more beneficial, for the laborers in villages where high levels of alternative demand existed (Table 6). The presence or absence of substantial labor demand influences conditions in all markets. In the two Akola villages, steady agricultural labor demand and demand from nearby government projects combine to put laborers into a superior bargaining position, which is reflected in high wages and incomes in all markets. Annual labor contracts have given way largely to shorter-term contracts that enable laborers to shift to the market with the most attractive terms over the course of the year. This high level of alternative

Table* 6. *Monthly salary arrangements* (*in rupees*) *for long-term farm servants* (*plowmen*), *and daily hired labor Incomes in six VLS villages, ICRISAT 1979/80 survey.

District/ village	Range of cash payments for long-term farm servants[a]	Range of cash equivalents of total monthly wages of long-term farm servants including payments in kind[a]	Monthly daily-wage equivalent 1975/76[b]	Income from hired labor participation per family 1976/77
Mahbubnagar				
Aurepalle	Nil	43	53	603
Dokur	70+	73 - 121	59	963
Sholapur				
Shirapur	42 - 63	77 - 98	54	985
Kalman	75 - 105	75 - 105	75	
Akola				
Kanzara	120 - 150	120 - 150	62	1416
Kinkheda	120 - 150	120 - 150	76	

a. Adjusted to 1975/76 prices.

b. Calculated on the assumption that a permanent servant is willing to work for daily wages 30 days/month but subject to the village average involuntary unemployment probability, derived from Ryan, Ghodake, and Sarin (1980; listed in "Publications").

demand may have led as well to substantial erosion of the role of caste in controlling access to labor opportunities, although sexual divisions of labor market access seem to have been fully maintained here as elsewhere. It seems that the operating factor improving laborers' bargaining positions has been the growth of an agroeconomic environment in which there is steady demand for labor from a variety of sources. Moreover there is evidence that the Maharashtra State Government's Guaranteed Employment Scheme has been instrumental in consolidating these gains in the conditions of rural labor, providing an important addition to the factors of labor demand that began to grow at least a hundred years ago with the rapidly increasing importance of cotton in the area.

In Sholapur District, alternative labor opportunities have existed for a long time, since the city of Sholapur is an important textile mill town, and since there is also a long history of drought-relief public works in that area. While less well off than their Akola counterparts, laborers in Sholapur still enjoy relatively favorable conditions. A recent intensification of government projects in the Sholapur area also seems to have led to a decrease in the importance of long-term farm servant positions and made the terms of such employment more flexible.

While Dokur has neither nearby government projects nor an urban labor demand, a strong labor demand deriving from irrigation and opportunities for seasonal labor migration appear to have led to relatively substantial labor incomes (compared to a standard monthly wage equivalent calculated on the basis of daily labor market wages). The migration opportunities provide an alternative source of loans and employment for men who would otherwise take long-term farm servant positions in the village, and these have virtually replaced this kind of monthly paid work for adult males.

Laborers in Aurepalle, where there are few alternatives to agricultural labor demand, are penalized in all markets. Lack of nearby alternatives for laborers appears to allow farmers to exercise monopsony control in at least the market for plowmen. This is the only village in which payments to plowmen on long-term contracts fall substantially short of the standard monthly wage equivalent based on employment in the daily labor market, and this shortfall may be interpreted as a monopsony profit.

Villagers' Preferences for Sorghum Qualities

Previous analysis of urban market prices of sorghum (von Oppen 1978, Economics Program discussion paper 7) indicated that high prices were significantly associated with such desirable characteristics as light color, large seed size, and absence of molds. Preferred cryptic characteristics such as good swelling capacity, high protein content, and high fat content were also important.

It has also been argued that quality preferences as derived from urban market prices may only reflect urban consumers' preferences and not those of the rural masses (Bapna and von Oppen 1980, Preference for sorghum qualities among village consumers; Economics Program mimeographed paper).

In order to help resolve such issues, the Economics Program at ICRISAT is endeavoring to determine whether consumer preferences for particular food grains are the same from one region to another, from one season to the next, and for urban and rural consumers, as well as across income groups. Our hypothesis is that, regardless of where in the urban environment consumer preferences are measured, the results will not be statistically different; and preferences expressed by rural consumers will be congruent with preferences measured on the basis of urban market prices.

To test this hypothesis, we conducted an experiment in Kanzara village, one of the villages in the Economics Program's VLS.

The village is located in Akola district of north central Maharashtra State, about 500 km north of Hyderabad. Sorghum occupies an important place in the cropping pattern of the village and in the consumption pattern of the people.

Various sorghum varieties were purchased from the Hyderabad wholesale market on a particular day. Our panel members prepared and ate food from the Hyderabad sorghum samples given to them in order to form an opinion on their quality. Fifteen varieties with a price range of Rs 0.91-1.42/kg were used in the study. Alphabetic codes were randomly assigned to the varieties, two of which were selected as reference varieties. Each respondent was given two to three varieties of sorghum to consume each day.

Local helpers were employed to distribute the samples, and the double-blind procedure was used. The panel member was shown only the alphabetical names of the samples, while their prices remained unknown to him. Grain (which villagers had to grind before preparing their usual type of flat bread) and flour samples were distributed on a random basis to the panel members. The use of grain as well as flour allowed us to test whether the respondent's preferences depended more upon evident grain characteristics or upon the qualities of the flat bread made from it. The decision to supply grain or flour was determined randomly for each respondent. As a consistency check on the consumers' capabilities of distinguishing varieties, ten respondents, selected randomly, were given flour packets that were of the same variety except that one packet was labeled and the other unlabeled. Nine of the ten clearly stated that they did not find any difference in the varieties.

The consumer panel consisted of 40 respondent heads of household in the ongoing VLS: 30 farmers (with small, medium, and large farms) and 10 agricultural laborers. Thus, the sample was a cross section of all the economic and social strata in the village. To test consistency in answers, we replicated the experiment four times.

The following conclusions emerged from the experiment:

1. Estimated consumer preferences using a previously derived index based on evident and cryptic grain qualities for market samples in Hyderabad concur with preferences of laborers and small and medium farmers in Kanzara village in Maharashtra.
2. Small and medium farmers and also laborers are more successful than large farmers in assessing sorghum qualities in line with market prices. Large farmers were more likely to eat wheat regularly, not sorghum, and were less consistent in expressing preferences. In selecting panel members for future studies of this kind in such areas, small and medium farmers and laborers should be given preference over large farmers.
3. Assessments were consistent, whether the sample was in the form of grain or flour. This indicates that not only evident but also cooking and other cryptic characteristics influence consumer preferences, as evident characteristics are made undetectable by grinding. Thus plant breeders must take cryptic characteristics into consideration when selecting for good consumer acceptance.
4. Consumer preferences measured in Kanzara village were more closely related to preferences predicted on the basis of breeders' judgements and laboratory tests of cryptic characteristics than to actual market prices. This may be because preference predictions derived from the analysis of market prices of many other samples are more reliable than actual market prices, which are subject to certain degrees of randomness. The implication of this finding is that for future panel tests with village consumers it may be sufficient to use any set of breeders' samples instead of market samples and to compare only the predicted preferences (and not actual market prices) with consumer rankings.

Market Efficiency for Crops in SAT India

Market margins and price correlation analysis were compared as measures of relative marketing efficiency for ICRISAT's five mandate crops in three markets of Andhra Pradesh (Raju and von Oppen 1979, 1980; see "Publications"). The data used were from a survey of market committees, traders, millers, retailers, and farmers in 1975/76.

Margins at different points in the marketing chain for the selected crops and markets were estimated with the help of the concurrent method, using annual average prices. Predictably, the results indicate that the producers' share in the consumers' rupee decreased with increases in the amount of services required for transformation of the raw product into a consumable commodity. Wholesale traders' gross margins decrease as one goes from sorghum and pearl millet to chickpea and pigeonpea and to groundnuts. The retailers' gross and net margins in percentage terms remained about the same across crops, but in absolute terms these margins increased with the increase in value of, and services required for, producing and retailing the final commodity. The estimates of marketing margins in each of the three markets showed significant differences between markets at all trade levels.

For correlation analysis, this study used weekly market prices of the 1974/75 crop year for the five selected crops collected from the price records of 29 markets included in a wider survey. Among these crops, pigeonpea shows the highest correlation of market prices between pairs of markets, followed by chickpea, pearl millet, sorghum, and groundnut. Compared with correlation coefficients of weekly prices, daily prices produced higher correlations for three of the four crops. This is probably due to the fact that, especially for crops with varying market arrivals, simple averaging of daily prices into weekly prices without taking the weights of daily market arrivals introduces random variation, which is reflected in lower correlations of weekly prices compared to daily prices.

An experiment using existing price series from two markets and assuming a 50% increase in traders' margins was conducted to study its impact on price correlation. Results showed a significant decrease in price correlation coefficients only for those crops that have high initial price correlation coefficients.

Workshop on Yield Gap Analysis

In February 1980 an international workshop was held at ICRISAT on the gap between yields obtained at experiment stations and demonstration plots and those obtained by SAT farmers. This is reported in more detail in the "International Cooperation" section, "Conferences, Workshops, and Seminars."

Looking Ahead

In the coming years we plan to monitor and understand the variations in and constraints to adoption of new technologies in the SAT. Where technologies have been partially adopted, we will attempt to explain the reasons for differences between the performance of these technologies under research conditions and in farmers' fields. These studies will involve continued collaboration between agricultural and social scientists in ICRISAT and national programs.

During the past 3 years, our on-farm research in three SAT Indian villages has included the underwriting and subsidization of improved soil, water, and crop management technology by ICRISAT. After the 1980/81 season this financial assistance will cease, and we will monitor farmers' reactions to assess their adoption patterns and evaluate the effects of the technology.

Research will be initiated on the likely consequences of new technology for production, prices, consumption, and welfare in SAT India. This will draw on previous research we have conducted on market supply and demand elasticities for sorghum, millet, pulses, and groundnuts.

The administrative, technical, and economic feasibility of a Tank Irrigation Authority in South India will be studied. Previous research in the Economics Program suggests there may be substantial benefits in improving the management of traditional tanks in this manner.

In the coming year we will initiate studies to determine farmers' preferences for private versus group ownership of the Tropicultor and of small sources for supplementary irrigation.

Studies on the relationship between farmers' risk aversion, yield risk, and genotype selection criteria will be completed.

An evaluation will be made of the desirability of incorporating an economics research component into ICRISAT's emerging East African Program.

We propose to initiate research into the use of common property resources such as groundwater, pastures, and forest lands. This will embrace the issues of public versus private costs, and social organization.

We will also monitor the development of technologies aimed at generating alternative energy sources and assess their economics in the context of SAT agriculture.

Publications

Institute Publications

ICRISAT. 1980. Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, 19-23 Feb 1979, Hyderabad, India. (Available from ICRISAT, Patancheru, A. P. 502 324, India).

Journal Articles

Raju, V.T., and von Oppen, M. 1979. Marketing margins and price correlations as measures of marketing efficiency for important crops in SAT India. Indian Journal of Agricultural Economics 34(4):217. (Abstract.)

Conference Papers

Binswanger, H. P., Doherty, V.S., Balaramiah, T., Bhende, M.J., Kshirsagar, K. G., Rao, V. B., and Raju, P. S. S. 1979. Common features and contrasts in labor relations in the semi-arid tropics in India. ADC-ICRISAT Conference on Adjustment Mechanism of Rural Labor Markets in Developing Areas, 22-24 Aug, ICRISAT, Patancheru, A. P., India.

Binswanger, H. P., and Ryan, J. G. 1980. Village-level studies as a locus for research and technology adaptation. Pages 121-129 *in* Proceedings of the International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, ICRISAT, Patancheru, A. P., India.

Doherty, V.S. 1980. Human nature and the design of agricultural technology. Pages 107-119 *in* Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, 19-23 Feb 1979, Hyderabad, India.

Jodha, N. S. 1979. Agricultural tenancy in semi-arid tropical parts of India. ADC-ICRISAT Conference on Adjustment Mechanism of Rural Labor Markets in Developing Areas, 22-24 Aug, ICRISAT, Patancheru, A. P., India.

Raju, V. T., and von Oppen, M. 1980. Rural marketing and interregional trade in India. National Seminar on Settlement

Systems of India, 20-23 Mar, Osmania University, Hyderabad, India.

Ryan, J.G., and Binswanger, H.P. 1980. Socioeconomic constraints to agricultural development in the semi-arid tropics and ICRISAT's approach. Pages 57-67 *in* Proceedings of the International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer, 28 Aug-1 Sept 1979, ICRISAT, Patancheru, A. P., India..

Ryan, J. G., and Ghodake, R.D. 1979. Labor market behavior in rural villages of South India: effects of season, sex and so socioeconomic status. ADC-ICRISAT Conference on Adjustment Mechanisms of Rural Labor Markets in Developing Areas, 22-24 Aug, ICRISAT, Patancheru, A. P., India.

Ryan, J. G., Ghodake, R.D., and Sarin, R. 1980. Labor use and labor markets in semi-arid tropical rural villages of peninsular India. Pages 357-379 *in* Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, 19-23 Feb 1979, Hyderabad, India.

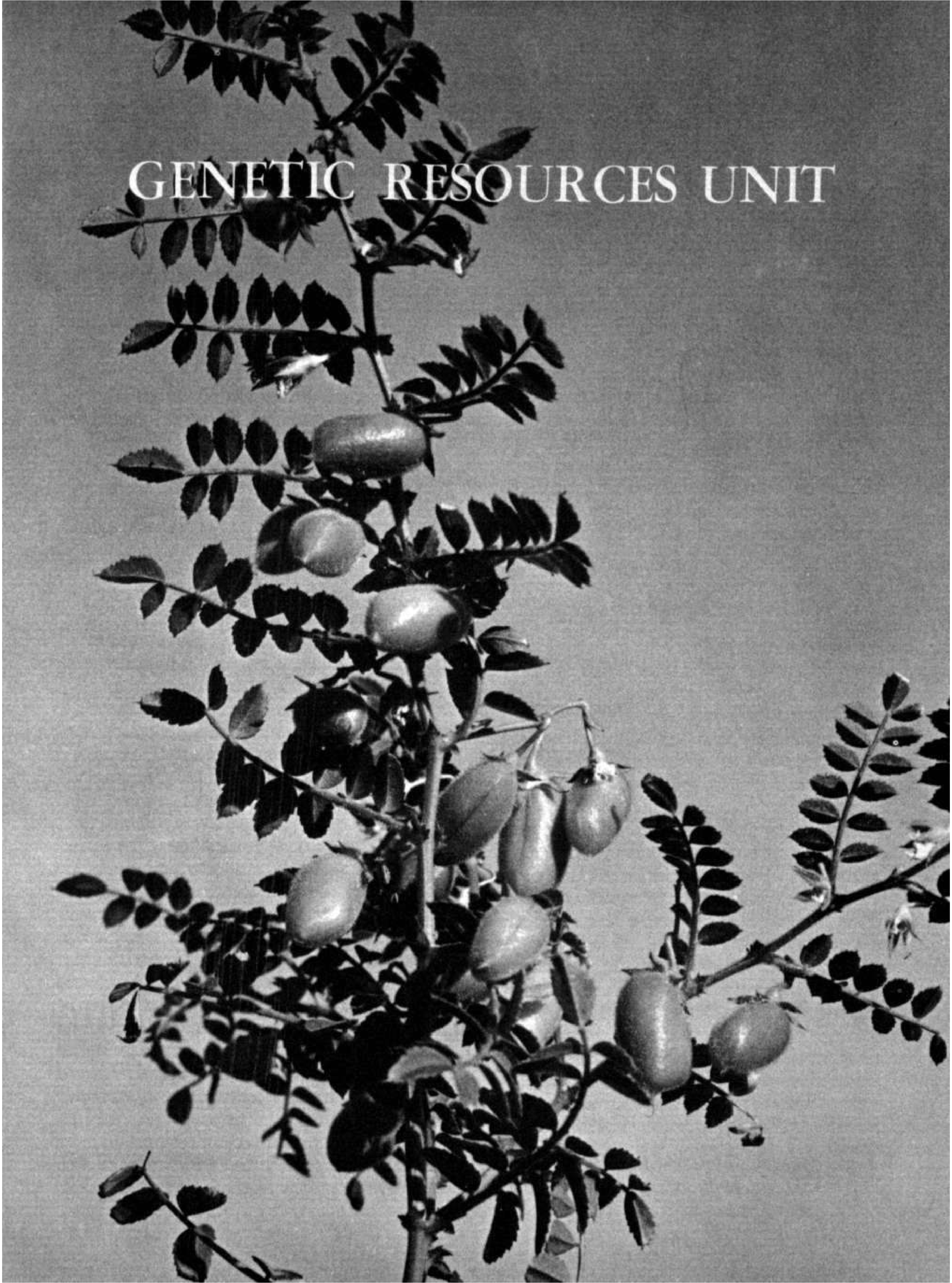
Ryan, J.G., Sarin, R., and Pereira, M. 1980. Assessment of prospective soil-, water-, and crop-management technologies for the semi-arid tropics of peninsular India. Pages 52-72 *in* Proceedings of the International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, 19-23 Feb 1979, Hyderabad, India.

von Oppen, M., and Subba Rao, K.V. 1980. Tank irrigation in semi-arid tropical India. National Seminar on Economic Criteria for Fixation of Irrigation Charges for Various Sources of Irrigation, 18-20 Mar, Indian Agricultural Research Institute, New Delhi, India.

Theses

Rathore, M.S. 1979. Factor combination and resource use efficiency on small and large farms—a comparative study of hill agriculture and the semi-arid tropics. Ph.D. thesis, Dept. of Agricultural Economics, Himachal Pradesh University, Simla, India.

GENETIC RESOURCES UNIT



Contents

Section cover: the cover photograph Illustrates a prolific chickpea accession with three pods per axil instead of the usual one pod.

GENETIC RESOURCES UNIT

Established on 1 January 1979 to serve as a major center for the collection, evaluation, maintenance, documentation, conservation, and distribution of germplasm of the mandate crops, the Genetic Resources Unit (GRU) maintains several types of germplasm collections:

1. Accessions 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 stocks collection—selfed lines with known and useful genetic traits for special qualities and/or resistance to stresses of disease, insects, drought, *Stviga,* etc.
5. Conversion collection — converted lines with particular characteristics, tall or short, photosensitive or insensitive, late or early, etc.
6. Other types of collections, such as basic, bulks, and population, are being developed.

Consolidated efforts continued to obtain geographical and genotypic representation of the five ICRISAT mandate crops and six minor millets. Table 1 gives the number of germplasm accessions collected or donated in the 1979/80 reporting year. The major source of the new accessions was expeditions which we carried out or collection programs in which we participated with the International Board for Plant Genetic Resources (IBPGR) and national organizations. Other samples were obtained through correspondence and often served to fill gaps in collections assembled earlier.

The main thrust of collection continued to be on the African continent, where countries like Botswana, Somalia, Sudan, Tanzania, and Zambia were explored for original landraces, mainly of cereals, while pulses collection trips were directed to Nepal, Thailand, Burma, Sri Lanka, and various regions in India. Groundnuts were obtained from India, China, Malawi, Nigeria, USA, and Zimbabwe. The reference herbarium was further enriched with voucher specimens of related wild species, weeds, and companion species.

Evaluation and rejuvenation was carried out separately or in combination in the appropriate seasons in one or more locations, including ICRISAT Center. Data obtained are stored in computer disk files for retrieval when required for documentation of lists or particular characters, or planning of further collection efforts.

Sorghum Germplasm

This year 1399 new accessions were added to the sorghum gene bank, raising the total to 17 986 from 68 countries. In addition, more than 6500 samples are presently in quarantine or transit and expected to be released. Sorghum was the main target of collections in Somalia, Sudan, Botswana, and Zambia.

As demand for seeds remained heavy, 6836 accessions were rejuvenated for seed increase. Screening germplasm for resistances in collaboration with other disciplines has been intensified: 7874 cultivars were under test for shoot fly resistance and 6600 for stem borer resistance at Hyderabad and Hissar; 324 lines of Indian and Sudanese origin appeared promising for shoot fly resistance.

In order to utilize tropical, tall, photoperiod-sensitive germplasm in the breeding program, the conversion program continued, using the landrace cultivars of subrace Zera-zera(race caudatum), and 2219-B as donor parent for daylength insensitivity. The material is in the F_2 stage.

Table 1. New germplasm accessions acquired during 1979/80 and total in ICRISAT Center's gene bank.

Country of collection/ donation	Sorghum	Pearl millet	Pigeonpea[a]	Chickpea	Groundnut	Minor millets
Bangladesh	0	0	0	33	0	0
Botswana	9	0	0	0	0	0
Chad	13	0	0	0	0	0
Chile	0	0	0	146	0	0
China	0	0	0	0	2	25
Ethiopia	205	0	0	0	0	0
India	5	747	7	280	0	518
Indonesia	13	0	0	0	0	0
Kenya	432	0	0	0	0	253
Malawi	311	221	0	3	34	0
Mexico	0	0	0	93	0	0
Nepal	1	0	0	39	0	0
Nigeria	81	0	0	0	24	0
Senegal	8	0	0	0	0	0
Somalia	0	3	0	0	5	0
South Africa	11	0	0	0	0	0
Sudan	183	0	0	0	0	0
Syria	1	1500[b]	0	0	0	464
Tanzania	0	136	0	0	0	0
Uganda	17	0	0	0	0	0
USA	35	0	0	0	618	6
USSR	2	0	0	2	0	191
Others	72	0	0	2	1	7
Total acquired in 1979/80	1399	2607	7	598	684	1464
Total in gene bank	17 986	14 074	8815	12 195	8363	3540
In transit	6592	297	225	1871	912	715

a. Almost all new accessions still in transit as on 31 May 1980.

b. Probably duplicates.

Members of the FAO/IBPGR Advisory Committee for Sorghum and Millet Germplasm visit ICRISAT's Genetic Resources demonstration field.

Pearl Millet Germplasm

We received 2607 pearl millet germplasm accessions this year, raising the total number to 14 074 from 25 countries, and 297 additional accessions are in quarantine or transit. Collections were made in Malawi (Shire Valley, Central and Southern provinces) and Tanzania (Morogoro, Irringa, Dodoma, and Singada areas), both in collaboration with the Ministries of Agriculture and IBPGR; and one in Uttar Pradesh, India, was made jointly with the Indian Council of Agricultural Research (ICAR) and the C.S. Azad University of Agriculture and Technology, Kanpur.

Reintroduction from ICARDA (Syria) of 1622 IP lines originally assembled by the Rockefeller Foundation enabled us to fill many gaps in our IP collection.

During the rainy season 2885 accessions from Mali, the Central African Republic, Cameroon, Senegal, Niger, Kenya, and India were tested for various morpho-agronomic characters. The working collection, now totalling 552 lines, and genetic stocks were also evaluated. An ORSTOM representative evaluated the African material, the phenotypic expression of which is often quite different from that in its original habitat.

Some accessions produced earheads representative of various landraces. Some cultivars from Tamil Nadu, India, were found to have sweet stalks (8.6-11.9% sugar content, compared to the usual 2.3-5.1%). The range in characters was very wide: 50% flowering ranged from 33 to 135 days, plant height from 30 to 475 cm, spike length from 5 to 165 cm, spike diameter from 1.5 to 7.7 cm, and 1000-seed weight from 2.34 to 12. 84 g. The earliest cultivar was Bhilodi from Gujarat, India; M-67-2, originating in Tanzania, produced the thickest heads (7. 7 cm).

The working collection was crossed with the male-sterile line 5141-A to identify restorer and maintainer lines. Of the 435 F_1 hybrids, 79 restorers and 74 maintainers were identified.

Pigeonpea Germplasm

In multipurpose collection trips, pigeonpea landraces were obtained from Sri Lanka, Thailand, Burma, West Nepal, and India (Punjab). Wild relatives of the pigeonpea (subtribe Cajaninae) were collected in the Western and Eastern Ghats of India, *including Atylosia cajanifolia from* the *locus classicusin* the forests of the Puridistrict. *A. goensis* and *A.volubilis* were collected in Thailand. *A. goensis* appeared to be more common in the Karnataka ghats than was earlier thought. *A. volubilis,* including an endemic variety, was found in Burma.

The number of accessions in our pigeonpea world collection totalled 8815 in June 1980, of which 8189 are from India. Wild relatives amount to 129 accessions belonging to 36 species of six genera.

In all, 1517 lines were grown, 1100 for evaluation and seed increase and 407 for rejuvenation. The new material from India, Burma, Kenya, and other countries was

Wild relatives of pigeonpea maintained in the botanical garden at ICRISAT Center, evaluated, A replicated yield trial of 36 selected germplasm lines, standard check cultivars, and elite breeding lines resulted in the highest yield of 1654 kg/ha for ICP-6982, a field collection from Andhra Pradesh; the yield of BDN-1 was 1534 kg/ha.

During the year, the unit screened 4540 lines for photosensitivity, and 738 were found to be less photoperiod sensitive.

In the perennial trial, cultivars ICP-9892 (ICP-5733-1) and ICP-9970 (ICP-8121-8) were most affected by senescence. The best yielder was ICP-9991 (ICP-8155-8) with 2071 kg/ha obtained in two pickings. The yields from perennating lines will be compared with those of the new crop, up to a total of four seasons.

Our germination tests showed that after 4 years at ambient room conditions of temperature and humidity pigeonpea seeds lost viability (e. g., ICP-2624 germinated to 53%, and ICP-6997 died). In the temporary cool room (15-20°C), viability of ICP-6997 dropped to 85% after 3 years and 77% after 4 years, while all other cultivars remained over 90% viable. In ambient room conditions, plastic bottles were better than paper or cloth bags; at the temperature of the temporary cool room, containers did not differ in performance.

Our pathologists screened large amounts of germplasm and identified 31 cultivars resistant to wilt, 66 to sterility mosaic (SM), 122 to *Phytophthora* blight, 12 to wilt plus SM, 3 to wilt plus blight, and 17 to SM plus blight.

The taxonomical revision of *Atylosia* and *Cajanus* has been completed and will be published in 1981. In total, 32 species more closely related to the pigeonpea are distinguished in one genus, *Cajanus,* The revision describes new species from Australia and the Philippines.

Chickpea Germplasm

ICRISAT's world chickpea collection is the most complete of all ICRISAT crops, as far as can be ascertained. However, some gaps remain and collection will continue. The Indian Punjab was explored to ensure adequate and well-documented coverage. Samples were also collected from the Western Tarai of Nepal and Burma.

The chickpea collection now totals 12195 accessions. Careful editing of the passport descriptor computer file caused some shifts in accession numbers, because the station of selection or geographical indication of the accession name (identity) are considered to be more important or appropriate than the station that supplied the seeds.

At ICRISAT Center and at Hissar 2634 and 1328 germplasm accessions, respectively, were grown for morpho-agronomic evaluation. In Hyderabad, growth was average; at Hissar it was poor due to soil problems.

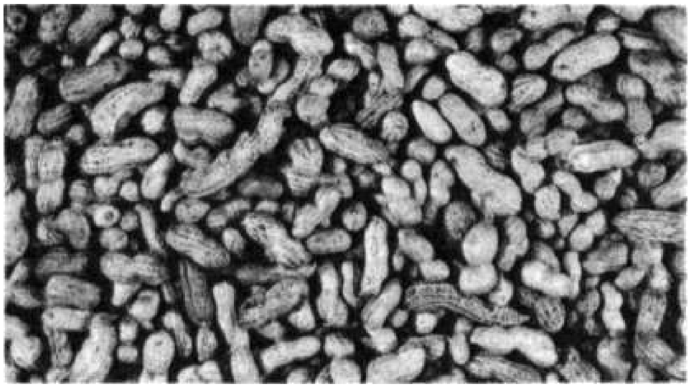
Viability of different chickpea cultivars varied between 83 and 49% after 28 months of storage at cool conditions (15-20°C, 50% RH) and dropped to between 57 and 19% at room temperature.

Colchicine-treated young chickpea seedlings produced sectorial tetraploids; seed treatment induced fully tetraploid C_1 plants at a very low frequency. A study of chickpea root tip chromosomes showed that the 16 somatic chromosome number included one pair of satellite chromosomes.

Groundnut Germplasm

The existing collection was enriched with 684 accessions, raising the total to 8363. New accessions of wild species include *Arachis rigonii,A. hagenbeckii,A. repens,* many accessions of the section *Rhizomatosae,* and five unnamed species. About 900 samples are in quarantine and are expected to be released.

About 5200 accessions were rejuvenated and simultaneously evaluated for various morpho-agronomic characters. Many cultivars were screened by ICRISAT pathologists, entomologists, virologists, and microbiologists; results are discussed in reports of the programs concerned.



Groundnut pods showing wide genetic variation in size and shape.

The IBPGR/ICRISAT committee on groundnut germplasm recommended in September 1979 the formation of a subcommittee on groundnut descriptors. The subcommittee was formed and met once in the USA, and the descriptors are being completed. ICG numbers have been assigned to 8122 accessions.

Minor Millets Germplasm

Germplasm of six important minor millets is being collected and assembled in the ICRISAT gene bank, as requested by IBPGR and approved by the Governing Board of ICRISAT. As major emphasis is given to the collection of ICRISAT's mandate crops, almost all of the germplasm of the minor millets has so far been assembled through correspondence or donations.

This year 1464 accessions were received from ICARDA (Syria), Kenya, China, the USA, the USSR, and India. The total number of all six minor millets has now reached 3540, while 715 samples are in quarantine or transit. These include material from Malawi, Zambia, Nepal, Ethiopia, Tanzania, and the USA.

Late in the rainy season, 2363 accessions were rejuvenated to raise enough seeds for distribution. Evaluation of the most important morpho-agronomic characters was continued for the new accessions.

Germplasm Distribution

Germplasm distribution is a major task of the Genetic Resources Unit. The seeds are supplied free of charge to all scientists around the world for use in research pro-

Table 2. Germplasm distribution of ICRISAT mandate crops and minor millets in 1979/80.

Receiving areas/countries	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets
India	3192	3220	1195	1127	1958	1032
Asia excluding India	606	12	273	237	253	326
Africa	2519	126	226	20	217	837
America	281	286	11	10	3	863
Oceania	397	0	0	64	50	0
Europe	184	130	12	12	56	38
Total	7179	3774	1717	1470	2537	3096
Total to SAT countries	5841	3427	1343	1166	2188	1944
Total to other countries	1338	347	374	304	349	1152

grams. Germplasm distribution of all crops in the ICRISAT mandate and of the six minor millets increased again this year. Table 2 gives the number of samples supplied in 1979/80.

Looking Ahead

In order to achieve the goals set at the initiation of ICRISAT and consolidated with the establishment of the Genetic Resources Unit, we will:

- continue to obtain appropriate representation of mandate crop genotypes through planned collections in priority areas. As funds become available, we will launch minor millets collections in areas where they are facing extinction.
- continue systematic evaluation of the germplasm at ICRISAT Center and other biologically suitable locations in India, Africa, and elsewhere.
- improve collaborative links with national and international organizations and genetic resources workers.
- conserve seed samples in medium-term storage (+4°C, 30-40% RH).
- plan the required new laboratories and long-term cold storage facilities (-18°C), which will be ready in mid- 1980.

Publications

Journal Articles

Prasada Rao, K.E., and House, L.R. 1979. Introgression of exotic germplasm. Sorghum Newsletter (North America) 22:6.

Prasada Rao, K.E., and Mengesha, M.H. 1979. Assembly of sorghum germplasm at ICRISAT. Sorghum Newsletter (North America) 22:6-7.

Prasada Rao, K.E., and Murty, D.S. 1979. A *basmati* (scented) sorghum from Madhya Pradesh. Current Science 48-18:824-825.

van der Maesen, L. J. G. 1979. Genetic resources of grain legumes in the Middle East. Pages 140-146 *in* Proceedings, Food Legume Improvement and Development, an ICARDA/IDRC workshop held on 2-7 May 1978 at the University of Aleppo, Aleppo, Syria (eds., Hawtin, G. C., and Chancellor, G. J.).

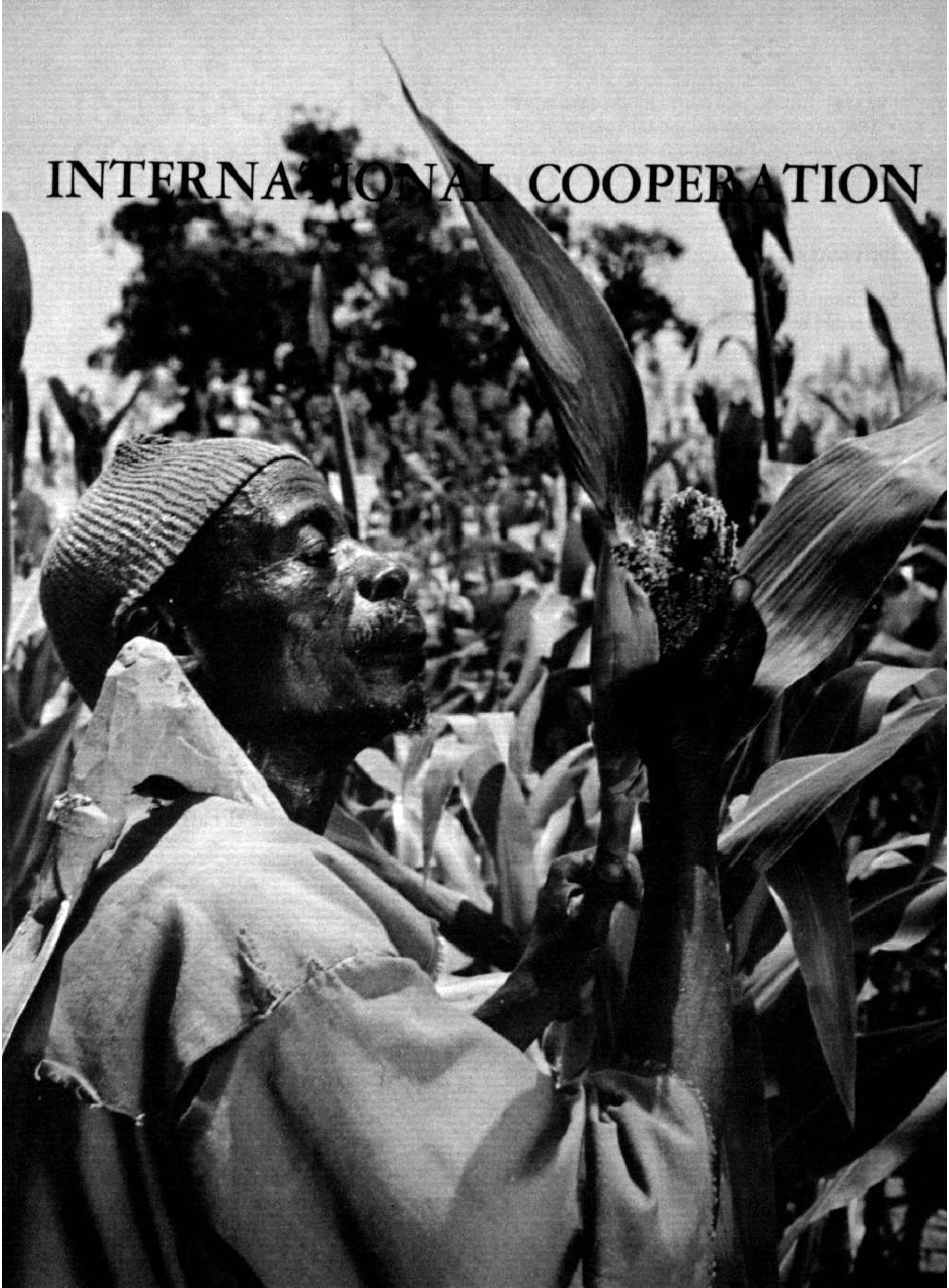
van der Maesen, L. J. G. 1980. Wild pigeonpeas in Africa. Plant Genetic Resources Newsletter 40:8-10.

van der Maesen, L.J.G. 1980. Observations on pests and diseases of wild *Cicer* species. Indian Journal of Plant Protection 7-1:39-42.

Miscellaneous Publications

Auckland, A. K., and van der Maesen, L.J.G. 1980. Chickpea, Chapter 15 (pp 249-259) *in* Hybridization of Crop Plants (eds., Fehr, W.R., and Hadley, H.H.) Madison Wis. (USA): American Society of Agronomy and Crop Science Society of America.

INTERNATIONAL COOPERATION



Contents

INTERNATIONAL COOPERATION

Introduction

During the 1979/80 crop year, we significantly increased the amount of work undertaken in sorghum and millet improvement in Africa. Additionally, very useful results were obtained from our millet and expanded sorghum programs in Mexico. Our chickpea program based at ICARDA, Syria, produced important information on disease resistance and winter sowing.

In this 2nd year of the Phase II program funded under UNDP/ICRISAT contract GLO/77/002, staffing remained essentially as reported last year, with all posts filled for most of the year. USAID continued to fund the Mali program, which has cereal breeding and agronomy components. The *Striga* program funded by IDRC and based at Kamboinse developed rapidly and the physiologist/breeder made significant progress with the sorghum crop, but little work was done on *Striga* in millet. Scientists were identified for all four OAU/SAFGRAD posts, one in Upper Volta and three in Nigeria; it is hoped that they will all be on post in late 1980. The Cereal Breeding Program in Tanzania was funded under a subcontract with IITA/USAID.

All 18 ICRISAT scientists posted in Africa (mainly West Africa) work at national research centers of the countries concerned. The Upper Volta Government Station at Kamboinse serves as a base for the largest ICRISAT multidisciplinary team in Africa, composed of a sorghum and a millet breeder, an entomologist, a pathologist, an agronomist and assistant agronomist, and an economist. Extensive improvements begun last year were completed on this station's laboratory and field facilities.

The In-House Review of ICRISAT African programs took place on 3-5 March 1980. This year for the first time it was held in East Africa, taking advantage of the fact that many of our scientists were involved in the Annual SAFGRAD/OAU Workshop, which was also being held at this venue.

Sorghum Cooperative Program

The commonly grown cultivars of sorghum in West Africa are usually tall, photosensitive, late-flowering, and low-yielding. Early in the breeding program ICRISAT began introducing and developing non- or less-photosensitive types more suitable for the drier areas and for growing on shallow soils with low water-holding capacity. These types would have higher yield potential and would be complementary with late types.

However, there is still a need for photosensitive types, when a sowing at the normal time fails to establish. If a photoinsensitive cultivar is sown late it flowers late and usually suffers moisture stress at the end of the season. Photosensitive types tend to flower on a fixed date regardless of the time of sowing, thus providing protection against lack of moisture at the end of the season. Lately the sorghum improvement program has widened its scope to breed both photoinsensitive and photosensitive types, with high yield potential and desirable agronomic traits such as stress resistance and good grain quality. The availability of the two types with high yield characteristics will provide more flexibility in farmers' cropping calendars.

We have increasingly collected and evaluated germplasm of West African local sorghums for utilization of their desirable agronomic traits in breeding programs. Crossing of these local sorghums to adapted exotics will be increased with a view to recovering the resistances and the adaptation of the locals in higher yielding cultivars. This constitutes an approach to developing cultivars with greater stability and improved yields under stress conditions, suitable for the West African environment.

Our evaluations of sorghum hybrids in West Africa indicate that they can provide high yields in both favorable conditions and in the harsh environment of the semi-arid tropics. We plan to develop and test sorghum hybrids in different agroecological zones to determine their suitability for West African farming.

In addition to these major breeding objectives, there is interest in two management situations, the first when water is limiting and inputs are low and the second when water is generally nonlimiting and inputs more justified. Recently more emphasis has been placed on developing a range of cultivars useful in both situations.

ICRISAT sorghum breeder in Upper Volta discusses the performance of a sorghum cultivar with local farmers.

Progress in Sorghum Breeding

Upper Volta

The ICRISAT sorghum breeding program in Upper Volta began in 1974 at Bobo-Dioulasso, and later moved to Saria. In 1976 our breeder moved to Kamboinse, 15 km north of Ouagadougou, and introduced breeding material from ICRISAT Center and from Ford Foundation's ALAD program. In screenings of this material over the subsequent few years much was learned about local environmental constraints, such as soil type, quantity and distribution of rainfall, and local agricultural practices. The emphasis has been on breeding suitable material for the 400-850 mm annual rainfall zones, including the northern half of Upper Volta, with priority on selecting pure-line varieties. Sorghum of three maturity cycles is needed in Upper Volta:

1. 150 days for planting in early June in soil with good moisture-holding capacity.
2. 120 days for slightly later planting on medium-deep soil.
3. 100 days for late planting in lower rainfall regions and on shallow soil.

In 1979 three of the best lines identified in previous years were tested on farmers' fields. Other elite lines were included in a multilocational trial.

Cultivar E-35-1, of Ethiopian origin, yielded over 4000 kg/ha in research station trials and an average of 1850 kg/ha when planted by 25 local farmers. At three sites E-35-1 yielded 53% more than the local check. Another cultivar, VS-702, yielded an average of 2130 kg/ha on 18 farmers' fields, 85% more than a local variety. A third cultivar SPV-35 is of short duration and was tested in a low-rainfall area on light sandy soil where it outyielded a local check by 100%.

The ICRISAT breeder conducted a multilocational regional trial comprising seven entries from a 1978 regional trial and eight new entries, including a hybrid and a local check cultivar. Two entries were contributed from Senegal. Yield data were reported from Senegal, Mali (three locations), Cameroon, Togo, and eight sites in Upper Volta. Considering all locations, the best entries were 940, 193-2, 38-3, SPV-35, VS-702, 9289, and E-35-1; the first five named entries ranked high in Upper Volta. Entries of both short and medium duration were included in this trial, but in the future separate tests are envisioned for each maturity group.

Four international trials, three originating at ICRISAT Center and one from Ethiopia, were grown at Kamboinse in 1979. The International Sorghum Preliminary Yield Trial-1 (ISPYT-1) included 29 experimental lines with E-35-1 as a check. The best experimental entries were not significantly better than the check and usually matured earlier. Many of them were severely affected by grain mold, but some had superior yield and excellent cooking quality. The higher yielding lines will be planted in a lower rainfall area in the 1980 crop season as ISPYT-2, comprising 59 entries with E-35-1 as a check. The Sorghum Elite Progeny Nursery (SEPON) included F_3, F_4, and F_5 selections from crosses with grain mold resistant sorghum. The trial was affected by drought, but some panicles were selected for further evaluation. An Ethiopian trial of 134 experimental hybrids was also grown at Kamboinse, but all entries were very early and suffered extensive grain mold damage and leaf disease.

Screening of 776 local cultivars from Senegal, Mali, Niger, and Upper Volta took place under conditions of high midge (*Contarinia sorghicola*) and leaf disease incidence. The best lines were those collected near Fada N'Gourma, about 200 km east of Ouagadougou; many appeared to possess resistance to insect pests and disease.

Crossing has continued since 1975, and segregating generations this year included F4 lines; selections from these will be evaluated for yield next year. The cross 940 x CSV-4 produced lines with as many as five synchronous tillers. This year our crosses were directed at grain mold and sorghum midge resistance. Outstanding local cultivars were crossed with high-yielding elite sorghum lines. Our breeder also began a backcrossing program to convert several high-yielding varieties (VS-701, VS-702, SPV-35, and WA x NIG) from purple (anthocyanin) to tan (nonanthocyanin) plants. E-35-1 was used as a recurrent parent in a backcross scheme with various adapted lines to improve its seedling emergence, early vigor, and head emergence.

Mali

This country's 4-year-old sorghum breeding program received considerable impetus this past year with the presence of a full-time ICRISAT breeder, who intensified the crossing and testing program and germplasm evaluation. A major objective of the program has been the development of short-season elite material with higher yield potential than the traditionally grown sorghum varieties in the 400-800 mm/year rainfall zone.

In collaboration with the Malian Food Crop Research Service, the Malian sorghum collection of 800 accessions was evaluated at different latitudes and planting dates at four locations to detect photoperiod sensitivity and wide adaptation. Evaluation revealed great variability in the Malian sorghums: five major sorghum groups were discerned by use of 10 plant characters. The Malian sorghums generally displayed excellent seedling vigor and had a degree of disease and insect resistance, and white seeds with a thick pericarp. All of the plants were purple, indicating that breeders need not be limited to only tan-colored plants for acceptability in Mali. Flowering cycles ranged from 50 to 160 days, with a photoperiodism ranging from strictly insensitive to intermediate to strictly sensitive. Plant height ranged from 1.5 to 5 m and seed size from 15 to 80 g/1000 seed. Twenty-four sorghum lines with local names suggesting *Striga* resistance were discovered. One accession, CMS-205, displayed a proliferation of crown roots in the early seedling stage. Several lines exhibited stable head length and grain fill at all four locations. Material selected will be exploited for desirable traits and their F_1 hybrids will be evaluated in the 1980 growing season.

In this year's SEPON trials two entries - (SC423 x CS3541) E-35-1/-2 and (SC423 x CS3541) E-35-1/9 — performed very well in a drought-affected nursery at Cinzana. Both were consistent for stand and panicle size, showed grain mold resistance, and were relatively tolerant to sooty stripe. Advanced, less-mold-susceptible F_4 lines matured during the rainy month of September at Sotuba, allowing selection of mold-free heads. Seeds of these selections were increased and were simultaneously crossed onto female (male-sterile) lines at Babougou off-season nursery. Crosses were made between these selections and AT x 523, and the F_1 combination will be tested. In the *Striga*-affected nursery plot at Mintimbougou, the lines IS-8686, N-13, and IS-2203 showed remarkable *Striga* resistance, while local checks and the 2219B susceptible check did not set seed.

ISPYT-1, with 30 entries, was planted at Barbe. Two entries appeared worthy of future testing: (FLR-101 x CS-3541)-3-1-4 and (FLR-101 x CS-3541)-1-1-3.

The 58 entries of ISPYT-2 were also tested at Cinzana. None were retained for future testing as the material was severely affected by grain mold and many entries were susceptible to charcoal rot.

The ICRISAT breeder in Upper Volta supplied 136 selections made in Sudan, and from SEPON, ISPYT, and ALAD (Near East sorghums) nurseries. Many of the Sudan and SEPON selections looked promising for yield, but the former were Milo types with compact panicles, poor exsertion, and large and soft seed. The SEPON selections, made from Sudan and SEPON materials, were included in the Babougou off-season crossing program. The ISPYT and ALAD selections were generally grain mold susceptible.

Bulk seed lots of two Texas populations, TP-11 and TP-12, were planted at Sotuba. The TP-11-12 blend provided some plants with both sooty stripe resistance and large panicle size, and sibbed and selfed seed was obtained. Separate population crosses of early materials, Seguetana lines, and a promising local variety ("Sarro"), were made onto TP-11 and TP-12 females. Separate F_1 bulks were advanced at Babougou, and many promising twin-seeded "Sarro" combinations were identified.

At Sotuba our breeder evaluated 184 entries of diverse material from the world sorghum collection held at ICRISAT Center, the ICRISAT Center breeding program, the Indian and Honduran national programs, and the Institute for Tropical Crops Research (IRAT). The most outstanding materials had already been utilized elsewhere: the Texas line SC-108, the Indian lines CS-3541 and GPR-148, and the IRAT lines CE-90 and 63-18 (landrace Hadien-Kori). CE-90 supports a high grain load on its relatively small panicle, and its yield stability across Africa has been amply demonstrated. In view of the wide adaptation of Malian caudatums and CE-90—whose parent, Hadien-Kori, is a Mauritanian caudatum—an increased number of crosses will be made between Hadien-Kori and Mali caudatums.

Several introduced varieties were evaluated for suitability in preparation of Malian *to*. To is a firm gel paste that requires good

A former ICRISAT trainee examines the panicle of a good sorghum cultivar with an ICRISAT breeder in Mali.

overnight keeping qualities, which the local varieties provide. Often to from introduced varieties becomes mushy and undesirable; for example, the variety E-35-1, which is acceptable for to preparation in Upper Volta is not acceptable in Mali because it becomes mushy in reaction to the pH difference in the water used to prepare to. This points to the care that should be exercised in extending conclusions regarding food preparation and quality from one place to another.

Several simple screening tests for drought resistance using tolerant local checks and susceptible introductions were devised. These tests are being improved by ICRISAT Center's sorghum physiologist. One student underwent graduate training in our program at Sotuba and studied genetic resistance to seedling drought in sorghum.

Sudan

Although sorghum accounts for nearly 75% of the cereal production in Sudan, average yields are low (around 700 kg/ha). The main objective of ICRISAT's breeder in this country has been development of sorghum varieties and hybrids with superior yield performance and agronomic traits.

At Wad Medani, Gadambalia, El Obeid, and Abu Naama stations, several hundred sorghum lines including local germplasm, an array of introductions, breeding lines, and experimental hybrids were evaluated in 1979/80 for agronomic superiority, as well as for resistance to certain pests and diseases.

A major effort during the year was to evaluate the Sudanese sorghum germplasm that has been collected over the years. Because many of these accessions had not yet been well characterized and documented, all IS entries of Sudanese origin maintained at ICRISAT and all the original local sorghum accessions available at Wad Medani (2071 lines) were planted for this purpose.

Cross-comparison of the entries received from ICRISAT and their counterparts maintained at Wad Medani revealed that both collections were incomplete, and the deficiencies in the collection were corrected. The seed storage facilities at Wad Medani were improved.

In November 1979 a sorghum collection mission was undertaken with the assistance of the national program and In collaboration with the Genetic Resources Unit at ICRISAT Center. Some 158 wild and cultivated sorghum types from eastern Sudan (Kassala, Gezira, and Blue Nile) were collected and these will be evaluated both at Wad Medani and ICRISAT Center.

To expand the genetic base for breeding, a range of material was introduced, including 160 short and early photoperiod-insensitive converted lines from Texas A&M University (USA), 16 recovered Gambella (subrace Zera-zera) derivatives known to have wide tropical adaptation from Purdue University (USA), and a selected group of 44 yellow endosperm lines from the Ethiopian sorghum improvement project. Of 220 entries tested, 68 were selected as sources of useful material for the crossing program and for prenational yield testing.

In our varietal development program in the Sudan, 514 F_2 populations, derived from intercrosses of elite introductions and adapted locals, were evaluated at Wad Medani. Seed from 1698 F_2 plants selected on the basis of general adaptation, plant stature, head size, grain size and color, and disease reaction will be evaluated at four stations representing different ecological conditions in Sudan. The aim is to generate useful sorghum material adaptable to different zones of the country.

In the clay plains of Kassala, Gezira, and Blue Nile provinces,which essentially constitute the rainfed sorghum belt of the Sudan, the large farm size with mechanized sorghum production necessitates use of short combinable types. Thus there is scope for superior sorghum hybrids identified under local conditions, and our hybrid program has been accelerated. In summer 1979 over 500 experimental hybrids were evaluated at Wad Medani, Gadambalia, and E1 Obeid.

The general performance, including grain quality, of most of these hybrids was good at Wad Medani, where irrigation was possible. Evaluations at Gadambalia and E1 Obeid were not successful because of late planting and severe drought. About 50 elite hybrids were selected for multilocational, replicated yield evaluation in summer 1980.

On the basis of the performance of the experimental hybrids, female lines IS-10454A and IS-10360A and Texas lines 622A, 623A, and 624A produced elite hybrids in combination with both Sudanese and exotic pollinators. The improved Sudanese lines Cr. 54:18/17 and Cr. 65:30/27 were identified as the best local pollinators. The other elite pollinators were introductions from ALAD and selections from Karper's nursery.

An array of A and B lines was introduced from several sources and 115 A and B pairs were grown at Wad Medani in summer 1979 for seed increase and observation. The unusually severe infection of *Cercospora* in the station nursery enabled our breeder to select 40 pairs of A and B lines resistant to this disease. Many were high-yielding seed parents with favorable agronomic characteristics. Seed was multiplied for making hybrids with selected females in the winter nursery.

Based on previous years' observations, 45 agronomically superior B lines were identified. To further screen these and identify the most elite seed parents, they were grown in a two-replication trial for evaluation. On visual scores of agronomic adaptation and disease reaction, the best were CK-74B, AKIB, IS-10240B, IS-10252B, IS-10446B, TX-622B, TX-6236, and TX-624B.

Of 215 potential restorer lines introduced from several sources and evaluated for agronomic eliteness, head exsertion, grain quality, pollen shedding ability, and general potential as a male parent in a hybrid program, 144 were selected. These and 66 elite lines selected from trials and nurseries evaluated in summer 1979 were used as pollinators for making new experimental hybrids during the 1979/80 winter, which will be evaluated in summer 1980.

Four international trials and nurseries were grown in Sudan and useful source material for grain mold and drought resistance was selected.

Tanzania

The ICRISAT sorghum breeder worked for a second year at Ilonga Research Station at Kilosa under an agreement with IITA. In the first year, effort was directed at introduction and evaluation of a wide range of sorghum germplasm, including indigenous sorghums, improved varieties, and breeding lines from sorghum improvement programs all over the world, and suitable genotypes were identified for further testing or for the breeding program. In the 1979/80 season, the program was expanded to include multilocational testing and variety observational nurseries at key locations in the country, and collection of indigenous germplasm was continued.

The emphasis of our program in Tanzania was on varietal development based on the crossing program initiated in 1978, which involved evaluated local sorghum landraces and adapted exotics. The main objective was to combine desirable traits of locals and exotics and synthesize improved cultivars. A range of genetically diverse material in the F_1, F_2, and F_3 generations was derived from these crosses, and 917promising selections were advanced to the F4 generation. The most promising of these selections will be tested in the F_5 generation for their yield performance.

This year two national variety trials were conducted with 59 introductions. The preliminary trial with 31 varieties and 5 hybrids originating from ICRISAT Center and from India, Ethiopia, and Uganda was tested at three locations. Cultivars E-35-1, 2K x 71/5/2, ET-185-2, and ET-1966 yielded well at Ilonga. Serena, the local improved variety, and 5D x 135/13/1/3/1, a brown-seeded variety, were superior to other varieties in grain yield. All varieties tested were distinctly inferior to sorghum hybrids under test at Ilonga and Hombolo. In the sorghum varietal trial, 23 promising varieties mostly originating from Serere, Uganda, were tested at 20 locations, 15 of which returned satisfactory data for analysis. Significant differences for grain yield were obtained at all locations except Lubaga. The brown-seeded 5D x 135/13/1/3/1 gave the highest mean grain yield, but yields from Serena were not significantly different. Three new white-seeded varieties derived with 2K as a parent yielded well at many locations and significantly outyielded Lulu D (a local improved cultivar) at nine new locations. The cultivar 2K x 17/B/I performed well for the second successive season, with a mean grain yield of 2712 kg/ha across all 10 locations, compared with a location mean grain yield of 2353 kg/ha. It also performed well at Msumba, with a yield of 2011 kg/ha, where a severe stem borer infestation occurred. Further testing may prove this cultivar suitable for evaluation by farmers. In a variety observation nursery at Ilonga, introductions from India, USA, and Ethiopia did not perform well compared to improved varieties from Serere, Uganda.

Five hybrids, synthesized using local restorers, were tested in a preliminary trial at three locations, along with cv Himidi, an adapted hybrid developed at Serere. Significant differences occurred between entries, though all hybrids produced good and stable grain yields across all three locations. Four of the hybrids significantly outyielded the best varieties under test. The average yield of the five hybrids at the three locations was 3575 kg/ha, compared to 2970 kg/ha for the best yielding variety. The maturities andheights of all five hybrids fall within acceptable ranges. The superiority of sorghum hybrids in this trial confirms earlier results in East African trials, where sorghum hybrids produced significantly higher yields than varieties. Other hybrids (made with selected male steriles and entries from Ethiopia) gave promising results in unreplicated trials at all three sites; yields were 9-40% higher than those obtained from Himidi. Over 1000 other hybrids, many from Ethiopia, were evaluated in observation plots, and the best ones were selected for further tests.

Our breeder introduced a range of male steriles into Tanzania from India, Uganda, and USA. These were screened at Ilonga in 1978, and 34 promising male steriles were selected with their corresponding B-lines. Several B-lines performed well at Ilonga and Bihawana; seven of these will be used for production of hybrids.

Two international yield trials (ISPYT-1, ISPYT-2) and an elite progeny observation nursery (SEPON-78) sent by ICRISAT Center were sown at Ilonga. Most lines in the yield trials were of poor grain quality and susceptible to grey leaf spot. Most of the SEPON entries were of better grain quality than Lulu D but did not have the desired corneousness. Nonetheless several selections looked sufficiently promising for further testing. Scant information was obtained from the six international pest and disease nurseries, mainly due to low infestation and disease levels during the season. However, three sources of resistance to stem borer infestation were identified for future use in the breeding program, as levels of this pest were high.

Germplasm collection was continued in the important sorghum-growing regions, and about 300 accessions are now available. Several of these lines have attractive grains and good food and keeping qualities. In one landrace the kernel is completely corneous and is reputed to store well for several years.

Sorghum *Striga* Research

Work on *Striga* which is an important obligate root parasite of cereals causing significant yield losses, was started in May 1979 at Kamboinse, Upper Volta. (Initially this work had been based at ICRISAT Center at Patancheru, India.) The objectives of the program are to breed sorghum cultivars (and later, pearl millet) resistant to the pest, to assess the regional importance of the pest in both sorghum and millet crops, to determine whether distinct physiological strains *of Striga exist,* and to assist in coordination and evaluation of genetic material to locate resistance to the pest.

Of 40 sorghum cultivars tested against *Striga* at 23 locations in 10 countries, two (IS-8686 and N-13) were stable across locations. The former performed particularly well in Mali, and both lines stood up well to both *Striga* and drought at Kolo, Ethiopia. Another cultivar, SPV-103, also showed considerable promise against *Striga* attack.

Many lines developed by our breeding program at ICRISAT Center were tested for the first time in Upper Volta, and H-513 (555 x 168) and HS-548 (148x Framida-8-1) showed a good level of resistance to *Striga.* Of 700 sorghum lines identified at ICRISAT Center as having low stimulant production, 195 were sent to Sudan and Ethiopia for field testing. Three lines (S-582, S-583, and S-587)were resistant at both locations. In the Sudan, IS-9830 also exhibited resistance and compared favorably with the existing cultivars for yield. Tests of the same material in Upper Volta enabled it to be divided into groups with different maturities for testing in different zones, and several good photosensitive types were identified for testing in Upper Ghana, Togo, Benin, and the southern higher rainfall areas of Upper Volta.

Nine lines were also selected from 585 lines of a working collection sown in Sudan and Ethiopia to locate resistances other than low stimulant production. A pointed collection of local cultivars whose local names indicated that they have resistance to *Striga* was assembled. Three Ethiopian lines - ETS-04762, ETS-05399, and ETS-05408; 21 Segutana landrace accessions from Mali; a cultivar named Tetron from Sudan; and several apparently resistant lines from Upper Volta were added to this collection. These samples will be tested in 1980 in situations of high *Striga* pressure.

Information gathered this year indicates that there are distinct physiologic strains of *Striga* specific to sorghum and pearl millet. These conclusions will be confirmed by experimentation.

Testing of strigol analogues as apossible means of control of the weed was begun in Upper Volta. Further work is in progress.

Progress in Sorghum Pathology

The two ICRISAT pathologists, who have responsibility for both sorghum and millet, continued to work during the year at Kamboinse in Upper Volta and Samaru in Nigeria. Both share regional responsibilities while working closely with country programs. Research emphasis was placed on grain molds, charcoal rot, and leaf diseases, which are economically more important in West Africa.

Upper Volta and Mali

Our pathologist at Kamboinse is charged with regional responsibility that extends his area of work to neighboring Mali.

GRAIN MOLD. At Farako Ba three trials comprising 144 entries were assessed for grain mold development. One of these trials, the International Sorghum Grain Mold Nursery (ISGMN), was also grown at Sotuba in Mali. The combined results of these trials indicated the repeatedly good performance of several lines.

CHARCOAL ROT. Of 36 entries in this year's International Sorghum Charcoal Rot Nursery, 4 look promising for low susceptibility (Table 1).

LEAF DISEASES. The reaction of susceptibles in resistance screening at Farako Ba indicated the presence of adequate disease

Table 1. The performance of selected entries in charcoal rot screening in Kamboinse, Upper Volta, 1979.

Entry	% lodging	% soft stalks	Nodes crossed
Low-susceptibles			
Nes-1077	0	23	0
5-33	0	23	0.2
20-67	3	0	0.2
604	8	17	0.2
High-susceptibles			
CSH-5	33	54	0.5
CSH-6	69	85	1.2
IS-121	76	65	0.6

pressure of anthracnose, grey leaf spot, and zonate leaf spot. Cinzana, Mali, was selected for sooty stripe disease testing in view of repeated appearance of the disease in previous years. Combined results from leaf disease screening at Farako Ba and Cinzana showed that IS-4150, E-35-1, M-35586, and M-36204 were very resistant to all four diseases, and M-36381, IS-7254, M-35544 were very resistant to three of the four diseases. All entries in the trial, except H-112, showed a good level of resistance to at least one of the four diseases.

Nigeria

At Samaru, our pathologist continued evaluation of international nurseries and local varieties for resistance to grain molds, grey leaf spot, anthracnose, sooty stripe, and oval leaf spot, all of which are of immediate and considerable importance. Molds caused considerable loss in quality and quantity of the early- and short-duration varieties. Limited work on downy mildew was also initiated.

In the International Sorghum Grain Mold Nursery, IS-9225, IS-2435, M-62508, M-66203, and M-66209 were relatively free from mold; four entries performed poorly despite the relatively low humidity at grain maturity. Of 23 entries evaluated in the International Sorghum Anthracnose Virulence Nursery, SC-237-14 and SC-328C were highly resistant to the three symptom types common in Nigeria. All entries except TAM-428 showed some resistance to the typical patchy type of anthracnose infection. None of the entries in the International Sorghum Adaptation Yield Trial was superior to the local improved check, Ex Bauchi, in yield or disease reaction.

For the 3rd year, 59 local sorghums were evaluated for yield and disease resistance. Many were susceptible to the range of common diseases (sooty stripe, oval leaf spot, grey leaf spot and anthracnose) and there was wide variation in yield potential. The best in terms of grain yield entries were Kiru-3, Lafiya-2, SPS-7911, Kuru, Makarifi, SPS-7913, and SPS-7221.

Of the 354 entries identified by Dr. Webster (USAID/OAU-STRC JP-26 Project) in 1965 as having resistance to downy mildew; 348 were evaluated for their reaction to downy mildew and other leaf spot diseases. Their reaction to disease was very variable, but many yielded well.

Progress in Sorghum Entomology

Our work on sorghum entomology continued at Bambey, Sefa, and Nioro du Rip in Senegal, and a program was initiated in Upper Volta with the arrival of an entomologist on the staff in September 1979.

Senegal

Surveys of losses caused by pests were carried out on farmers' fields and cataloging of the insect pests of sorghum continued during the year. Heavy infestations (up to

80%) of *Atherigona* were observed in surveys carried out in the Senegal River and Diourbel regions, particularly on late-sown crops. Locally, *Spodoptera exempta* severely attacked seedlings. Local sorghums were heavily infested by *Rhopalosiphum maidis,* over 50% of the plants examined at Bambey were attacked. Stem borers, particularly *Acigona ignefusalis* and *Sesamia* sp, were important on both local and improved sorghums. Damage ranged from 8 to 28% deadhearts in the areas surveyed. Sorghum midge was particularly severe on research stations at flowering. Several head worms including *Heliothis armigera* and *Pyroderces* sp were present, especially in compact heads. The relative importance and effects of insect pests on sorghum production are being assessed. Experiments using local and improved cultivars took place at Bambey, Nioro du Rip, and Sefa; at Bambey cultivar Congossane suffered up to 33% yield loss due to shoot fly, and in CE-90, 54% was caused by midge and 16% by head worm.

Studies on the biology and population dynamics of sorghum shoot fly continued. *Atherigona soccata* was tne dominant fly reared in the laboratory from sorghum, millet, and grasses with deadhearts. Other species reared included *Anatrichus erinaceus* and *Soolipthalmus micantipennis.* Trapping of shoot flies using fishmeai bait continued at the three centers. Over 89% of the flies trapped were female. *A.soccata* was an important species at Bambey and Nioro du Rip, while *A. tineata* and *A. marginifolia* were more important at Sefa (Table 2). At all centers the highest numbers were recovered in August/September. The life cycle of *A.soccata* in two cultivars of sorghum was studied. The average development time in Congossane was 3. 6 days for the egg, 11.1 for the larval, and 6.5 for the pupal stage. The larval stage took an average of 2 days longer on the partially resistant cultivar CE-90. In a test of lines with suspected resistance to shoot fly, IS-5604, IS-5622, IS-1522, IS-4661, and IS-4712 were least attacked.

Three cultivars of sorghum were examined for stem borer incidence at harvest, by splitting 1000 stems of each cultivar. Four species of stem borer were recorded: *Acigona ignefusalis, Sesamia calamistis, S. botanephaga,* and *Eldana sacharina.* Infestation was heaviest in the improved cultivar MN-1056: an average of more than one larva per stem was recorded. *Sesamia* spp were important in the other two cultivars (Table 3). Regular sampling of stalks in the season confirmed that MN-1056 was susceptible to *Acigona.*

At Bambey, large populations of sorghum *midge* (*Contarina sorghicola*) were recorded in October. In mid-October all panicles examined were infested with up to 15 adults per panicle. The pest was absent from Jan-

Table 2. Number of shoot flies trapped using fishmeal bait at five sites in 1979/80 in Senegal.

	No. of flies trapped	No. of females	No. of males	Percent male	No. of males identified	Percent *A.soccata* males
Bambey	4594	4280	314	6.8	297	70.4
Nioro du Rip	42	25	17	40.5	17	14.2
Sefa	7358	6395	963	13.1	846	16.2
Louga	204	174	30	14.7	26	7.7
Fanaye	136	133	3	2.2	2	50.0

Table 3. Incidence of stem borers in sorghum stalks at 1979 harvest in Senegal.

Cultivars	No. of stems dissected	No. of larvae per 100 stems			
		Acigona	*Sesamia*	*Eldana*	Total
Congossane	1000	13	56	0	69
MN-1056	1000	118	15	1	134
7749	1000	22	18	0	40

uary to March 1980. Two important parasites were recorded, *Tetrastichus diplosidis* and *Eupelmus popa,* but neither had a marked effect until very late in the season. Laboratory and field studies indicated that AF-28, DJ-6514, SGIRL-MR1, IS-2501, and IS-12666-C had some resistance to midge attack. NK-300, CE-90, and Swarna were very susceptible. The relative resistance of AF-28, SGIRL-MR1, and IS-12666-C was confirmed in an additional international pest nursery.

Upper Volta

After the ICRISAT entomologist had studied existing information and made contact with other entomologists in the region, he defined the cereals entomology program of research in Upper Volta. Studies were initiated to identify the major sorghum pest species and their distribution in Upper Volta and northern Nigeria. Sorghum midge, stem borer, and shoot fly were given priority in initial studies. Monitoring of pest species was begun at Kamboinse, and surveys of pest species were carried out in agronomic and farmers' field trials conducted by the agronomists and breeders.

Initial results from surveys indicated that stem borer damage was higher on research stations than on farmers' fields. There were also indications that attack was greater in the higher rainfall areas. In general, damage by *Atherigona soccata* was lower than anticipated.

Preliminary studies were made on the spittle bug (*Poophilus costalis*), which has caused damage to sorghum in the vicinity of Kamboinse and elsewhere in Upper Volta. Damage symptoms were initially confused with those of sorghum downy mildew disease. The characteristic symptoms include bands of chlorotic tissue and spots on the leaf blades.

Progress in Sorghum Agronomy

Upper Volta

By 1979, the sorghum breeding program had identified several promising cultivars for preliminary yield testing and for use in both preliminary and advanced agronomy trials. It had been noted that marked improvement in yield was possible when maturity and growth characteristics of the cultivars were matched to the various rainfall zones and soils occurring in the West African SAT environment.

The main ecological zones of Upper Volta were characterized with respect to sowing date, flowering, and harvesting time of desirable cultivars. In a multilocation variety trial for sorghum cultivars based at locations along a north-south transect in the country, vital data were obtained to refine the tentative adaptation requirements worked out for the different sorghum varieties (photosensitive, partially sensitive, and insensitive) in the major ecological zones of Upper Volta. Testing of new cultivars will continue in order to develop agronomic recommendations before releasing a cultivar for on-farm testing. This approach is imperative to fully exploit the genetic potential and to prevent failures at the farm level.

Adapted and improved cultural practices are needed for optimal use of the environmental factors, to maintain fertility of SAT soil, and to use the potential of the introduced cultivars.

In advanced testing of introduced sorghum cultivars on a toposequence with different soil types, E-35-1 and VS-702 indicated yield superiority over the Kamboinse local cultivar. A strong varietal/soil-type interaction was noted, with highest yields recorded for the well-drained soils of lower slopes, where the two cultivars yielded twice as much as on the upland soil. The local landrace was least responsive to soil type. The effect of the interaction between variety and soil type on days to 50% flowering was equally interesting. The local landrace flowered on a fixed date irrespective of the date of planting or soil type and both E-35-1 and VS-702 flowered 7-10 days later on upland than on lowland soil.

A preliminary trial indicated that partially or nonphotosensitive material should be sown at higher plant densities than the tillering photosensitive types. Consequently these cultivars would also demand a higher labor input at planting time as long as this operation is done by hand—an important consideration for farmers in their choice of cultivars.

Our breeders' aim has been to generate nonphotosensitive cultivars that flower a few days earlier than local ones in order to avoid midge and drought stress problems if rains cease early in September. The sorghum toposequences study showed that both E-35-1 and VS-702 matured earlier on deep soils, but grain molds became a problem on these soils, particularly with early planting. Seed from these two cultivars sown during the rainy season for multiplication showed a lower germination percentage than acceptable for agronomic purposes. Therefore, more emphasis will be given to obtaining grain mold resistance in these materials.

Difficulties associated with seedling emergence and stand establishment due to genotype selection as well as hardening of the soil profile or crusting of the soil surface will receive more attention. The breeders will search among the available germplasm for the following important agronomic traits: good seedling emergence, high seedling vigor, and good tillering characteristics.

Mali

Agronomic research on the traditional sorghum/cowpea intercrop combination in Mali continued with two experiments. In one, two methods of planting were tested, "in pocket" and "interline," at four cowpea plant densities. In certain locations in-pocket planting produced a synergistic interaction between the two crop species as the density of cowpea increased to a maximum of 50 000 plants/ha. With interline planting the highest sorghum yields were obtained at the lowest densities: the yields were depressed at high plant densities. The same pattern was obtained with yields of cowpea hay.

In the second experiment on intercropping, cowpea cultivar TV x 1841-1-C gave the most consistent yields when intercropped with a range of sorghum cultivars, but the erect determinant-type TV x 1193-9-F was superior in combination with local sorghum. The "local" cowpea cultivar performed best with the short-statured sorghum cultivar VS-702. Cowpea yields increased with higher cowpea plant populations, particularly in the instance of introduced cultivars.

A study was made to determine the interaction of the three soil conditions on a toposequence with three sorghum cultivars and a local millet. Soils were shallow sandy at the top of slopes, transitional at the midslope, and deep alluvial with a high clay content at the lower slope. Yields increased with soil depth, and the introduced cultivar E-35-1 gave yields superior to locals as the soil situation improved. Millet outyielded sorghum on all but the deepest soils,

A forage trial was sown at five village sites using two tillage treatments on a local millet, a local sorghum, and the Dalahani local millet. The Dalahani millet, which is from the south of Mali, had a longer growing cycle and produced yields that were competitive with those produced from sorghum. Plowing gave a 40% increment in yields over a simple ridge treatment.

Pearl Millet Cooperative Program

The primary objectives of ICRISAT's cooperative program in West Africa for the improvement of pearl millet are (1) to develop varieties, synthetics, and possibly hybrids that produce stable and consistently higher grain yields, and (2) to identify and utilize resistances for diseases such as downy mildew, ergot, and smut; the parasitic weed *Striga;* and insect pests.

While the West African landrace varieties possess excellent adaptation to their local environment and to existing cultivation methods, their yield potential is limited by: a tendency to flower very late, low harvest index due to excessive plant height, unbalanced tillering habit and abundant foliage resulting in inefficient conversion of dry matter into grain, partial susceptibility to insects *and Striga,* and insufficient grain accumulation in response to improved management.

ICRISAT's strategy is to modify the undesirable characters of the landraces of pearl millet by crossing the local populations with exotic material that can contribute earliness (from a few days or more, as appropriate), short to medium-tall stature, and moderate vegetative development and even tillering, while retaining and improving where possible the local varieties' adaptation to the biotic environment. Lines derived from such crosses are used to produce synthetics and breeding composites (from which varieties can be developed by recurrent selection). Only by conducting breeding in situ can the combination of desired attributes with adaptation to the local environment be obtained. Research on hybrids in West Africa has been only exploratory, partly because single-cross hybrids are intrinsically more susceptible to downy mildew and ergot as shown in India (where disease pressures are less than in West Africa) and partly because hybrid-seed production is costly in technical resources. However, the potential of hybrids of various types will be explored as suitable seed parents become available.

The main components of our pearl millet crop improvement program in West Africa are introduction and evaluation of new genotypes, and breeding using both population improvement and variety crosses. Multi----ational, regional, and international testing is an important feature of the program. This crop improvement effort is undertaken by multidisciplinary teams consisting of breeders, entomologists, pathologists, and agronomists from ICRISAT and from the national programs of the countries concerned.

Progress in Millet Breeding

In 1979/80, under the UNDP/ICRISAT Program five millet breeders were in position, one each in Senegal, Upper Volta, Niger, Nigeria, and the Sudan. The cereal breeders in Mali and Tanzania funded by USAID and USAID/IITA were primarily concerned with sorghum but did carry out limited work on millet breeding.

Upper Volta

After 3 years' work on millet improvement in Upper Volta, our breeders' conclusion has been that currently the best selections are coming from West African x West

Germplasm scientists and breeders from ICRISAT and IRAT assess the performance of millet cultivars in one of the several nurseries grown in West Africa.

African crosses. Experimental varieties from locations outside Upper Volta are not well adapted or agronomically acceptable locally. This year the breeding program was expanded considerably, and 530 composite progenies and 2535 F_3 progenies from a wide range of crosses were evaluated at Kamboinse, Ouahigouya, and Gorom-Gorom. Some promising selections were made from F_2 populations from West African x West African crosses evaluated at Kamboinse and Gorom-Gorom. Dori local was found to be a good combiner at Gorom-Gorom, and Ex Bornu a useful parent at Kamboinse. In yield trials at the three centers of 12 varieties and 43 synthetics developed by the program as well as other West African lines, Ex Bornu and EB-K79 were the best varieties at Kamboinse and Ouahigouya, and Souna III was the best overall experimental variety. At Gorom-Gorom 3/4-S-GG-78 and CIVT-II were superior. In general the synthetic varieties tested were susceptible to ergot and smut and had unacceptable head and grain type.

At Farako Ba 1132 entries of photosensitive germplasm accessions from Senegal, Mali, Cameroon, the Central African Republic, and Togo were evaluated and classified into variety groups. Additionally, 160 West African germplasm accessions and 80 F_2, F_3, and F_4 progenies derived from ergot-resistant parents were evaluated for resistance to ergot, and some useful selections were made.

In view of the demonstrated utility and variation in African germplasm for breeding, preferred traits are being incorporated into breeding lines by crossing. There were indications that ergot resistance is present in West African material.

Three composites— Ex Bornu Kamboinse, 3/4 Kamboinse, and 3/4 Gorom-Gorom— were in the second cycle of improvement by recurrent selection, and 13 selections were made to form experimental varieties. Two composites were retained for the next cycle. In a trial of composite progenies five were retained for further testing. From the Best Progenies Trial, only one entry, WC-8097, looked agronomically acceptable.

The ICRISAT team also evaluated 141 crosses, progeny selections, and inbred lines provided by other millet breeders in West Africa. In general, material from ICRISAT Center that was evaluated at Kamboinse in a number of nurseries and trials was not well adapted and was susceptible to ergot and smut.

Senegal

The season at Bambey this year was characterized by abnormally low rainfall (486 mm), and yields were lower than those recorded the previous season.

Results from the D_2 Composite Progeny Trials and ICRISAT Late Composite Trials were good, the mean yield for 12 selected entries from the former was 2502 kg/ha and for the latter, 2597 kg/ha. In the D_2 trial, incidence of downy mildew was 4% and there was a moderate level of resistance to smut. In the Late Composite Trial, mildew incidence was just over 1%. Experimental varieties constituted from the best entries in these trials were grown at Bambey in the

1979 rainy season, and SSC-K78, IVS-S-78, and D_2 BB-78 were identified as good performers. SSC-K78 yielded 23% higher than the improved control Souna III, while the other two were superior to the check. In general, the experimental varieties had much better resistance to downy mildew than the local check. The 11 best progenies of the D_2 Composite Trial were evaluated to identify potential hybrid parents or material for use in synthetics.

In the Elite Varieties Trial, hybrid ICH-226yielded 1607 kg/ha, 7% more than Souna III, while the best synthetics (ICMS-7818, ICMS-7703) and experimental variety (SSC-H76) gave about 80% of the yield of the improved local check. The best progenies in the trial, SC1-7034 and IVS-5454, gave 91%) and 88% of the yields obtained from the check. Downy mildew incidence in the trial was around 5%.

A program was set up at Bambey to generate variability for synthetics and hybrids, using the best introduced genetic material. In one set of material tall lines were used and in the other, dwarf lines. Only three lines stood out: BP-5 from the tall material and P-1052 and BP-33 from the dwarf material. In subsidiary trials the general and specific combining abilities of such lines were examined and it was determined that line 16688 had the best combining ability. Performance testing of synthetics and hybrids from ICRISAT Center and from Indian national programs continued in multilocational tests. ICMS-7819, derived from a Souna D_2 and Ex Bornu-2 cross, yielded 25% above the Souna III control. ICMS-7812 and ICMS-7825 also performed well. Over the past 3 years at Bambey, ICMS-7819, with an average yield of 2135 kg/ha, has given an average of 17% yield advantage over Souna III.

Work on development of hybrids continued, although the five male-sterile lines available in Bambey were poorly adapted. Eighteen hybrids developed from a downy mildew resistant version of $23D_2$ B/A were tested in an observation nursery and one, a dwarf

Scientist from our programs in Mali and Senegal assess pearl millet cultivars with a colleague from ICRISAT Center in a field in Ouagadougou.

with a long spike and bristles, performed better than Souna III and yielded 2143 kg/ha. Three other hybrids-ICH-118, ICH-165, ICH-303 —had low downy mildew scores but failed to outyield the check. ICH-118 and ICH-303 (two hybrids based on the male-sterile line 111A) and ICH-165 had low downy mildew scores, but failed to outyield the check. In 3 years of testing, ICH-118 and ICH-165 have always outyielded the check—by as much as 20-25% in the more favorable rainfall regions during the rainy season. In poor rainfall conditions the best hybrids only equalled the local check.

In a series of international and regional trials, material from Niger showed good adaptation, but that from Sudan was poor. The best entries were 77002 (derived at Bambey from Super Serere Composite in 1977), F_3 ENDO-4 (a pedigree selection in M-142 x 700542), and two entries from Niger —SN-(Niger local 5) and SN-(EC/DC-248-1). In general, in the West African

Regional Trial, Souna III with a 2-year mean yield of 1783 kg/ha has outyielded all other entries. In the 5 years that IPMAT has been conducted at Bambey, the good average performance of ICH-118, ICH-165, and WC-C75 is noteworthy.

Niger

The emphasis in our program in Niger during the year under review was on integration of newly acquired breeding material with previously available sources, testing of promising lines identified by the program, and development of new varieties and populations. During the 1979 rainy season, 19 trials and nurseries utilized selections from material obtained from ICRISAT Center and national breeders in Africa. Material from crosses made in previous years was also tested. Selections were made from inbreds, interpopulation crosses made in 1977/78, and F_1 and F_3 material involving African x Indian and African x African lines. Four gene pools were set up using available Indian and African lines —tall (African), semi-tall (Indian), dwarf (D_2 derivatives), and bristled. Future work will produce composite populations and experimental varieties after two or three recombination cycles. More genetic material will be added to the gene pools.

Evidence to date suggests that African x African population crosses are more valuable than African x Indian crosses. The development of hybrids has been given low priority, but preliminary results showed that the hybrids developed using African inbreds as male parents and 5141-A as the female parent were not useful. Male steriles with an African background and long heads are necessary to fully exploit hybrid vigor in the region.

Trials using materials from the African national programs over the past 2 years have shown that in Niger no single cultivar stands out as having a markedly superior yield. The local Niger varieties HKP and CIVT have good grain-filling characters and produce a number of productive tillers, making them in no way inferior to lines introduced from elsewhere in Africa, including Nigeria and Senegal.

Results from international trials were disappointing in general. Most materials from ICRISAT Center and from the Indian national programs matured 7-10 days earlier than African material and had small heads, synchronous flowering, and high tillering ability. They were poorly adapted to the local sandy soils of low fertility. Yields produced were inferior to those obtained from HKP and CIVT. However, for the drier northeastern area of Niger, where early-maturing varieties are grown, improved types are needed, and Indian material may be useful in breeding. It is proposed to include WC-C75 and IVS-A75 in next year's trials.

During the year the amount of seed exchanged between Niger and other countries in the region increased considerably. Twenty breeding lines and two experimental lines (one from the INRAN program and the other from the ICRISAT program) were contributed to the African pearl millet exchange nursery. Material sent from Maradi to the SAFGRAD agronomist in Cameroon appeared to be better adapted there. Seed of three of the lines-ICS-7703(T), WC-C75(T), and CIVT—was sent for more extensive trials in 1980. A range of material was provided to the national program for test and evaluation, and material from Niger programs was sent to ICRISAT Center, Patancheru, India, for evaluation.

Nigeria

The ICRISAT millet breeder carried out work at Samaru and Kano in Nigeria. At Samaru, the rainfall received during the year was above normal (1183 mm)—33 mm more than the previous year's total. At Kano the total was about half that received at Samaru.

The primary breeding objective continued to be the development of diverse improved millet genotypes with high and stable grain yield potential, resistance to downy mildew, ergot, and smut; early maturity; and lodging resistance. Because intercropping is widely practiced and high synchronous tillering compensates for the wide-spaced planting used by farmers, this character was selected for. During the year a major shift in research emphasis in the breeding program was made towards the use of local West African germplasm.

In population improvement work, mainly S_1 and S_2 evaluation was used to obtain improved genetic parental lines for crossing and for development of composites and synthetics. New genetic variability is created simultaneously in the main population in the course of improvement. A total of 191 S_1 entries were evaluated in five nurseries during the 1979 crop season. These entries were evaluated for major disease reactions and agronomic performance.

Of 280 S_2s evaluated at Kano in several nurseries, 30 entries in the S_1-I (local) nursery were better than those in the S_1-II nursery. Of these, over half showed promise for downy mildew resistance and were good agronomic ally. Seed of 47 entries in the S_1-III nursery derived from self-pollinations of previously open-pollinated S_2 plants will be further tested. An S_1-IV (local bulk) derived from collections made in Nigeria in 1976 by the IBPGR/FAO was grown, and self-pollinated single plants were selected for S_2 evaluation in the coming season. Half-sibs from selections in the 1978 Super Serere Composite (SSC) progeny nursery received from ICRISAT Center were grown in the S_1-V(SSC) nursery. The entries were early maturing (range, 43-49 days), and shorter than the local genetic materials; selections will be further improved.

The improved local varieties, i. e., Nigerian Composite, World Composite, and Ex Bornu, were used in crosses with F_5 and F_6 selections. The selections originated from the F3 and F_4 Uniform Progeny Nurseries (UPNs) at ICRISAT Center. Some self-pollinations were made to obtain F_2 seed, but most of it was not agronomically promising.

Seven lines obtained from USDA (Tifton, Georgia, USA) and 11 lines from the millet breeder at the Hays Station of Kansas State University (USA) were crossed with local varieties -Nigerian Composite, World Composite, and Ex Bornu- and with some selected local S_2 lines under irrigation during the 1979 dry season. The objective was to select for shorter plants and to improve tillering in local varieties. The seed obtained was then grown as F_1s in the crop-growing season, and self-pollinations and backcrosses were made to local parents. In general, the USA and Indian germplasm has serious limitations in Nigeria due to its susceptibility to downy mildew disease.

Crosses were made between S_3 lines (IBPGR/FAO local collection, 1976) and the locally improved cultivars (World Composite, Nigerian Composite, and Ex Bornu) using the bulk pollen-crossing method. The objectives were to incorporate the useful germplasm traits from the local improved varieties into the derived S_3 progenies, and to generate new genetic variability. A number of progeny looked promising agronomically and had some downy mildew resistance. Progenies involving Nigerian Composite and Ex Bornu were agronomically better than those involving the World Composite.

Initial crosses made with irrigation in 1978 using three local cultivars and selections from the 1977 Intervarietal Synthetic Progeny Trial nursery from ICRISAT Center were backcrossed in order to incorporate early maturity and good tillering from ICRISAT genotypes while maintaining most of the local characteristics. Many of the entries looked promising agronomically with good growth and early maturity, and further improvement will be undertaken. Yield testing of 35 entries will be carried out in replicated plots in 1980/81. In addition, 35 F_3s utilizing Nigerian and World Composite cultivars were carried forward.

Four nurseries to improve the germplasm base included two exchange nurseries from ICRISAT breeders in West Africa, the Uniform Progeny Nursery from ICRISAT Center and selected lines from Kano. A large number of selections were made, except from the second exchange nursery where seed set was poor.

One regional and five international replicated yield trials were conducted. However, there were no local yield trials, as insufficient seed was obtained from the preceding dry (irrigated) season. These trials provided an opportunity for selection and exchange of germplasm and information. In the West African Regional Trial, no entries were superior to the local check. In general, results from the international trials showed that exotic material was not superior to the local entries.

Mali

Our breeder's main activity in pearl millet in this country was to conduct the international trials and nurseries. Both IPMAT with 23 entries and the Pearl Millet Hybrid Trial with 49 entries were evaluated at Sotuba and Koporo Keniepe. Diseases, particularly ergot, downy mildew, and smut, were severe, and none of the exotic material was adapted to Malian conditions. The regional trial, consisting of seven entries from other ICRISAT breeders in Senegal, Upper Volta, Niger, and Nigeria, was sown at Koporo Keniepe and Same and suffered drought stress. However, at Koporo Keniepe the local check performed well, as did the Nigerian variety CIVT, which did, however, suffer from lodging. In view of its good seedling establishment and long, well-filled spikes, attempts will be made to improve this cultivar, as with additional stalk strength it may provide a well-adapted cultivar for the area.

A. Striga trial was conducted at Mintimbougou, on behalf of the ICRISAT *Striga* scientists based in Upper Volta. All entries proved susceptible in this first year of testing. At Kogola (about 75 km south of Mabako) the SAFGRAD/Mali scientist identified a local millet that may be resistant to *Stviga.* Seed collections from this area will be evaluated at Mintimbougou in 1980.

A useful screening of 375 Malian pearl millet accessions (CMM-1 to CMM-375) was carried out at Sotuba and Baramaudougou. Data were obtained on several characteristics, including flowering dates, plant height, and downy mildew resistance. Several entries appeared to have low downy mildew incidence, and 16 had no symptoms. One entry, CMM-250, has rigid awns that give some apparent resistance to attack by birds.

Sudan

In the past 3 years, Serere Composite-2 has consistently outperformed the local variety Kordofani, in both favorable and unfavorable conditions in Sudan. The respective mean yield in 11 trials (three trials were irrigated) conducted during 1977-79 was 1061 kg/ha in favorable conditions and 678 kg/ha in unfavorable conditions. In rainfed conditions in eight trials in Western Sudan, Serere Composite-2 yielded 599 kg/ha, compared with 528 kg/ha for Kordofani. Serere Composite-2 was accepted for pre-release multiplication by the Variety Release Committee of Sudan and will be considered for release for general cultivation in 1980.

Our breeder evaluated 176 ear-to-row progenies of 20 elite accessions identified in 1978 from the indigenous germplasm. Fourteen progenies derived from six accessions were selected on the basis of uniformity and desirable agronomic and head characteristics for use in crossing to generate new breeding material. A wide range of crosses between exotic and local pearl millet material from diverse geographic and edaphic backgrounds was made and grown. Much of this material was in the F_3 and F4 generations. Eight lines were selected for preliminary yield trials.

A national yield trial of 10 entries, consisting of 7 ICRISAT selections, 2 major Sudanese varieties, and Serere Composite-2, was grown at five locations. The performance estimates indicated that introduced varieties performed better than the locals. Selections from the 1978 breeding material and international trials and nurseries were tested at Wad Medani and E1 Obeid in two replicated Initial Yield Evaluation Trials (IYET-1 and IYET-2). The test entries consisted of eight new synthetics (SYN-1 to 8), one experimental variety (SCI-S-79), and two inbreds (SUP-12 and SUP-13) developed at Wad Medani. The remaining genotypes were selected from ICRISAT's international trials and nurseries. The entries SYN-3, SYN-4, SYN-6, SYN-7, EB-180-2-1 (SMT-81), EB-83-2-1 were found promising in IYET-1, and SCI-E20 and SSC-E176 showed good promise in IYET-2.

A range of material from within Africa was tested in replicated trials. Two entries from the African Regional Trial, ICMS-7703 and Ex Bornu, were agronomically desirable. Ten entries were selected for use in Sudan from 43 advanced breeding lines submitted by the Niger program. Four additional lines, also from Niger, were selected from 41 elite lines submitted by ICRISAT breeders in neighboring countries. Eleven entries from Senegal were selected in the rainy season, on the basis of agronomic characteristics, for initial yield evaluation.

Ten international trials and nurseries were received from ICRISAT Center and evaluated during the year. The highest yielding individual entry was ICMS-7803 with a yield of 1583 kg/ha in IPMAT. A range of germplasm from these trials was selected for use in our breeding program in Sudan.

Six progenies from the Serere Composite Trial and five from the Super Serere Composite Trial were used to constitute experimental varieties. A number of single-plant selections were also retained from both trials for further evaluation.

Although diseases are not generally severe in Sudan, smut has been observed and some entries from ICRISAT Center material have been utilized in the breeding program.

Use was made of an irrigated summer nursery to increase seed of selected lines for our variety crosses and synthetics program.

Pearl Millet *Striga* Research

The basic objectives of our pearl millet *Striga* program in West Africa are similar to those outlined for sorghum *Striga.* While the program was initiated at Kamboinse, it is anticipated that most of the work will be carried out in northern Upper Volta and Niger.

In an observation nursery of 32 entries sown at 14 locations in 10 African countries, data was received from only Ouahigouya, Upper Volta, and Maradi, Niger. None of the entries was very resistant, and only six were retained for further testing. In IPMAT none of the entries exhibited satisfactory levels of resistance, although two hybrids were less susceptible.

A small collection of millet lines based on the observations of the millet breeders in Upper Volta and Niger was assembled for systematic screening for *Striga.* Four Malian millet lines —Tukuku, Sulafinko, Djiko, and Sanyoba—that are claimed to be resistant *to Striga,* together with 13 lines that were apparently *Striga* -free in Upper Volta, will be tested in 1980.

Progress in Millet Pathology

The disease pressure at West African locations provides very useful screening. Our pathologist in Upper Volta also covered sites in Mali and assisted with evaluations in Senegal. Although our pathologist based at Samaru, Nigeria, concentrated primarily on sorghum, he carried out some work on millet at Kano.

Upper Volta

DOWNY MILDEW. The development of West African sources of resistance to this disease was intensified during the year. Selections made from disease-free plants in 44 lines tested at Kamboinse in 1978 and multiplied during the dry season were planted under disease nursery conditions at two locations. Ten lines showed no evidence of attack by pathogens at either site; six of these had been disease-free at Kamboinse in 1978: D-316/1, D-1163/1, IP-2742/1, P-3 Kolo (P-1)/1, P-3 Kolo (P-D/2, and 3/4-HK(P-15)/3. Of particular note was the durability of mildew resistance in D-1163, which had not been infected in a test at Samaru, Nigeria, in 1978. All lines at Kamboinse were bagged in groups of 2-3 plants to permit outbreeding under controlled conditions. At Ouahigouya 51 lines with a very low infection index were selected for multiplication in the future.

INTERNATIONAL NURSERIES. In the International Pearl Millet Downy Mildew Nursery (IPMDMN) and the Preliminary International Pearl Millet Downy Mildew Nursery (PIPMDMN) 195 entries were screened. No mildew symptoms developed in 13 lines tested for the first time at Kamboinse. Zero infection was noted in five lines of the IPMDMN.

In a study of the inheritance of resistance to downy mildew, progenies of all 66 possible combinations of 12 lines selected for a range of susceptibility for this disease were tested at Kamboinse. Two lines, P-7 and 700251, did not develop any infection. Though susceptible, 7636-P-4 was able to impart complete resistance to four lines, which themselves were highly susceptible. Considering all crosses, 7636-P-4 imparted greater resistance than the other two lines.

The success in downy mildew control achieved with metalaxyl (Ridomil, Ciba Geigy) in 1978 when applied to seed as dust was further confirmed with this year's experiment.

ERGOT. In the International Pearl Millet Ergot Nursery (IPMEN) grown at Kamboinse, flowering heads were artificially inoculated with conidial suspensions. On evaluation, nine entries were selected for low ergot development. This study showed that successive years of repeated selection for ergot resistance in J-2238 had reduced its susceptibility to the disease.

Ergot development was observed to be favored by continual rainfall and appeared to diminish where rain ceased for at least 2 days immediately before flowering.

SMUT. In all the entries in the International Pearl Millet Smut Nursery (IPMSN) tested at Kamboinse and at Bambey (Senegal), infection pressure was high because of relative dryness and high temperatures. One line at Bambey had no smut development. At Kamboinse 10 lines had no smut development, suggesting low infection pressure at this location.

Nigeria

This year emphasis was placed on screening for and isolation of genotypes resistant to the three major millet diseases in Nigeria: downy mildew, ergot, and smut. As in previous years, most research effort went into conducting six international nurseries, five of them for downy mildew, sent from ICRISAT Center. These totaled 340 entries, which were sown at Samaru and Kano. In addition, the 1977 local collections were evaluated further for disease resistance and selections were made. A downy mildew disease "sick plot" was established to provide field evaluation of various materials.

Downy mildew incidence and intensity was higher at Kano than at Samaru. Of the 50 entries tested in the IPMDMN trial, B-Senegal-6, T-128-3 x 700404-1-5-5, 700429, J-1486 x 700787-2-10, and EB-83-2 showed a high level of resistance to downy mildew at both locations at seedling stage. No entries were free from infection at dough stage at either location. There was positive evidence of variation in the downy mildew pathogen since differential varietal response was observed at Samaru and Kano. Of the pearl millet synthetics evaluated at the two sites, the entries ICMS-7860, -7845, -7816, -7818, and -7704 were moderately resistant (less than 10%) to downy mildew at both locations. At Kano 14 other entries also showed good resistance. It appears that the synthetics tested are better suited to the low-rainfall sandy areas of the country. None of the improved experimental varieties was better than local varieties in overall performance. There is scope for improving the disease resistance and yield of the entries IVS-A-75 and SSC-C-75. Downy mildew incidence was low in several of the IPMAT-5 trial entries, and though MBH-110 was the least downy mildew infected, its grain yield was poor, possibly due to late planting and high ergot disease, UCH-4, though not highly resistant to downy mildew, gave a higher yield than the local check. Among 165 entries in the Pre-IPMDMN trial 23 were highly resistant to downy mildew. Entries J83-1 and 700646 had resistance to most of the important diseases. Local material was evaluated, and 30 entries were found highly resistant to downy mildew, 15 to ergot, and 19 to smut. Combined resistance to all three diseases was observed in eight local entries. The fungicide metalaxyl applied as Apron SD-35 (©Ciba-Geigy) slurry at 2g/kg of seed gave good protection from downy mildew at seedling and up to dough stage at Kano but not at Samaru. Metalaxyl applied as Ridomil did not control downy mildew, although positive results were obtained elsewhere in West Africa.

Progress in Millet Entomology

Senegal

In view of the major emphasis placed by our entomologist on sorghum in 1979/80, only a limited amount of work was done on pearl millet pests in Senegal this year. The stem borer (*Acigona ignefusalis*) was found to be damaging, particularly on research stations. Pearl millet trials sown by the ICRISAT program at Bambey were assessed for damage by earhead caterpillars, mainly *Raghuva albipunctella.* Incidence was high in all trials, as much of the material was of early maturity. There were detectable differences in the levels of attack, and a list of the relatively less susceptible material was drawn up. Some of the local African material was clearly less susceptible than the exotic lines.

Upper Volta

This year we posted an entomologist to Kamboinse station in Upper Volta who initiated work on millet entomology. To date very little information appears to be available on pearl millet pests in this country. Thus the entomologist will aim to identify major pests and their distribution and population, study their life histories, assess yield losses due to pest damage, and ultimately to develop control strategies for the major pests. Pests known to be of significance in pearl millet in Upper Volta are stem borers, head caterpillars, and the Sudan millet bug.

PEARL MILLET STEM BORER. Surveys made on 22 farmers' fields and 2 fields at the Kamboinse station showed that incidence of this pest was greater in the high rainfall zone (900-1000 mm) than in the drier Sahelian Zone (about 300 mm). Damage levels were highest at Kamboinse station, a reflection of diverse planting dates, growing of mixed maturity cultivars, and an all-year-round cropping system. More extensive sampling is planned for the next season to determine areas of priority for research on millet pests.

Progress in Millet Agronomy

Upper Volta

On the basis of our team's preliminary testing of several pearl millet cultivars, the early cultivars, ICMS-7703 and WC-C75, and the intermediate one, Ex Bornu, were the most promising in agronomic trials this year. In the advanced toposequence study, the soil type and interaction between soil type and planting date had significant effects on millet grain yields. In an experiment to study the effects of thinning and transplanting with the improved millets Ex Bornu and Souna III, thinning resulted in greater tillering, more panicles per plant, and higher 1000-grain weight, although no yield advantage was recorded. However, transplanting brought about a reduction in yield by 50%, whether thinned or not.

Our agronomist's studies in Upper Volta indicated that plant populations of photosensitive material should be adjusted in relation to the planting date to obtain maximum possible yields under varying rainfall conditions. Nonphotosensitive millet varieties are not adapted to early planting in the Ouagadougou zone and further north, since time of flowering coincides with heavy and frequent rainfall in August, resulting in pollen wash, and also bird damage causes grain loss. During the year, two major groups of varieties were identified for the Center Zone based on the length of the cropping cycle. Here millet varieties with a growth cycle of 85-95 days are suitable for planting at the end of. June, and varieties with a growth cycle of 75-80 days for late planting in the first half of July.

In the traditional African system, intercropping is an important practice and relevant to farming systems based on exploiting the entire cropping season, minimizing risks of crop failure, maintaining soil productivity, and protecting the soil against erosion. In the current studies, major emphasis was placed on crop combinations suitable for specific soil conditions commonly present along the toposequence. Several experiments were carried out with sorghum/maize, sorghum/millet, millet/cowpea, and millet/groundnut crop combinations. Data indicate that the groundnut/millet (photoinsensitive) combination on sandy upland soils and sorghum/maize associations on lowland soils may increase overall production by 25%. The sorghum/millet combination also seemed to give advantages, particularly in stabilizing overall cereal yields on soils that are marginal for sorghum.

Mali

The main research emphasis at six locations was on the effects on yield of intercropping and soil type along the toposequence. Usually in Mali pearl millet is intercropped with cowpea, and there is a need to determine the utility of new cultivars in the system and the interactions between plant population and plant types. A local millet and M-12 were used with three cowpea cultivars, at three plant densities, at three locations. Generally the millet yields were stable over densities, and the introduced cultivar outyielded the local. The cowpea yields were higher when planted with the local millet, and the best combination was local millet plus local cowpea. Local cowpea hay yields were more affected by the millet cultivar used than were the introduced cowpea cultivars. There was a very distinct location interaction, different systems and genotypes performing differently at different sites with regard to productivity and profitability.

In toposequence trials, as in Upper Volta, yields increased as the soils became deeper and more alluvial in character. Interactions between soil type, planting date, and cultivar were observed.

Progress in Farming Systems

Upper Volta

A study of local farming systems at the village level continued during the year in Upper Volta. An on-farm trial for toposequence effects was conducted with local varieties of cowpea, sorghum, millet, and maize. Yields were low, but responses due to position on the toposequences, reflecting soil differences, were noted. Comparison of these low yield levels, reflecting low soil fertility, with those from verification plots shows the magnitude of the fertility problem in farmers' fields in Upper Volta. The impact of cotton fertilizer and legumes as sources of fertility, particularly nitrogen, will be studied in the coming year.

At the village level, local technology surveys were carried out, and the improved sorghum variety VS-702 was introduced to farmers in a demonstration on how to plant and manage it. Farmers have indicated their interest in a similar field program for the next season, and E-35-1 and VS-702 are proposed as the experimental varieties.

Experiments were also conducted with different systems of soil, land, and crop management. Soil preparation; cultivation techniques; use of ridges, hills, or beds; utilization of crop residues; soil conservation techniques; and crop rotations were studied to explore the possibilities of improving the germination, moisture infiltration, water retention, and nitrogen soil status,

Economics Research

A program in economics research at the farm level in the West African region was set up with the posting of an ICRISAT economist to Kamboinse, Upper Volta, in December 1979. Research will concentrate on two aspects: production and marketing. In the early phase, production issues will receive the major emphasis. The objective of the program will be identification and development of improved production technologies through an analysis of existing farming and marketing systems and evaluation of the improved technologies to assess the socioeconomic constraints to and consequences of their adoption. Program activities constitute village studies, operational-scale agroeconomic trials, and tests of promising technologies under farmers' management. Small-farmer-oriented agroeconomic research will add a new dimension to ICRISAT's multidisciplinary team already posted at Kamboinse. The findings are expected to facilitate the development of farmer-adapted technologies by providing greater understanding of the small farmer's resource situation and by gaining insights into his decision-making process.

Cooperation with Other Countries in Africa

Very close links were maintained with the Ethiopian Sorghum Improvement Program through considerable scientist-to-scientist contact, and the leader of the Ethiopian Sorghum Improvement Program was a participant at the in-house review of our African programs held at Mombasa, Kenya. The Ethiopian program provided ICRISAT with advanced breeding material for use in our breeding programs.

Germplasm breeding trials and pest and disease nurseries were provided to a large number of countries in eastern Africa, including Kenya (where there are links with the ongoing Kenya Government/ FAO Project), Somalia, Zambia, Malawi, and Botswana.

Asian Cooperative Programs

Most of ICRISAT cooperative research effort in Asia is focused on southern Asia, and in particular the Indian subcontinent, where a substantial proportion of the population of the semi-arid tropics lives. Increasing cooperation has developed with Thailand, particularly in the area of training and cereal improvement in the year under review. Our research in India is reported under the respective programs.

Cooperation with CIMMYT

The main objective of the CIMMYT-supported, IDRC-funded program in Mexico is to develop high-altitude, cold-tolerant sorghum varieties with good grain quality for making tortillas and with resistance to the sugarcane borer and fall armyworm, and to leaf diseases, particularly grey leaf spot.

Initially the germplasm base was diversified by introductions from the colder areas of Ethiopia, Uganda, and China, and more recently further introductions were made from Yemen and Ethiopia. Selections from advanced cold-tolerant lines that incorporated desirable traits were tested in two nurseries: The International Cold-Tolerant Sorghum Adaptation Nursery (ICTSAN) and the International Cold-Tolerant Sorghum Elite Nursery (ICTSEN). Of the 139 lines selected, 122 were white- or yellow-seeded and were suitable for human consumption. This material also overcame many of the undesirable features present in earlier lines and matured a great deal earlier. Earliness is a particularly important trait to be incorporated into varieties adapted to these regions. Some problems associated with photoperiod sensitivity and plant height still remain.

Breeding material from the program has been of use in Kenya, Mexico, and Latin America, especially at elevations around 1800 meters. The tested material has been sent to 19 locations in 14 countries and some of it has been incorporated into national sorghum breeding projects. Results obtained from the ICRISAT/CIMMYT Program indicate that yields in excess of 4 tonnes/ha can be expected (based on trials at six locations) in the highlands of Mexico. In the last 2 years, the breeding program has yielded two types that flowered as early as 65 and 70 days and other types with good grain quality.

Cooperation with ICARDA

The ICRISAT/IC ARDA joint chickpea breeding program was further strengthened with the posting of a second ICRISAT breeder to Aleppo, Syria, in 1980. The ICRISAT breeders are supported in their work by ICARDA pathologists, microbiologists, and entomologists who also have responsibility for other leguminous crops in ICARDA's mandate. This team has made excellent progress in the 2 years of joint chickpea research at Aleppo; their work on *Ascochyta* blight resistance is particularly promising.

The principal objective of the program at ICARDA remains the development of conventional and tall kabuli types with resistance to *Ascochyta* blight and with increased seed size and improved cold tolerance for different environmental situations in West Asia, North Africa, Southern Europe, and South and Central America.

Germplasm Evaluation

In a 1979/80 spring sowing at Tel Hadya, Syria, 3269 kabuli germplasm accessions were evaluated for 22 characters, and a catalog of these will shortly be produced.

More than 3000 lines were evaluated for cold tolerance in 1979/80 at Haymana and Erzurum in Turkey. Despite very low temperatures (-26°C at Haymana) several lines survived at both locations and will undergo further screening in the coming season.

BREEDING FOR SPRING SOWING. At Terbol, Lebanon, 270 crosses were made and the F_1s were grown in the off-season.

Advanced breeding lines for spring sowing were included in replicated yield trials for the first time at Tel Hadya and Terbol. At Tel Hadya the mean yield of the breeding lines was 1685 kg/ha compared with 1381 kg/ha for germplasm entries, indicating considerable potential for yield improvement.

BREEDING FOR *ASCOCHYTA* BLIGHT RESISTANCE. Provided *Ascochyta* blight is controlled by the use of resistant genotypes, winter-sown chickpea produces substantially higher yields than spring-sown crops and allows extension of production into zones drier than traditional chickpea-growing areas.

In 19 on-farm and station trials conducted in collaboration with the Syrian Ministry of Agriculture, winter-sown ILC-482 produced an average seed yield of 1839 kg/ha, exceeding the yield of spring-sown Syrian Local by 974 kg/ha, or 113% (Table 4). The superiority of ILC-482 was especially marked at locations where *Ascochyta* blight was so severe that in some cases there was total crop loss of both spring- and winter-sown Syrian Local.

More than 9000 germplasm and breeding lines were screened for *Ascochyta* blight resistance. Twenty-one genotypes have now maintained resistance for 2 and 3 years, and an additional 36 F_3-F_7 progenies and 32 ICRISAT germplasm lines showed resistance this season. The wild species *C.pinnatifidium, C.montbretti,* and *C.judaicum* were resistant, and *C. yamashitae*, *C. bijugum, C. ouneatum,* and *C. reticulatum* were susceptible. There was variation in disease reaction even within species, indicating a need for collection of the same species from several locations.

Of 40 to 50 entries in 1978/79 and 1979/80 Chickpea International *Ascochyta* Blight Nurseries (CIABN), three lines-ILC-191, -202, -3279—gave consistent resistance ratings in 12 trials from which reliable results were received. Some lines varied in reaction from place to place, suggesting that races of the disease may occur.

Table 4. Seed yields (kg/ha) of winter-sown ILC-482 and spring- and winter-sown Syrian Local chickpea in on-farm and experiment station trials in Syria in 1979/80.

Location	ILC-482 Winter	Syrian Local Winter	Syrian Local Spring
Izra	1666	1444	793
Gelline	1076	707	666
Hama	3427	3093	3190
Village near Hama	1831	1740	816
Horns	2833	1056	1555
Village near Horns	2222	1111	1389
Boustan E1-Basha	1667	0	0
Azes	836	501	401
Atareb	2110	701	477
Derkak	712	31	5
Ebben	1039	863	791
Kawkaba	1576	809	1674
Mohambel	1781	281	264
Maret Masrin	1417	706	1173
Breda	2481	146	104
Jinderis	2464	0	0
Kafarantoon	1357	1638	1658
Tel Hadya	1971	0	605
Mean	1839	824	865

F_2 populations of crosses involving ILC-72, -183, and -200 and ICC-4935 indicated that resistance was controlled by simple dominant genes and in ILC-191 by a simple recessive gene.

BREEDING FOR TALL PLANT TYPE. In winter sowings, seed yields were increased by increasing plant density from 30 to 50 plants/m^2, and tall types gave yields equivalent to conventional types, indicating their potential for winter sowing (Table 5).

BREEDING FOR INCREASED SEED SIZE. Large-seeded kabuli types gave higher seed yields than medium-seeded types in Initial (IYT), Preliminary (PYT), and Advanced (AYT) Yield Trials at Tel Hadya (Table 6).

International Nurseries

In 1978/79 seed of 85 chickpea trials was distributed to national programs from ICARDA, including 22 adaptation trials, 20 international yield trials (CIYT), 20 international screening nurseries, 9 international F_3 trials, and 14 international *Ascochyta* blight nurseries. Results were received from 54 trials.

In the CIYT, few entries produced significantly higher seed yields than the local check, except in Algeria where *Ascochyta* blight was very severe, but ILC-480 and ILC-51 gave above-average seed yields at most locations. The performance of cultivars varied between locations. The adaptation trials will be useful in characterization of genotype responses in different environments in order to develop more effective breeding and testing strategies.

More detailed reports of the 1978/79 and 1979/80 trials are available from ICRISAT's International Cooperation Program.

Table 5. Seed yields (kg/ha) of tall, mid-tall, and conventional plant types at two plant densities at Tel Hadya, Syria, in winter 1979/80.

Plant type	Entry No.	Plants/m^2 30	50
Tall	ILC-172	1976	2411
	-196	1186	1639
	-202	1995	2739
	-2952	1994	1719
	-3279	1843	2370
Mid-tall	ILC-191	1352	2157
	-195	1937	2304
Conventional	ILC-482	1982	2696
LSD (0.05)		351	551
CV (%)		12.7	16.2

Fellowships and Training

This year 138 agriculturists from state, national, or regional agricultural agencies in 27 countries completed ICRISAT training programs, which provided them with skill and concept development opportunities for work in the rainfed semi-arid tropics (Table 7). Theoretical and practical

Table 6. Mean seed yields (kg/ha) of large- and medium-seeded kabuli lines at Tel Hadya, Syria, in 1979/80.

Seed size	IYT No. of lines tested	IYT Seed yield	PYT No. of lines tested	PYT Seed yield	AYT No. of lines tested	AYT Seed yield	All trials No. of lines tested	All trials Seed yield
Large	145	1958	36	1937	16	1591	197	1924
Medium	75	1685	49	1528	49	1234	173	1513

Table 7. Participants completing training programs, 1979/80.

Name	Country .	Period (weeks)	Program
IN-SERVICE TRAINEES			
Abdel Kader Ndao	Senegal	32	Crop Improvement
Issa Hama	Niger	32	Crop Improvement
Tani Sani	Niger	32	Crop Improvement
Issoufou Bouzou	Niger	32	Crop Improvement
Moumouni Sanda	Niger	32	Crop Improvement
Moussa E. Manzo	Niger	32	Crop Improvement
Soumana Souley	Niger	32	Crop Improvement
Sidi Rachide	Mauritania	32	Crop Improvement
Aly Sy	Mauritania	32	Farming Systems
Ibrahime Karabinta	Mali	32	Crop Improvement
Bakary Nabe Diane	Mali	32	Crop Improvement
Moumouny Traore	Mali	32	Crop Improvement
Sibene Dena	Mali	32	Crop Improvement
Moussa G. Traore	Mali	32	Crop Improvement
Diarra Adama	Mali	32	Crop Production
Auta Audu	Nigeria	24	Plant Pathology
Saidu Amedu	Nigeria	24	Crop Improvement
Solomon K. Sackitey	Nigeria	24	Crop Improvement
Tag E. Osman Ahmed Hassan	Sudan	24	Crop Improvement
Osman M. Mohamed	Sudan	24	Crop Improvement
E.H.E.N. Yagoub	Sudan	24	Crop Improvement
M.E.H. Fadlalla Eissa	Sudan	24	Crop Improvement
Ali Abbas Ali	Sudan	24	Crop Production
Jean Detongnon	Benin	24	Crop Improvement
Charles D. Kitundu	Tanzania	24	Crop Production
B.W. Kolla	Tanzania	24	Crop Production
Joseph Anthony	Tanzania	24	Crop Production
S.N. Lubinza	Tanzania	24	Crop Production
P.A.M. Alberto	Uruguay	24	Crop Improvement
A. B. L. Shrivastava	India	24	Crop Production
M. Kokoro	Botswana	24	Crop Improvement
Miss M. Gasenone Seja	Botswana	24	Crop Improvement
G.K. Njehia	Kenya	24	Crop Improvement
N.O. Alwodi	Kenya	24	Crop Production
M. Fobasso	Cameroon	24	Crop Improvement

Continued

Table 7. Continued

Name	Country	Period (weeks)	Program
Johna George G. Bunkpirima	Ghana	24	Crop Improvement
J.C. Olela	Kenya	24	Cereal Entomology
W.N. Illangasinghe	Sri Lanka	24	Sorghum Production
H.M. Muthu Banda	Sri Lanka	24	Land and Water Management
Miss Sumitra Maneemaroat	Thailand	24	Cropping Systems
Pote Pimpanit	Thailand	24	Cropping Systems
Narong Bunmerowd	Thailand	24	Land and Water Management
Miss Taksina Pinsuwan	Thailand	24	Agroclimatology
Chairoj Wongwiwatchai	Thailand	24	Soil Fertility
Katia Tritrungtreekun	Thailand	24	Cropping Systems
Dickson K. Otieno	Kenya	24	Sorghum Improvement
E1 Tigani Siddig Mohamed	Sudan	24	Chickpea Breeding
Gerald P. Okomba	Kenya	24	Sorghum Improvement
Patrick Lusamamba	Kenya	24	Sorghum Improvement
Matute M. Muangalene	Nigeria	22	Cereal Pathology
Assadullah Habibi	Afghanistan	20	Chickpea Breeding
Kitti Wongpichet	Thailand	20	Pigeonpea Breeding
S. Venkateswarlu	India	20	Pigeonpea Breeding
Jokhu Ram	India	20	Pigeonpea Breeding
Chowdhury Doza Md. Sarwar	Bangladesh	20	Pigeonpea Breeding
Hemant Kumar	Fiji	20	Pigeonpea Breeding
Anil Kumar Mishra	India	20	Pigeonpea Breeding
Nirat Vanitvatanalumlog	Thailand	18	Pigeonpea Breeding
Mrs. Malee Chawanapong	Thailand	18	Sorghum Entomology
Mrs. Julee L. Tippayaruk	Thailand	16	Sorghum Breeding
Badri Barsi Saleh	Sudan	12	Microbiology
N.N. Sahu	India	7	Land and Water Management
F.J. Simon	India	5	Farm Equipment and Machinery
Mohammed Aleemullah Khan	India	5	Farm Equipment and Machinery
Mohinder Singh Sangwan	India	4	Chickpea Pathology
Gurdip Singh	India	4	Chickpea Pathology
Said Ahmed Md. Omar	Egypt	4	Chickpea Pathology
Mahendra Pal	India	4	Chickpea Pathology
Miss Om Gupta	India	4	Chickpea Pathology
Rajnarian Singh Tyagi	India	4	Chickpea Pathology

Continued

Table 7. Continued

Name	Country	Period (weeks)	Program
Birendra Kumar Sinha	India	4	Chickpea Pathology
Ram Nayak Singh	India	4	Chickpea Pathology
E1 Samani Ibrahim E1 Amin	Sudan	4	*Striga* Control Techniques
Is mat Mustafa Hussein	Sudan	4	*Striga* Control Techniques
Bakheit Mohamed Musa	Sudan	4	*Striga* Control Techniques
Anil Kumar Kush	India	4	Microbiology
Mrs. D. Bharata Lakshmi	India	4	Microbiology
K. R. Avadhanulu	India	4	Microbiology
P. Chandrasekhar Rao	India	4	Microbiology
Surapong Potipiboon	Thailand	4	Farming Systems
Sompong Summapruksakit	Thailand	4	Farming Systems
Satit Tayapat	Thailand	4	Farming Systems
Miss Wilailak Sommut	Thailand	4	Farming Systems
Mrs. Panpaka Sradokboa	Thailand	4	Farming Systems
Tawachai Na Nagara	Thailand	4	Farming Systems
Phattakun Chandhanamutta	Thailand	4	Farming Systems
Vishnu Pushpavesa	Thailand	4	Farming Systems
Narong Unyawong	Thailand	4	Farming Systems
Surasak Sangswasdi	Thailand	4	Farming Systems
Songchai Watanapayupkul	Thailand	4	Farming Systems
Vichai Hirunyupakorn	Thailand	4	Farming Systems
Nikul Tawisinboonyakorn	Thailand	4	Farming Systems
F.J. Opondo	Kenya	4	Pigeonpea Pathology
S.R. Kotasthane	India	2	Pigeonpea Pathology
Ram Nayak Singh	India	2	Pigeonpea Pathology
S.P.S. Beniwal	India	2	Pigeonpea Pathology
Graciela Godoy Manana	Dominican Rep	2	Pigeonpea Pathology
Satchidanand Gurha	India	2	Pigeonpea Pathology
B. G. Das Desai	India	2	Pigeonpea Pathology
Amar Nath Mishra	India	2	Pigeonpea Pathology
S.C. Odak	India	1	Pulse Entomology
Jagdish S. Naresh	India	1	Pulse Entomology
Masoom Husain	India	1	Pulse Entomology
K.S. Chhabra	India	1	Pulse Entomology
R. Rajendran	India	1	Pulse Entomology
Madan Mohan Sinha	India	1	Pulse Entomology
Sheo Shankar Lal	India	1	Pulse Entomology

Continued

Table 7. Continued

Name	Country	Period (weeks)	Program
H.K. Vyas	India	1	Pulse Entomology
Vinod Kumar Sehgal	India	1	Pulse Entomology
A. Abdul Kareem	India	1	Pulse Entomology
M. Vishakantaiah	India	1	Pulse Entomology
B.K. Dhanorkar	India	1	Pulse Entomology
C.B. Shinde	India	1	Pulse Entomology
APPRENTICES			
P. Balakrishnan	India	8	Farm Development Operations
W.S. William	India	8	Farm Development Operations
M. Ramjee	India	8	Farm Development Operations
Jagtap S. Shankar	India	8	Farm Development Operations
Malcolm M. Wilson	USA	8	Land and Water Management
C.R. Gopala Swamy	India	3	Land and Water Management
P. Radhakrishnaiah	India	3	Land and Water Management
C. Bhoopati	India	2	Farm Machinery and Maintenance
G. Lakshminarayana	India	2	Farm Machinery and Maintenance
RESEARCH SCHOLARS			
Kenneth W. Riley	Canada	164	Sorghum Breeding
Paul T. Gibson	USA	120	Sorghum Breeding
Soloman Tuwafe	Ethiopia	96	Chickpea Breeding
S.C.L. Premi	India	28	Farming Systems
G.V. Ranga Reddy	India	24	Economics
Indralal Kalu	Nepal	20	Farming Systems
Surendra Kaur Virk	India	8	Chickpea Pathology
D. Narayana	India	1	Sorghum Pathology
RESEARCH FELLOWS			
A.N. Rao	India	80	Agronomy and Weed Science

Continued

***Table 7.** Continued*

Name	Country	Period (weeks)	Program
B. L. Subba Rao	India	48	Pulse Pathology
E. Priyadarshini	India	26	Biochemistry
Antonio A. Marqueses	Philippines	12	Farming Systems
E.A. Menezes	Brazil	8	Intercropping Systems
M.X. dos Santos	Brazil	8	Intercropping Systems
L. B. Margado	Brazil	8	Soil Fertility and Plant Nutrtion
J. Kapasi Kakama	Kenya	1	Sorghum Quality Improvement

experience was given in research methods, crop improvement, crop production, socio-economics, farming systems, and extension.

Six international interns continue at the research center in microbiology, millet physiology, groundnut pathology, cropping systems, groundnut physiology, and groundnut pathology. Another intern is assigned to the sorghum improvement program in Upper Volta.

One of our former trainees instructs a local technician on emasculation of sorghum in an ICRISAT breeding nursery in Upper Volta.

One research fellow is studying weed science. Research scholars associated with eight universities are conducting thesis research in socioeconomics, millet breeding, microbiology, sorghum breeding, groundnut breeding, soil fertility, agricultural engineering, millet physiology, and cropping systems.

In-service trainees (47) from 19 countries continue training and reside in the research center facilities. Next year a larger number of agriculturists with postgraduate and BSc degrees will be accepted for educational programs and research experience; 70-80 can be accommodated at one time in our present training facilities. Correspondence, issuing of reports and germplasm samples, and visits have enabled contacts to be maintained with more than 400 agriculturists who completed ICRISAT training programs and are now employed by agricultural agencies.

Workshops, Conferences, and Seminars

Inaugural Symposium

A highlight of the week-long inaugural program of ICRISAT Center was the 5-day symposium, "Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer," attended by 250 scientists from 28 Aug-1 Sept 1979. This was the first conference held in the new 250-seat auditorium of ICRISAT Center.

Apart from ICRISAT scientists and their colleagues in national programs, representatives of four international organizations - the UNDP, World Bank, FAO, and the CGIAR— and government officials and representatives of development agencies of many countries attended the symposium. Delegates came from nine African countries, nine in Asia and the Pacific, seven in Europe, two in North America, and one in South America.

In seven separate sessions, the symposium delegates explored problems in the development and transfer of agricultural technology in the semi-arid tropics. It was emphasized that ICRISAT must work in close cooperation with national programs in the effort to convey its research findings to their ultimate user—the farmer, and that there must be clear channels of communication from the generation of knowledge, through development of technology, to its final application on the land. The proceedings of the symposium are available from Information Services, ICRISAT.

Yield Gap Analysis for Dryland Crops

In collaboration with the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), ICRISAT hosted the Working Group Meeting on "Yield Gap Analysis for Dryland Crops" from 17 to 23 February 1980, which was attended by 45 scientists. The objective of the workshop was to bring together economists and agronomists of three institutions—the International Rice Research Institute (IRRI), AICRPDA, and ICRISAT—to develop a methodology for analyzing factors responsible for gaps in yields (and economic productivity) between research plots and farmers' fields for dryland crops. The scientists from IRRI presented their well-developed method for analysis of constraints on rice yields. The applicability of this method was assessed using data gathered by AICRPDA economists/agronomists from 16 research stations in India over several years. ICRISAT economists presented two papers: one on analysis of data on watershed experiments at research stations and in villages in India, and the other using activity analysis for examining productivity constraints.

In several intensive discussion sessions and in smaller group meetings, principles were established regarding the method of analysis of the performance gap of new technologies in rainfed agriculture, and detailed guidelines of how to lay out experiments and surveys were finalized. An economic analysis showed that successful implementation of recommendations coming from gap analyses may vary for different crops. The report of the workshop is available from Information Services, ICRISAT.

Conference on Microbial Inoculants

The Fifth Southern Regional Conference on Microbial Inoculants in Crop Production, held 20-22 March 1980, was attended by 40 agricultural microbiologists from all over India. The conference concentrated on biological nitrogen fixation, with particular emphasis on new research techniques developed at ICRISAT.

Cooperators' Meeting on Sorghum Modeling

A Cooperators' Meeting was held 2-4 April 1980 to discuss the collaborative multilocation sorghum modeling experiments, which were conducted during 1979/80. About

33 scientists from the following institutions attended: ICRISAT; Texas A &M University, USA; Khon Kaen University, Thailand; and from India: IARI (New Delhi), Haryana Agricultural University (Hissar), Punjab Agricultural University (Ludhiana), Marathwada Agricultural University (Parbhani), India Meteorological Department (Pune), Mahatma Phule Krishi Vidyapeeth (Rahuri and Sholapur). The proceedings of the meeting are available from Information Services, ICRISAT.

Consultants' Meeting on Climatic Classification

Seven participants from UK, Canada, India, and FAO (Rome) met on 14-16 April 1980 to discuss present climate classification methodologies and a future plan of action. A compilation of the papers presented is available from Information Services, ICRISAT.

Field Days

Twenty-nine pigeonpea breeders from all over India and one from Bangladesh attended a meeting held on 11-13 December 1979, mainly to select material for their own breeding programs. The first day was devoted to a tour of the pigeonpea research plots and the second to selection of breeding material in the field and/or visits to ICRISAT laboratories and consultations with ICRISAT scientists.

SIXTH INTERNATIONAL CHICKPEA BREEDERS' MEET. The first part of this was held at ICRISAT Center on 18-20 February, and the second part at Hissar, 1-3 April 1980, in collaboration with Haryana Agricultural University (HAU). About 15 scientists from Bangladesh, Nepal, Pakistan, USA, and India visited the chickpea experimental plots of both HAU and ICRISAT. The visitors selected material for their own use and held wide-ranging discussions of problems of mutual interest.

Visitors' Services

Visitors at ICRISAT are received by the Visitors' Services of the Institute, which consists of two Scientific Liaison Officers and support staff. From June 1979 to May 1980, 9662 visitors came in 563 groups-averaging about two groups every working day, as against 7691 visitors in 1978/1979. Our biggest groups were farmers, the ultimate target of our research work, who came from far and near, usually in the winter months after harvest of the rainy-season crops. Our Inaugural Week celebration brought 750 people between 2 and 4 September, including farmers and general public. The next biggest groups were the trainees, extension workers, and agricultural students sent by institutions in and around Hyderabad. We also attracted 317 scientists from abroad and 460 from India.

Other visitors included school children, missionaries, doctors, journalists, administrators, state and central government officials, and housewives.

Among the foreign officials who visited ICRISAT were the British and Canadian High Commissioners in India; the Minister in Charge of Agriculture in the Prime Minister's Secretariat of North Vietnam; the Executive Vice President of the World Bank; the Alternate Executive Director, World Bank for India, Sri Lanka, and Bangladesh; the U. S. Consul General from Madras; the Australian Trade Commissioner; and the Technical Advisory Committee (TAC) Consultant, CGIAR.

PLANT QUARANTINE

Export of Plant Material

The export and import of quarantine seed material increased again this year. After quarantine clearance *by* the Government of India, 54 363 seed samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, minor millets, and some other crops were exported to 35 countries in Africa, 21 in Asia, 22 in the Americas, 12 in Europe, and 5 in Australasia (Table 1).

The minor millets exported included *Echinochloa crusgalli, Eleusine coracana, Setaria italica, Panicum miliaceum, Panicum miliare,* and *Paspalum scrobiculatum.* Other crops exported were maize, teosinte, heteropogon, castor, *Cicer* spp, and Napier grass.

Fifty *Rhizobium* cultures of chickpea, pigeonpea, and groundnut were examined in the quarantine laboratory and sent to nine countries for experimental purposes.

Import of Plant Material

During the year, we imported 16 087 samples of sorghum, pearl millet, pigeonpea, chickpea, and groundnut from 13 countries in Africa, 10 in Asia, 6 in the Americas, 4 in Europe, and 2 in Australasia (Table 2).

Seeds of *Atylosia* spp, *Cajanus kerstengii, Rhynchosia* spp, *Cassia* spp, *Crotolaria* spp, *Lens esculantum,* and *Vigna* spp were imported and cleared at the National Bureau of Plant Genetic Resources, New Delhi. After being grown in our postentry quarantine, these were used by our scientists in various experiments.

Table 1. Seed samples exported by ICRISAT during 1979/80.

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Others
AFRICA						
Algeria				174		
Botswana	14	67	14			16
Burundi	93					
Cameroon	114	1				
Capeverde Islands			45			
Egypt	60		25	174		
Ethiopia	644			573	25	282
Gambia	90					
Ghana	682	79	159		58	43
Guinea Bissau	90					
Ivory Coast			12			
Kenya	2722	325	417	254	5	259

Continued

Table 1 Continued

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Others
Malawi	690	453	7	7		
Mali	1164	10	151			30
Mauritania	168	6		5		
Morocco					49	
Mozambique			1		40	
Niger	829	1197				24
Nigeria	314	757	311		20	23
Republique du Benin	256				129	
Rwanda	84	45				100
Senegal	860	1621	70	10	109	18
Sierra Leone			13			
Somalia	250	12	18			21
South Africa	4					
Sudan	3302	1239	15	14	56	34
Swaziland			81			
Tanzania	63	50	118	77	74	6
Togolaise	90					
Tunisia				174		
Uganda	135	60	44			
Upper Volta	1593	3982	6	10		
Zaire		10	15			
Zambia	361	60	2			
Zimbabwe			19			
ASIA						
Afghanistan				230		
Bangladesh	195	4	292	861	8	2
Burma	311	60	150			
Indonesia						124
Iraq				174		
Israel	34	20		20		16
Japan	59		11	13		3
Jordan				174		
Malaysia			46	19	222	
Nepal	5		356	352	5	2

Continued

Table 1 *Continued*

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Others
Pakistan	630	306	171	1158	198	1270
Peoples' Rep. China	836	12		95	50	492
Philippines	334	7	58		21	316
Qatar	252					
Sri Lanka	126	5	108			
Syria	154			2260		
Taiwan	10	11	34	12		
Thailand	743	244	204	23	6	526
Yemen Arab Republic	320		19	317		
Yemen Dem. Rep.	491			5		
USSR	608	11				
AMERICAS						
Argentina	190			174		
Belize	311					
Brazil	143	66	10	10	4	116
Canada	89	1		25		32
Chile	9			247		
Costa Rica		7				
Dominican Rep.			85			
Ecuador	119					
El Salvador	114					
Guatemala	59		56			
Hawaii			1	1		
Honduras	181				12	
Mexico	871	118		516		132
Nicaragua	59					
Paraguay			1	182		
Peru	70		26			
Puerto Rico			3			
Surinam	70	133				
USA	114	17	23	295	4	588
Uruguay		2				
Venezuela	157	173	116			37
West Indies			54			

Continued

Table 1 *Continued*

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Others
EUROPE						
Austria	98					
Denmark	10	10	10	9	10	30
England	86	74	19	27	2	408
Fed. Rep. Germany						2
France	36	44			11	
German Dem. Rep.		5				7
Hungary	208					
Italy				10	37	
Netherlands	41	45		6	2	447
Spain				2		
Switzerland		8				1
Turkey						11
AUSTRALASIA						
Australia	1050	56	122	17	11	110
Fiji						4
New Zealand			4	72		
St. Helena			10	10	14	1
Tonga Islands					50	
Total	23865	11413	3532	8788	1232	5533

Table 2. Seed samples imported by ICRISAT during 1979/80.

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets	Others
AFRICA							
Botswana	2						
Ethiopia	1100						
Ghana							1
Kenya	8					19	
Malawi	297	238	101	3	18	232	3

Continued

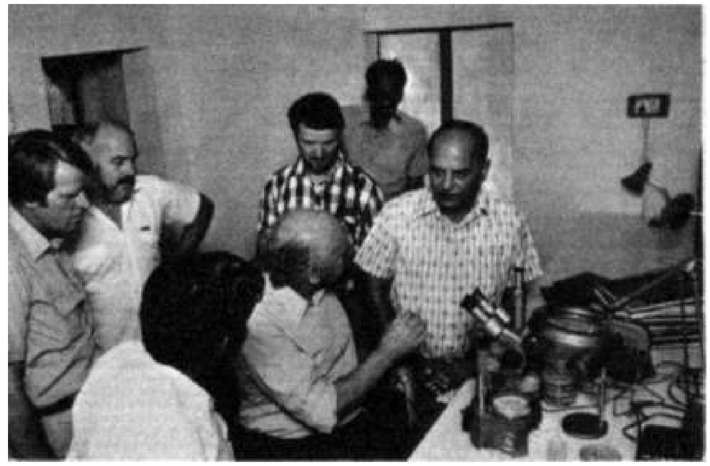
Table 2 Continued

Country	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut	Minor millets	Others
Mali	15						1
Nigeria		45					
Senegal	6						
Somalia	124	3			5		
South Africa					114		
Sudan	359	84		6			
Tanzania	228					5	
Upper Volta	29						
ASIA							
Bangladesh		2	32	33			3
Indonesia	14						
Malaysia	1						
Nepal			72			8	45
Peoples' Rep. of China	16				64	26	
Philippines	3157						
Sri Lanka	28						
Syria	2116	1620		205		832	
Taiwan	1						
USSR	2					191	
AMERICAS							
Chile				129			
Colombia			3				2
Mexico	316			93			
Puerto Rico	1260						
USA	756	6			289		
Uruguay	9						
EUROPE							
England					1078		
France	4						
Italy	338			5		28	1
Turkey				3			
AUSTRALASIA							
Australia	158		33	14			43
Fiji			5				
Total	10344	1998	246	491	1568	1341	99

Postentry Quarantine

During the year, we planted 4039 accessions of sorghum, 3335 of pearl millet, 38 of pigeonpea, and 513 of chickpea in the postentry quarantine isolation area. Six hundred and seventy samples of groundnut seed were grown in the Government of India net house at the Central Plant Protection Training Institute (CPPTI), Hyderabad; the 6-week-old seedlings were inspected, and those found free from exotic viral and fungal diseases were released to us for growing in postentry isolation. We tested 898 cuttings of *Arachis* spp, and hybrids grown in our quarantine net house by indexing on susceptible host plants. Seedlings that showed negative results were planted in our postentry quarantine area. We also planted 1504 samples of minor millets in this area.

These crops were inspected twice a week until harvest by the quarantine staff of the Government of India and ICRISAT, and plants showing any symptom of exotic diseases were incinerated. Seeds of healthy plants were released to ICRISAT crop improvement programs for experimental work.



Director (at microscope) of Danish Institute of Seed Pathology for Developing Countries, Copenhagen, examines germplasm material in the plant quarantine laboratory at ICRISAT Center.

Trips and Visitors

Our Quarantine Officer's visit to the quarantine facilities of USDA at Beltsville to discuss inspection procedures and quarantine regulations resulted in better cooperation in the exchange of seed material with the U.S. Quarantine Center.

Visits to the plant quarantine facilities at ICRISAT by the FAO Plant Quarantine Officer; the Director and the Deputy Director of the Danish Government Institute of Seed Pathology, Copenhagen, Denmark; and the Project Director, Plant Quarantine Services, Federal Government of Nigeria, also facilitated cooperation and exchanges with their countries/organizations.

COMPUTER SERVICES

The Computer Services Unit provides time-sharing services to ICRISAT personnel through the RSTS/E (Resource Sharing Time Sharing/Extended) operating system running on a DEC PDP-11/45 Computer System.

In order to achieve our goal to integrate the use of the ICRISAT computer system into the daily routine of research, administrative, and service departments of the Institute, we are (1) developing interactive systems that are easy to use, (2) providing data-entry services, and (3) conducting seminars on computer usage and programming.

Current Stage of Development

Version 6C of RSTS/E was implemented in October 1979, replacing Version 6A, which had been in use since January 1976. This new version of the operating system has provided additional flexibility for software development and disk-error recovery. CRISP (Crop Research Integrated Statistical Package), ECODEP (Economics Data Entry Program), and IDMRS (ICRISAT Data Management and Retrieval System) were modified to exploit the new features of version 6C. We have acquired a FORTRAN compiler, which permits the implementation of programs acquired from other installations without conversion to BASIC-PLUS, the primary language of RSTS/E. This year we also implemented the BMDP statistical package, originally developed at the University of California at Los Angeles (USA) and modified for the PDP-11 by Software Development Inc., Middlebury, Vermont, Programs were written to permit the conversion of CRISP formatted data to BMDP format, and users were thus provided with 33 well-tested statistical analyses.

A search for a more powerful computer system was initiated in September 1979 with the aid of our consultant from the University of New Hampshire (USA). A decision was taken in early February 1980 to purchase a VAX-11/780 computer system, manufactured by Digital Equipment Corp., USA. This computer system will have four million bytes of memory, three 176-million-byte disk drives, two dual-density tape drives, one 600-line-per-minute line printer, one 600-line-per-minute printer/plotter, five high-speed printing terminals for use as local printers, and 24 video terminals. Additionally, we will purchase two special terminals for quality printing of documents. Most of the terminals on the current computer system will be shifted to the new system, and most departments will have their own terminal. A large program size is possible on the VAX, and commercially available statistical, econometric, and mathematical programming packages will be purchased to provide additional analysis capabilities to ICRISAT scientists.

Our consultant returned in February 1980 for a 6-week stay to follow up on the selection of the new computer system and to continue research in statistical techniques for eliminating differences in responses due to field variation.

An uninterruptible power system (UPS) was installed in March 1980. The UPS is a battery-backed system that isolates the computer system from power failures and voltage surges, which are potential problems at ICRISAT Center. The batteries will provide power for 15 minutes, more than ample time for the ICRISAT emergency generators to be started. The UPS should permit uninterrupted computer usage and 24-hour operation.

The Computer Manager at IITA visited ICRISAT in July 1979 and was given a copy of CRISP for implementation on IITA's PDP-11/70 computer system.

A Programmer/Analyst from the Department of Agriculture, University of Queensland, Australia, visited ICRISAT for 3 weeks in January 1980 to implement computer programs developed at the University of Queensland that perform pattern analysis of genotype x environment means.

Statistics

A statistician joined ICRISAT in October 1979 to start the Statistics subprogram. This subprogram will provide professional statistical guidance to researchers on a continuing basis and will coordinate the development of statistical analysis software with Computer Services.

Looking Ahead

The major emphasis in the coming year will be on the modification and improvement of existing computer software for implementation on the VAX-11/780. The additional computing capacity will also permit the development and implementation of software to support the administrative functions of the Institute.

LIBRARY AND DOCUMENTATION SERVICES

The library moved into its new premises in the main campus building of ICRISAT Center at Patancheru during the year under report. It is now offering better reader facilities to more ICRISAT scientists, trainees, and visitors.

Acquisition

The library continued the policy of acquiring major research publications in the agricultural and sociobiological fields. The documents added during the year and the total holdings are as follows:

Documents	Additions during the year	Total holdings (June 1980)
Books	837	14149
Bound volumes of periodicals	664	8101
Annual reports	57	331
Microforms	139	961

The current serial acquisition is 744 periodicals, 200 newsletters, and more than 100 annual reviews and yearbooks.

Reprography

A reprography unit was added to the Department to cater to the photocopying and cyclostyling needs of various programs of ICRISAT. Most program-level reports are handled by this unit. On an average, the unit turns out 40 000 photocopies and 120 000 pages of cyclostyled material every month.

Sorghum and Millets Information Center (SMIC)

Although the systematic collection of information on sorghum and millets was started in the middle of 1977, the first step towards dissemination of information was taken with the publication of the *SMIC Newsletter* in August 1979. Three issues of the Newsletter were published during the period under report and distributed to nearly 1200 institutions and individuals.

Since October 1979, the Selective Dissemination of Information (SDI) service has been organized for ICRISAT scientists, both at ICRISAT Center and at the cooperative programs. The monthly SDI service consists of abstracts of articles selected from primary periodicals (about 600) received in the ICRISAT Center library. It is proposed to extend this service as Current Awareness Service to scientists all over the world.

SMIC brought out during the year *Sorgho: Bibliographie Annotee de la Documentation Internationale en Francais, 1900-1976,* This contains 863 references published in French. Two other bibliographies, *Sorghum Bibliography, 1970-76* and *Millets Bibliography, 1970-76* are nearing completion, and others are in preparation. Scientists all over the world are making good use of SMIC services, and a number of ad hoc bibliographies were compiled on demand. The demand for photocopies of reference material available with SMIC also increased. SMIC collected 905 bibliographical citations and 535 photocopies on sorghum, and 555 bibliographical citations and 276 photocopies on millets during the year.