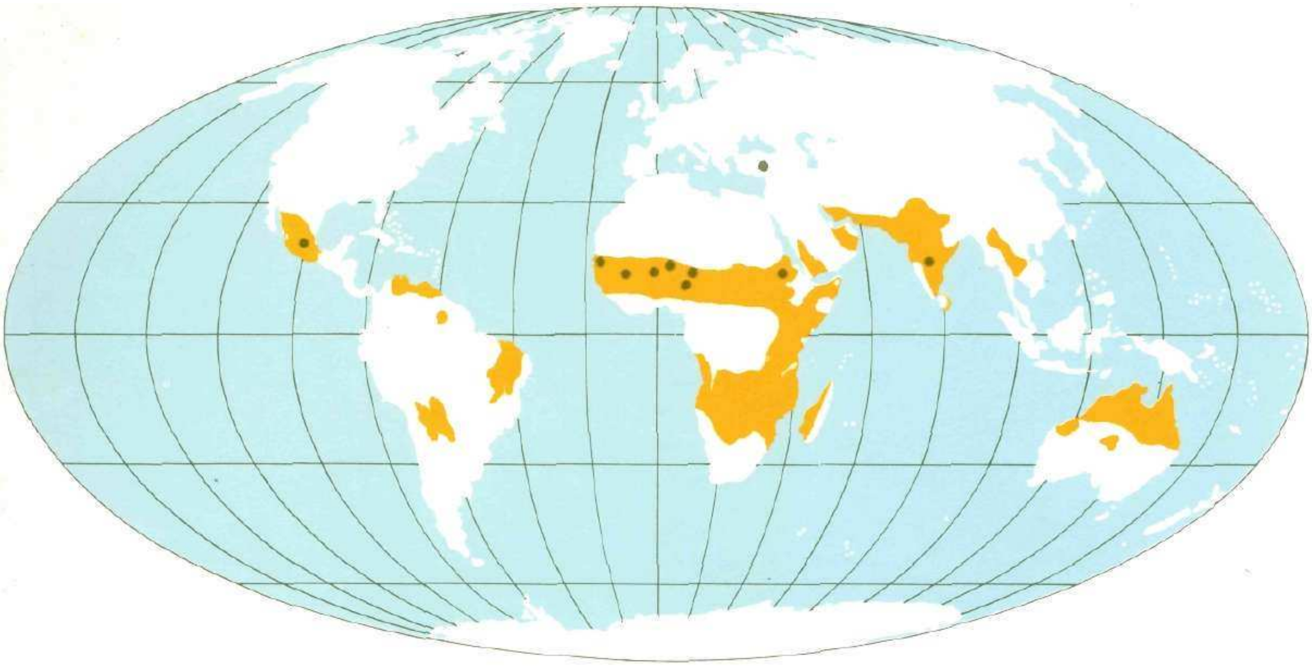
ICRISAT ANNUAL REPORT 1981



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

Cover: The semi-arid tropics are shown in yellow. The dots indicate the locations of ICRISAT resident scientific staff during June 1980 through December 1981.

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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 eighth Annual Report covers $1^1/_2$ years (June 1980 through December 1981) as a transition from our crop year reports (1 June to 31 May) to future reporting on a calendar year basis. Because of the different normal and experimental growing periods of our five mandate crops and the need for time after cropping seasons to analyze data, some of the reports do not cover the entire $1^1/_2$ years. The period under report is mentioned in each Program's introduction.

This year we have also changed the format in the crop improvement programs from reporting by separate disciplines to interdisciplinary reports on problem areas, which better reflects the interactive nature of our scientists' work.

This Annual Report includes work done at ICRISAT Center near Hyderabad, India, at research stations on the campuses of agricultural universities in four different climatic regions of India, and at national and international research facilities in the 10 countries of Africa, Latin America, the Middle East, and Australia 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. The work reported here is written up 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.

Contents

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	Petit mil	Pois d'Angole, pois cajan	Pois chiche	Arachide
Portuguese	Sorgo	Painco perola	Guando, feijao-guando	Grao-de-bico	Amendoim
Spanish	Sorgho, zahina	Mijo perla, mijo	Gaundul	Garbanzo, garavance	Mani
Hindi	Jowar, jaur	Bajra	Arhar, tur	Chana	Mungphali

Acronyms and Abbreviations Used in this Annual Report

ACT	Arhar Coordinated Trial
AICMIP	All India Coordinated Millet Improvement Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICPIP	All India Coordinated Pulses Improvement Project
AICRPDA	All India Coordinated Research Project for Dryland Agriculture
AICSIP	All India Coordinated Sorghum Improvement Project
APAU	Andhra Pradesh Agricultural University
APT	Advanced Population Trial
BBF	Broadbed and furrow
BHC	Benzene hexachloride
BYMV	Bean yellow mosaic virus
CFTRI	Central Food Technological Research Institute
CIAT	Centro Internacional de Agricultura Tropical
CIYT	Chickpea International Yield trial
CMV	Cucumber mosaic virus
CRISP	Crop Research Integrated Statistical Package
DONIAH	Disease Observation Nursery for Improvement of Advanced Hybrids
EBFS	Ex-Bornu full-sib
ECODEP	Economics Data Entry Program
ELISA	Enzyme-linked immunosorbent assay
EMS	Ethyl methane sulfonate
ESIP	Ethiopian Sorghum Improvement Program
ExVT	Experimental Variety Trial
FAO	Food and Agriculture Organization
GCVT	Gram Coordinated Variety Trial
GENSTAT	General Statistical Package
GIET	Gram Initial Evaluation Trial
GRS	Gezira Research Station
HAU	Haryana Agricultural University
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas
ICCT-DL	International Chickpea Cooperative Trial-Desi Long
ICCT-DS	International Chickpea Cooperative Trial-Desi Short
ICRRWN	International Chickpea Root Rots and Wilt Nursery
ICSN-DL	International Chickpea Screening Nursery-Desi Long
ICSN-DS	International Chickpea Screening Nursery-Desi Short
IDMRS	ICRISAT Data Management and Retrieval System
IDRC	International Development Research Centre
IFDC	International Fertilizer Development Center
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Center for Africa
ILT	Inbred lines test
INIA	Institute Nacional de Investigaciones Agricoles
INRAN	National Agricultural Institute of Niger
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet
IPMAT	International Pearl Millet Adaptation Trial
IPMDMN	International Pearl Millet Downy Mildew Nursery
IPMEN	International Pearl Millet Ergot Nursery

IPMON	International Pearl Millet Observation Nursery
IPMRN	International Pearl Millet Rust Nursery
IPMSN	International Pearl Millet Smut Nursery
IPT	Initial Population Trial
IRAT	Institute de Recherches Agronoiques Tropicales et des Cultures Vivrieres (Institute for Tropical Crops Research)
IRRI	Internationl Rice Research Institute
ISCRN	International Sorghum Charcoal Rot Nursery
ISFQT	International Sorghum Food Quality Trials
ISGMN	International Sorghum Grain Mold Nursery
ISMN	International Sorghum Midge Nursery
ISPHT	International Sorghum Preliminary Hybrid Trial
ISPYT	International Sorghum Preliminary Yield Trial
ISSFN	International Sorghum Shoot Fly Nursery
NifTAL	Nitrogen Fixation in Tropical Agricultural Legumes
NIN	National Institute of Nutrition
OAU/SAFGRAD	Organization for African Unity/Semi-Arid Food Grain Research and Development
ORD	Organisme Regional de Developpement
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (Overseas Scientific and Technical Research Office)
PEQIA	Postentry Quaratine Isolation Area
PMART	Pearl Millet African Regional Trial
PMEN	Pearl Millet Ergot Nursery
PMEVT	Pearl Millet Elite Varieties Trial
PMHT	Pearl Millet Hybrid Trial
PMIST	Pearl Millet Initial Synthetics Trial
PMNT	Pearl Millet National Trial
PMSN	Pearl Millet Smut Nursery
PMST	Pearl Millet Synthetics Trial
PMT	Preliminary Multilocation Trial
PMV	Peanut mottle virus
PSYT	Preliminary Sorghum Yield Trial
PYT	Preliminary Yield Trial
RSTS/E	Resource Sharing Time Sharing/Extended
SADCC	Southern African Development Coordination Conference
SAT	Semi-arid tropics
SEPON	Sorghum Elite Progeny Observation Nursery
SMIC	Sorghum and Millets Information Center
SMIN	Source Material Inbred Nursery
SMRLT	Sterility mosaic resistant lines test
SPHN	Sorghum Preliminary Hybrid Nursery
SSP	Single superphosphate
TMV	Tomato mottle virus
TRP	Telemsi rock phosphate
TSWV	Tomato spotted wilt virus
UNDP	United Nations Development Programme
UNU	United Nations University
UPN	Uniform Progeny Nursery
USAID	United States Agency for International Development
VAX/VMS	Virtual Address Extension/Virtual Memory System
VLS	Village-Level Study
VPPIT	Vegetable-type Pigeonpea International Trial

Introduction

Since ICRISAT's establishment in 1972, farmers in the semi-arid tropics (SAT) have been watching our experiments with the hope that some day they would be able to benefit from them. In the period of this report (June 1980-Dec 1981) we took a significant stride in that direction—by transplanting to the farm our field successes with improved technology for the deep Vertisols in areas of assured rainfall in India. The technology has several components, some developed by us and others refinements or modifications of existing practices. The on-farm project was launched on a 15-ha area of deep Vertisols in farmers' fields at Taddan-pally village, about 43 km northwest of ICRISAT Center, in collaboration

ICRISAT's Director General distributes to Taddanpally farmers leaflets on the Institute's proposal for transfer of improved technology to their fields. The farmers agreed to the proposal and the project was successfully launched with their participation.

Policymakers from Indian states visited ICRISAT and Taddanpally to discuss the feasibility of taking our improved technology to their states. They also saw experiments at our research farm above.

Village scene near ICRISAT's new Sahelian Center, about 35 km south of Niamey, Niger.

with the Department of Agriculture, Government of Andhra Pradesh; the Medak district officials; the All India Coordinated Research Project for Dryland Agriculture; and the Andhra Pradesh Agricultural University. Both the participating farmers and their neighbors were enthusiastic about the extra crop produced in the rainy season when this land normally remains fallow, and about the substantially increased profits. This success in technology transfer prompted teams of policymakers and agriculturists from six Indian states where large deep Vertisol areas exist to approach ICRISAT to discuss the feasibility of taking the technology to their states.

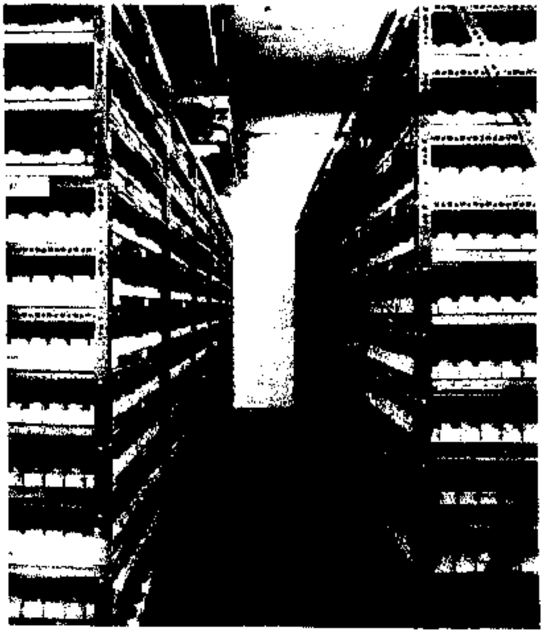
This year again we have intensified and expanded our research activities in the semi-arid countries of Africa. Through an agreement with the Government of Niger, we began work on the establishment of a Sahelian Center on a 500-ha site, about 35 km south of Niamey. In due course the Center will be the base for ICRISAT's work on millets and groundnuts, and on farming systems associated with these crops, in the Sahelian region of Africa.

On a request from the Southern African Heads of Government, we sent a fact-finding mission to the SADCC member countries to examine the state of research and development of ICRISAT mandate crops. Based on the recommendations of the mission, a strategy is being developed to provide ICRISAT support to these countries.

Our Genetic Resources Unit added 7190 accessions to our collection, raising the total to 71600. Although we now have the largest number of samples of our mandate crops assembled at any one place in the world, there are still many regions to be explored. In collaboration with regional and national gene banks, we have embarked on multilocation evaluation of our germplasm in order to characterize it at or near its place of origin to determine its full potential.

Our sorghum and pearl millet experimental varieties and cultivars continued to excel in both national and international trials. Our sorghum hybrids entered

A view of ICRISAT's medium-term cold storage facility where the Institute's germplasm is stored.



This year we succeeded in identifying kabuli-type chickpea lines resistant to fusarium wilt. One of these, ICCL-81001, is shown above.

regional trials in India for the first time in 1980 and were sent internationally for the first time in 1981. Our sorghum and pearl millet varieties undergoing national program prerelease tests in farmers' fields in India and Africa again performed well in terms of yield and resistance to diseases and pests. The Variety Release Committee of the Sudan approved the release of our pearl millet Serere Composite-2 for general cultivation and renamed it "Ugandi."

For the first time, kabuli-type chickpea lines with resistance to fusarium wilt were identified. Screening for *Botrytis* resistance was initiated at G.B. Pant University of Agriculture and Technology, Pantnagar, India. In *Ascochyta* screening work at ICARDA, our sister institute in Syria, several promising lines were selected. After 4 years of advanced testing, one of our medium-duration desi-type chickpea cultivars qualified for national program farmers' field testing in the central zone of India.

One of our first early-maturing pigeonpea hybrids yielded 3900 kg/ ha at our Hissar station in the 1981 rainy season. Besides yielding 33% more than the adapted check, T-21, the hybrid matured 10 days earlier than the check. This hybrid was one of four produced from two early-maturing cultivars in our male-sterility conversion program.

An ICRISAT scientist explains a groundnut experiment to some of the 1550 farmers who visited us on Farmers' Day.

In the relatively short span of 5 years our groundnut program has developed several advanced breeding lines and entered them into national trials. Several good sources of resistance to rust and leaf spot were identified for use in breeding work. Use of wild species in breeding for developing resistance against diseases continues to produce good results. Significant yield increases were recorded with *Rhizobium* inoculation.

We hosted nine workshops, conferences, and specialist meetings in 1980-81. And for the second year in a row we organized a Farmers' Day, to which about 1550 Indian farmers came to see our experiments and discuss their practical field problems with our scientists. Individualized training programs were completed by 196 scientists and technicians—the largest number ever—from 42 countries.

The progress mentioned above and reported in the following pages would not have been possible without the active support of our collaborators and cooperators in India, Africa, and other SAT areas; the Government of India, Upper Volta, and Niger; and the Government of Andhra Pradesh. Our excellent working relationship with many universities and research organizations in non-SAT countries also contributed much to our progress.

L.D. Swindale
Director General

ICRISAT'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 cooperative stations in India, in seven African countries, and in Mexico, Syria, and Australia. As background to our research reports, this section presents a brief description of the environments in which most of our research in India is conducted. Pertinent data for weather outside India is listed with experiments in the program reports.

ICRISAT Center

The Institute is located at 18°N, 78 E 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 drought prone, and Vertisols (black soils), which have great water-holding capacity. The availability of these two soil types provides an opportunity to conduct experimental work on the five crops in our mandate under conditions representative of many areas of the SAT.

Seasons. Three distinct seasons characterize much of India. In the Hyderabad area the rainy season, also known as monsoon or kharif, usually begins in June and extends into September. More than 80% of the 800-mm average annual rainfall occurs during these months, in which rainfed crops are raised. The postrainy winter season of October through January, also known as postmonsoon or rabi, is dry and cool and days are short. During this period crops can be grown on Vertisols on stored soil moisture. The hot and dry summer season is from February until the rains begin again in June. Any crop grown in this season requires irrigation.

Crops. The five ICRISAT crops have different environmental requirements that determine where and when they are grown. In the Hyderabad area 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 crop of early-maturing types is planted in December at the Center 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 at the Center, one during the rainy season and the other on Vertisols in the postrainy season. Chickpea, a single-season crop, is sown during the postrainy season on residual moisture in deep soils (Vertisols at ICRISAT Center). At ICRISAT, as in normal farming practice, these crops are often grown in various combinations and sequences, which we are working to improve. The cropping schedule generally followed at ICRISAT Center is shown in Figure 1.

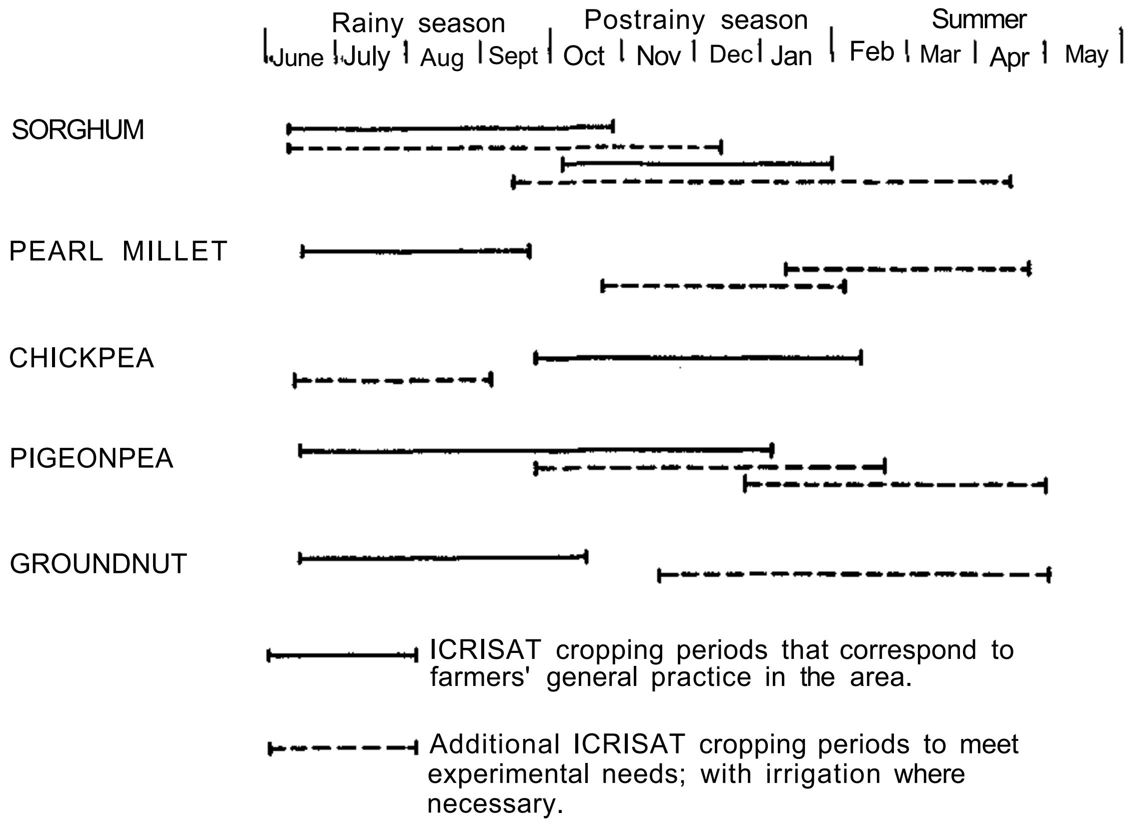


Figure 1. ICRISAT Center's cropping schedule.

Cooperative Research Stations

In cooperation with five agricultural universities in India, ICRISAT has established stations on their campuses to test the performance of breeding material under varying climatic conditions and latitudes. These are situated at Anantapur (15°N), Bhavanisagar (11°N), Dharwar (15°N), Gwalior (26°N), and Hissar (29°N).

Crops. Our oldest cooperative station at Hissar is also the largest, with 40 ha. Our cooperative work at Hissar was started in 1975 to test chickpea and pearl millet in the climatic conditions where these crops are mostly grown—a belt that stretches across north India (and the Middle East for chickpea, and the Sahelian zone of Africa for pearl millet). Hissar also provides a test site for early-maturing pigeonpeas in a region where they are increasingly being grown in rotation with wheat. Likewise the need for extending the work on sorghum to screen for diseases and pests was met at Dharwar (an especially good site for sorghum downy mildew screening), and Bhavanisagar, which also provides another test environment for pearl millet at a latitude (i.e., daylength analog) similar to the West African millet belt. Our research station at Gwalior provides us with an effective screening site in the region where most of India's late-maturing pigeonpea crop is grown; this station also provides an alternative site for selecting chickpea. Anantapur, our most recently acquired site (1980), is used during the rainy season for drought screening of pearl millet, sorghum, and groundnut.

The Weather

ICRISAT Center. In 1980 the total rainfall received during the rainy season (June to October) was 733 mm, against a normal rainfall of 690 mm for this period. Rainfall from June to October in 1981 was 1072 mm, which was 36% above the normal. Monthly rainfall and temperature data from June 1980 to December 1981 are presented in Table 1.

Anantapur. Of the 592 mm average annual rainfall, over 80% is spread over a long rainy season extending from May to October. However, the 1980 rainy season was well below the normal, producing only 193 mm of rainfall. In 1981, the rainfall was close to normal, as can be seen in Table 2.

Bhavanisagar. Normal rainfall data are not available for this station. The total rainfall received during June to December 1980 was 415 mm. In 1981 rainfall from

Table 1. Rainfall and temperature at ICRISAT Center, June 1980-December 1981.

	Rainfall (mm)		Temperature (°C)			
			Normal[b]		1980/81	
Month	Normal[a]	1980/81	Max	Min	Max	Min
June	115	141	34	24	33	24
July	171	127	30	22	30	23
August	156	306	29	22	30	22
September	181	153	30	22	30	22
October	67	6	30	20	32	18
November	23	0	29	16	30	16
December	6	2	28	13	28	14
January	6	16	29	15	27	14
February	11	0	31	17	33	16
March	13	77	35	20	34	20
April	24	3	37	24	38	23
May	27	2	39	26	39	26
June	115	203	34	24	35	24
July	171	209	30	22	31	23
August	156	218	29	22	28	22
September	181	287	30	22	29	22
October	67	155	30	20	30	20
November	23	2	29	16	28	15
December	6	0	28	13	27	14

a. Based on 1901-70 rainfall data.
b. Based on 1931-60 temperature data.

Table 2. Rainfall and temperature at Anantapur, June 1980-December 1981.

Month	Rainfall (mm)		Temperature (°C)			
			Normal[b]		1980/81	
	Normal[a]	1980/81	Max	Min	Max	Min
June	49	55	34.7	24.7	34.3	23.8
July	66	10	32.4	23.7	34.0	24.2
August	74	35	32.4	23.5	32.2	23.6
September	138	26	32.5	23.1	33.7	23.4
October	126	67	31.4	22.5	34.0	22.8
November	36	18	30.0	19.4	30.6	20.2
December	8	0	29.1	17.2	30.5	17.7
January	7	1	30.4	17.3	30.2	18.3
February	2	0	33.4	18.6	34.4	18.8
March	5	15	36.8	21.6	36.8	23.0
April	24	7	38.4	25.7	39.9	26.5
May	57	16	38.1	25.8	39.3	26.0
June	49	6	34.7	24.7	35.3	25.0
July	66	112	32.4	23.7	33.8	24.3
August	74	48	32.4	23.5	31.4	24.2
September	138	197	32.5	23.1	29.8	23.8
October	126	102	31.4	22.5	30.2	22.9
November	36	6	30.0	19.4	28.8	19.6
December	6	18	29.1	17.2	27.9	17.9

a. Based on 1910-69 rainfall data. b. Based on 1931-60 temperature data.

Table 3. Rainfall and temperature at Bhavanisagar, June 1980-December 1981.[a]

Month	Rainfall (mm) 1980/81	Temperature (°C) 1980/81	
		Max	Min
June	6	33.5	27.0
July	19	33.1	26.9
August	90	32.9	25.9
September	42	35.4	27.4
October	136	32.1	24.8
November	103	30.9	22.9
December	19	30.6	22.4
January	0	31.2	21.8
February	0	32.4	19.0
March	9	34.5	23.9
April	9	36.9	26.0
May	83	37.4	26.5
June	8	32.8	25.5
July	7	34.6	26.5
August	25	32.8	26.1
September	115	32.5	25.2
October	166	31.2	24.9
November	48	27.2	23.8
December	9	29.6	20.0

a. Rainfall and temperature data for past years are not available for Bhavanisagar.

Table 4. Rainfall and temperature at Dharwar, June 1980-December 1981.

Month	Rainfall (mm) Normal[a]	Rainfall (mm) 1980/81	Temperature (°C) Normal[b] Max	Normal[b] Min	1980/81 Max	1980/81 Min
June	96	159	29.1	20.8	27.9	21.2
July	175	202	26.5	20.5	26.2	20.7
August	122	149	26.4	20.1	25.6	20.2
September	103	127	28.2	19.6	28.4	19.7
October	126	43	29.7	19.1	31.4	19.0
November	48	23	28.6	17.0	29.8	16.8
December	12	1	28.4	13.7	29.3	13.9
Januury	2	3	29.3	14.3	28.3	17.3
February	2	0	32.1	16.3	32.2	15.9
March	9	3	34.8	18.8	35.2	18.1
April	48	22	36.3	20.8	36.9	20.5
May	75	108	34.9	21.1	33.9	20.9
June	96	127	29.1	20.8	27.5	20.6
July	175	183	26.5	20.5	25.9	20.3
August	122	123	26.4	20.1	25.3	19.9
September	103	95	28.2	19.6	27.2	20.0
October	126	80	29.7	19.1	29.5	18.6
November	48	12	28.6	17.0	28.7	14.8
December	12	0	28.4	13.7	27.2	14.3

a. Based on data for the period 1901-50. b. Based on data for the period 1972-81.

Table 5. Rainfall and temperature at Gwalior, June 1980-December 1981.

	Rainfall (mm) Normal[a]	Rainfall (mm) 1980/81	Temperature (°C) Normal[a] Max	Normal[a] Min	1980/81 Max	1980/81 Min
June	83	82	40.8	30.2	38.5	28.2
July	274	290	34.1	26.6	32.2	26.2
August	259	575	31.9	25.4	32.2	25.3
September	192	0	32.4	24.4	33.6	24.9
October	35	21	33.2	18.0	35.3	20.2
November	2	0	29.4	10.5	29.7	12.4
December	8	14	24.8	7.2	24.3	8.4
January	18	0	23.2	7.5	23.2	7.8
February	8	0	26.6	10.0	27.0	10.4
March	8	20	32.9	16.0	30.4	15.8
April	3	0	38.5	22.3	38.3	21.8
May	9	14	42.6	28.0	41.3	26.7
June	83	42	40.8	30.2	42.2	29.3
July	274	251	34.1	26.6	33.1	26.7
August	259	115	31.9	25.4	33.4	26.2
September	192	54	32.4	24.4	35.8	25.6
October	35	6	33.2	18.0	34.6	14.6
November	2	63	29.4	10.5	27.8	5.1
December	8	7	24.8	7.2	23.7	5.1

a. Based on data for the period 1931-60.

Table 6. Rainfall and temperature at Hissar, June 1980-December 1981.

Month	Rainfall (mm)		Temperature (°C)			
			Normal[a]		1980/81	
	Normal[a]	1980/81	Max	Min	Max	Min
June	34	10	41.3	27.7	40.6	27.6
July	122	138	37.3	27.3	35.4	26.7
August	114	46	35.5	26.1	35.9	26.1
September	81	0	35.7	23.9	36.3	22.4
October	15	8	34.6	17.4	34.7	17.9
November	8	7	29.6	9.8	28.0	10.5
December	5	29	24.1	6.0	22.0	6.4
January	19	27	21.7	5.5	19.9	7.0
February	15	22	25.0	8.1	25.6	8.3
March	17	43	30.7	13.3	26.6	12.3
April	6	0	37.0	19.0	37.1	18.3
May	11	13	41.6	24.6	41.4	24.4
June	34	95	41.3	27.7	42.8	26.5
July	122	171	37.3	27.3	34.2	26.7
August	114	59	35.5	26.1	35.5	25.7
September	81	27	35.7	23.9	36.2	23.1
October	15	0	34.6	17.4	33.7	15.2
November	8	61	29.6	9.8	25.9	10.8
December	5	0	24.1	6.0	22.6	4.7

a. Based on data for the period 1931-60.

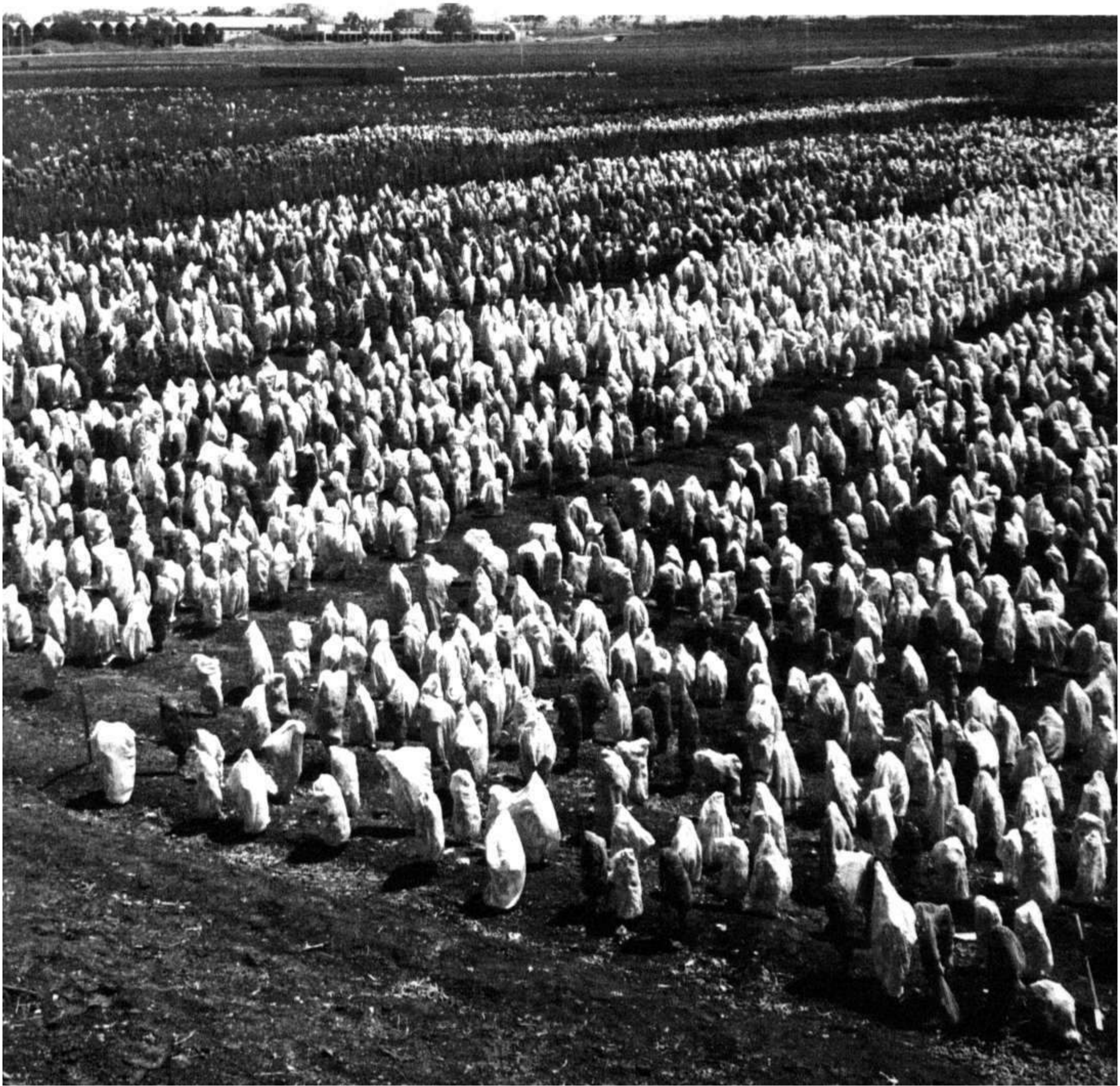
April to December was 470 mm. Monthly rainfall and temperature data for the period under report are presented in Table 3.

Dharwar. Data on rainfall and temperature recorded at Dharwar are given in Table 4. During the 1980 rainy season (early May to October), 714 mm of rainfall was received, while in 1981 it was 716 mm—the normal rainy season rainfall is 697 mm.

Gwalior. The 968 mm of rainfall received during the 1980 rainy season (June to October; see Table 5) was 15% above the normal rainfall for this period. However, during the 1981 rainy season the rainfall for the corresponding period (468 mm) was 45% below normal.

Hissar. At Hissar, 71% of the normal annual rainfall is received during the period from July to September. Rainfall received during the 1980 rainy season (184 mm; Table 6) was 42% below normal, while in 1981 it was 19% below normal.

GENETIC RESOURCES UNIT



Contents

GENETIC RESOURCES UNIT

The Genetic Resources Unit (GRU) continued to make steady progress in collection, maintenance, conservation, evaluation, documentation, and distribution of germplasm of ICRISAT's mandate crops and six important minor millets for utilization in the crop improvement programs. Our main emphasis continues to be on collection and conservation so that the germplasm on the verge of vanishing can be saved.

In the past 1-1/2 years (1 June 1980-31 Dec 1981) we added 7190 accessions to our collection. We now have over 71 600 accessions (Table 1) of our mandate crops and six minor millets. Major expeditions during this period were launched in Ethiopia, the Gambia, Ghana, Mozambique, Nigeria, Tanzania, Zambia, the Philippines, and several areas in India. Detailed report on each collection mission is available from GRU. Although we have the largest number of samples of each crop assembled at any one place in the world, there are yet many regions to be explored. Our present areas of priority for germplasm collection include:

Western Africa — sorghum and millets
Eastern Africa — sorghum, millets, pigeonpea, and chickpea
Southern Africa — sorghum, millets,pigeonpea, and groundnut
Central Asia — chickpea
South Asia — sorghum, millets, pigeonpea, chickpea, and groundnut
Southeast Asia — pigeonpea and groundnut
Far East — sorghum, millets, and groundnut
Central America — groundnut and pigeonpea

We annually review and determine the priority areas of collection in close consultation with crop scientists and the IBPGR/FAO. Collection expeditions are launched jointly by ICRISAT scientists and national progam scientists, often with the support and close collaboration of the IBPGR. The collected material is also shared accordingly.

Almost all the Institute germplasm is now being maintained and conserved in the temporary medium-term cold storage at 4-5°C and 30-40% relative humidity. Germination tests are conducted periodically to monitor the viability of seeds during storage. For maximum safety, the groundnut seeds are conserved unshelled, thus occupying relatively more space. Therefore some of the seeds are still in short-term storage at about 18°C. This problem will soon be solved when we move to our new Genetic Resources Laboratory, presently under construction.

In collaboration with regional/national gene banks, in 1980/81 we embarked on multilocation evaluation of our germplasm in order to characterize and evaluate it at or near its origin to determine its full potential.

An important service provided by the Genetic Resources Unit is the worldwide distribution of germplasm to interested workers. Table 2 shows the number of samples distributed since June 1980 to scientists within and outside India. All seed despatches abroad are inspected and cleared through the Government of India's quarantine services.

Sorghum Germplasm

To the existing collection of 17 986 sorghum accessions we added 3278 during the report period, thus raising the total collection to 21 264. The new additions were assembled from 48 countries through collection expeditions and correspondence. This also includes 847 missing IS numbers in the world collection that were recovered from other gene banks.

A total of 851 accessions from Tanzania, Ethiopia, South Africa, Malawi, the Gambia, Yemen, Mozambique, Upper Volta, Australia, USA, Senegal, West Germany, Hungary, and

Table 1. Germplasm collection status at ICRISAT as of 31 December 1981.

Location	Number of accessions				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
AFRICA					
Algeria	0	0	0	16	0
Angola	29	0	0	0	6
Benin	4	0	0	0	9
Botswana	190	45	0	0	0
Cameroun	1 835	171	0	0	3
Central African Rep.	39	58	0	0	0
Chad	138	62	0	0	10
Congo	0	0	0	0	11
Egypt	22	0	0	53	8
Equatorial Guinea	0	0	0	0	11
Ethiopia	4 113	0	0	161	0
Gambia	1	17	0	0	18
Ghana	64	1	1	0	10
Guinea	0	0	0	0	16
Ivory Coast	1	0	0	0	57
Kenya	761	47	64	0	30
Lesotho	7	0	0	0	0
Liberia	0	0	0	0	10
Libya	0	0	0	0	1
Malagasy Republic	1	0	1	0	28
Malawi	370	223	17	3	93
Mali	111	527	0	0	21
Mauritania	0	1	0	0	0
Mauritius	0	0	0	0	13
Morocco	3	0	0	56	9
Mozambique	0	0	0	0	133
Namibia	1	0	0	0	0
Niger	408	1 032	0	0	4
Nigeria	1 173	492	27	3	203
Senegal	230	304	10	0	157
Sierra Leone	3	0	0	0	2
Somalia	125	3	0	0	6
South Africa	659	16	0	0	60
Sudan	2 255	168	0	11	688
Swaziland	19	0	0	0	1
Tanzania	133	136	5	1	121
Tunisia	0	0	0	30	0
Uganda	612	48	0	0	68
Upper Volta	216	34	0	0	39
Zaire	24	0	0	0	4
Zambia	210	25	14	0	88
Zimbabwe	186	52	0	0	430

Continued

Table 1. *Continued.*

Location	Number of accessions				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
ASIA					
Afghanistan	6	0	0	674	0
Bangladesh	9	0	57	33	0
Burma	8	0	63	9	16
Cambodia	0	0	0	0	1
China	68	0	0	0	162
Cyprus	1	0	0	22	5
India	4 027	10 727	9001	5 319	1774
Indonesia	32	0	4	0	97
Iran	7	0	0	4 099	6
Iraq	4	0	0	18	0
Israel	22	0	0	48	41
Japan	111	0	0	0	50
Jordan	0	0	0	24	0
Lebanon	179	71	0	18	0
Malaysia	0	0	0	0	63
Nepal	8	0	116	77	0
Pakistan	29	5	15	150	0
Philippines	5	0	13	0	16
Saudi Arabia	1	0	0	0	0
South Korea	2	0	0	0	0
Sri Lanka	25	0	66	3	17
Syria	4	0	0	13	1
Taiwan, China	13	0	3	0	36
Thailand	5	0	7	0	10
Turkey	51	0	0	435	4
Yemen	27	0	0	0	1
Yemen DR	1	0	0	0	0
EUROPE					
Belgium	1	0	0	0	2
Bulgaria	0	0	0	5	3
CzechosJavakia	0	0	0	8	0
France	5	0	20	1	0
German DR	0	0	0	1	0
Greece	1	0	0	25	4
Hungary	22	0	0	4	2
Italy	8	0	5	30	0
Portugal	6	0	0	4	0
Spain	3	0	0	78	1
UK	1	0	0	0	0
USSR	69	12	2	98	55
Yugoslavia	0	0	0	2	0

Continued

Table 1. *Continued.*

Location	Number of accessions				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
THE AMERICAS					
Argentina	16	0	0	0	228
Bolivia	0	0	0	0	94
Brazil	0	0	7	0	322
Chile	0	0	0	138	12
Colombia	0	0	5	1	0
Costa Rica	0	0	0	0	1
Cuba	3	0	0	0	11
Dominican Rep.	0	0	6	0	0
Ecuador	0	0	0	0	2
El Salvador	1	0	0	0	0
French W. Indies	0	0	4	0	0
Guatemala	6	0	0	0	0
Guyana	0	0	7	0	0
Honduras	1	0	0	0	4
Jamaica	0	0	18	0	1
Mexico	234	0	2	360	6
Nicaragua	1	0	0	0	0
Paraguay	0	0	0	0	118
Peru	0	0	5	2	72
Puerto Rico	0	0	45	0	21
Trinidad	3	0	22	0	6
Uruguay	1	0	0	0	24
USA	1 867	48	3	109	1692
Venezuela	1	0	15	0	12
AUSTRALIA AND OCEANIA					
Australia	28	4	47	0	45
Fiji	0	0	0	0	2
New Guinea	1	0	0	0	0
UNKNOWN	397	11	0	233	2 502
Total	21 264	14 340	9697	12 375	9911

Minor millets collection at ICRISAT

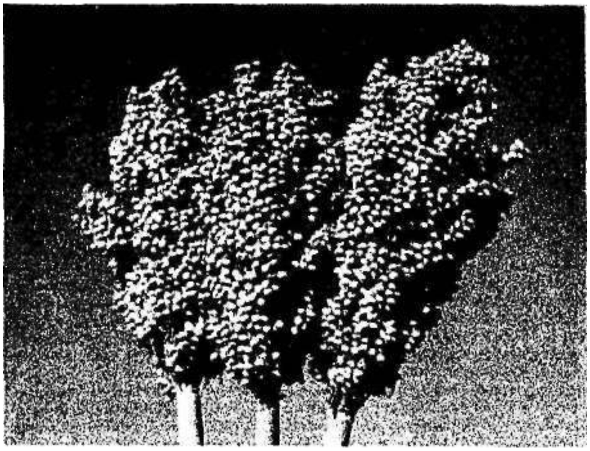
Species	No. of accessions
Eleusine coracana (finger millet)	1241
Setaria italica (foxtail millet)	1160
Panicum miliaceum (proso millet)	715
Panicum sumatrense (little millet)	243
Echinochloa cruagalli (barnyard millet)	380
Paspalum scrobiculatum (kodo millet)	300
Total	4039

Table 2. Germplasm distribution from 1 June 1980 to 31 December 1981.

	No. of samples distributed[a]		
Crop	Within India	Outside India	Total
Sorghum	5 276	6 898	12 174
Pearl millet	1 875	2 434	4 309
Pigeonpea	3 197	1 010	4 207
Chickpea	5 724	12 942b	18 666
Groundnut	3 509	1 721	5 230
Minor millets	3 996	1 982	5 978
Total	23 577	26 987	50 564

a. The figures do not include over 65 000 samples of germplasm supplied to ICRISAT scientists.

b. 10 334 samples were supplied to ICARDA, Syria.



Three heads of the highly prized zera-zera sorghum germplasm collected in 1981 from Gambella, Ethiopia.

Lesotho were planted in our Postentry Quarantine Isolation Area (PEQIA) for inspection and release.

Pointed collections organized in the Gambella area of Ethiopia and in northern Nigeria resulted in acquisition of a good number of zera-zera, kaura, fara-fara, and guineense sorghum accessions. These are highly prized for their agronomic superiority, including grain quality. Other expeditions during the year were to Zambia, Mozambique, Tanzania, Ghana, and India.

To meet the increasing requests for seed, 7824 accessions were selfed and rejuvenated in the 1980 postrainy season and 112 male-sterile lines were maintained by hand pollination. A total of 4850 newly assembled accessions were characterized and evaluated for their morphoagronomic characters during the 1980 postrainy and 1981 rainy seasons.

We continued screening sorghum germplasm for insect and disease resistance in collaboration with other program scientists. A number of lines were identified as promising sources of resistance to grain mold (236), leaf diseases (148), shoot fly (233), stem borer (128), and head bug and midge (250). These lines are under further testing for confirmation.

We have selected a basic collection of about 1000 accessions from the world collection, stratified taxonomically and geographically, based on their ecological adaptation at the Patancheru location. This collection is being used by sorghum scientists in their crop improvement research. This year the entire Ethiopian Sorghum Improvement Program (ESIP) germplasm collection (4479 accessions) has been evaluated and classified in Ethiopia through a cooperative effort between the Plant Genetic Resources Center of Ethiopia, ESIP, and ICRISAPs GRU.

During the year we standardized and published internationally acceptable descriptors in collaboration with IBPGR. In addition to the data that we have already computerized, the evaluation of important descriptors with passport information from IS-10051 onwards was carried out and the data were tabulated for computerization.

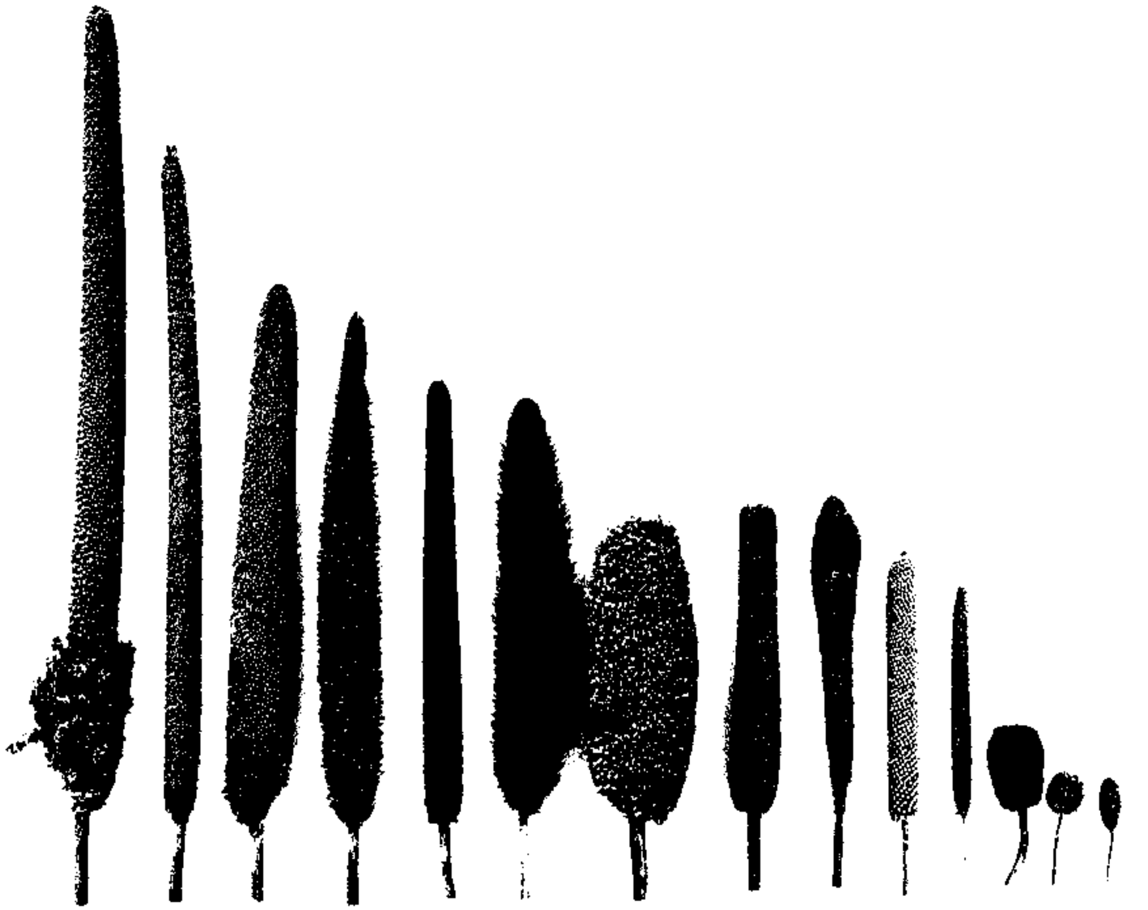
For an effective and rapid flow of tropical germplasm into sorghum improvement programs around the world, we initiated an introgression and conversion project. At present we are in the process of converting zera-zera landraces from Sudan and Ethiopia to photoperiod-insensitivity. These landraces are highly prized for their superior agronomic characters, yet they have been of restricted utility because of their photoperiod sensitivity and plant height. Desirable F_2 segregants have been selected and planted to make the first backcross using zera-zera lines as recurrent parents.

Pearl Millet Germplasm

With the 748 accessions added this year, our pearl millet germplasm total rose to 14 340. The new additions are from Sudan, Botswana, Zimbabwe, Zambia, South Africa, Upper Volta, Cameroon, the Gambia, Nigeria and India. New additions to the wild species of *Pennisetum* are *P. schweinfurthii* collected from Sudan; *P. macrostachyum* from Mysore University, India; and *P. violaceum* from Mali (5), Senegal (3), and Niger (3) collected by ORSTOM. Further additions to the already existing wild species are *P. purpureum, P. polystachyon, P. pedicellatum,* and *P. hohenackeri.* We also received three induced autotetraploids from Andhra University, Waltair, India.

A total of 829 pearl millet accessions from Ghana, Italy, Mexico, Mozambique, Tanzania, Upper Volta, and USA, were planted in PEQIA for quarantine inspection and multiplication. Another 4826 accessions were rejuventated for seed increase. A total of 9112 accessions were evaluated and characterized for various morphoagronomic traits during the 1981 rainy season.

As part of our collaborative multilocation germplasm evaluation program, 343 diverse



Heads of some landraces of pearl millet showing genetic diversity.

pearl millet germplasm lines from 16 countries were evaluated at Kamboinse and Bobo-Dioulasso, Upper Volta; Maradi, Niger; and Bhavanisagar, Hissar, Ludhiana, Durgapura, and ICRISAT Center in India. The data are now being analyzed.

Souna IP-6271 (P-242) from Mali was found to be consistently good in Upper Volta, Niger, and India. Our breeders crossed it extensively with several adapted lines. Souna (IP-5870) from Senegal, Gaouri (IP-6352) from Mali, Tamangagi (IP-5383) and Zongo (IP-5411) from Niger, Saouga Local from Upper Volta, and IP-7440 from Tanzania appear promising. Accession IP-4021 from Gujarat was the earliest to flower (33-35 days) during both the seasons. Breeders selected several accessions from the multilocation evaluaton trials.

The sweet-stalked character found in lines collected from Tamil Nadu, India, last year has now been found in lines from the Central African Republic. Several sterility maintainer lines for 5141 A have been identified and are being confirmed.

One of the wild relatives of pigeonpea, Atylosia albicans, *maintained at ICRISA T Genetic Resources Unit.*

Pigeonpea Germplasm

We collected 318 landraces of pigeonpea from the Philippines and Tanzania, and planted most of them in PEQIA for quarantine inspection. Pointed collections were carried out in the Kumaon Hills and the Western and Eastern Ghats of India. Several samples of the following wild relatives were collected: *Atylosia albicans, A. lineata, A. cajanifolia, A. goensis, A. platycarpa, A. mollis, A. volubilis, A. scarabaeoides, Rhynchosia rothii,* and *Paracalyx scariosa.* The "Attappadi pigeonpeas" known for their superior quality for dhal were collected from the Attappadi Hills of the Western Ghats. Explorations into forests of the Silent Valley in the Attappadi Hills revealed many *Atylosia* species, the first report on the occurrence of *Atylosia* in the area.

All the lines developed at ICRISAT—elite breeders line, disease-resistant lines, and pest-tolerant lines—were transferred to GRU for recharacterization and maintenance. Presently, 9697 accessions of pigeonpea are maintained in our gene bank, including 882 new additions. Wild relatives consist of 144 accessions belonging to 38 species of 6 genera. *Atylosia lanceolata* and *A. latisepala* from Australia and a Burmese variety of *A. volubilis* are among the new additions to the secondary gene pool of *Cajanus.*

In the past 1-1/2 years we characterized 1916 pigeonpea lines. The material included germplasm of Indian origin stored at Puerto Rico and subsequently transferred to ICRISAT and newly collected material from Nepal, Bangladesh, Malawi, and India. The photoperiod-insensitive Queensland lines showed poor expression at Patancheru and could not be characterized properly. These lines, like other extra-early types, must be evaluated elsewhere. Several landraces, such as ICP-6982 and ICP-2223, have been identified for their high-yielding potential and are currently being utilized by our breeders.

The search for more high-yielding lines with good agronomic background was continued with the use of 60 diverse germplasm lines.

During the report period 1500 lines were screened for response to photoperiod sensitivity, and 49 additional lines with potential for photoperiod insensitivity have been identified. So far 6040 lines were screened at ICRISAT over 4 years, and the number of promising lines for photoperiod insensitivity now stands at 787. This development presents high potential for the wider adaptation and utilization of pigeonpea around the world.

Screening for male sterility resulted in identification of two new sources: ICP-7188, an IARI-developed late-maturing cultivar, and ICP-10914, a Queensland selection from Pant A-8, which belongs to the extra-early-maturing group.

In the BDN-1 induced mutation (M and M_3) material maintained by our pulse physiologists, we identified 14 plants with translucent anthers and sterile pollen. These are now being test-crossed with the known heterozygous male-sterile line MS-3A. If this observation is confirmed it is likely to broaden the genetic base of male-sterile parents for future use in hybrid production. A new mutant with sesame-like leaflets has also been isolated from ICP-8289.

Systematic screenings by ICRISAT's pathologists and entomologists continued. Of several germplasm lines screened for disease resistance, 48 were found to be resistant or tolerant to wilt, 17 to blight, and 2 to Sterility Mosaic Virus (SMV). Of 442 lines screened for insect resistance, 83 showed some degree of tolerance to pod borer, or podfly, or both. For the first time, ICRISAT microbiologists undertook large-scale screening for nodulation and nitrogenase activity, which revealed variation among lines in nodule number and weight, and nitrogenase activity. Screening for cooking quality, initiated by ICRISAT biochemists, indicated variation in cooking time ranging from 16 (ICP-8177) to 65 (ICP-7867) minutes across cultivars.

We completed classification of the world collection of pigeonpea on the basis of phenology and morphoagronomic characters. A working collection has been constituted, with adequate representation of the major genetic diversity present in the primary and secondary gene pools. Evaluation data on 8815 pigeonpea accessions are now documented and entered in ICRISAT's computer, using the ICRISAT Data Management and Retrieval System (IDMRS). Of the 53 descriptors recorded, 33 find definite place in the computer-based catalog. The complete list of pigeonpea descriptors was published in collaboration with IBPGR.

Our efforts to cross *Atylosia platycarpa* and *A. volubilis* using style amputation and mentor pollen techniques have so far been unsuccessful. Two Australian species, *A. grandifolia,* and *A. lanceolata,* were successfully crossed with *Cajanus cajan,* cv. Prabhat, for the first time. A vegetable-type pigeonpea, ICP-3783 has also been successfully crossed with *Atylosia albicans.* The F_1s are now being grown in our introgression block.

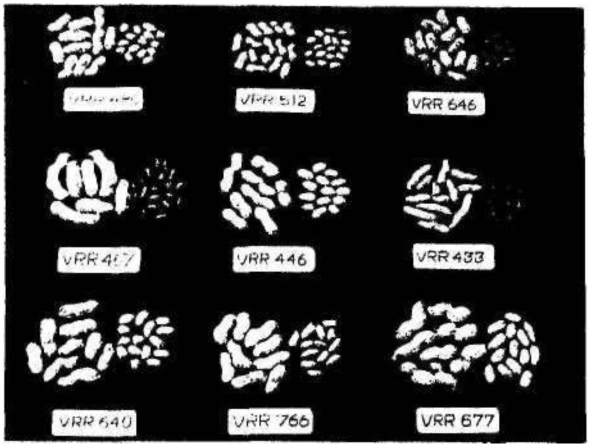
During the 1980 postrainy and 1981 rainy seasons, 2690 accessions were rejuvenated and seed of most of the base collection and wild relatives is now stored in medium-term cold storage.

Chickpea Germplasm

The chickpea germplasm accessions in our collection now number 12 375 from 39 countries. During the past 1-1/2 years, 47 new accessions were collected, 84 were received through correspondence, and 49 were generated through newly bred/developed strains at our Institute.

During the report period 1934 late-maturing chickpea accessions were sown at Patancheru for evaluation and rejuvenation, and 1000 accessions at Hissar for evaluation. Most of the materials were affected by botrytis disease epidemic at Hissar, which hampered evaluation. The evaluation data recorded from 1974 to 1980 on about 11 000 accessions have been computerized in the IDMRS. The germplasm accessions are being classified into 11 groups based on origin, utilization, and several characters.

Some new morphological types have been identified in the course of our chickpea evaluation and characterization work. A natural mutant that has one to three functional carpels per flower and two flowers per peduncle was observed during our evaluation and characterization activities. Its seeds are larger than the normal parent. We also identified a mutant with trilobed vexillum. In the cultivar Annigeri autotetraploidy was successfully induced through colchicin application. The C_2 selected autotetraploids showed increased seed weight and near normal fertility and pod setting. This work as well as our attempts to induce mutations by ethyl' methane sulfonate (EMS) treatment has generated new variability in chickpea.



Variation in pods and seeds of groundnut germplasm collected in 1981 from Maharashtra State, India.

Groundnut Germplasm

During the period under report we added 1608 samples to the existing collection, raising the total to 9911 accessions. The material included accessions obtained from North Carolina State University, USA, Indonesia, China, and Senegal, as well as that collected by ICRISAT in Malawi, Malaysia, Burma, Zambia, the Gambia, Mozambique, the Philippines, and India.

New wild species added to the collection during this period are *Arachis batizogaea, A. prostrata, A. monticola, A. glabra la, A. helodes,* and four other yet unidentified species belonging to sections *Arachis, Erectoides,* and *Rhizomatosae.*

The groundnut accessions are rejuvenated in precision fields. Material is space-planted and appropriate protection measures are taken. Only pods attached to plants are harvested to avoid mixtures. During the period under report, 5895 accessions were rejuvenated. Presently 7440 accessions are conserved in medium-term cold storage.

A total of 3219 accessions were evaluated and characterized for various morphoagronomic characters. Germplasm screening in collaboration with ICRISAT pathologists, virologists, and entomologists resulted in identifying lines resistant or tolerant to rust (2), late leaf spot (10), yellow mold (3), and clump virus (5). Only one line appears to have no seed transmission of peanut mottle virus. ICRISAT entomologists have found several lines with resistance to jassids (13 accessions), thrips (4), and termites (15). Some germplasm lines in our collection have shown resistance to more than one pest or disease, and seed of these has been passed on to the breeding program for utilization.

The groundnut descriptors list has been finalized and is being published jointly with the IBPGR. The passport descriptors for 8000 accessions have been listed for computerization.

Minor Millets Germplasm

During the past 1-1/2 years we assembled 499 new accessions from 24 countries, raising the total to 4039. A total of 227 of these were planted in PEQIA from Zambia, Sri Lanka, South Africa, and Nepal. During the 1981 rainy season we rejuvenated for seed increase 711 accessions of proso millet, 343 of foxtail millet, and 266 of finger millet.

In collaboration with the University of Illinois, USA, we characterized and classified 311 accessions of barnyard millet and 301 accessions of kodo millet. This joint evaluation effort will be continued.

Looking Ahead

Pointed and other general collecton missions in genetic diversity areas will be undertaken in the future depending on the progress made in the priority areas, the availability of funds, and clearance from the countries concerned.

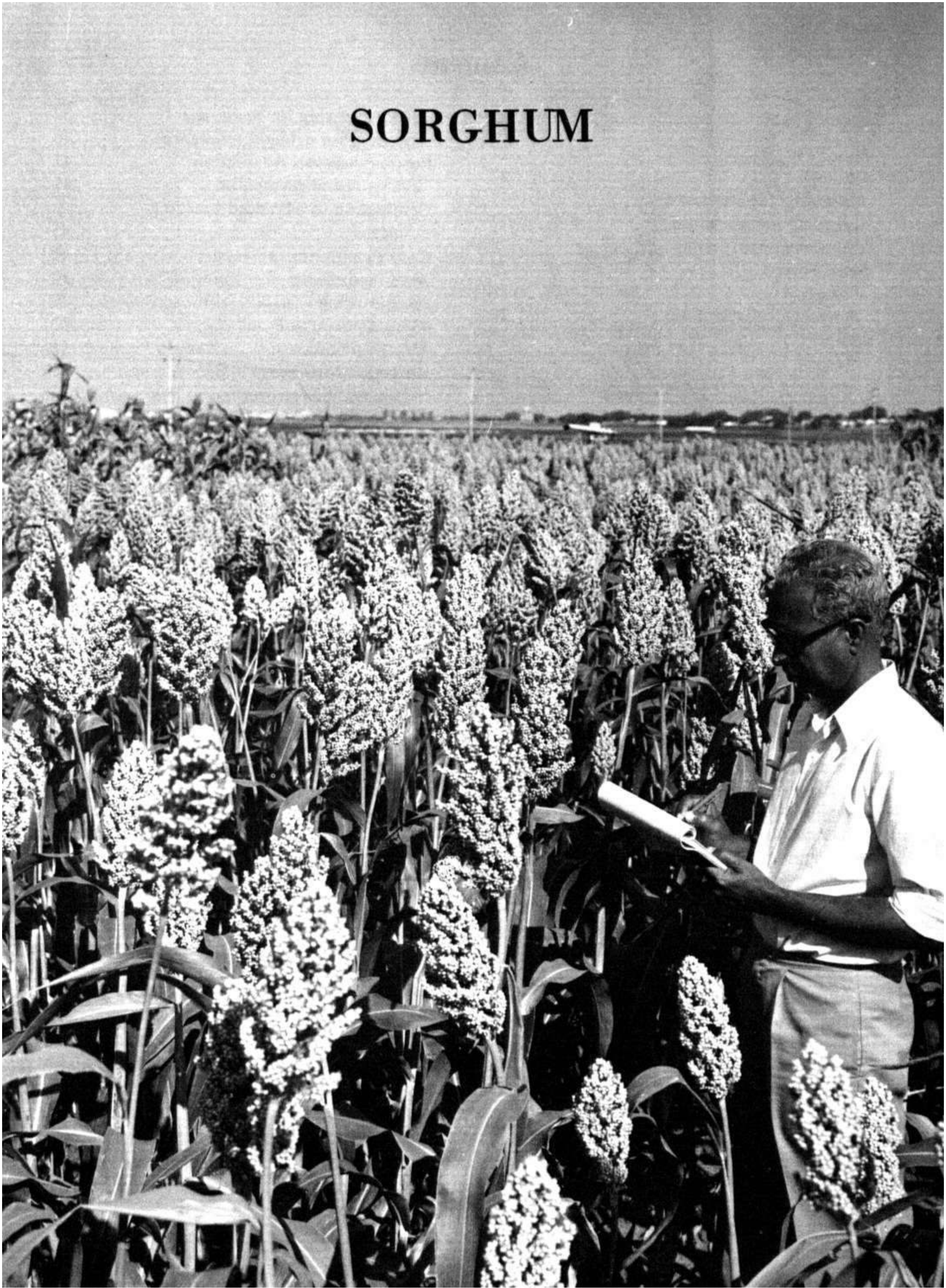
The new genetic resources laboratory building is under construction with financial aid from Japan. The laboratory will be fully equipped with the latest cold storage chambers and facilities with Asian Development Bank aid.

Evaluation and screening of all our germplasm will be continued at ICRISAT Center in collaboration with other crop improvement scientists. Special efforts to evaluate our germplasm at or near their center of collections will continue.

The development of Genetic Resources regional centers in West and East Africa is being considered. The first regional center may be established at the ICRISAT Sahelian Center, Niger. Regional centers would help in the evaluation and conservation of the germplasm at or near the area of collection or origin and would also facilitate more manageable germplasm mobilization. Loss of germplasm due to quarantine restrictions and rejections would also be minimized.

For an effective utilization of tropical germplasm in various crop improvement programs, the introgression and conversion project will be continued.

SORGHUM



Contents

SORGHUM

During the period under report (June 1980 to Dec 1981) the Sorghum Program arrived at its full complement of scientists at the Center, enhancing our ability to meet our sorghum improvement objectives. A major effort during the first few years of the eighties will be the development and improvement of techniques to screen for major problems limiting yield and stability.

In an effort to internationalize the sorghum program, we have identified geographic functional regions that are of an appropriate size and continuity for effective coordination of research. Each region has been subdivided into adaptation zones, and priority problems within each zone have been identified. This concept has been widely reviewed and accepted, and a beginning has been made towards its implementation.

Hybrids entered regional trials in India for the first time in 1980 and were sent internationally for the first time in 1981. Some of the ICRISAT developed best seed parents for hybrids are already being evaluated in hybrid combination. New sources of resistance have been identified and in some cases—for example grain mold, midge, and shoot fly—resistance is being developed in plants with good agronomic traits.

Two important events held at ICRISAT in 1981 were the symposia, "Sorghum in the Eighties" and "Sorghum Grain Quality," sponsored by the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), the Indian Council of Agricultural Research (ICAR), and ICRISAT (see International Cooperation section of this Annual Report for details.)

Additionally this year, scientists in all disciplines of the Sorghum Program have increased their contributions to the training program—as lecturers, as advisors for thesis problems, and as partners in cooperative work with visiting scientists.

Insect Pests

Shoot Fly

Biology. At ICRISAT Center shoot fly (*Atherigona soccata*) monitoring continued throughout the year with fish-meal-baited traps. In collaboration with the Max-Planck Institute, Munich, we studied the attraction to fish-meal extracts of shoot fly. Five extracts—FM 130, FM 131, FM 134, FM 135, and FM 136—were tested in traps placed 25 m apart and replicated four times. FM 134 attracted about eight times more shoot flies than raw fish meal. The other four extracts did not show significantly better attraction than the raw fish meal.

Screening for resistance. During the 1980 rainy season and 1980/81 postrainy season, we tested 323 germplasm lines previously selected as having low susceptibility to shoot fly at ICRISAT Center, and 195 lines selected from these were retested at Hissar during the 1981 summer season. Of these, 23 lines showed a consistently low-susceptible reaction in all three tests. The three best lines were IS-2162, IS-2205, and IS-5566 showing 31, 39, and 43% deadhearts, compared to 88% in the control.

In addition, we tested 2668 lines from our germplasm collection during the rainy season using infester rows and fish meal, and selected 18 low-susceptible lines for further testing. Of 73 glossy and 27 nonglossy lines tested in the postrainy season, 50 glossy and 9 nonglossy lines showed low susceptibility to shoot fly. Among the glossy lines, IS-2122, IS-5613, and IS-8977 showed less than 30% deadheart incidence, while among the nonglossy lines only IS-5635 showed similar low damage.

Breeding for resistance. A component analysis was done on factors contributing to shoot fly resistance: trichome intensity, glossy intensity, eggs laid per plant, and percent deadhearts. Low shoot fly incidence was found to be highly associated with the glossy seedling trait, indicating that this trait contributed to resistance. On partitioning the correlation coefficients into their direct and indirect effects we found that, although the glossy trait was highly associated with shoot fly resistance (r = -0.935), it had very little direct effect on the resistance (r= -0.166). This suggests that the glossy trait might be an indicator trait for some other trait that contributes to shoot fly resistance. The presence of the glossy trait was found to be negatively correlated with yield (r = -0.453). This requires further investigation.

In early 1981, a shoot fly nursery of nearly 3900 progenies was planted at Hissar. About 281 lines showed low susceptibility. In the summer season, an observation nursery of 643 advanced promising shoot fly resistant lines was planted at Bhavanisagar to assess their agronomic performance and 270 progenies were selected for further testing.

Multilocational testing. The 1980 International Sorghum Shoot Fly Nursery (ISSFN) comprising 20 entries was sent to 12 locations in Asia and Africa. Data returned from only five locations were of value, since shoot fly pressure at the other locations was low. Six lines—IS-2162, IS-2263, IS-2291, IS-4660, IS-17739, and IS-18390—performed consistently well at all five locations. However, at ICRISAT Center these entries showed high susceptibility under extremely high shoot fly pressure.

Stem Borer

Biology. Regular monitoring of stem borer (*Chilo partellus*) moths using synthetic pheromone (supplied by the Tropical Products Institute, London) and light traps was continued at ICRISAT Center. At the beginning of the crop season (July) when the natural population of *Chilo* was low, little difference was observed between male moth catches in pheromone and light traps (Fig. 1). From the 3rd week of August until April, male moth catches in light traps were higher than in pheromone traps.

Screening for resistance. The mass rearing of *C. partellus* on an artificial diet developed at ICRISAT Center for field infestation with larvae was continued. During the 1980 rainy season, we tested 2156 germplasm lines from our previous screenings under artificial larval infestation at ICRISAT Center, and under natural infestation at Hissar. At Hissar, natural infestation was extremely high (100% infestation in checks), and only 10% lines were found low-susceptible. At ICRISAT Center 1200 lines were selected for further screening because of low stem borer pressure. In addition, 37 agronomically elite lines, 323 shoot fly low-susceptible lines, and 20 lines from the 1980 International Sorghum Stem Borer Nursery were also planted at Hissar. Of these, 114 lines found to be low-susceptible were selected for further testing. Another 2359 entries, mostly advanced breeding lines, and 504 new introductions were also tested at Hissar; 152 low-susceptible entries were selected.

During the postrainy season, 1797 lines selected from our previous screenings were tested under artificial larval infestation at ICRISAT Center, and 917 lines found to be low-susceptible were selected for further testing.

Midge

Biology. In order to determine the best time for screening of our experimental lines against sorghum midge (*Contarinia sorghicola*), we planted CSH-1, the susceptible check, and TAM-2566, a resistant line, at fortnightly intervals during 15 May to 30 September 1980 at ICRISAT Center and at Dharwar. Midge incidence and buildup of adult flies is shown in Figure 2.

Diurnal activity of midge flies around sorghum heads was recorded between 0630 and 1830 hr. Maximum activity was observed between 1000 and 1100 hr at Dharwar and 0930 to 1030 hr at ICRISAT Center. *Tetrastichus coimbatorensis, Tetrastichus* spp, and *Eupelmus*

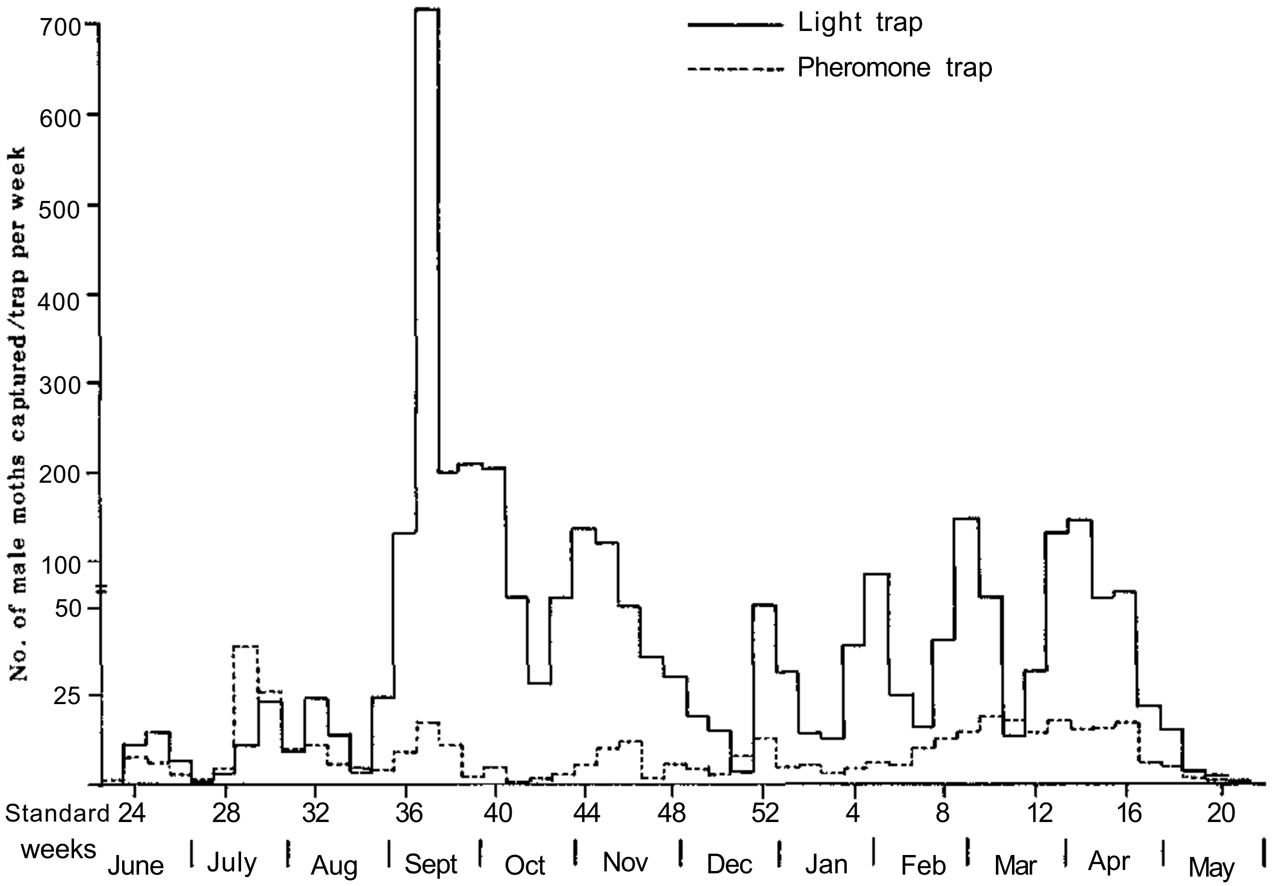


Figure 1. ***Chilo*** **catches in light and pheromone traps at ICRISAT Center, 1980/81.**

popa were recorded as the most important natural enemies at ICRISAT Center.

Screening for resistance. Major constraints for meaningful screening under natural infestation are the varying day-to-day midge populations and staggered flowering of sorghum genotypes. To overcome these difficulties, we attempted to develop methods for increasing the midge population and for screening under uniform midge pressure.

To increase midge populations, mixed maturity infester rows were sown in large plots (0.25 ha) 20 days earlier than the test material and midge-infested heads containing diapause larvae were spread along the infester rows. Midge counts were taken on 100 earheads at 50% flowering, and incidence in florets was recorded 15 days after head emergence. Midge incidence was found to be higher in plots where infester rows and midge-infested sorghum heads were used.

To test cultivars against midge under uniform midge pressure, we covered the sorghum heads with a wire-supported muslin cloth cage and released 20 midge flies into each cage when anthesis began at the top of the head. Since the midge adult lives for only 24 hr, a new set of 20 flies was released into each cage after 24 hr. This method produced over 80% midge damage in the susceptible check CSH-1. Of 40 genotypes (identified resistant sources and susceptible checks) evaluated by this caging technique during rainy and postrainy seasons, 24 lines appeared to be low-susceptible in both seasons.

In the 1980 rainy season we evaluated 1000 lines for midge resistance at Dharwar where natural midge incidence is high. From these, 250 lines were selected and tested in the postrainy

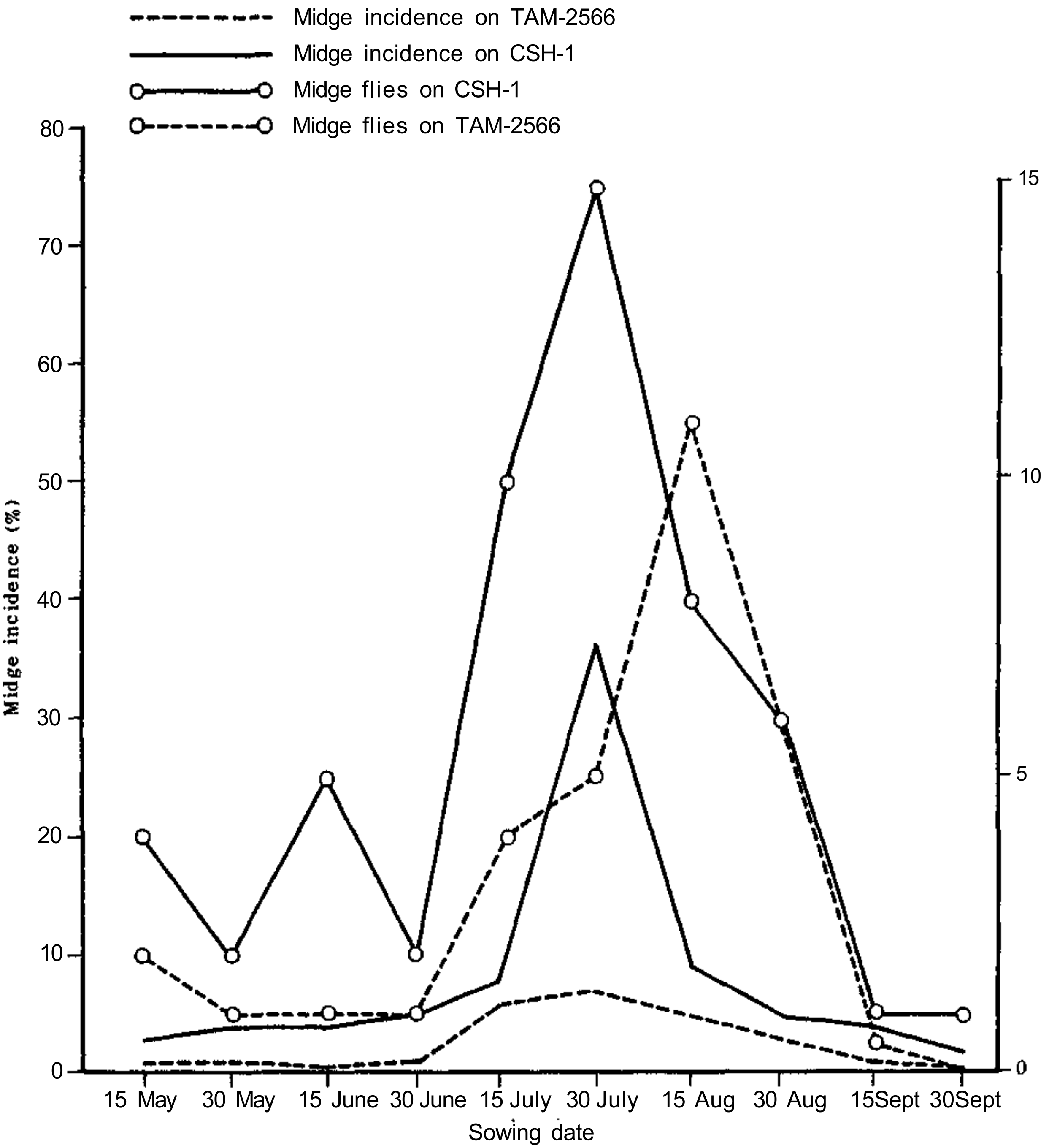


Figure 2. Midge incidence and adult midge fly activity at fortnightly plantings at ICRISAT Center, 1980.

season at ICRISAT Center and in the summer at Bhavanisagar. Of these, 112 low-susceptible lines were selected for further testing.

Breeding for resistance. In 1980 rainy season 140 low midge susceptible lines were agronomically evaluated at ICRISAT Center. PMR-1110-1, PMR-1130-2, PMR-1134-1, PMR-1052, and PMR-1061 yielded higher than the CSH-1 hybrid check. DeKalb Seed Company also tested 15 low midge susceptible entries at Salto, Argentina; eight entries showed more than 80%

seed set against 3% in the local check. These eight entries and PMR-2086-6 and PMR-2108-1 were contributed to the 1981 All India Coordinated Sorghum Improvement Project (AICSIP) midge nursery for testing in India.

A midge nursery consisting of 1254 progenies from different generations was tested at ICRISAT Center in the 1980 postrainy season; only 221 lines were less susceptible. Most of the midge-resistant lines were derivatives from crosses involving DJ-6514, IS-12573-C, TAM-2566, AF-28, and S-girl-MR-1.

Of 200 advanced progenies tested under caged conditions, 13 progenies showed low levels of susceptibility to midge. Most of them were derivatives from crosses involving IS-12573C. The 13 lines were sent to various cooperators in Africa and Latin America for further testing.

Multilocational testing. The 1980 International Sorghum Midge Nursery consisting of 13 entries was sent to five locations in India and seven in Africa. At Kamboinse (Upper Volta) the differences between the control and the test entries were nonsignificant; however, S-girl-MR-1 and IS-12666-C showed low damage levels (12%) compared to control CSH-1 (24%). At ICRISAT Center IS-2816, AF-28, S-girl-MR-1, DJ-6514, IS-3574, IS-12573-C, IS-12664-C, and TAM-2566 showed significantly lower damage compared to the check. At Dharwar (India) all entries showed significantly lower damage than the local check. Lines IS-2816, AF-28, S-girl-MR-1, DJ-6514, IS-12573-C, IS-12666-C and TAM-2566 had low midge damage ratings at all Indian and African locations.

Headbugs

Biology. In the 1980/81 postrainy season at ICRISAT Center, four headbug species, *Calocoris angustatus, Creontiades pallidus, Eurystylus vellevoyei,* and *Campyloma* sp were found damaging sorghum earheads. Their distribution in relation to head maturity and soil type is given in Table 1.

Preliminary information was collected under laboratory conditions on the biology of *C. angustatus* and *C. pallidus.* The *C. angustatus* females laid banana-shaped eggs within the glumes after a preoviposition period of 2 to 4 days. The eggs hatched in 7-8 days, and the four nymphal instars completed development in 8-12 days. In the field, maximum activity was observed from August to September. *C. pallidus* laid eggs in the milky grains after a preoviposi-

Table 1. Distribution of four headbug species in relation to head maturity and soil type at ICRISAT Center, 1980.

	No. of bugs/10 earheads			
	Calocoris	*Creontiades*	*Campyloma*	*Eurystylus*
Soil typo				
Alfisols	3	1	47	1
Vertisols	186	2	82	1
Growth stage of the head				
Preanthesis	23	0	2	0
25% anthesis	55	0	1	0
50% anthesis	63	1	5	0
Full anthesis	45	1	4	0
Postanthesis	39	0	6	0
Milky grain	87	0	10	4
Hardened grain	46	1	40	15
Harvestable grain	8	0	104	4

tion period of 2-5-days, which hatched in 6-8 days: The five nymphal instars completed development in 8-18 days. Adult longevity was 10.5 days for males and 12.6 days for females. In the field, the population increased from October to November.

Screening for resistance. In the 1980 rainy season 10 germplasm lines selected earlier for low susceptibility to headbugs were retested. Germplasm lines showing resistance to shoot fly and stem borer were also evaluated for their reaction to headbugs during the postrainy season. From these, 300 lines were selected for further testing. Eighteen lines showing low susceptibility to headbugs were included, in the International Sorghum Headbug Nursery.

Breeding for resistance. A yield trial consisting of 58 progenies with low susceptibility to headbugs was conducted at ICRISAT Center and 13 entries were found to give good yield. In a headbug nursery of 435 test entries, mostly advanced-generation derivatives, grown in the postrainy season at ICRISAT Center, 18 showed low susceptibility to headbugs.

Oriental Armyworm

This pest, *Myihimna separata,* is a voracious foliage feeder of sorghum and pearl millet. Larval population counts at ICRISAT Center were high during August 1980, being higher in sprayed areas than in the pesticide-free area and farmers' fields. We have been monitoring adult populations since 1974. Maximum moth activity has been recorded in August-September.

An initial study of the antifeedant properties of neem (*Azadirochta irtdica)* against *Mythimna* showed that alcoholic extracts from shell and kernel powder decreased the leaf area and dry weight consumption by the larvae (Table 2). Alcoholic extract from a mixture of powdered fruit pericarps was the most potent antifeedant in the no-choice situation.

Table 2. Effect of neem shell and kernel powder and its alcoholic extracts on the feeding of *M. separata.*

Treatment	Leaf area consumed (cm^2)	Dry matter eaten(mg)
Shell powder (1%)	48.3	28.3
Kernel powder (1%)	54.9	29.5
Shell extract (1%)	33.6	37.0
Kernel extract (1%)	47.1	22.3
Control	97.9	70.8
SE ±	5.67	9.98

Diseases

Grain Molds

Field screening technique. In our efforts to improve the field-screening techniques for resistance to grain molds, in the 1980 rainy season we compared three treatments in a randomized block design for their ability to promote mold development on susceptible genotypes: (1) panicles inoculated with a mixture of *Fusarium moniliforme, F. semitectum* and *Curvularia lunata* and then bagged for 15 days to increase humidity, (2) panicles inoculated with the same mixed inoculum but left unbagged, and (3) panicles not inoculated and not bagged. All the treatments were sprinkler-irrigated on rain-free days from flowering to grain maturity. All three produced high levels of grain mold that were not significantly different from each other. There was thus no advantage in the laborious and expensive treatments of inoculation and bagging over no inoculation and no bagging. This was confirmed in the 1981 rainy-season trials. Consequently, our future routine screenings will use only sprinkler irrigation to promote mold development from flowering to grain maturity.

Identification of resistance sources. In routine field screening for resistance using methods described in our previous reports (ICRISAT Annual Report 1977/78, p 52, 1978/79, pp 38-39), 32 brown-seeded germplasm lines showed high levels of resistance to grain molds. The most resistant lines were IS-118, IS-307, and IS-

20727. Most of these lines were resistant at both ICRISAT Center where panicles were inoculated and sprinkler irrigation was used to promote mold development and at Bhavanisagar under natural infection conditions. The most significant observation was that the resistance was maintained for at least 2 to 3 weeks after physiological maturity under conditions favorable for mold development.

Multilocational testing. The 1980 International Sorghum Grain Mold Nursery was sent to eight locations in Africa and Asia. Data of selected entries at seven locations, where grain mold pressure was sufficient for meaningful evaluation of the entries, are presented in Table 3. These data confirm the low susceptibility to grain molds of germplasm lines E-35-1, IS-14332, and IS-2328.

Breeding and Selection for Resistance

Selection for mold resistance in early generations. In large-scale field screening, 1200 F_4, F_5, and F_6 progenies were evaluated for resistance to grain molds, and 136 entries were selected for further evaluation. F_2 progenies originating from 614 crosses between low mold susceptible selections, adapted varieties, and selected lines from the germplasm were grown in the rainy season, and 709 single-plant selections were made. Ft hybrids of 231 crosses were grown and 118 of them were advanced to the F_2 generation. A fresh set of 294 crosses involving selected lines from germplasm and pest- and disease-resistant sources were made.

Performance of advanced varieties. Four varieties—(SC-108-3 x CS-3541)-3, (SC-108-3 x CS-3541)-19, (SC-108-3 x CS-3541)-51, and (SC-108-3 x E-35-1)-29-2—remained best for yield and grain mold resistance at Dharwar, Bhavanisagar, and ICRISAT Center in the 3rd year of testing. At ICRISAT Center tests were conducted under both low-fertility (20 kg N and 20 kg P_2O_5/ha) and high-fertility (130 kg N and 84 kg P_2O_5/ha) conditions in Alfisols and Vertisols. The yield of (SC-108-3 x CS-3541)-19 was

Table 3. Range of field grain mold scores[a] from two replicates of selected sorghum lines in the 1980 International Sorghum Grain Mold Nursery at various locations.

	Range of field grain mold rating at							
	Upper Volta	Thailand	India					Across-location mean
Entry	Farako Ba	Farm Suwan	Bhavanisagar	Coimbatore	ICRISAT Center	Pantnagar	Rajendranagar	
IS-14332	1-1	5-5	1-1	1-1	2-2	1-2	1-1	1.8
IS-2328	2-3	3-3	2-2	1-1	3-3	3-3	1-1	2.2
E-35-1	1-1	3-3	2-3	3-3	3-3	3-4	2-2	2.6
M-60578	2-3	5-5	2-3	2-2	4-4	3-3	2-2	3.0
M-60792-2	2-2	3-5	2-2	2-3	3-3	NA	2-2	2.6
M-61140-1	2-2	3-3	2-2	3-3	4-5	NA	2-2	2.7
M-90324	2-2	5-5	2-2	2-3	3-4	2-3	2-2	2.8
SPV-104[b]	5-5	5-5	4-5	4-4	5-5	5-5	4-4	4.6
CSH-1[b]	3-5	5-5	1-2	3-3	5-5	5-5	5-5	4.1

a. Mold score based on a 1 to 5 scale where 1 = no mold and 5 = panicle severely molded with more than 50% of grains showing discoloration and mold growth.
b. Susceptible check.
NA = Data not available.

Table 4. Grain yield performance of advanced varieties during 1978-80.

Variety	Days to 50%[a] flowering Mean	Plant height[a] (cm) Mean	Grain yield (kg/ha) High fertility 1978	1979[b]	1980[b]	Mean	Low fertility[c]	All India[d] average 1979	1980
(SC-108-3xCS-3541)-3 (SPV-350)	64	153	5240	4835	4992	5029	3464	3381	3122
(SC-108-3xCS-3541)-19 (SPV-351)	68	193	5661	5870	5268	5600	3186	3746	3403
(SC-108-3xCS-3541)-51 (SPV-352)	75	162	4178	5728	4462	4789	2051	3406	2765'
(SC-108-3xE-35-1)-29-2 (SPV-354)	70	196	5575	5513	4169	5086	2350	3613	2752
CSV-4(Check)	70	150	3905	4625	4362	4297	2633	3208	2343

a. Average over 3 years and three locations.
6. Average of replicated plot yields from three locations (Bhavanisagar, Dharwar, and ICRISAT Center) at high fertility (130 N 84 P_2O_5), CV = 8 to 25%.
c. Averaged over replicated experiments conducted on low fertility (20 N, 20 P_2O_5) Vertisols (CV = 24%) and Alfisols (CV = 18%) in 1980.
d. Averaged over 33 locations in India. (Reproduced from the 1980/81 A1CSIP Report).

best across locations and fertility conditions (Table 4).

Performance of preliminary varieties. Seven varieties were evaluated for yield and grain mold resistance under high-fertility conditions at Dharwar, Bhavanisagar, and ICRISAT Center and under low-fetility conditions at ICRISAT Center. The yield of (SC-108-3 x CS-3541)-88 was highest (6052 kg/ha under high fertility and 2593 kg/ha under low fertility) while that of the variety check CSV-4 was 4493 kg/ha and 2633 kg/ha under high and low fertility conditions, respectively.

Charcoal Rot

Our toothpick inoculation technique for this disease (*Macrophomina phaseolina* [Tassi] Goid) has failed to detect consistent genotype reaction over locations or in replicates at the same location. This may be due to environmental and crop management factors. Accordingly, our research strategy now emphasizes studies of the relationship between moisture stress, crop management, and disease development as they relate to resistance screening.

Our preliminary results in 1980/81 postrainy season showed that severe charcoal rot incidence, as measured by lodging, occurred at the highest plant population of 266 700 plants/ha subjected to moisture stress when the final leaf was visible in the whorl of most plants. These experiments are continuing.

Sorghum Downy Mildew (SDM)

Resistance screening technique. At Dharwar station where environmental conditions are usually favorable for SDM, we conducted an experiment in 1981 to determine the distance over which conidia of *Peronosclerospora sorghi* can be dispersed from an infection focus and cause infection in susceptible plants. The results showed that windborne conidia caused 70-100% systemic infection of susceptible plants placed 10 m from the source of inoculum. It thus appears possible to use the infector-row technique for large-scale field screening for resistance to SDM at Dharwar. This possibility will be evaluated in 1982.

Breeding for resistance. Crosses were made to transfer SDM resistance genes from the highly stable source of resistance in Q1-3 and its sister lines to agronomically elite and genetically diverse backgrounds.

From 145 crosses involving QI-3 as a female parent, 621 single-plant selections from the F_2 were screened for SDM resistance; 35 lines had the same resistance level as QI-3. These promising lines were advanced in the 1980 postrainy season, and 77 single-head selections were made for improved agronomic characters.

Multilocational testing. The 1980 International Sorghum Downy Mildew Nursery (ISDMN) was sent to nine locations, but downy mildew pressure was sufficient only at two locations (Dharwar and Mysore in India) of six from which data were returned. At both these locations QI-3 and its sister lines 2-7,2-26,3-23, and 3-36 were free from downy mildew, and UChV-2, M-36203, and 3-3 had less than 5% downy mildew infection, compared to 80-100% in the susceptible cultivar DMS-652.

Leaf Diseases

Rust. Severe rust (*Puccinia purpurea* Cooke) infection occurs naturally on late-planted, rainy-season susceptible sorghum genotypes at Dharwar, India. We used this location in 1980 for large-scale field screening of germplasm and breeding lines for resistance to rust, employing an infector-row technique. In this technique seven rows of test entries were planted between two infector rows of the highly rust-susceptible line, Khundi jowar, which had been planted 16 days earlier. Rust severity, as measured by the percentage of leaf area damaged, was recorded at the soft dough stage on the top four leaves of 10 plants in each test row of 4 m. In preliminary screening, high rust resistance was observed in 151 agronomically elite sorghum lines out of 781 lines from various breeding projects. In advanced screening of 346 lines, 23 lines consisting of germplasm and ICRISAT-bred agronomically elite lines were found to be free from rust. Notable among the rust-free entries were the converted lines USDA-Texas A&M IS-2816-C, IS-3574-C, IS-6882-C, IS-6906-C, IS-7778-C, IS-7907-C, IS-7994-C, and IS-12605-C, and ICRISAT lines (IS-3443 x DH 599-77R)-7-1-1, IS-1331 x E-35-1)-3-2-1, (E-185-2 x 16-9)-4-2-1, and (IS-12573-C x IS-12666-C)-2-1-1-1.

Anthracnose. In our exploratory trials in 1980 we found Pantnagar, U.P., North India, to be suitable for large-scale field screening for resistance to anthracnose (*Colletotrichum graminicola* [Cesati] Wilson) under natural infection conditions, as the disease occurred early and in severe form on the highly susceptible line H-112. We evaluated 24 sorghum lines, reported to be resistant, and the resistance of four was confirmed: IS-2319, IS-4225, IS-9569, and IS-18521. In addition, at this location grey leaf spot (*Cercospora sorghi*) and zonate leaf spot (*Gloeocercospora sorghi)* also occurred in severe form on susceptible lines and provided meaningful evaluation of test material.

Multilocational testing. The 1980 International Sorghum Leaf Disease Nursery consisting of 23 test entries and seven susceptible checks for anthracnose, leaf blight, rust, grey leaf spot, zonate leaf spot, rough leaf spot, and sooty stripe was evaluated at six locations in Africa and Asia. The best entries, which showed resistance to several leaf diseases, are listed in Table 5.

Striga

Striga, a root parasite of cereals, is an economically important parasite of sorghum in Africa and India. Since *S. hermonthica* is more important in West and East Africa, our major research activity on this species is based at ICRISAT's West Africa Program, in Upper Volta (see International Cooperation section, this Annual Report). Research at ICRISAT Center is on *S. asiatica,* the more important species in India.

Table 5. Range of leaf disease scores[a] of selected sorghum lines in the 1980 International Sorghum Leaf Disease Nursery.

	Leaf disease and range of disease score[b]					
Pedigree	Anthrac-nose	Leaf blight	Rust	Grey leaf spot	Zonate leaf spot	Sooty stripe
E-35-1 (IS-18758)	1-2	2-2	1-5	2-2	2-2	2-2
IS-115	1-2	1-2	2-4	2-3	2-2	2-2
IS-4150	1-2	1-2	1-5	2-3	2-2	2-2
IS-7322	1-2	2-5	2-5	2-2	2-2	2-2
(Swarna x CS-3687)-6-1	1-2	2-2	1-2	3-5	2-4	2-2
(CS-3541 x IN-15-2) IS-9327-16-1	1-2	1-1	1-4	1-3	1-2	4-4

a. Based on a 1 to 5 scale where 1 = no symptom and 5 = more than 40% area of top four leaves damaged by the disease.

b. Disease score at locations where sufficient leaf disease occurred. The locations were Farm Suwan (Thailand), ICRISAT Center (India), and Pantnagar (India) for anthracnose; Farm Suwan and ICRISAT Center for leaf blight; Farm Suwan and Kovilpatti (India) for rust; Farm Suwan, Laguna (Philippines), and Pantnagar for grey leaf spot; Laguna and Pantnagar for zonate leaf spot; and Cinzana (Mali) for sooty stripe.

Screening for *Striga* resistance. Low production by the host roots of a stimulant considered a prerequisite for the germination of *Striga* seeds has been identified as a mechanism for field resistance. To verify the relationship of low-stimulant production with field resistance to *S. asiatica,* we grew sets of low-stimulant lines in *Striga*-sick fields at different locations. We found that not all low-stimulant lines were resistant in the field, and the expression of resistance varied from location to location.

White-flowered Striga asiatica (*arrowed*) *is a serious root-parasitic weed of sorghum in India. The crop growth is stunted and head formation is poor.*

Analysis of field reaction data on selected source lines for resistance to *S. asiatica* in multilocational testing during 1977, 1978, 1979, and 1980 showed that, though there was no absolute resistance to *S. asiatica,* sorghum lines N-13, 555, 16-3-4, Serena, IS-2203, IS-4202, IS-7471, and IS-9985 could be valuable in breeding programs as sources of some degree of resistance.

Breeding for *Striga* resistance. Work continued in 1980 on the development of agronomically elite *Striga*-resistant cultivars by crossing *Striga*-resistant source lines with adapted high-yielding lines. Segregating progenies were advanced both in *Striga-sick* and *Striga*-free plots, and selection was made for suitable height and maturity, pest and disease resistance, apparent seed quality characteristics, and absence of *Striga.* The results indicated that not all resistance sources are good 'breeding stocks' for *Striga* resistance since they carry many undesirable traits. One resistant source line, 555, has been a parent in a number of useful advanced lines. We now have several breeding stocks that are improvements over the original source lines and are being confirmed for *Striga* resistance. During the 1980 rainy season, 156 advanced-generation uniform lines were screened at three locations in multilocational testing, and 23 lines were selected for further testing. Of these, seven lines—SAR-1 [(555 x 168)-1-1], SAR-2 [(555 x 168)-16], SAR-3 [(555 x 168)-23-1-BK], SAR-4 [(148 x 555)-BK], SAR-5 [(148 x 555)-1-2], SAR-6 [(148 x 555)-33-1-3], and SAR-7 [(Framida x 168)-9-2-3]—were selected for inclusion in the 1981 AICSIP *Striga* resistance nursery.

***Striga* resistance screening technique.** Improved techniques for field screening are being evolved. One technique is a three-stage testing process where test entries are increasingly grown in proximity to susceptible checks. Only preliminary data are available, and the usefulness of the technique is being verified.

Physical Environment

Drought

Field screening for resistance. The line-source (LS) sprinkler irrigation technique, described in our 1978/79 Annual Report (p 31), was used to screen sorghum cultivars for drought resistance. The methods used to analyze the data are discussed below.

During the 1980 postrainy season we conducted two experiments to evaluate both germplasm lines and advanced selections (F_6 progenies) from the drought resistance breeding project.

In the first experiment, we studied the response of 18 genotypes to linearly decreasing levels of water supply ranging from fully adequate to nil (following three uniform irrigations for crop establishment). Harvest of each cultivar was taken from two replications (one on either side of the LS). The relationship of decrease in grain yield with declining levels of available moisture from the LS and rainfall (regression) was determined for each genotype (Fig. 3, Table 6). The yield potential was determined from the intercept with the 'y' axis and was taken as the yield potential in the absence of moisture stress. The faster the yield declined with reduced moisture availability, the more susceptible a variety or hybrid was to moisture stress. This decline in yield with increasing stress can be estimated from the slopes of the lines for each entry.

While the genotypic differences in the intercept and slope were notable, generally the genotype with higher yield potential also showed greater decline in yield as the stress level increased (e.g., CSH-6 has high intercept but its slope is also high). Computation of the correlation between yield potential and drought suscep-

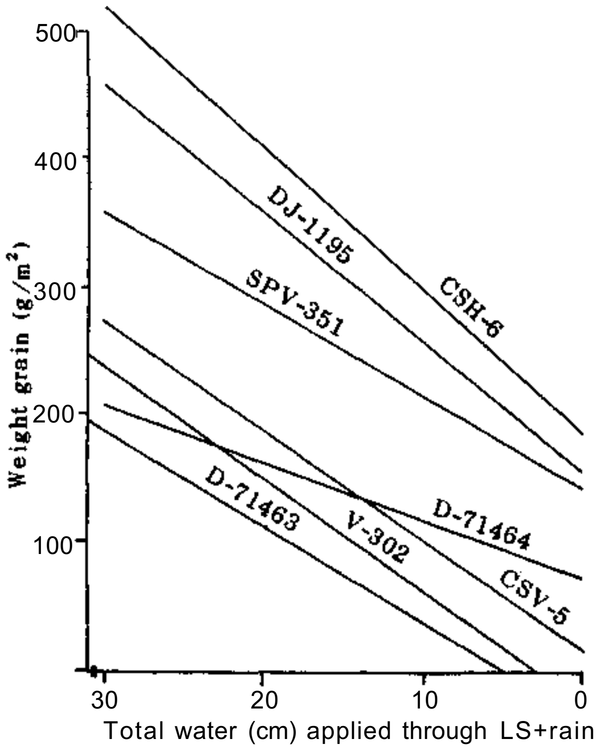


Figure 3. Genotype evaluation for drought resistance using line source (LS) sprinkler irrigation system: Relationship between irrigation water applied through LS plus rain (after three uniform furrow irrigations to recharge the profile during crop establishment phase) and grain yield. (Field RP11B at ICRISAT Center, 1980 postrainy season; regressions for only 7 out of 18 genotypes are shown; for all correlations n = 18; *P* < 0.001).

Table 6. Linear relationships between water supply(x) and grain yield(y) of sorghum entries and Eberhart and Russels' stability analysis. The regression coefficient is derived from regression of yield on environmental index (yield at each level of water).

	A. Regression analysis of LS data				B. Stability analysis[c]		
Entries	Yield (g/m^2) at 36 cm water (Intercept)	Slope	r[a]	SI[b]	Mean yield (g/m^2)	b^{ERd}	Residual sum of squares (S^2_{di})
D-71305	397	- 8.93	0.93	2.25	187	0.99	156
D-71500	269	- 6.61	0.92	2.46	113	0.75	1291
D-71463	232	- 7.36	0.95	3.17	95	0.90	1454
D-71464	236	- 4.51	0.84	1.91	145	0.55	544
Rs/RxCS-3541	403	- 8.29	0.92	2.05	209	0.96	1363
Rs/B-8785	386	- 8.45	0.93	2.19	187	0.96	1079
GG-1483	398	- 8.91	0.92	2.24	231	1.04	1399
SPV-386	430	-10.63	0.95	2.47	231	1.31	903
SPV-351	409	- 7.38	0.85	1.81	235	0.83	981
SPV-387	456	- 9.30	0.91	2.04	237	1.03	744
DJ-1195	517	- 9.87	0.95	1.91	285	1.14	1756
IS-12611	403	- 7.39	0.85	1.83	229	0.85	819
CS-3541	441	- 8.95	0.75	2.03	231	1.10	5701
CSV-5	329	- 8.52	0.96	2.60	128	0.94	1070
CSH-8	486	-11.66	0.78	2.40	212	1.41	8959
V-302	294	- 8.80	0.90	2.99	97	1.13	955
CSH-6	592	-11.12	0.86	1.88	286	1.26	4824
M35-1	331	- 7.39	0.89	2.23	157	0.86	661

a. Correlation coefficient.
b. Susceptibility index. Ratio of rate of decline in yield to yield at 36 cm water (slope/intercept) expressed as percentage.
c. Eberhart, S.A., and Russell, W.A. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.
d. Regression coefficient: grain yield regressed against environmental index (i.e., mean grain yield of all genotypes at each observed level of water supply).

tibility revealed that they were mutually opposed ($r = 0.813$, $P < 0.001$). This poses a serious problem for combining high yield potential with least drought susceptibility. Hence we used the following approach for selecting drought-resistant genotypes. The values for yield potential (intercept) were compared with the values for slope (Table 6), forming the array of points appearing in Figure 4. The genotypes showing above-average yield potential (points on right-hand side of broken vertical line) and slope with low values for slope (less than regression predicted values, i.e., genotypes at points above the regression lines) were selected as drought-resistant types. The diagonal line in Figure 4 is the regression of yield potential with slope. Similarly, the genotypes below the regression line and on the left-hand side of the broken vertical line were identified as susceptible to drought. Using this procedure, it is possible to select entries with good yields and better resistance to moisture stress. Interestingly, D-71463 and D-71464 are sister lines arising from the same cross. In the field screening for leaf firing (1979/80 Annual Report, p 30) under hot dry summer conditions, D-71464 was found to be more drought resistant

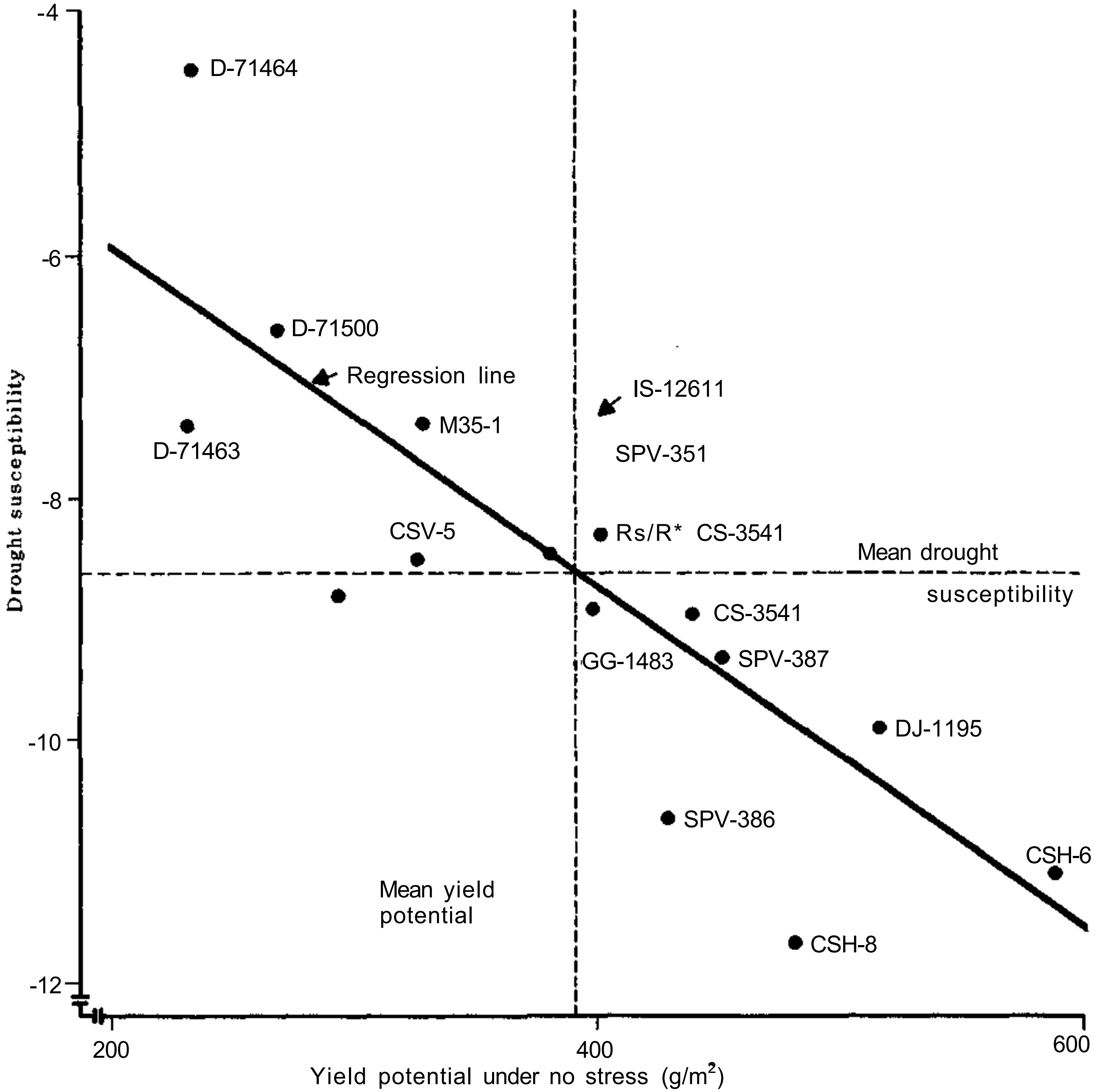
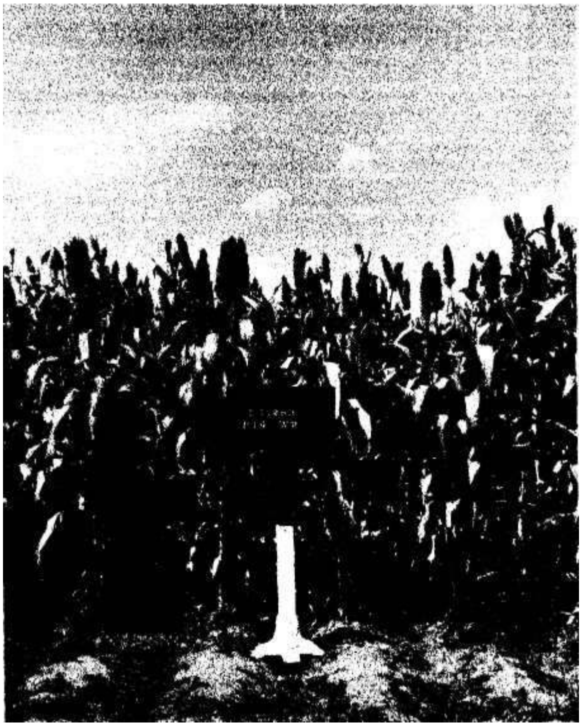


Figure 4. Relationship between yield potential and drought susceptibility on field RP11B at ICRISAT Center (postrainy season 1980 data for 18 genotypes are shown).

than D-71463; the former also recovered faster. It was apparent that while the difference in the yield potentials was very small between sister lines there was considerable variation in drought resistance (Figs.3 and 4).

Traditionally, genotype stability is assessed by multilocational trials. If water availability is the major constraint in the test locations, LS can be used to create the needed levels of water supply. Using the data generated from the above experiment, Eberhart and Russel's stability analysis was carried out (Table 6). Besides high mean yields of cultivars, the two parameters—slopes of the regression line b^{ER}) and the deviations



One of our lines which has recovery drought resistance performed very well under normal moisture conditions and low fertility.

from the regression lines (residual sum of squares in Table 6)—are useful in characterizing the genotypes. A stable cultivar has high mean yield, unit regression coefficient (b^{ER} =1.0), and deviations from the regression as small as possible (S^2_{di} = 0). It was observed that the correspondence between this analysis and the first one described above was good, suggesting that the data collected on a small piece of land at a single location can be used to select drought-resistant types. To ascertain the least susceptible genotypes (within the high-yield potential group), one can compute the "susceptibility index" (SI) as the ratio of drought susceptibility to yield potential (Slope/Intercept; Table 6) expressed as positive percentage of the latter. SI can thus be used as an indicator of drought susceptibility and we will aim at selecting high-yielding genotypes with the lowest susceptibility index.

In the second experiment, 64 F_6 progenies were tested along with eight checks without any replication. Two-row plots of each cultivar were planted in 75-cm row spacing at right angles to the line source, and each plot was harvested in successive segments of 1.5 m. The yield potentials were again highly correlated with drought susceptibility (r = 0.958, $P < 0.001$). Using the technique described above, selections were made for drought resistance.

In both experiments the hybrid checks showed highest yield potential and, in spite of steeper slopes, they outyielded all varieties at all levels of water supply used. This substantiates the general experience that hybrids are more stable than varieties even under stress.

Breeding for drought resistance. Breeding material generated from crosses involving parents selected from our earlier field screenings was evaluated both at ICRISAT Center and at the dryland agricultural research station, Anantapur (in a drought-prone area of Andhra Pradesh) under natural conditions.

At Anantapur, about 146 mm rain fell during crop growth. The drought was severe but rainfall was distributed over several weeks. Sorghum lines were evaluated for recovery on a 1 to 5 scale (1 = least scorched leaves and 5 = severely scorched leaves and no recovery or regrowth) and heading ability (where 1 = 90% or more plants headed, 10 = less than 10% headed). The known drought-resistant checks, M-35-1 and CSH-6, recovered well at both locations.

The materials in advanced generation were screened in three replicated trials at the fruit research station, Sangareddy, Andhra Pradesh, during the 1980 summer (see ICRISAT 1979/80 Annual Report, p 31). Differences in genotypic effects in all three trials for recovery were highly significant, indicating that selection for this trait is effective.

Susceptible lines D-71305 and D-71463 identified in these screenings may be used as indicators in future. The selected lines will serve as sources for drought resistance. The sister lines D-71463 and D-71464, which showed contrasting responses at Sangareddy, can be utilized in physiological studies to elucidate the drought resistance mechanisms, particularly recovery from drought stress. The responses of these genotypes for recovery at Gadamballia, in the Sudan were similar to those observed at Sangareddy, India.

All the lines screened at Sangareddy and Anantapur were yield-tested at ICRISAT Center in Alfisols. These trials indicated that the yield levels of the selected lines were comparable to the released hybrids (such as CSH-5) and that these lines had higher levels of drought resistance (recovery) than the released variety, CS-3541.

Postrainy-season Adaptation

Evaluation of germplasm. Earlier, based on visual selection, we used the known Indian postrainy-season lines as parental source material. Subsequently, in an effort to diversify the genetic base, 7251 lines in the germplasm block were visually evaluated, and 32 lines were selected as parents in the program. The geographical distribution of these 32 parents is: India (7), Nigeria (2), the Sudan (3), Niger (1), Dahomey (1), Ethiopia (11), Kenya (1), Malawi (2), and USA (4). These varieties are generally tall and late.

Segregating materials were generated from crosses involving adapted photoperiod-insensitive types. The segregating materials (446 F_2s and 461 F_3s) were evaluated late in the season (October) in Vertisols at ICRISAT Center, thus enhancing the chances of encountering terminal drought stress. In addition, 1150 advanced-generation lines were also evaluated in Vertisols.

In cooperation with the University of Agricultural Sciences (UAS), Bangalore, a similar set of segregating material and avanced selections were evaluated at UAS research station at Bijapur, situated in a major postrainy-season growing area in Karnataka State, India.

From ICRISAT Center evaluations, 270 F_3s, 112 F_4s, and 500 advanced-generation lines were selected for further testing and selection. From the Bijapur screenings, 58 single-plant selections and 9 F_5s were obtained.

Evaluation of advanced breeding lines. The advanced-generation lines selected earlier from the rainfed postrainy season were evaluated in two separate trials. There were 100 entries (including three checks) in each trial and a triple lattice design was used. Each of these trials was grown in Vertisols at two locations—ICRISAT Center and Bijapur. In order to account for the variation in sowing time usually followed by farmers there were two different dates of planting (early and late) at ICRISAT Center.

All entries in both trials, including the checks, M-35-1, SPV-86, and CSH-8R, wilted completely at Bijapur.

The early-planted trials at ICRISAT Center were conducted on fields that had received less than 500 mm rainfall during the preceding rainy season and the crop had experienced severe terminal stress. Emphasis in selection was given to seedling emergence, vigor, days to flowering, and agronomic score, and a total of 28 selections were obtained for furter testing in advanced yield trials. The selected lines had good food grain characteristics and three of these, D-82066, D-82073, and D-82039, possessed trichomes, a trait known to confer shoot fly resistance. Parents M35-1, VZM-B, SPV-105, 2077B, EI85-2, IS-6928, and IS-1038 were in the pedigrees of most final selections.

Crop Establishment

Soil temperature. Fifty sorghum lines were tested in ICRISAT Center Alfisol beds for their emergence ability over a wide range of soil temperatures by planting on different dates between October 1980 and April 1981. Two different soil temperature profiles were obtained at each planting by use of kaolin and charcoal as surface covers (Fig.5). We found that emergence was significantly affected by (1) date of planting (environment), (2) surface (kaolin and charcoal cover), and (3) genotype. Significant genotype x treatment (2 + 3) interactions were found.

It was evident that with the increase in temperature from January to April, there was decrease in emergence in the charcoal treatment: in the kaolin treatment the emergence was always higher than in the charcoal treatment. In general, during winter months, emergence took a

Figure 5. Effect of temperature (simulated by charcoal and kaolin) on seedling emergence in sorghum (in brick flats at ICRISAT Center).

longer time in kaolin than in charcoal due to the prevailing lower temperature in the former.

High soil surface temperature did not adversely affect seed germination, but it damaged the emerging seedlings. After reaching the soil surface, the coleoptile tips of the susceptible genotypes bent laterally or coiled, possibly because of the high temperature. Also, the coleoptile tips (or the expanding leaves) showed signs of scorching.

The technique for the selection of lines for tolerance to high soil surface temperature is simple and inexpensive and a few lines (including IS-301 and IS-8264) were selected.

Soil crusting. Techniques for studying emergence ability through a simulated crust are being developed in the field and also in brick flats (Fig.6) at ICRISAT Center. A field technique was described in the ICRISAT 1979/80 Annual Report (p 32). For the technique in brick flats, the soil is levelled and then saturated with water. The following day the seeds are sown at 40-mm depth, and water is applied from rose cans held at 1-m height in an attempt to simulate rainfall and facilitate formation of crusts on hot sunny days.

Collaborative research with Haryana Agricultural University (HAU) was initiated during 1980 to study the relative performance of sorghum genotypes under surface crusting in Aridosols at Hissar. These soils situated in arid and semi-arid climates are structurally unstable, low in organic matter, and susceptible to surface crusting. The first trial included 31 genotypes. In the second trial, 45 genotypes (including 19 from the previous trial) were studied for their emergence ability under crust and no-crust situations. During 1981, 102 genoypes were tested and distinct genotypic differences were observed (Fig.6).

Genotypes showing good emergence ability both at ICRISAT and HAU were IS-4349, IS-5977, IS-2705, IS-1072, IS-10022, Naga White, and IS-5642). At HAU some lines emerged well in the presence of a soil crust, while others failed miserably (Table 7).

Soil moisture. In 1980, 100 lines from the drought breeding project and several germplasm lines were evaluated for drought resistance at the seedling stage. Significant variability was found to exist for drought resistance at this stage, and 20 lines with high resistance were selected.

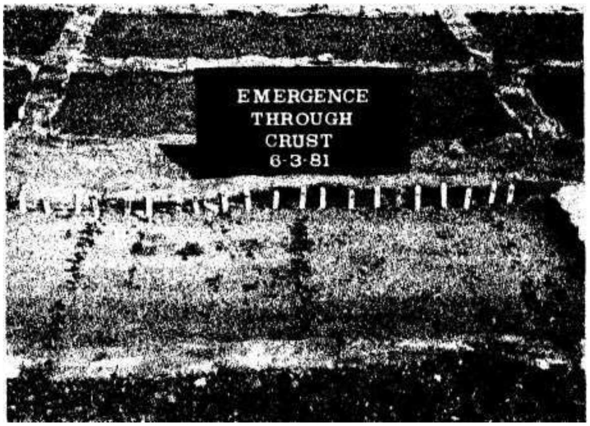


Figure 6. Brick flat experiment: Emergence through soil crust (a few genotypes emerged well, while many failed to emerge).

Table 7. Seedling emergence behavior of some sorghum genotypes at HAU, Hissar.

Genotype	Seedling emergence (%) Crust	No crust
IS-4474	67	69
IS-684	52	63
IS-155	60	69
IS-3510	59	73
IS-923	3	40
IS-4663	7	77
IS-4542	11	49
IS-8962	13	59

In order to investigate whether selection for drought resistance at the seedling stage is related to drought resistance at the advanced growth stage, 21 lines with good agronomic traits that had been selected at the seedling stage were exposed to continuously depleting soil moisture during the panicle development and grain-filling stage in an Alfisol field during the 1980 postrainy season. The results showed that lines IS-4405, IS-5567, IS-2394, IS-4776, and IS-1096 selected for drought resistance at the seedling stage also showed reasonable levels of resistance at advanced growth stages. Some of these lines gave reasonable yields both under irrigated and nonirrigated treatments (2900 to 5700 kg/ha in irrigated and 2100 to 3800 kg/ha in nonirrigated plots). The yields of IS-4405, IS-2394, IS-1696, and IS-5567 were comparable to the two standard checks, CSH-8 and CSH-6.

Seedling vigor (seedling size) was found to be significantly correlated with emergence through crust and also with drought resistance at the seedling stage ($P < 0.01$).

The glossy lines-IS-4663, IS-5484, and IS-923—showed reasonable resistance to soil crusting and to drought at the seedling stage, as well as to shoot fly.

Plant Nutrition

Selection for nitrogen efficiency. Considering the small farmer's conditions and traditional agricultural practices in the SAT, it is important to produce cultivars that preform reasonably well under both low and high fertility conditions. We therefore initiated a study of the selection results in both conditions.

Selection was carried out from So progenies of three random mating populations under both high (100 kg N/ha) and low (20 kg N/ha) fertility conditions during S_0-S_2 generations of three populations. Our final objective was to test whether the top-ranking selections made under either fertility levels retained similar ranking at both levels of fertility. From each population and fertility level, 16 final selections were grown for seed multiplication during the 1979 postrainy season. Yield trials were conducted during the 1980 rainy season with S_4 progenies. For testing at each level of fertility, the selections made from both levels of fertility were planted along with four checks in a 6 x 6 lattice design. In addition to testing, selection continued under each level of fertility and the S_5 seeds were multiplied during the 1980 postrainy season. The test was repeated in the 1981 rainy season with S_6 progenies.

The Spearman rank correlation coefficients between ranks of two groups of selections for grain yield under high and low fertility conditions were separately computed. The correlation was found to be positive and significant in all cases. This indicates that the best selections made under high fertility also retain similar ranking under low fertility.

Nitrogen-fixation studies. A test tube culture technique was developed in 1980 to test the effect of host genotype and bacterial culture on nitrogenase activity. Plants are grown in 25 x 200-mm tubes containing 20 cc of soil, soil: sand mixture, or vermiculite medium (Fig. 7). Nitrogenase activity could be detected 3 days after planting, and by 15 days there were usually differences between genotypes in stimulating this activity. We are now standardizing this method and determining the correlation with activity of older, field-grown plants because plant and bacterial material can be screened for nitrogenase activity much more readily using the tube culture method.

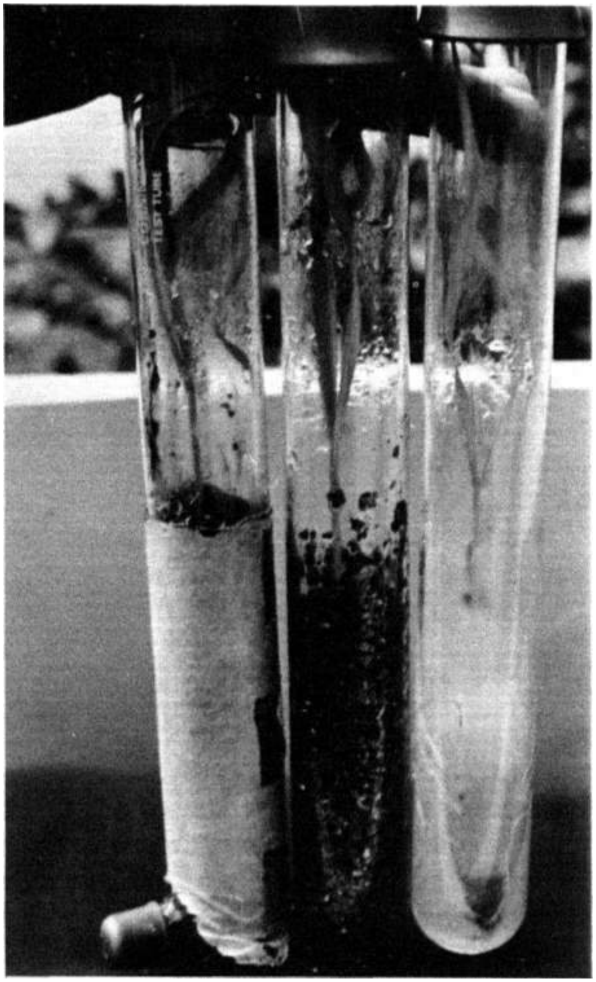


Figure 7. Tube culture technique for estimating nitrogenase activity of sorghum plants.

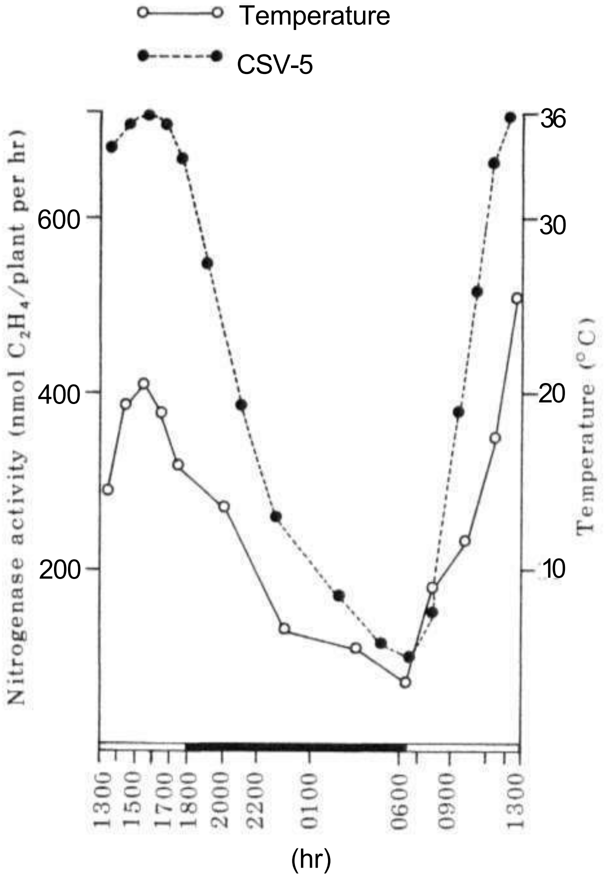


Figure 8. Diurnal pattern of nitrogenase activity of intact sorghum plants (CSV-5).

Using the intact plant assay method reported in our 1979/80 Annual Report (p 66), we have observed a marked diurnal pattern for nitrogenase activity of sorghum (Fig. 8). The activity increased during the day, with most occurring between 1600-1700 hr and a marked decline during the dark period. This pattern closely followed the one for soil temperature, but our experiments on the effect of incubation temperature on nitrogenase activity of root-soil cores indicated only a twofold increase as the temperature rose from 20°C to 35°C. This suggests that much of the 13-fold variation in diurnal activity observed with intact plants was not due to temperature, but rather to the photosynthetic activity of the plants.

Using a line-source irrigation system on an Alfisol at ICRISAT Center in the dry summer season we found a significant correlation (r= 0.54) between the soil-moisture content and nitrogenase activity in hybrids CSH-6 and CSH-8. Most nitrogenase activity occurred in both genotypes when they were sampled 2 m away from the sprinkler where the soil-moisture content was 8.9% on a soil dry-weight basis. Thereafter, nitrogenase activity declined as the distance from the sprinkler increased and the soil contained less moisture. In another experiment, 47-day-old plants of CSH-1 grown in an Alfisol were assayed for nitrogenase activity as root plus soil cores (ICRISAT Annual Report 1976/77, p 43). Different amounts of water were added to the cores, and after an equilibration period of 1 hr these were then assayed for nitrogenase activity over a 5-hr incubation period. There was again a significant positive correlation (r = 0.61) with increasing amounts of water added (Fig. 9).

Pure cultures of *Erwinia herbicola* and *Enterobacter cloacea,* which grow in the rhizosphere of sorghum, did not show nitrogenase activity, but mixtures of these cultures produced considerable activity. If such synergism exists in the rhizosphere of sorghum, it would be difficult to choose organisms for use in single-strain inoculants.

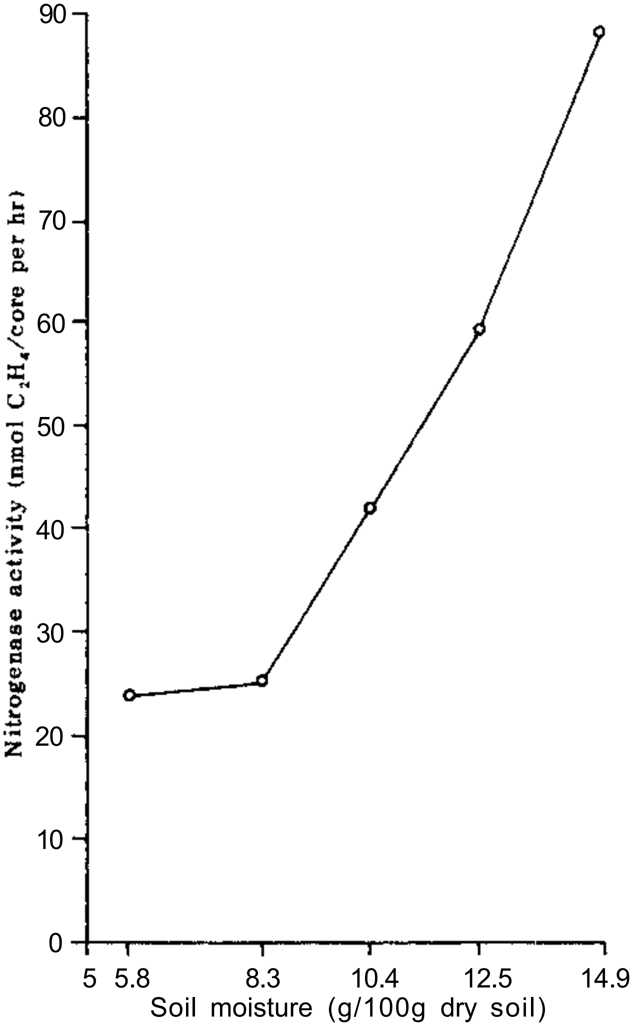


Figure 9. Effect of different soil-moisture levels on nitrogenase activity of the sorghum hybrid CSH-1 grown in an Alfisol field and assayed in 15-cm dia cores.

Incubation temperature also affected nitrogenase activity of pure cultures, and most activity was obtained at 30°C for *Azotobacter chroococcum,* and35°C for *Azospirillum lipoferum.*

In a pot experiment with the sorghum hybrid CSH-1 grown in unsterilized Alfisol, inoculation with nitrogen-fixing bacteria produced a significant increase in grain and total dry-matter production (Table 8). Adding the equivalent of 20 to 40 kg N/ ha fertilizer as ammonium sulphate also increased yields. The crude inoculum prepared from an extract of ground up roots of field-grown Napier bajra (a cross between pearl millet and Napier grass) gave the most consistent response (Table 9).

Food Quality

Sankati Cooking Quality

In several regions of South India sorghum grain is consumed in the form of *sankati,* a preparation traditionally made with grits from either dehulled or whole grains. Grain samples of 25 cultivars in the International Sorghum Food Quality Trials (ISFQT, ICRISAT Annual Report 1979/80) were evaluated for sankati quality at Bhavanisagar with the aid of six farm women as panelists. M-50013, CSH-5, Mothi, and M-35-1 were rated as best for good sankati quality.

Dehulled sorghum grain is also cooked to make rice-like products called *chorru* or *annam,* which are consumed in South India and other regions of the SAT. To determine the range of variation for various cooking quality characteristics, grain samples of 112 cultivars of diverse origin were evaluated. The time required for cooking a standard quantity (20 g) of whole grain ranged from 54 to 114 min (Table 10). Percent increase in the volume of the grain as a result of cooking varied from 100 to 273, while the weight increase ranged from 107 to 186%. The texture range of cooked grain varied from 1.1 to 4.7 on a scale of 1 to 5 (1 = good). Dehulled as well as whole-grain samples of 25 cultivars in the ISFQT were evaluated. In general, the volume and weight of the cooked product from

Table 8. Effect of inoculation with nitrogen-fixing bacteria on sorghum grain yield (g/pot).[a]

Culture	kg N/hectare 0	20	40	Mean	Regression equation
Azospirillum lipoferum	9.7	13.1	18.9	13.9	Y = 9.31 + 0.23 N
Azotobacter chroococcum	9.3	10.9	15.9	12.1	Y = 8.7+0.16 N
Napier bajra root extract	10.0	12.8	22.0	14.9	Y = 9.94-0.18N +0.008 N^2
Uninoculated broth	7.1	9.9	17.9	11.6	Y = 6.32 + 0.27 N
SE ±		1.11		0.64	
Mean	9.0	11.7	18.7		
SE ±		0.55			

a. Average of four replications. Four plants were grown in each replicate pot in unsterilized Alfisol in a glasshouse for 103 days.

Table 9. Effect of inoculation with nitrogen-fixing bacteria on sorghum dry-matter production (g/pot).[a]

Culture	kg N/hectare 0	20	40	Mean	Regression equation
Azospirillum lipoferum	66.4	79.8	93.5	79.9	Y= 66.4+0.68 N
Azotobacter chroococcum	58.5	74.0	93.7	75.4	Y = 57.8 + 0.88 N
Napier bajra root extract	62.2	81.5	96.1	79.9	Y = 62.9 + 0.85 N
Uninoculated broth	48.1	67.2	85.4	66.9	Y = 48.26 + 0.93 N
SE ±		4.37		2.52	
Mean	58.8	75.6	92.2		
SE ±		2.19			

a. Average of four replications. Four plants were grown in each replicate pot in unsterilized Alfisol in a glasshouse for 103 days.

dehulled grains was twice that of the whole grain and the cooking time was 60% lower. The texture and color appeal of the dehulled cooked product was much better than that from the whole grain. Correlation coefficients between physical grain characters and cooking quality attributes indicated that percent increase in volume *of* the cooked grain is positively correlated with grain density (r= 0.66) and corneousness (r= 0.54), while cooking time was positively correlated with 100-grain weight (r= 0.46).

Chapati Quality

Dough and chapati qualities of 60 sorghum cultivars were evaluated. Sticky, easily Tollable dough produced good quality chapati. The stickiness of the dough was measured with a back-extrusion cell using the Instron food testing machine. The good dough of variety M-35-1 required more force for deformation, than the poor dough of IS-12611. A poor dough was compressed in the cell, and was not extruded, so

Table 10. Variability for some grain and cooking quality attributes of 112 genotypes of sorghum.

Attribute	Mean	SE ±	Range
Corneousness score[a]	2.70	0.09	1.0- 5.0
Grain weight (g/100 seed)	3.31	0.09	0.7- 6.8
% water absorption of grain[b]	24.90	0.49	15.7- 40.2
Breaking strength (kg)	7.60	0.22	1.8- 15.0
Initial volume of grain (cc/20 g)	15.68	0.10	14.0- 20.0
Time required for cooking (min)	81.15	1.02	54.0-114.0
Weight of cooked grain (g)	48.91	0.30	41.5- 57.2
Volume of cooked grain (cc)	44.00	0.31	36.0- 52.5
% increase in weight	143.00	1.50	107.0-186.0
% increase in volume	182.00	2.70	100.0-273.0
Cooked grain texture[c]	3.20	0.10	1.1- 4.8

a. Corneousness was scored on a scale of 1 to 5 (1 = highly corneous, 5 = completely floury).
b. Water absorption of the grain after 5 hr of soaking in water.
c. A random sample of 10 grains was independently evaluated on a scale of 1 to 5 (1 = very soft and 5 =very hard) and the scores were averaged.

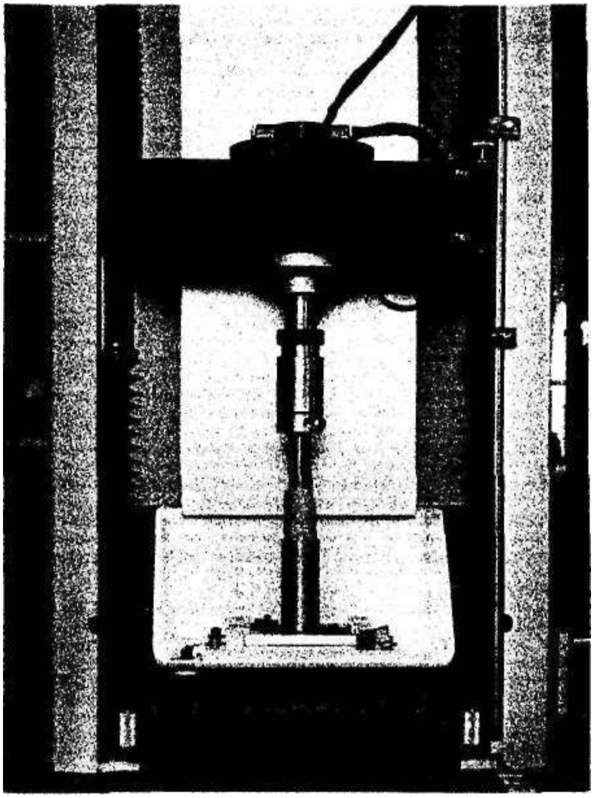
Table 11. Textural characteristics of chapati dough from eight cultivars.[a]

Cultivar	Kneading[b] quality	Rolling[b] quality (cm)	Initial force for extrusion (kg)	Extrusion yield point (kg)	Work done (sq. cm)	Slope
Simila	Very poor	c		(a single peak—no extrusion)		
P-721	Poor	c				
PJ-12K	Medium	22	12.5	20.0	10.8	0.25
Karad local	Medium	22	19.3	25.7	15.3	0.24
269	Good	24	27.5	39.0	24.1	0.40
1S-12611	Good	24	35.0	48.8	28.4	0.49
IS-1235	Good	23	43.3	53.7	32.4	0.40
M35-1	Good	24	41.8	58.0	34.3	0.60

a. Using back-extrusion cell in an Instron machine.
b. Fifty grams of dough were subjectively evaluated for kneading quality and maximum rollability.
c. Difficult to roll into chapati.

an increased force was required for compression. The slope and area (work done) under the force-distance curve (Table 11) was higher for cultivars having good dough characteristics and low for poor dough characteristics.

We also studied the effect of the environmental factors, nitrogen fertilizer level, and moisture stress on grain and chapati quality characters. A split-plot design with six cultivars at four levels of nitrogen application (0,60,120,



Instron food testing machine used for measuring sorghum dough stickiness.

and 200 N kg/ha) was used. Nitrogen level produced no significant effect on chapati quality of the grain samples. Similarly, chapati quality of clean and plump grain samples from 10 genotypes affected by moisture stress did not differ from that of grain samples obtained from their corresponding control plots. In another experiment, where nitrogen fertilizer x irrigation treatments were studied using commercial hybrid CSH-8, chapati quality of grain from the various treatments also showed no significant differences, as judged by taste panelists.

Sorghums for popping. In India popped sorghums are traditionally used in snack foods. Cultivars with inherent popping quality are desirable, and popping quality can be particularly improved by controlling the moisture level of the grain. Grain samples of 3682 accessions from India were scored for popping percentage on a scale of 1 to 5 (1 = 80 to 100% and 5 = 0 to 20% popped grain). Of 36 accessions exhibiting superior popping quality (score of 1 to 2), the best were IS-5111, IS-5285, IS-5566, IS-5604, IS-5638, IS-5646, and IS-5655. Most of these had small grains and were white with medium to thick pericarp, hard endosperm, and a very low germ/endosperm size ratio; the germ was often located at a corner of the hilar region.

Population Improvement

The improvement of sorghum populations by the S_2 progeny testing method continued during the period under report. Five existing populations—US/R, US/B, RS/R, RS/B, and West African Early—and a new population, Indian Synthetic, are being carried forward.

Selection Advance in Populations

Of the five populations currently being improved, the two most advanced populations, US/ R and US/ B, were used to measure the progress made by recurrent selection. We found that the selection advance in three cycles for grain yield was 51.7%; per cycle gain varied from 7.5% to 19%. Similarly, the grain yield of the US/B population increased by 34% over three cycles, with a range of 7.2 to 14.5% per cycle. The advanced cycles of both populations showed significantly delayed maturity, as the base populations were extremely early. Mean plant height varied from cycle to cycle, with an overall increase of 9.2% in the US/R and 5.3% in the US/ B population. The range and the coefficients of genetic variability for grain yield were maintained over cycles, indicating that following the present system of selections the populations can be successfully improved by selection for several more cycles. In addition to grain yield, overall desirability of the populations for grain quality and plant type was also improved. The advanced populations showed increased uniformity in plant height and maturity.

Recurrent Selection

During 1980, S2 progenies trials of US/R and

US/B and West African Early populations were conducted at ICRISAT Center, Dharwar, and Bhavanisagar. From each population 195 progenies with five checks were grown. On the basis of grain yield and agronomic desirability over locations, 28 S_2 progenies from US/R, 32 from US/B, and 41 from West African Early were selected for recombination. During recombination, 11 additional lines in US/R, 5 lines in US/B, and eight in the West African Early population were incorporated.

Population-derived Lines

From the above S_2 progeny trials, 198 plants from US/R, 296 from US/B, and 192 from West African population were advanced for pedigree selection. The progeny rows from these plants were grown at Bhavanisagar during the summer season; only 178 lines were selected for further evaluation.

During the 1980 rainy season, 1123 advanced-generation progenies from populations and their crosses were reevaluated in a breeding nursery and the most uniform and promising lines were identified for inclusion in the 1981 preliminary yield trials.

Varietal Trials

Preliminary Yield Trial-1 (PYT-1). This trial consisted of 84 early-maturing entries (81 test entries and three checks) in randomized complete block (RCB) design with two replications. Twenty-six entries selected on the basis of their yield performance and agronomic desirability were selected for advanced tests in 1981. It was observed that 31 entries at ICRISAT Center, 5 entries at Dharwar, and 3 entries at Bhavanisagar gave significantly higher grain yield than hybrid check CSH-6. On the basis of mean grain yield, some of the top-yielding entries were (E-35-1 x US/R 408)-8-2, (IS-2579-C x FLR-101)-4-3, and Ind Syn 600-3-3, which gave 6120, 5673, and 5518 kg/ha, respectively, as compared to 4951 kg/ha of the best hybrid check, CSH-5. The released varietal check, CSV-4, ranked 80th in the 84-entry trial.

Preliminary Yield Trial-2 (PYT-2). This trial consisted of 147 test entries of medium to medium-late-maturing varieties with three checks: variety CSV-4 and hybrids CSH-5 and CSH-6. A randomized complete block design with two replications at each location was used. In 1981, 21 varieties were advanced for testing internationally. The top-yielding entries CSV-4 x (GG x 370)-2-1-4, (CSV-4 x GG x 370)-2-2-2, and E-35-1 x US/B 487-2-1-4 gave 4857, 5278, and 5264 kg/ha, respectively, as compared to 4362 kg/ha of the best hybrid check, CSH-5.

Development of Hybrids

Development of Male Steriles

Ten lines that we earlier identified as potential female parents, derived from the grain quality breeding project, have undergone six successive backcrosses to convert them to male steriles. Their corresponding A and B lines are ready for evaluation as female parents in hybrid combination. These new male steriles showed good yield potential and grain quality. Twenty more potential parents were identified and were backcrossed twice to convert them to male steriles.

A large number of nonrestorers derived from the nonrestorer populations are being converted to male sterility. We now have 777 pairs of A and B lines in various generations of backcrossing. Fifteen of the A and B pairs appeared uniform and were distributed to interested breeders in the SAT. New hybrids based on these male steriles were made and evaluated in the 1981 rainy season. The results will be reported in the 1982 Annual Report.

Identification of Potential Nonrestorer Lines

The development of A and B pairs by backcrossing requires time and resources, and not all A and B lines produce desirable high-yielding hybrids. It is, therefore, desirable to evaluate nonrestorer lines for their combining ability prior to conversion by backcrossing. In a modified lines x tester analysis, we successfully evaluated male-sterile hybrids from crosses of nonrestorer lines with cytoplasmic male steriles by use of interlards of fertile hybrids to provide pollen for testing the hybrids. This technique was found satisfactory, and three nonrestorer lines out of 20 lines evaluated were found superior in combining ability and were recommended for conversion to male steriles.

Evaluation of Hybrids

A large number of hybrids based on three male steriles (2219A, 2077A, and 296A) were made with several varieties derived from the sorghum populations and grain quality breeding projects. These were evaluated at ICRISAT Center, Bhavanisagar, and Dharwar; results on the best hybrids are presented in Table 12. Several

Table 12. Grain yield (kg/ha) of selected hybrids based on commercial Indian female parents 2219A, 2077A, and 296A with restorers derived from the grain quality breeding project evaluated at three locations in India during the 1980 rainy season.

Trial	Pedigree	Location			Mean
		Patancheru	Dharwar	Bhavanisagar	
1	2219Ax(SC-108-3xCS-3541)-1-3-2	6012	4815	3078	4635
	2219Ax(SC-108-3xGPR-148)-18-1-1	5084	4907	4125	4705
	2219Ax(SC-108-3xCS-3541)-1-3-2	4790	5509	4734	5011
	2219Ax(SC-108-3xCS-3541)-14-1	4978	5528	4094	4866
	2219Ax(SC-108-3xCS-3541)-11-2-3	5002	5740	3688	4810
	2077Ax(SC-108-3xGPR-148)-12-5-3	4954	5556	3516	4675
	2077Ax(SC-108-3xCS-3541)-20-2-2	6224	5277	3891	5132
	CSH-5	5525	5000	2813	4446
	SE ±	210	345	577	
	CV (%)	6.9	11.1	24.4	
2	2219Ax(SC-108-3xE-35-1)-29-2-1	5481	6111	5000	5531
	296Ax(SC-108-3xCS-3541)-11-2-3	5369	6852	5146	5789
	296Ax(SC-108-3xCS-3541)-29-1-1	5756	5787	5208	5584
	296Ax(Swarna x CS-3687)- 6-1-3	5441	6713	6042	6065
	296Ax(SC-108-3xE-35-1)-25-1	4909	5602	6500	5669
	296Ax(SC-108-3xCS-3541)-27-2-1	6963	5463	4313	5580
	2077Ax[(SC-108-3xSwarna)xE-35-1]-6-1-1	6226	6574	4771	5857
	CSH-9	5261	6065	4896	5407
	SE ±	312	343	490	
	CV (%)	10.3	11.4	20.7	
3	296AxFLR-101xIS-1082-4-3-3	6492	5722	4792	5669
	296AxFLR-101xIS-1082-4-4-1-1	5908	5861	4514	5428
	296AxFLR-101xCSV-4-1-1-1-1	6633	6028	5069	5910
	296AxFLR-101xCSV-4-4-3-2	6458	5833	5208	5831
	296AxDiallel-475-746-4-4-2-1-2	5508	6500	4549	5519
	296AxDiallel-475-746-4-5-3-1	5983	6639	4653	5758
	296AxDialle 1-475-746-2-3-1	6117	6417	4444	5659
	CSH-5	4733	5667	2882	4427
	SE ±	720	444	656	
	CV(%)	19.2	11.1	24.0	

hybrids were significantly superior in performance to the check commercial hybrids.

Of 1000 new hybrids based on several male steriles evaluated in unreplicated nurseries at ICRISAT Center in the 1980 rainy season, 260 exhibited superior performance over the commercial hybrid checks and were selected for further yield testing.

International Trials and Nurseries

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

The 1980 ISPYT-1 consisted of 20 entries, including varietal check CSV-4, hybrid check CSH-6, and an improved local check contributed by our cooperators. The trial was sent to 46 locations in 29 countries; data were received from 21 locations in 10 countries. The grain yield of selected entries is given in Table 13.

International Sorghum Preliminary Yield Trial-2 (ISPYT-2)

The 1980 ISPYT-2 consisted of 43 test entries, plus one varietal check (CSV-4), one hybrid check (CSH-5), and a local check contributed by our cooperators. The trial was sent to 46 locations in 29 countries. Data on the performance of selected lines at 16 locations in 12 countries are presented in Table 14.

Entries Ind Syn 387-3-1 and Ind Syn 387-3-3, both sister selections of Ind Syn 387 (designated as SPV-394 in India) performed consistently well for the 3rd year in this trial, RS/ B-8785 also performed well for the 2nd year at locations in India.

Table 13. Grain yield (kg/ha) of selected entries in the 1980 ISPYT-1.

	Location							
Pedigree	Indian Subcontinent (11)[a]	Thailand	Sudan	Niger	Southern Africa (2)[a]	Qatar	Somalia	Overall Mean
<FLR-266xCSV)-4-4-3-7-2	3292	2571	2212	2675	4487	4083	4369	3395
	(11)[b]	(11)	(6)	(5)	(8)	(11)	(1)	(9)
(E-35-1xUS/B-287)-2-1-2	3300	3827	2032	2788	4743	5146	3482	3505
	(9)	(3)	(7)	(2)	(5)	(5)	(6)	(4)
(E-35-1 x WA x Nigerian)-3-2	3298	3517	1991	2500	5488	3979	2475	3430
	(10)	(5)	(8)	(8)	(2)	(13)	(17)	(7)
(M-35-1xRs/R 195)-3-2	3512	3569	2574	2613	4187	3062	3262	3449
	(6)	(4)	(2)	(7)	(11)	(18)	(8)	(5)
Ind.Syn.323-1-3	3990	3394	2407	2725	4830	5437	3050	3921
	(1)	(6)	(3)	(4)	(4)	(2)	(12)	(2)
Ind.Syn.Tall.600-2-1	3849	2045	1841	1788	4311	4312	3659	3589
	(3)	(14)	(10)	(17)	(10)	(9)	(4)	(3)
CSV-4 (check)	2884	2879	733	1925	2558	3625	3085	2728
	(18)	(8)	(20)	(14)	(19)	(15)	(10)	(19)
CSH-6 (check)	3962	3867	3040	3550	5282	4750	4234	4200
	(2)	(2)	(1)	(1)	(3)	(7)	(2)	(1)
SE ±		395	455	402		405	369	
CV (%)	c	21	37	23	c	14	18	

a. Number of locations.
b. Figures in parentheses are ranks.
c. CV (%) of the Indian subcontinent ranged from 12 to 33 and of southern African locations, 11 to 30.

Table 14. Grain yield (kg/ha) of selected entries in the 1980 ISPYT-2.

Pedigree	Location[a] Indian Subcontinent (2)[b]	Thailand (2)[b]	West Africa (3)[b]	Southern Africa (2)[b]	Sudan	Qatar	Overall Mean
FLR-101 xIS-1082-4-5-3	3858 (6)[c]	2273 (26)	1922 (10)	4976 (4)	2757 (2)	5167 (7)	3774 (5)
E-35-1 x Rs/R -253-2-1-1-2	3910 (4)	3907 (2)	1829 (11)	3707 (33)	1616 (28)	5333 (4)	3874 (2)
E-35-1 x RS/B-394-1-1-2	3947 (3)	4196 (1)	2263 (4)	4153 (17)	1908 (20)	5000 (10)	3961 (1)
E-35-1xUS/B-487-1-1	3485 (13)	2947 (15)	2026 (5)	4433 (11)	3015 (1)	4812 (14)	3757 (8)
Rs /RxCSV-4-1525-1-1-4	3758 (7)	2768 (17)	1677 (19)	4488 (9)	1454 (36)	5792 (3)	3629 (7)
Ind.Syn.112-1	3168 (22)	1590 (44)	2277 (3)	5250 (2)	2374 (8)	4125 (23)	3294 (14)
Ind.Syn.387-3-1	4030 (1)	1992 (37)	1978 (7)	4268 (14)	1674 (25)	4958 (12)	3681 (6)
Ind.Syn.387-3-3	3997 (2)	1168 (45)	1981 (6)	4728 (6)	1474 (34)	4708 (16)	3825 (3)
CSV-4 (check)	2933 (32)	1990 (38)	2813 (1)	2710 (32)	887 (44)	3208 (35)	2677 (37)
CSH-5 (check)	3862 (5)	2256 (27)	1360 (32)	5264 (1)	2462 (6)	4617 (17)	3824 (4)

a. CV (%) of the Indian subcontinent locations ranged from 17 to 37; West African locations, 18 to 49; southern African locations, 17 to 23; and Thailand two locations was 22.

b. Number of locations.

c. Figures in parentheses are ranks.

Sorghum Elite Progeny Observation Nursery (SEPON)

The 1980 SEPON comprised elite progenies in advanced generations of crosses between adapted, low-mold susceptible, and good grain quality parents. The nursery was organized into three separate sets—early (105-110 days), medium (110-135 days), and late (135 days and above) maturity with 39, 60, and 39 entries, respectively. The entries included a local check, a commerial hybrid (CSH-6) check, and varieties that performed well in the 1978 and 1979 SEPON. The trial was sent to 40 locations in 30 countries, and data were received from 10 locations in six countries. The grain yield data of selected entries are presented in Table 15.

Contributions to National Programs

A list of varieties from ISPYT-1, ISPYT-2,and SEPON, that performed well in Africa and have been selected for further yield testing in national trials is presented in Table 16.

Six hybrids were accepted by AICSIP for inclusion in Preliminary Hybrid Trials in 1980 and four of these (SPH-185, 187, 188 and 221) were promoted to the Advanced Hybrid Trial in 1981. Seeds of 85 hybrids divided into two trials and an observation nursery, were distributed to

Table 15. Grain yield (kg/ha) and mean grain mold score of selected varieties from the 1980 SEPON.

Pedigree	Location							Mean grain mold score[c]
	Malawi[a]	Sudan (Wad Medani)	Senegal (Bambey)	Honduras	Thailand (Khon Kaen)	India[b]	Mean	
(SC-108-4-8xSC-3541)-88 (SPV-386)	3815	3333	2166	832	4011	4323	3080	2.8
[(SC-423xCS-3541)xE-35-1]-2 (SPV-387)	4199	2500	3999	2412	4322	4457	3648	2.5
(IS-12611xSC-108-3)-1-1-2 (SPV-389)	2304	3416	3895	746	3844	4189	3066	2.2
(IS-12611xSC-108-3)-7-2-1	2534	2833	3312	2730	4356	3742	3251	2.0
[IS-12611x(SC-108-3xCS-3541)-38-1]-3-1	3415	2666	5541	1539	2800	4257	3370	3.7
(TAM-428xE-35-1)-4	3617	2083	3333	2215	5822	3811	3480	2.2
[(SC-423xCS-3541)xE-35-1]-9	3838	1750	3353	1717	5122	4033	3302	2.6
[(148xE-35-1)-11xCS-3541 deri]-2-3-1	3754	2116	3999		4478	4065	3682	2.5
[(E35-1xTAM-428)xTAM-428]-7-4	1690	1833	1770	1033	1311	2596	1705	2.2
[(IS-12622x555) (3612C x 2219B)-5]xE-35-1-5-2-1	3338	2000	3499	1663	4022	4063	3097	2.9
CSH-6	2662	3000	3249	1657	2333	4056	2826	3.9
Local[d]	2621	1900	1270	3330	2044	3584	2458	5.0

a. Mean grain yield (kg/ha) over two Malawi locations – Ngabu and Nsanje.

b. Mean grain yield (kg/ha) over four Indian locations – Patancheru, Bhavanisagar, Dharwar, and Kovilpatti.

c. Mean grain mold score over three locations– Pantnagar, India; Farako-Ba, Upper Volta; and Japan. (1 represents good mold resistance and 5 poor).

d. Local checks variable: local cultivar/improved cultivars/improved hybrids.

Table 16. Varieties that performed well in some African countries and were selected for further yield testing in national trials.

Varieties	Countries in which variety selected
(IS-12611 x SC-108-3)-1-1-2-1	Nigeria and Senegal
[(IS -12611x(SC-108-3xCS-3541)-38]- 1	Senegal
[(CS-3541xET-2039)-11x(SC-108-3x148)-12-10]-1	Mali
Rs/B-878-1-1-3	Malawi
Ind.Syn.323-1-3	Sudan and Malawi
FLR-266xCSV-4	Somalia
FLR-101xIS-1082-4	Sudan and Malawi
CSV-4xBulk-y-55	Malawi
FLR-101xIS-1082-4-4-2-1	Zimbabwe
Ind.Syn.112-1	Zimbabwe
E-35-1xUS/B-487-1-1	Sudan
Ind.Syn.387-3-3	Malawi

six countries (Mexico, Upper Volta, Mali, The Sudan, Ethiopia, and Nigeria).

Looking Ahead

Insect pests. Population monitoring of shoot fly and stem borer will continue at ICRISAT Center, and we will try to develop suitable means of monitoring midge and headbug populations. We will make predictive models to forecast infestations of shoot fly, stem borer, midge, and armyworm.

We will continue screening for resistance to shoot fly, stem borer, midge, and headbug and will emphasize development of efficient screening techniques against midge and headbug. Multilocational testing through international pest nurseries to identify broad spectrum and stable resistance sources will continue. An interdisciplinary study will be initiated on the mechanism and inheritance of resistance.

Our collaborative studies with Max-Planck Institute in West Germany and with the Center for Overseas Pest Research will continue. We expect to initiate collaborative studies on sorghum midge with entomologists at Texas A&M University in the USA and to develop more joint projects on sorghum insects around the world.

Diseases. In breeding for resistance to grain molds, we will utilize new sources of resistance to diversify the genetic base and will intercross low mold-susceptible selections to achieve further improvement.

The identified sources of resistance to sorghum downy mildew (SDM) will be used to diversify the resistance genes in various genetic backgrounds. SDM resistance will also be incorporated into the male-sterile background. We will also study the genetics of resistance.

Our *Striga* research will continue to identify and confirm sources of resistance and to improve their agronomic quality. Since we do not have any identified B-line with *Striga* resistance, we will emphasize B-line screening and improvement for this trait. Efforts to improve screening methodology will continue, and the effect of crop management on *Striga* infestation will be studied.

Physical environment. Our major research thrust will continue on factors affecting crop establishment and on drought. Greater emphasis will be placed on research on crop performance under severe stress (summer) conditions. The interactions of water, heat, and nitrogen stress will be examined further, together with a closer examination of the overall comparative performance of hybrids and varieties under these stress conditions.

Drought-resistant local varieties from the drier parts of Africa and from Karnataka in India will be crossed with the drought-resistant (recovery) lines identified earlier in the program to generate more variability. Also, the sister lines D-71464 and D-71463 with contrasting response under drought will be utilized to study the mechanisms involved in recovery drought resistance.

Another important activity in the coming year will be identification of varieties and hybrids adapted to the postrainy season and incorporation of the glossy-trichome traits for shoot fly resistance.

Our nitrogen-fixation studies will concentrate on improving the acetylene reduction assay for nitrogenase activity using seedlings grown in test tubes and intact plants grown in pots. We will use ^{15}N to measure the amounts of nitrogen fixed. We also 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 may be occurring.

Food quality. Future efforts will be devoted to the development of simple and reliable laboratory techniques for the evaluation and prediction of food quality in different sorghum food products and to use these techniques to routinely evaluate advanced breeding lines.

Population improvement. Significant improvement in agronomic desirability, yield, and grain quality has been achieved in the five populations under recurrent selection. The superior lines extracted from these improved populations will be selected for uniformity and evaluated for adaptation and yield stability in multilocational trials. Selections from these will be evaluated further for their stability and adaptation in comparison with hybrids in multilocational trials. We will also attempt to increase their resistance to insects. A large random-mating population composed of our germplasm collection lines will be established and improved by recurrent selection under low selection pressure to ensure the efficient utilization and preservation of useful variability in the germplasm collection.

Development of hybrids. We will continue our work on the development of a diverse array of male-sterile lines. A few male steriles with good yield potential will be evaluated as female parents in hybrid combination.

International yield trials. Superior varieties and hybrids will be distributed to national programs, and included in international trials for evaluation of their performance and adaptability.

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PEARL MILLET

Contents

PEARL MILLET

Abiotic Stresses

Seedling Emergence and Establishment

Suboptimal plant stands (Fig. 1) are thought to be one of the major constraints to the production of sorghum and millet in large areas of the SAT. However, we have not been able to find sufficient data, particularly from farmers' fields, which are of use either in quantifying the problem or in identifying its causes.

In order to place a firm base under research into genetic variation for stand establishment capability, we began a systematic survey of seed rate, sowing conditions, and plant stands on farmers' fields in Aurepalle village (Andhra Pradesh, India) in the 1981 rainy season.

Soils in this village are generally sandy and shallow, with a low moisture-holding capacity. Land preparation and sowing are done with traditional bullock-drawn implements. Farmers mainly grow either an intercrop of pigeonpea and mixed cereals (sorghum and pearl millet) or castor as a sole crop. Little or no chemical fertilizers are used, and the crop varieties are generally traditional ones.

We collected bulk seed samples from each field at the time of sowing and later separated them into component parts (in the case of mixtures). The percent of damaged seed was estimated and the germinability of undamaged seeds measured. Information on the source of seed and seed treatment used (if any) was obtained from each farmer.

Sowing depth and seeding rate were recorded in the field at the time of sowing. Seeding rate was estimated by counting all seeds in the furrow for a distane of 2-3 m of row before the furrow was closed. Five to ten such samples were taken at random to obtain a mean for each field. In the case of seed mixtures, the number of seeds of each component was estimated from the ratios of the components determined from the bulk seed sample.

Soil samples were taken from the seed zone at the same time for estimation of moisture content. Seedbed temperature was measured with an infrared thermometer.

Seedling emergence was recorded on two occasions from 10 to 15 random locations in each field. At each location, seedlings were counted in 3-m length of row from three to five adjacent rows.

Most farmers used locally produced seed that was not pretreated, although a limited supply of commercial castor and pigeonpea seed was available in the village. Seed damage due to insects was common in locally produced seed; mean species' values ranged from 6% damaged seed in sorghum to 16% in pigeonpea, with occasional seed lots being severely damaged. *Rhizopertha dominica* appeared to be the main insect pest in cereals and *Callosobruncus chinensis* in pigeonpea. Mean germinability (of undamaged seed) of all four crops was reasonably good,

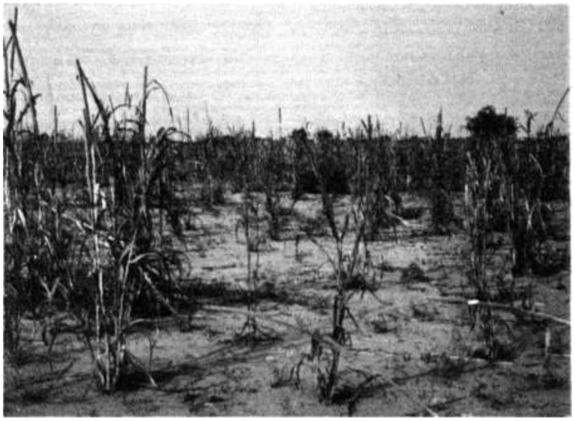


Figure 1. Farmer's field in Niger indicative of difficulties in obtaining sufficient plant population.

varying from 75% for sorghum to 93% for pigeonpea (Table 1). Most of the fields were not prepared prior to sowing. The farmers used bullock-drawn plow to make furrows, seeded by hand, and closed the furrows with a light blade harrow. Sowing depths ranged from 3 to 8 cm for all four crops, despite the large differences in seed size among crops. Sowings took place over a 4-week period, as early monsoon rains were erratic and scattered. As a result, soil-moisture content in the seedbed at the time of sowing varied widely (Table 1). Soil temperature also showed considerable variation, part of which, however, may have been related to the time of day of observation, which was not standardized.

Sowing rates for the cereals were generally quite high and quite variable, especially in the case of millet where rates ranged from 200 000 to 700 000 seeds/ ha (Fig. 2). Yet for both crops the emergence percentage of seeds sown was low: 27% for sorghum and 18% for millet. Even adjusting these percentages for damaged and nongerminable seeds, the emergence rates were only 39% for sorghum and 25% for millet. More

Table 1. Seed quality and sowing observations of pearl millet, sorghum, pigeonpea, and castor from Aurepalle, India, 1981.

	Mean ± SD[a]	Range[b]
Seed damage (%)	7.6±16.8	0- 57
Germinability (%)[c]	85.2 ± 9.9	79-100
Sowing depth (cm)	4.4 ± 1.2	3- 8
Soil water content (%)	7.6 ± 3.3	2.7- 18.6
Seed bed temperature (°C)	40 ± 6.0	32- 50

a. Mean value for all four crops.
b. The data used to indicate the ranges are individual field values.
c. Based on undamaged seed.

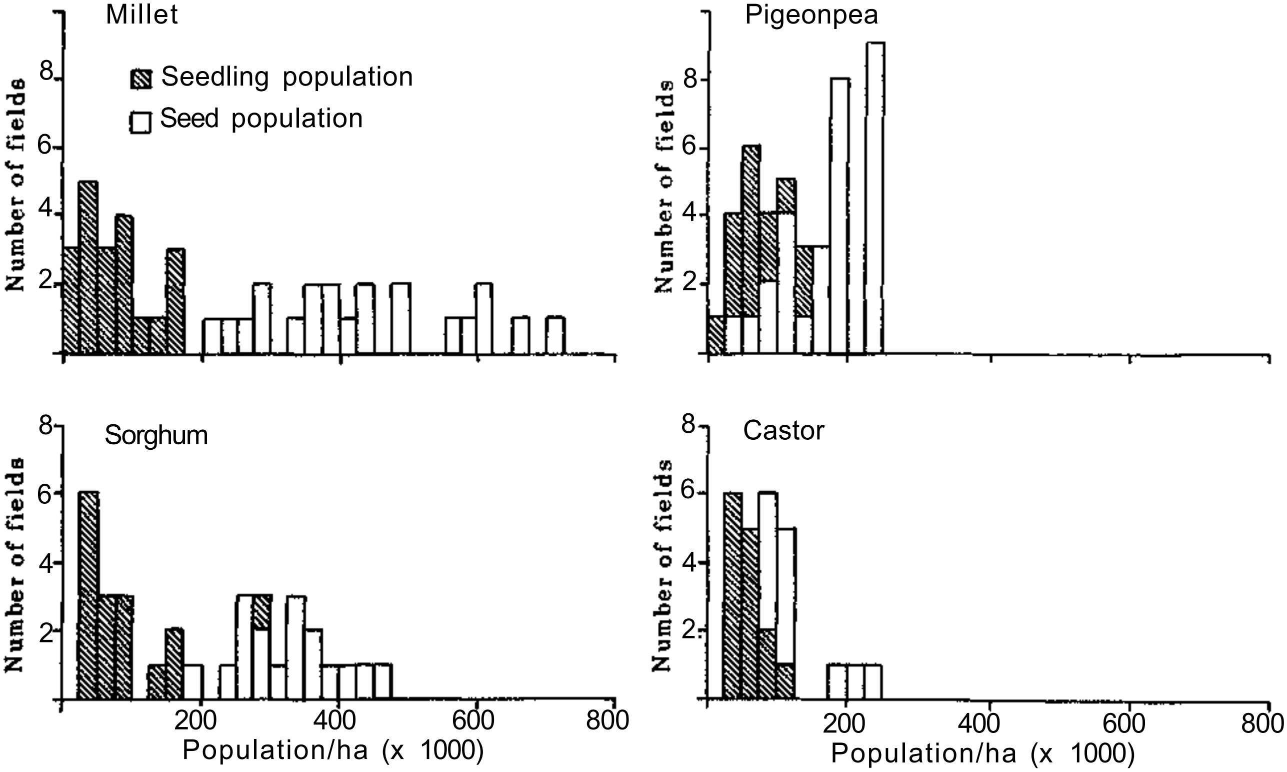


Figure 2. Distributions of sowing rates and seedling plant stands for the four crops studied. The data are individual field means.

important, however, was the variation in emergence rates, which resulted in very low plant stands (<50 000 plants/ha) in a large proportion of fields (Fig. 2), contrasting markedly with the recommendations of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) of 180 000 and 220 000 plants/ha for sorghum and millet, respectively. Emergence rates for castor and pigeonpea were considerably better (52 and 50% for total seed sown and 67 and 63% for good seed, respectively). However, sowing rates for these two crops were considerably lower than for sorghum and millet (Fig. 2), resulting in relatively low populations in many fields, compared to AICRPDA recommendations (50 000 and 70 000 plants/ ha, respectively).

Even making allowance for the desirability of somewhat lower-than-recommended plant populations for shallow, infertile soils such as Aurepalle's, many fields had suboptimal crop stands, especially among the cereal fields. The problem evidently occurs somewhere between sowing and emergence, as seed quality (undamaged and germinable seed) generally was acceptable and sowing rates were good. This hypothesis is supported by two observations: (1) a very high correlation between the emergence percentage of sorghum and millet sown together in the same field (r - 0.96, $P< 0.001$), which suggests that species differences were unimportant relative to field differences and (2) a low correlation (r = 0.33, $P< 0.04$) between sowing rate and stand, indicating that this fact was also unimportant. (This also suggests that the farmers' strategy of raising sowing rates to compensate for poor emergence was ineffective this year.)

Thus our attempts to identify the factors responsible for poor emergence for sorghum and millet were not successful, as emergence rate was not related to any of the seedbed and sowing conditions measured. These studies will be continued, as there is clearly a problem, but one for which the explanation may be more complex than originally thought.

Drought

We previously field screened millets for drought response by withholding irrigation to impose moisture stress in off-season crops (ICRISAT Annual Report, 1976/77 and 1978/79). Recently, however, several techniques have become available by which gradients of stress can be created to evaluate varieties for their response to a range of stress environments. The most popular of these is the line-source sprinkler method (Hanks, R.J. et al., 1976, Soil Sci. Soc. Am. Proc. 40:426-429) in which a single row of closely spaced overhead sprinklers apply a linear gradient of water at right angles to the line. The varieties to be evaluated are planted in strips at right angles to the sprinkler line, along the moisture gradient. The uses of such a technique are obvious, but interpretation and analysis of the data from such experiments is not always simple, either statistically or conceptually.

Evaluation of pearl millet genotypes over a gradient of drought stress from a line source (at left).

We examined some of the conceptual problems using a data set from a line-source comparison of 16 cultivars conducted in the dry season (Feb-May) of 1981. In this comparison a gradient of stress was applied during the grain-filling stage to a crop which had been fully irrigated up to the time of flowering. Two replicates were used to compare the responses and mean grain yields for all varieties at each point in the gradient were used to determine the stress environment at that point.

Yield under stress. The line source technique can be effectively used for comparing performance of breeding or germplasm lines at any selected level of moisture stress, particularly in severe stress environments. Response of individual cultivars to the moisture gradient is determined by regression of individual cultivar yield on mean yield for each point on the gradient (Fig. 3). Cultivars can be compared for any point on the gradient; for purposes of illustration, a severely stressed environment of 100 g/m^2 (1000 kg/ha) mean yield has been chosen. MBH 110 was clearly superior in this environment, followed by ICH 220, ICH 226, and BK 560. WC-C75 was similar to the mean and ICH 162 and Serere 17 were poorer (Fig. 3). Yields in the severe stress environment were found to be highly correlated with date of flowering (r = -0.81, P < 0.01) indicating that differences in time of flowering were responsible for the majority of the differences among cultivars in grain yield (Table 2). Thus drought escape through early flowering, rather than drought resistance, appeared to be the major factor in differences among cultivars. Regression analysis (of estimated yields at 100 g/m^2 against days to flowering) was used to examine individual cultivar performance under severe stress, independent of drought escape (Fig. 4). The better yields of

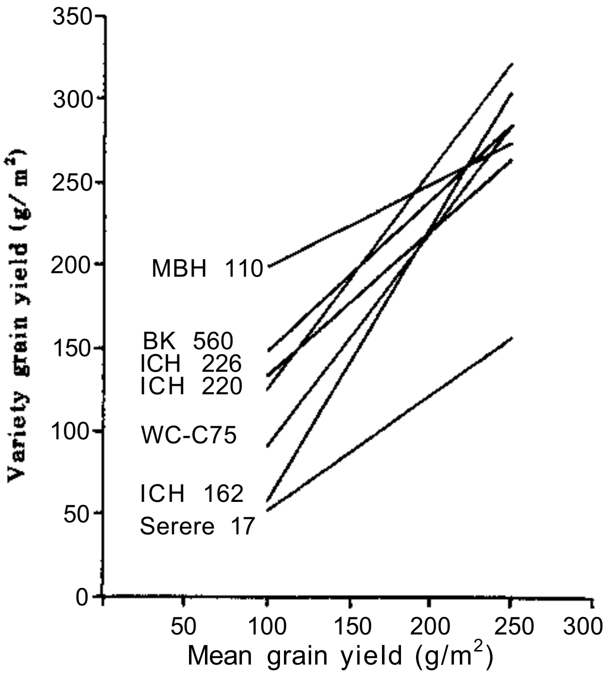


Figure 3. Individual cultivar responses to a moisture gradient during grain filling. Grain yields in a severe stress environment (mean yields of 100 g/m^2) and a mild stress environment (mean yields of 250 g/m^2) were chosen as examples for comparison in the analysis.

Table 2. Correlations of genotype yields in the severe and mild stress environments, days to flowering, and regression coefficients for response to the entire gradient.

	Yield in stress environment	Days to flowering	Yield in mild stress environment
Days to flowering	-0.81**		
Yield in mild stress	+0.45	-0.28	
Regression coefficient	-0.43	0.44	0.61*

* P < 0.05; ** P < 0.01.

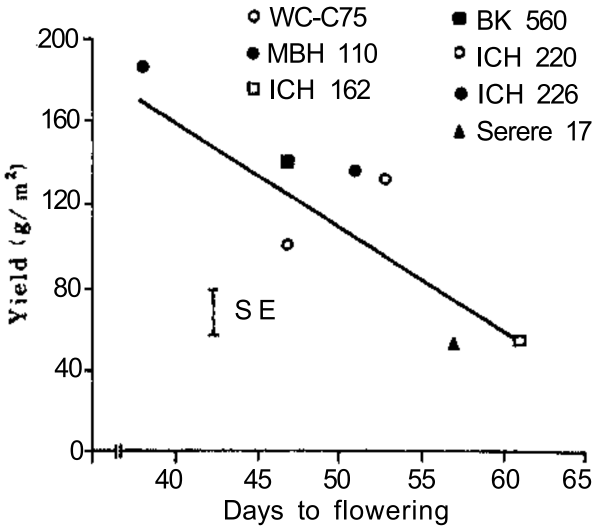


Figure 4. Relationship between grain yields in the severe stress environment and days to flowering for all cultivars (solid line). Actual data points for individual cultivars of interest in the analysis are indicated on the figure.

MBH 110 and BK 560 can be explained by their date of flowering as their actual values are within one standard deviation from the prediction line. The yields of ICH 220 and ICH 226 were better than those predicted by the date of flowering, indicating that their better performance under these conditions is not dependent on escape.

A similar procedure can be used to compare performance in any environment along the gradient, for example a mild stress environment such as 250 g/ m^2 (see Fig. 3). In this environment also there were significant cultivar differences, but here date of flowering was unrelated to yield ability (Table 2), as escape is a less important factor in mild stress environments. Therefore, actual performance in the mild stress environment is adequate for cultivar evaluation.

Cultivar performance in the mild stress environment was positively correlated with the regression coefficient for response to the entire gradient between the severe and mild stress environments (Table 2). Thus for lines selected for good performance in the severe stress environment, the regression coefficient would serve as a useful secondary selection criterion for performance in less severe conditions as well. For example, ICH 220 would be preferred to ICH 226 by this criterion (see Fig. 3), although they perform equally well under severe stress.

Stability of advanced lines under stress. A second application of the line-source technique is in the evaluation of the stability of advanced, high-yielding lines under stress. Here the yield potentials of the test entries are assumed to be good, and relative rather than absolute yields can be used in the analysis for both the individual cultivars and the environmental index (Fig. 5). This places all entries on an equal basis in the nonstressed portion of the gradient and allows the investigator to focus on the stability of each line under stress. Stability is estimated by the regression slope of an individual cultivar's relative yield on the environmental relative yield. In the test data set, MBH 110, ICH 226 and BK 560 are clearly better than average (regression slopes > -1.0), while ICH 220 and WC-C75 are similar to the mean, and ICH 162 is poorer than the mean (Fig. 5). Drought escape also plays an important part in genotype stability in this analysis, as indicated by a high correlation (r = 0.81, $P < 0.01$) between slope and date of flowering. As in the previous example, regression analysis can be used to identify those cultivars whose stability is largely a function of drought escape and those that may have some physiological adaptation to stress which gives them a more stable performance along the gradient. This is done by

Comparison of selection environments for pearl millet: single-plant selection under drought stress.

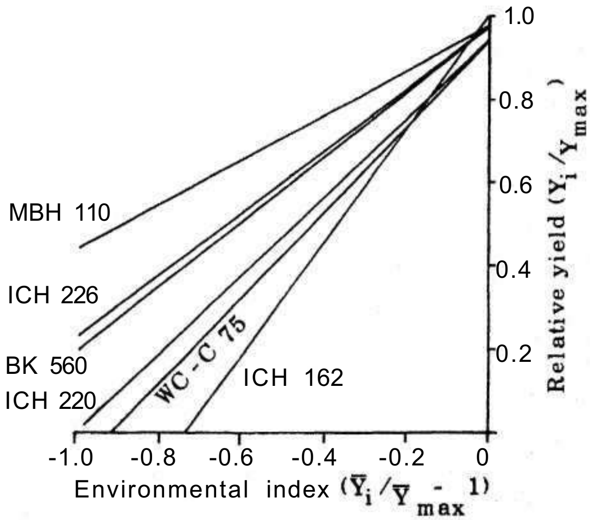


Figure 5. Stability of individual cultivar yields under stress, expressed as changes in individual cultivar relative yield in relation to relative environmental index.

regressing the slope against date of flowering and looking for those cultivars whose slope is higher than that predicted by the date of flowering. The better performance of MBH 110 and BK 560 can be explained by their flowering pattern, as can the performance of ICH 220 and ICH 162. Only ICH 226 shows evidence of better yield stability under stress that is not dependent on escape. Similarly, WC-C75 appears to have a significant instability or susceptibility to this type of stress pattern.

Although we have used a single data set to illustrate both types of analysis, we would expect that these analyses would be applied differently. The first is most useful for identifying source material from germplasm accessions or from breeding lines that have superior yield performance under stress and particularly those materials whose superior performance is not based on drought escape. The second analysis, as pointed out, is more useful for advanced breeding lines with already established yield potential, disease resistance, etc., to determine yield stability. Both analyses have an important place in breeding programs concerned with developing cultivars for rainfed environments.

Low Fertility

We have examined the factors affecting the nitrogenase activity of millet when estimated by the soil-root core assay method (ICRISAT 1976/77 Annual Report, pp 43-44). After sampling, the cores are generally transported from the field to the laboratory for assay. Our studies this year revealed that the mechanical disturbance during transportation greatly reduced nitrogenase activity. Significantly higher nitrogenase activity (three-fold more) with the soil cores transported with minimal disturbance was recorded as compared to the activity of the soil cores transported from the field with normal disturbance. Activity was greatest when the time interval between cutting the tops off the plants and injection of acetylene was reduced to 30 min (Table 3). It varied with the growth stage of the plant, increasing until grain filling was completed and then declining (Fig. 6). It also varied with the time of day at which sampling was done, and was highest for plants sampled at the end of the day (Fig. 7).

By assaying an intact plant (see ICRISAT 1979/80 Annual Report, p 66) throughout the day we have shown that nitrogenase activity follows a marked diurnal pattern, with most activity at 1700 hr followed by a decline during the dark period (Fig. 8). This suggests a close link between nitrogenase activity and current photosynthesis.

This year soil samples from around the roots of millet plants grown in traditional cultivation areas in the northwest Indian states of Gujarat and Maharashtra were examined for nitrogen-fixing bacteria. After the soil was serially diluted, plating the extract directly onto nitrogen-free media enabled us to count and follow the growth of the different bacteria and to isolate and characterize them. The number of nitrogen-fixing isolates obtained varied from 10^6 to 10^7/g soil. Alternatively, the soil extract was added to small vials of medium containing 100 mg/ liter yeast extract as the only nitrogen source and either malate or sucrose as the carbon source, and after incubation, nitrogen-fixing activity of the soil dilutions in the tubes was determined. From the pattern of activity over the range of soil dilutions, we calculated the most probable number (MPN) of nitrogen-fixing bacteria originally present in 1 g of soil.

Table 3. Effect of time interval between cutting off tops and C_2H_2 injection on nitrogenase activity of millet cultivar NHB 3.

Interval (hr)	nmol C_2H_4/plant/hr[a] 1-5 hr
4	17 ± 2.3
3	8 ± 1.5
2	12 ± 3.2
1	24 ± 4.7
0.5	104 ±41.7

a. Plants were 66 days old and at flowering stage; mean of 20 replicate cores.

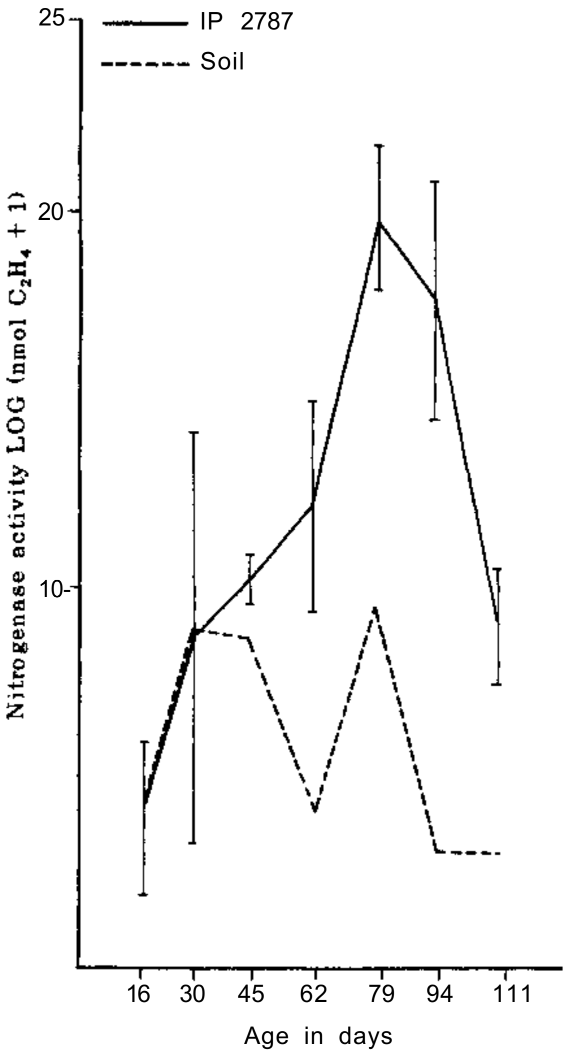


Figure 6. Nitrogenase activity of millet cultivar IP 2787, grown in black plastic bags in a greenhouse, at different growth stages.

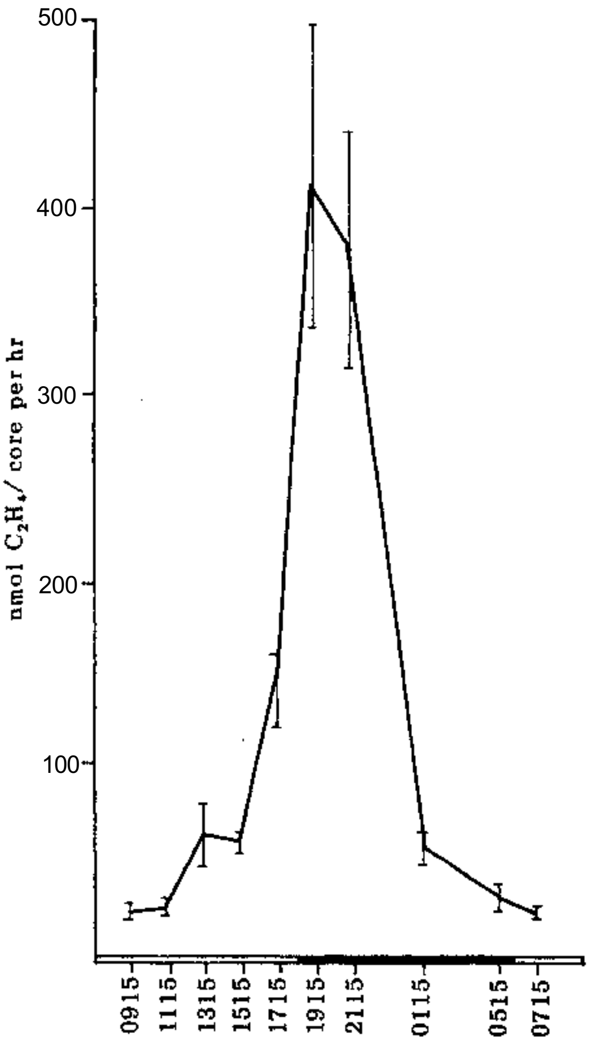


Figure 7. Diurnal variation in nitrogenase activity of millet cultivar NHB 3 assayed in metal cores.

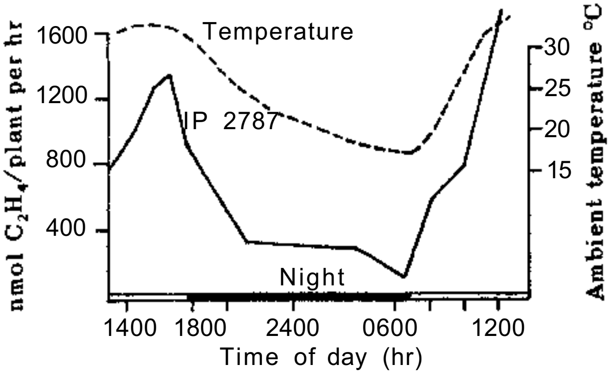


Figure 8. Diurnal pattern of nitrogenase activity of intact millet plants grown in pots in a glasshouse at ICRISAT Center.

This MPN ranged from 10^2 to 10^5 depending on the soil type and location.

Based on colony morphology, we picked 3760 isolates from nitrogen-free media using sucrose or malate as the carbon source. Nitrogenase activity was shown in 42% of the isolates, and 95% were able to grow on MacConkey bile salt medium, a semi-diagnostic test for Enterobacteriaceae. The isolates unable to grow on MacConkey medium were all originally picked from a sucrose medium. Some of the isolates were mixed cultures of bacteria and Actinomycetes, which lost their nitrogenase activity when purified to a single type of bacteria. The nitrogenase-positive isolates could be classified into at least 24 different colony types. Using this character together with their growth on different media, we have chosen 59 apparently different types of bacteria for more detailed characterization and identification. Many are *Enterobacter* spp and a few are *Azospirillum,* but others appear to be species not previously recorded to be able to fix nitrogen,such as *Pseudomonas* spp, *Acinetobacter* spp, and *Flavobacterium* spp.

Biotic Stresses

Diseases

Biology and Epidemiology of Pearl Millet Diseases

Heterothallism. This year we established and maintained six isolates of pearl millet downy mildew (DM) pathogen *Sclerospora graminicola* in plants of a susceptible pearl millet cultivar, from sporangia collected from infected leaves of field-grown plants that showed no evidence of oospore formation. The isolates were used singly and in all paired combinations in two experiments to inoculate seedlings of pearl millet cultivar 7042, which is known to be highly susceptible to DM. Some seedlings on which the first leaf never unfolded became completely necrotic by 12 to 14 days after inoculation (DAI). Oospores were detected in the necrotic tissue of seedlings inoculated with certain combinations of isolates. No necrosis or sporulation were observed on any of the water-treated check seedlings. The total numbers of infected seedlings, total numbers of seedlings with oospores, and the relative abundance of oospores are presented in Table 4.

While inoculations of all paired combinations of isolates 1,4, and 6 and of isolates 2, 3, and 5 did not produce oospores, oospores were produced when any one of isolates 1, 4, and 6 was paired with any one of isolates 2, 3, and 5. In these combinations the abundance of oospores varied, but large numbers of oospores were found in seedlings that had shown little or no asexual sporulation. Abundant oospores were also correlated with extensive necrosis. Oospores with a mature morphology were observed 13 DAI on some seedlings that had produced sporangia, and therefore sexual sporulation probably began at the same time or shortly after asexual sporulation. No oospores were observed in the roots of seedlings or in the segments of the leaves used to provide the initial inoculum of the six isolates. The results obtained clearly demonstrate that *S. graminicola* exhibits heterothallism and that among the isolates tested two sexual compatability types exist. The study of a large number of *S. graminicola* isolates from diverse locations is needed to determine whether additional mating types exist and the relative frequency of the mating types in natural populations of the pathogen.

Further experimentation is required to determine whether the sparse production of oospores in a few seedlings inoculated with isolate 6 is due to a slight degree of self-compatibility or to contamination of the isolate with a small proportion of the second mating type.

Relative DM susceptibilities of seedling roots and shoots. Seedlings of pearl millet cultivar 7042 were raised in 1% water agar on plastic plates in such a way that seedling roots were separated from shoots by a layer of agar. Roots or shoots of 3-day-old seedlings were dipped into a sporangial suspension (8.3 x 10^5 sporangia/ml) of *S. graminicola* for 2 hr at 20°C. After the dip-inoculation, seedlings were transplanted into pots, which were maintained in a net house. Final DM incidence records were taken 17 days after inoculation. The experiment was conducted twice, and each time greater incidence occurred when shoots rather than roots were inoculated (64% vs 32% in Experiment 1, and 75% vs 48% in Experiment 2).

Germination of ergot sclerotia. Sclerotia of *Claviceps fusiformis,* the causal agent of pearl millet ergot, were successfully germinated in the field, in potted soil in a glasshouse, and in sterile sand in petri plates in the laboratory.

Table 4. The numbers of downy mildew infected seedlings of pearl millet cultivar 7042, the number of infected seedlings containing oospores, and the relative abundance of oospores following inoculation with six isolates of *Sclerospora graminicola* singly and in all paired combinations, in two experiments at ICRISAT Center, 1980/81.

	Experiment 1			Experiment 2		
Isolate combination	No. of plants infected	No. of plants with oospores	Oospore abundance[a]	No. of plants infected	No. of plants with oospores	Oospore abundance[a]
1	11	0	-	24	0	-
2	12	0	-	18	0	-
3	14	0	-	9	0	-
4	11	0	-	16	0	-
5	12	0	-	24	0	-
6	13	1	+	22	1	+
1x4	8	0	-	4	0	-
4x6	17	0	-	9	0	-
1x6	10	0	-	15	0	-
2x3	12	0	-	20	0	-
2x5	12	0	-	11	0	-
3x5	13	0	-	15	0	-
1x 2	13	2	+++	19	2	+ + +
1x3	11	2	+ +	15	2	+ + +
1x5	14	4	+ + +	10	1	+ +
2x4	10	4	+ + +	18	3	+ + +
2x6	15	1	+	12	4	+ + +
3x4	13	3	+ +	21	3	+ + +
3x6	18	5	+ + +	18	4	+ + +
4x5	17	8	+ + +	20	10	+ + +
5x6	16	8	+ + +	19	9	+ + +

a. Abundance of oospores in seedlings: + =sparse (a few scattered oospores), + + = intermediate (oospores encountered in several microscope fields, but in easily countable numbers), + + + = abundant (oospores encountered throughout tissue,too numerous to easily count).

The sclerotia germinated by producing one to several stipes that terminated in a stroma containing perithecia (Fig. 9). The first germinated sclerotia were observed 40 days after seeding in all three environments, and in the sterile-sand culture in the laboratory sporadic germination occurred for more than 400 days. The infectivity of ascospores produced in these perithecia on the germinated sclerotia was demonstrated by the production of ergot symptoms in pearl millet inflorescences that were exposed at the protogyny stage. Additional evidence for the role of sclerotia in the initiation of pearl millet ergot was produced in two field experiments with pearl millet hybrid ICH 105 grown in 10-m x 10-m isolation plots and seeded with and without ergot sclerotia (Table 5).

Inoculation technique to screen for resistance to smut. We conducted several experiments to determine the cultural methods and media required to produce viable inoculum, to examine the effectiveness of several types of inoculum, and to determine the effects of flowering stage at inoculation and the effects of various inoculation methods. The most effective inoculation was achieved by injecting an aqueous smut sporidial suspension (about $1x10^6$ sporidia/ml,

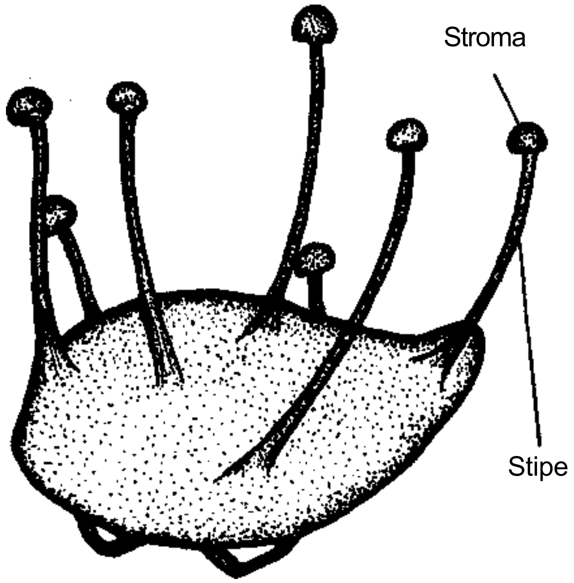


Figure 9. Germinated sclerotium of *Claviceps fusiformis.*

Table 5. Percent ergot incidence in pearl millet hybrid ICH 105 following seeding in 10 x 10 m isolation plots with and without ergot sclerotia in two experiments at ICRISAT Center, 1980/81.

	Percent ergot incidence			
	With sclerotia at		Without sclerotia at	
	48 DAP[a]	56 DAP	48 DAP	56 DAP
Expt. 1[b]	2	53	0.2	18
Expt. 2[c]	10	19	0	5

a. Days after planting.
b. Single isolation plot per treatment.
c. Two isolation plots per treatment.

from a 6 to 10-day-old culture grown at 35°C on potato/carrot agar) into the boot just prior to initiation of inflorescence emergence, followed immediately by bagging the inoculated tillers and providing sprinkler irrigation twice a day for 15-20 days. This technique was used successfully in the field to screen 200 pearl millet cultivars at ICRISAT Center during the 1981 rainy season, producing more than 90% severity on heads of susceptible lines. This achievement will facilitate movement of the major smut resistance screening activity from Hissar to ICRISAT Center, which will allow more material to be screened, better control of humidity because of the sprinkler irrigation facilities at the Center, and simultaneous screening for resistance to downy mildew, ergot, and smut.

Identification and Utilization of Disease Resistance

During the report period the identification and utilization of resistance to downy mildew, ergot, smut, and rust continued to be a major activity in the Program, in cooperation with ICRISAT's pathologists and breeders. As in previous years, the large-scale field screening for downy mildew and ergot was conducted at ICRISAT Center, for rust at our Bhavanisagar cooperative research station in southern India, and for smut at our Hissar station in northern India (though a successful screening technique for smut was also used in the field at the Center in the 1981 rainy season). The multilocation testing of sources of resistance identified at the Center was continued in cooperation with ICRISAT cooperative program staff and with national program staff in various African countries and in India. All trials of the All India Coordinated Millet Improvement Project (AICMIP) were screened for resistance to three diseases. Breeding lines from individual plant breeders in India and the USA were also screened, as a service to the pearl millet improvement research community. Breeders and pathologists worked together in the continuing program of utilizing downy mildew resistance, in efforts to transfer ergot resistance into hybrid seed parents, in utilization of smut resistance, and in the study of the genetics of disease resistance.

1. Downy Mildew

Resistance screening at ICRISAT Center. Approximately 7000 breeding lines were screened in the field each season for DM resistance during the 1980 rainy season, the 1980/81 postrainy season, and the 1981 rainy season, using the infector-row screening technique. After 5 years of such screening in two seasons each year, all but the newest materials in the program now carry an acceptable level of DM resistance that is effective in India.

The results from screening germplasm and AICMIP trials are summarized in Table 6.

Multilocation testing. The multilocation testing program continues to be invaluable in the identification of stable and location nonspecific resistances.

The 150-entry 1980 Pre-International Pearl Millet Downy Mildew Nursery (PRE-IPMDMN) was evaluated in Upper Volta (Kamboinse), Nigeria (Samaru), and India (ICRISAT Center). One entry (P 1423) was DM-free at all three locations, 60 entries were either free or had less than 10% DM at all locations, and an additional 15 entries had no more than 15% DM at any location. Distinct location-specific reactions were evident for several entries. These entries were either free or had less than 10% DM at ICRISAT Center and at Kamboinse but developed high levels of DM at Samaru.

The 45-entry 1980 IPMDMN trial was sent to cooperators at 20 locations in India and West Africa. Data were received from 11 locations. No entry was DM-free at all locations. Three entries (E 298-2-1-8, WC 8220, and MPP 71472-1) had no more than 10% DM at any location, and 33 entries had less than 10% across-location mean severity values.

Table 6. The total number of lines screened for DM resistance in germplasm and All India Coordinated Millet Improvement Project Trials, and the numbers of lines free of DM or with less than 10% incidence.

Material/trial		Number of lines free or with < 10% DM in two seasons	
		Rainy 1980	Rainy 1981
Germplasm	Total	527	135
	free	293	75
	<10%	211	34
AICMIP-1 (initial hybrids)	Total	20	16
	free	0	4
	<10%	10	11
AICMIP-II (advanced hybrids)	Total	25	20
	free	1	0
	<10%	16	12
AICMIP-IV (initial populations)	Total	14	16
	free	0	1
	<10%	13	15
AICMIP-V (advanced populations)	Total	14	18
	free	0	0
	<10%	12	16
CMPT (Coordinated Millet Pathology Trial)	Total	40	17
	free	4	8
	<10%	9	5
% DM in indicator rows		94	73

The 150-entry 1981 PRE-IPMDMN trial was evaluated at ICRISAT Center and at Samaru. MBP 8104, P 2904, and P 535 were DM-free at both locations; P 13, P 1520, P 452, P 35, and P 227 had less than 10% DM at both locations, and 40 test entries had across-location mean severity values of less than 10%.

The 45-entry 1981 IPMDMN trial was sent to cooperators at 20 locations in India and Africa. Data were received from 11 locations. No entry was DM-free at all locations, but five entries (P 13, P 1520, P 452, P 35 and P 227) developed less than 10% DM at all locations, and 39 entries had mean DM severity values of less than 10% across locations.

Development of DM resistance in an ultrasusceptible line. We initiated this study in 1979 with IP 7042, an ultra-DM-susceptible cultivar from Chad. In the 1979 rainy season about 2000 plants were raised in our pearl millet DM nursery, and 20 DM-free plants were selected and selfed. In subsequent seasons, progenies were advanced in the DM nursery by selfing and sibbing DM-free plants. In the 1981 rainy season, 251 S_4 progenies were raised; 6 remained DM-free, while 12 had less than 10% DM severity indices. These results provide additional evidence and highlight the exciting possibilities for development of DM-resistant versions of any pearl millet cultivar, exploiting the scattered resistance genes within the population while maintaining the cultivar's other original characteristics.

2. Ergot

Resistance screening at ICRISAT Center. During the 1980/81 crop seasons we screened more than 1300 pearl millet lines in unreplicated initial trials, including germplasm lines from Tamil Nadu (India), ICRISAT breeding trial entries, AICMIP trial entries, IPMDMN entries, and IPMSN entries. Most of these entries were highly ergot-susceptible (more than 30% ergot severity), and the remaining few entries with less ergot had very poor seed set on inoculated inflorescences and so no selections were made (Table 7).

In our advanced screens, 131 single-plant selections from the 1979 initial screening were tested in a replicated trial. About 120 single plants from less susceptible entries (<10% ergot) were selected for further evaluation.

From a 75-entry Pearl Millet Ergot Nursery (PMEN) grown in the 1980 and 1981 rainy seasons, 59% of the entries had less than 10% ergot; 292 single plants were selected from these entries for further evaluation.

Multilocation testing. The 32-entry 1980 IPMEN was tested at two West African and seven Indian locations. Five entries (SC-2(M)-5-4-E-1-6,700448-1-E-2-DM-3, ICMPE 193-7, ICMPE 192-16, and ICMPE 140-3) had across-locations mean ergot severities of not more than 10%, compared with 35% in the trial check BJ 104. Three of these entries (the ICMPE lines) were ergot-resistant F_5 lines developed at ICRISAT Center. All five ergot-resistant lines also possessed high levels of resistance to smut and downy mildew in India.

The 1981 IPMEN with 29 entries was sent to cooperators at 16 locations in India and West Africa. Results received from six locations (up to 10 Dec 1981) show that five entries, developed at ICRISAT Center, had less than 10% ergot at all four Indian locations, but they had higher levels of ergot at the two African locations (Table 8).

By the end of the 1981 rainy season we had selected more than 2000 lines, at the F_2 to F_8 stages of testing, to develop sources of ergot resistance. These were derived from crosses involving ergot low-susceptible germplasm lines of African and Indian origins identified in our initial and advanced screens. Thirteen F_7-line bulks tested as F_8 lines in a replicated trial for ergot reactions during the 1981 rainy season were found highly resistant to ergot (mean severity < 2%), compared to the check lines (Table 9). In addition these lines were highly resistant to smut and downy mildew in India.

Utilization of resistance. Ergot resistance is needed most in hybrids; to do this it is necessary

Table 7. Number of pearl millet lines in various categories of mean ergot severity and resistant plant selections at ICRISAT Center, June 1980 to October 1981.

Screen and Trial	No. of entries	No, of lines with mean ergot severity of <10	11-20	21-30	> 30	No. of single plants selected
Initial[a]						
Germplasm lines	172	1	0	1	170	0
ICRISAT breeding trials	725	41	159	190	335	0
AICMIP trials	315	0	10	20	285	0
IPMDMN	90	0	0	1	89	0
IPMSN	32	1	2	3	26	0
Advanced[b]						
Selections from initial screens	131	11	17	18	85	120
PMEN[c]	75	44	12	8	11	292

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

Table 8. Percent ergot severity of the five best 1981 IPMEN lines at four Indian and two West African locations.

Entry	Percent ergot severitya at ICRISAT Center	Jamnagar	Aurangabad	Pune	Kano[b]	Samaru[b]
ICMPE 134-6-9	<1	<1	8	5	38	46
ICMPE 134611	<1	<1	8	7	61	43
ICMPE 134-6-41	<1	<1	9	6	48	35
ICMPE 134-6-34	<1	1	8	7	43	35
ICMPE 134-6-25	<1	<1	10	5	27	44
Susceptible check	95	47	36	26	29	51

a. Mean of 20-40 inoculated heads in two replications.
b. Northern Nigeria.

to first incorporate it into both parents involved. However ergot resistance will also be useful in synthetic varieties.

More than 700 testcross F_1 hybrids were made by ICRISAT breeders utilizing 20 ergot-resistant F_5 and F_6 lines. All the hybrids were highly susceptible to ergot (37-98% mean severity range), indicating that susceptibility is dominant. Ergot-resistant F_6 lines were crossed to B lines to incorporate resistance into male-sterile lines.

In the 1980 postrainy season, we screened 14 F_2 populations derived from crosses between two maintainer lines (5054B and 5141B) and three F_4 progenies less susceptible to ergot (< 20% ergot) for ergot incidence under artificial

Table 9. Ergot, smut, and downy mildew (DM) reactions of some of the best ergot-resistant F_7 lines during the 1981 rainy season at ICRISAT Center.

Entry[a]	Ergot sev.[b] (%)	Smut sev.[b] (%)	DM incidence[c] (%)
ICMPE 134-6-18	<1	0	0
ICMPE 134-6-25	<1	0	0
ICMPE 134-6-40	<1	0	0
ICMPE 13-6-9	<1	<1	0
ICMPE 134-6-10	<1	0	2
ICMPE 134-6-11	<1	0	0
ICMPE 134-6-41	<1	0	0
ICMPE 134-6-9	<1	0	0
ICMPE 134-6-30	<1	<1	0
ICMPE 13-4-38	<1	<1	0
ICMPE 13-4-20	<1	<1	0
ICMPE 140-2-4	1	<1	7
ICMPE 13-4-3	2	1	0
WC-C 75 (Check)	74	3	2
BJ 104 (Check)	83	54	32

a. ICMPE-ICRISAT Millet Pathology Ergot, derived from crosses J 2238 x J 2210-2 and J 606-2 x J 2238.

b. Based on 40 inoculated heads from two replications, both ergot and smut inoculations were made on tillers of the same plants.

c. Based on DM reactions during 1980/81 postrainy season in ICRISAT Center DM nursery.

epiphytotic conditions. More than 20% of the plants in each F_2 population (400 plants were inoculated in each population) registered 0-10% ergot. However, of this 20%, only 73 plants (1.3%) had adequate seed set. We inoculated 10 plants of each of these 73 F_3 progenies, from which we selected 52 ergot-free plants with good seed set. These F_4 progenies will be planted in the ergot nursery in the 1981 postrainy season to select further for ergot resistance and make test-crosses (to evaluate nonrestorer reaction) and backcrosses to the nonrestorer line. Another set of 66 F_2 populations was generated in the 1981 rainy season, using more advanced ergot-resistant lines and four maintainer lines. Two of the lines with stable ergot resistance (ICMPE 134-6-9 and ICMPE 134-618) were also discovered to be maintainers on ICM ms 81A. This observation presents the possibility of converting them directly into new ergot-resistant seed parents.

We used 12 ergot low-susceptible F_5 lines to constitute three synthetics, one of which (ICMS 8034) had low ergot (14% mean severity) and reasonably good yield, compared with BJ 104. Under open-head inoculations, synthetics and varieties generally appear less ergot-susceptible than hybrids, which is due to the propensity of varieties and synthetics to escape through pollen interference.

3. Smut

Resistance screening. We screened 1570 pearl millet lines for smut resistance during the 1980 and 1981 crop seasons at Hissarand ICRISAT Center in initial and advanced trials. In the initial trials more than 600 lines were tested—including ICRISAT breeding trial entries, AICMIP trial entries, and IPMDMN and IPMEN entries. Most of the ICRISAT breeding trial entries and AICMIP trial entries (particularly hybrids) were highly susceptible (>30%). Some inbreds and populations showed less than 10% smut. Many of the IPMEN and IPMDMN entries showed high levels of smut resistance (< 1% smut). More than 800 single heads (with selfed seed) were selected for further evaluation and selection.

In the 1980 and 1981 rainy seasons, 77 promising entries from the advanced screens were tested in replicated trials in the Pearl Millet Smut Nursery (PMSN), and 57% of them were highly resistant. More than 400 single heads were selected for further evaluation and selection to be included in the International Pearl Millet Smut Nursery (IPMSN).

Multilocation testing. The 32-entry 1980 IPMSN was tested at three West African and three Indian locations. Two entries (SSC-FS 252-S-4 and EBS 137-2-S-I-DM-I) were highly resistant (mean severities between 0 and 4%) across locations, and 22 of the entries had across-location mean severities of less than 10%. In the 1981 IPMSN with 29 entries tested at seven locations in India and West Africa, 12 entries (including SSC-FS 252-S-4) had across-location mean severities between 2 and 5%. In both years Samaru and Kano provided the greatest smut pressure, with indications of possible existence of pathogenic variability (Table 10).

Development and utilization of resistance. Ten F_2 populations, 311 F_3 lines, and 520 F_4 lines derived from crosses between smut-resistant lines, were screened for smut resistance at Hissar during the 1980 and 1981 rainy seasons. About 30 promising lines (less than 5% smut and agronomically good) were identified and more than 600 smut-free single plants were selected for further evaluation and selection.

In hybrids, we tested 118 testcross F_1s at Hissar, using 25 smut-resistant lines as pollinators on 5 ms lines (111 A, 5141 A, 5054A, 23D2A, and 81 A); 13 of these had no more than 10% smut. These hybrids will be retested at ICRISAT Center in the 1982 rainy season.

During 1979, we made crosses to incorporate smut resistance from five smut-resistant sources (EB 24-1, EB 74-3, EB 137-1-1, WC-FS 148, and SSC-FS 252) into ICM ms 81 A. In the 1981

Table 10. Percent smut severity of the seven best lines in the 1980 and 1981 IPMSN at several locations in India and West Africa.

Entry	Percent smut severity[a] at: Hissar 1980	Hissar 1981	ICRISAT Center 1980	ICRISAT Center 1981	Jamnagar 1980	Jamnagar 1981	Bambey 1980	Bambey 1981	Samaru 1980	Samaru 1981	Kano 1980	Kano 1981
SSC-FS-252-S-4	0		0	0	0	0	0		4	4	3	8
EBS 137-2-S-1-DM-1	<1	<1	<1	0	<1	1	<1	3	3	4	3	39
ICI 7517-S-1	0	<1	0	0	0	<1	1	0	10	3	8	24
NEP 588-590-S-8-4	<1	<1	<1	<1	0	<1	<1	3	8	7	12	15
EB 132-2-S-5-2-DM-1	<1	1	<1	1	<1	1	<1	2	15	6	7	23
EB 112-1-S-1-1	<1	0	0	0	0	0	<1	<1	14	4	4	32
WC-FS 151-S-1-1	1	6	1	3	2	2	1	7	11	4	33	50
Susceptible check	30	11	61	91	31	25	31	72	68	51	72	52

a. Based on 20-40 inoculated heads in two replications, except at Bambey where direct inoculations were not made.

rainy season, 57 d_2 dwarf progenies derived from these crosses and their respective testcrosses on ICM ms 81A were planted in our Hissar smut nursery. Smut incidence on the F_4 progenies was much lower than on the testcrosses (Table 11). Twenty-two testcrosses were sterile, and the progenies derived from the corresponding maintainer parents for smut resistance will be retested for possible conversion into seed parents.

Using 37 smut low-susceptible lines, a composite population was constituted in 1979. In the 1980 and 1981 rainy seasons, 562 S_1 and 244 S_2 progenies, respectively, were screened at Hissar. At S_2 testing about 54% of the progenies showed high smut resistance (< 1% severity), compared to only 8% of progenies showing less than 1% smut at S_1 stage, indicating rapid improvement for smut resistance in this composite.

4. Rust

Initial screening. Germplasm and other disease-resistant material were initially screened at the south Indian rust "hot-spot," Bhavanisagar, in the 1980 and 1981 rainy seasons.

Table 11. Percent[a] smut incidence on F_4 progenies and their testcrosses (Hissar, 1981 rainy season).

Smut incidence (%) class	Testcrosses No.	Testcrosses Frequency (%)	F_4 progenies No.	F_4 progenies Frequency (%)
0-10	1	2	50	88
11-20	5	9	3	5
21-30	15	26	1	2
31-40	11	19	0	0
41-50	5	.9	1	2
51-60	14	25	1	2
61-70	4	7	1	2
71-80	1	2	0	0
81-90	1	2	0	0
91-100	0	0	0	0
Total	57		57	

a. Based on 10 inoculated plants (one head/plant) per entry.

In 1980, 1259 germplasm accessions were screened; 298 were rust-free, and 468 had less than 10% rust. Many of the remaining accessions had 65-100% rust.

In 1981, 1072 germplasm accessions were screened; 276 were rust-free, and an additional 414 had less than 10% rust severity on the top four leaves.

Of 58 ergot and smut low-susceptible lines tested in 1981, none was rust-free; 20 entries had less than 10% rust, and rust was moderate to severe on the remainder.

Rust reactions of DM-resistant entries included in 1980 and 1981 PRE-IPMDMN trials were also evaluated. Of the 300 PRE-IPMDMN entries, 35 had no rust, 68 had only 5% rust, 110 showed 10% rust, while the remaining entries had 25% or more rust.

Multilocation testing. In 1980 we sent a 33-entry International Pearl Millet Rust Nursery (IPMRN) trial to cooperators in India and received results from six locations. Rust pressure was low at Ludhiana, low to moderate at Hissar and Bhavanisagar, moderate at Kudumiamalai and Kovilpatti, and severe at Pune. No entry was rust-free at all locations. Entries 700481-21-8 and IP 2084-1 developed less than 10% rust at all locations, and P 15 had less than 10% rust at all locations except Kovilpatti. Other promising entries were Souna Mali, D 212-PI, 700481-7-5, and 700481-35-7. Several entries showed distinct differential reactions among locations.

Alternative Disease Control Methods

Ergot control through pollen management. Based on our last year's results (ICRISAT 1979/80 Annual Report), we conducted a replicated trial in isolation plots during the 1980 rainy season at ICRISAT Center to further evaluate the potentials for ergot control through pollen management. Hybrid BJ 104 was sown in nine isolation plots (32 rows x 20 m) with or without the pollen donor line SC 2(M)5-4. In three plots the pollen donor line was planted between every four rows of BJ 104 and between every eight rows in the other three plots. The remaining three plots were planted without the pollen donor. All nine plots were spray-inoculated four times with honeydew conidial suspension at 2-day intervals during the protogyny stage of flowering. Ergot incidence and severity observations were recorded from the center 10 m of the 16 central rows in each plot. Plots with the pollen donor, in both combinations, had significantly less ergot than the plots with no pollen donor (Table 12).

In the 1981 rainy season we grew a demonstration trial of hybrid ICH 206 and pollen donor line SC 2(M)5-4 in the ergot nursery. Two plots were established (32 rows x 20 m) with the hybrid alone, and two with the pollen donor planted between every four rows of the hybrid. High ergot pressure was created by spray-inoculating the plots six times during flowering, and by providing high humidity through overhead sprinkler irrigation. Data from the center 10 m of the central 16 rows of each plot showed that ergot incidence and severity were significantly reduced in the plots with the pollen donor (Table 12). The results of these two seasons' trials further highlight the potential for ergot control through pollen management.

Insect Pests

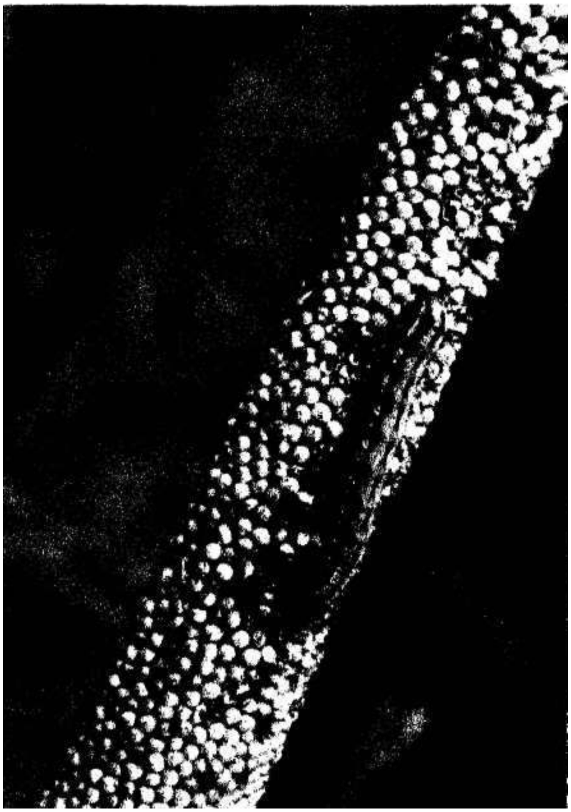
In continuance of observational activities to establish norms for pest levels on this crop at ICRISAT Center, we monitored insect incidence on four cultivars in 1980/81: hybrids BJ 104 and ICH 105, variety WC-C75, and a "local" landrace from the eastern Ghats of India.

In the 1980 rainy season the aphid (*Rhopalosiphum maidis*) population was fairly high (152-467 aphids/10 seedlings) during the first week of August. The shootbug (*Peregrinus maidis*) appeared 1 month after planting, with maximum activity during the first week of September (4-43 bugs/10 plants). Insects of minor importance observed on the crop were shoot fly *(Atherigona approximata*), stemborer (*Chilo partellus* and *Sesamia* sp), armyworm (*Mythimna separata*), red pumpkin beetle (*Aulacophora foveicollis*), red cotton bug (*Dysdercus keongi*), stink bugs (*Nezara viridula* and *Bagrada* sp), headbug (*Calocoris angustatus*), head worm (*Heliothis armigera*), and thrips (*Thrip* sp). During the 1980/81 postrainy season, only the shootbug (*P. maidis*) showed higher activity during the first week of March (75-112 bugs/100 plants) compared to the rainy season. Minor pests that were seen

Table 12. Percent ergot incidence and severity[a] in two pearl millet hybrids (BJ 104 and ICH 206) grown with and without the pollen donor line SC-2(M)5-4 in different combinations and inoculated with ergot during the 1980 and 1981 rainy seasons.

	Ergot infection			
	BJ 104[b]		ICH 206[c]	
Treatment	Incidence (%)	Severity (%)	Incidence (%)	Severity (%)
Hybrid alone	86	69	100	62
Hybrid + pollen donor (4 rows + 1 row)	67	8	57	5
Hybrid + pollen donor (8 rows + 1 row)	62	7		
SE ±	13.5	2.3	1.9	4.3

a. Based on 150 randomly selected infected inflorescences in three replications.
b. Grown in the 1980 rainy season in isolation plots.
c. Grown as demonstration plots in the 1981 rainy season in ergot nursery; the hybrid-alone plots were planted 10 days before the hybrid + pollen donor plots.



Heliothis *larva feeding on developing grains of pearl millet.*

in the postrainy season not observed during the rainy season were the leaf beetle (*Chaetonema minuta*), the dusky cotton bug (*Oxycarenus* sp), cutworms (*Agrotis* sp), and *Spodoptera litura.*

Observations on leaf damage caused by armyworm and cotton grey weevil (*Myllocerus* sp) in hybrid trials at ICRISAT Center and Hissar, respectively, showed that hybrids where 111A was the female parent were damaged less.

Screening for resistance. During summer 1981, 347 germplasm lines were exposed to a natural attack of shoot fly at Bhavanisagar; damage varied between 0 and 46%. We will retest 99 lines that showed less than 5% damage.

We tested a set of 40 germplasm lines in a screenhouse at ICRISAT Center against the oriental armyworm. A set of five resistant and five susceptible lines together with two hybrid checks (BJ 104, MBH 110) was picked up from these lines and reevaluated under "no choice" conditions. Souga Local, 700112, PIB 228, MBH 110, and D 1050-1 were less damaged compared to SAR 57, BJ 104, and SAD 4031 (Table 13).

Grain and Food Quality

Grain Nutritional Quality

About 4200 lines of pearl millet representing composites, synthetics, and inbreds and 1040 germplasm accessions were analyzed for protein and lysine contents using rapid methods. Protein content in these samples ranged from 5.3 to 22.1%, A limited study with 100 selected germplasm accessions that originated from Niger and Nigeria showed that their protein content varied from 15.5 to 20.2%, while their 1000-grain

Table 13. Leaf area and dry-weight consumption by third instar larvae of *Mythimna separata* on pearl millet genotypes[17] tested in a screenhouse at ICRISAT Center, 1981.

Genotypes	Leaf area consumed/ ($100\ cm^2$)	Dry weight consumed/ (100 mg)	Damage rating
Souga Local	35	24	1.8
MBH 110	44	22	2.3
D 1051-1	59	54	2.2
700112	67	35	2.3
NEP 310-5685	68	51	2.7
PIB 228	70	38	2.5
P 184	81	55	3.3
P 3081	82	53	4.0
SAD 4031	88	53	4.7
P 27511	88	56	4.0
BJ 104 (check)	94	59	5.0
SAR 57 (check)	99	66	5.0
SE ±	9.0	7.5	0.4

a. One larva per plant was caged for 24 hr.
b. 1= < 10% leaf damage, 2 = 10-20, 3 = 25-40, 4 = 40-60, 5 = >60%.

weight ranged from 3.2 to 12.8 g. The correlation between protein content and grain weight was significant but weak ($r = -0.24$, $P < 0.05$). Further studies on the utility of these lines are in progress.

Food Quality

We evaluated 30 germplasm accessions obtained from Uttar Pradesh for their chapati-making quality, including dough stickiness. A few of the cultivars with creamy white grains (SAR 2042, 2075, 2049, and 2074) produced acceptable chapatis.

Millet grains are used to make different kinds of porridges (thick or thin in consistency) in several regions of Africa and India. In Africa the thick porridges are known by such local names as *ugali, mboussiri, koko, kalo, aseedh, nshima, kali,* etc. The thin porridges are called *mbor, tuwo, uji, busera, kuzh, ganji,* etc. We evaluated the porridge-making quality of 25 millet cultivars. The grains were ground in a Udy cyclone mill to pass through 0.4-mm screen. A 10-g portion of whole-grain flour was cooked in 50 ml boiling distilled water for 7 min, and the contents were transferred to petri dishes and allowed to cool at room temperature for 30 min. The stickiness and appearance of the porridge were subjectively evaluated by three panelists using a scale of 1 to 5, where 1 is rated good and 5 is poor. Cultivars DC 3, HS 1, BJ 104, and Samarka local were good for making thick porridges, while BK 560, MC-K77, ICH 226, and ICMS 7703 were good for thin porridges. The latter group of cultivars did not produce thick porridges even after prolonged cooking. Further studies are under way to elucidate the factors that influence the cooking quality of the porridges.

Millet grain is also cooked like rice in India and is called *soru* (Tamil Nadu), *ghugri* (Gujarat), and *Anna-koot* or *kolab* (Rajasthan). In tests of 12 genotypes for their *soru*-making ability, the grains were dehulled by the traditional method, winnowed, and cooked like rice by boiling 5 g of dehulled grains of each cultivar in 50 ml distilled water. During cooking, softness of grains was tested by pressing them periodically between two glass slides to ascertain the time needed for cooking each sample. The cooking time varied from 18 to 25 min, and the volume and weight of grains after cooking increased by about 212 and 156% over the initial volume and weight, respectively (Table 14). The quality of the cooked *soru* was evaluated for appearance and softness independently by three panelists. The cultivars LCB 10 and Joli were rated good, while ICH 226 and MBH 110 were rated poor.

Plant Improvement

In the development of genotypes our primary objective has been to produce useful material for other breeders and agronomists, to develop new varieties and hybrids for international testing, and to discover the inheritance of useful traits and how to best utilize them. To this end we have increasingly mobilized new variability from germplasm, worked more closely with pathologists, physiologists, and microbiologists, and utilized different locations for early-generation selection.

Mobilization of Germplasm

Mobilization of germplasm is handled by ICRISAT Center's source-material project, which has grown in recent years into the major source of new variability, feeding other ICRISAT Center projects and national breeders (Fig. 10). Material from this project has proved particularly useful to ICRISAT breeders in Africa. The progenies from crosses made in the first phase of this project during 1976-1979, which included a number of West African breeders' populations, are now sufficiently inbred to enter the permanent Source Material Inbred Nursery (SMIN), which now has 419 entries.

In phase two, which, began in 1979, crosses were first made between groups of lines with specific characteristics and selected accessions from West Africa. In 1980 designated crosses and backcrosses with varieties identified by ICRISAT breeders in West Africa were also included.

Table 14, Cooking characteristics of pearl millet *soru.*[a]

Cultivar	Cooking time (mm)	Volume increase (%)	Weight increase (%)	Gruel solids (g/100 g)	Quality score[b]
UCH 4	20	233	174	9.8	2.0
MBH 110	21	144	113	7.5	4.0
BK 560	20	229	155	6.9	3.0
MCK 77	21	200	148	10.1	2.0
ICH 241	23	200	151	8.6	2.5
SSC-M 76	23	200	154	7.0	2.5
ICH 226	24	221	151	8.9	3.5
WC-C75	25	242	168	8.3	2.0
ICMS 7703	23	250	195	8.2	2.5
PSB 8	19	200	151	8.9	1.5
Joli	21	200	147	9.7	1.0
LCB 10	18	225	163	9.5	1.0
Mean	22	212	156	8.6	2.3
SE ±[c]	1.0	13.2	6.4	0.67	0.4

a. 5 g dehulled grains were cooked with 50 ml water over a hot plate at 275°C.
b. Evaluated for appearance and softness by three panelists on 1-5 scale: 1=good, 5=poor.
c. Standard error of estimation of repeat checks.

F_1 and F_2 populations of these crosses have provided useful selections in Mali, Upper Volta, Niger, Nigeria, Senegal, and Sudan. The same populations grown in India have also provided new lines, which are now in the F_3 to F_5 stage.

In the 1980 postrainy season, a wide range of varieties from West Africa were planted in the postentry quarantine isolation area (PEQIA), where crosses were made among these and with 13 established inbreds. Over 700 F_1s were generated using this material. In response to requests, an assortment of these F_1s was sent to our six African locations for evaluation in the 1981 rainy season. A selected set was also planted at Bhavanisagar in India, in order to select combinations that would hold promise for India. The African programs, retained a proportion of these F_1s, based on visual evaluations, maturity, plant height, head characteristics, and disease resistance, to be grown as F_2 populations in 1982.

Preliminary analysis of the data returned indicated that Togo x Souna combinations were valuable at Samaru, Maradi, Bhavanisagar, Bambey, and Cinzana. Togo x Sanio crosses were found promising at Cinzana, Kamboinse, and El'Obeid; Souna (early) x Sanio (late) crosses showed promise at Cinzana and Samaru; and crosses of Souna millets of Mali with Barbe, NBB, Heine Kheri (Precoce), Ex Bornu, and Zanfarwa were found to be of value at Kamboinse. The data returned indicate that the probability of a cross being useful is high when one of the parents involved is of local origin. However, it seems that some cross combinations show a wide adaptability (example: Togo x Souna), supporting the hypothesis that some particular landraces can be moved with ease across latitudes in West Africa.

The Togo population obtained from our station at Kamboinse in Upper Volta is of special parental worth because of its earliness (42 days to 50% bloom), short height (150 cm), open canopy, bold grain (9 g/1000 grain), and free tillering. About 300 S_1 progenies were evaluated at Bhavanisagar in 1981 in a replicated trial, and

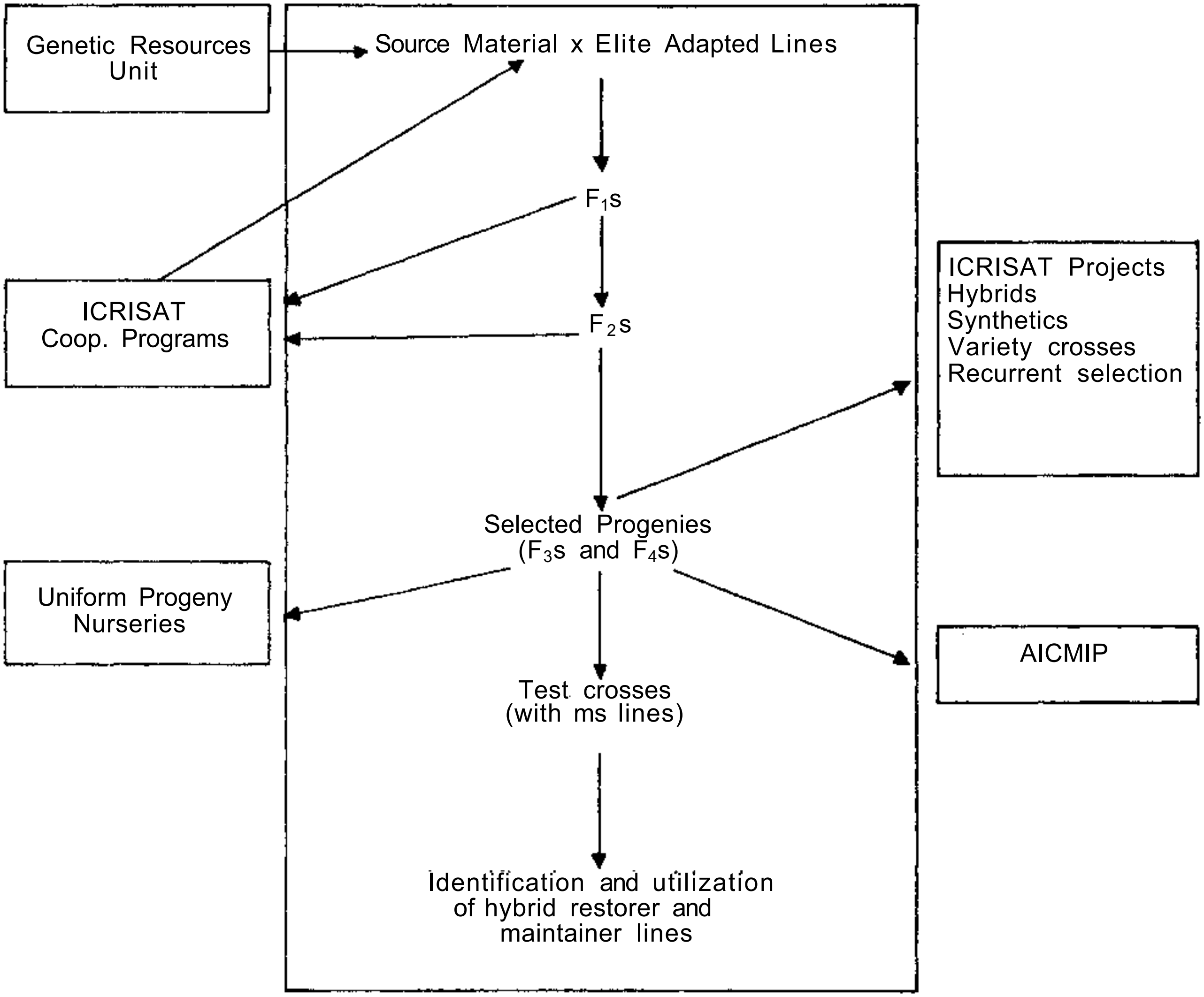


Figure 10. Source-material project at ICRISAT Center.

over 600 S_2 progenies were developed for evaluation in 1982. This population also combines well in cross-combinations.

We have identified several sources of downy mildew and smut resistance in the progenies derived from source material x adapted inbreds crosses. AICMIP Resource Nursery initiated in 1981 and distributed to five locations in India contains 34 source material inbreds.

Increase in Biomass Production

Our earlier analysis of the growth of short-season millets stressed that early floral initiation results in reduced leaf-area development and radiation interception in the whole of the crop life cycle (ICRISAT 1977/78 Annual Report). Although these millets are efficient in partitioning dry matter into grain production, their yields are probably limited by low radiation interception and low dry-matter production. Our planting date studies indicate that a relatively small variation in the length of the vegetative period (7 days) can result in two- to threefold variation in leaf area at panicle initiation. It therefore appeared likely that a small increase in the vegetative period would result in a substantial increase in dry-matter production and possibly in grain yield. Because pearl millet is a quantitatively short-day plant, this hypothesis can be tested by using artificial daylength extension to delay floral initiation and to extend the vegetative period. We conducted such an experiment in the 1981 rainy season with three tall and three dwarf F_1 hybrids, in both normal and extended daylength conditions at ICRISAT Center. The dwarf hybrids were included because we thought that their generally better harvest index would improve the potential for grain yield increase in the extended daylength conditions.

Effects of daylength on phenology and crop growth. Extension of the normal daylength of 13.0-13.5 hrto 16.0-16.5 hr from emergence to40 days later resulted in delay in panicle initiation (PI) of approximately 13 days in all cultivars and a 21-day delay in flowering for the tall hybrids (BJ 104, MBH 110, and ICH 412) and 15 days for the dwarf hybrids (ms 81A crosses) (Table 15). Leaf-area index (LAI) at PI increased at least twofold in all cultivars (Fig. 11). The relationship of LAI at PI and days to PI appeared similar for all cultivars, with an increase of 0.5 m^2 leaf area/m^2 (=0.5 LAI) for each 5.5 days delay in PI.

The additional leaf area developed in response to delay in PI produced an increase in the radiation interception and in dry matter prior to flowering in the extended daylength treatment. As in the case of days to PI and LAI relationship , dry weight at flowering also increased in proportion to the time taken to flowering for all cultivars.

In addition to the total dry-matter increase at flowering, there was an increase in dry weight of the heads (reproductive structures) at flowering, indicating a potential for increased grain yields. This increase was also proportional to time to

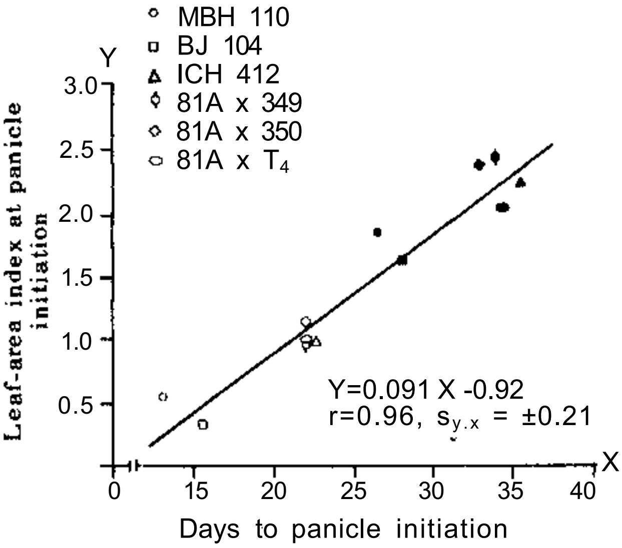


Figure 11. Leaf-area index (LAI) at panicle initiation (PI) in normal (open symbols) and extended (solid symbols) daylength treatments for six cultivars.

Table 15. Mean days to panicle initiation (PI) and flowering (FI) as influenced by artificial extension of daylength in pearl millet.

	Days to PI		Days to FI	
Genotype	Normal daylength[a]	Extended daylength[b]	Normal daylength	Extended daylength
BJ 104	17	29	44	65
MBH 110	14	28	41	62
ICH 412	23	36	60	80
81A x 349	23	35	52	68
81A x 350	23	34	50	64
81A x T4	23	35	50	64

a. Normal: 13.0 to 13.5 hr.
b. Extended: 16.0 to 16.5 hr.

flowering, but of a lesser magnitude than the increase in total dry-matter production (Fig. 12), e.g., a 15-day delay in flowering was equivalent to an increase of 45 g/m^2 in head weight for an early cultivar—slightly more than 50%.

Effects of daylength on yields and yield components. For tall hybrids, the yield of individual heads was increased by 70%, due to an increase in grain number per head (Table 16, Fig. 13), However, this resulted in only a 10% overall increase in grain yield, because of significant decreases in productive tiller numbers (those tillers that produce grain) per square meter for all cultivars in the extended days (Table 16). This productive tiller number decrease with extended days had been observed by us earlier also. Low productive tiller numbers are a common feature of African cultivars also that flower in 60-80 days. Why this occurs is not known, but it appears to be an apical dominance phenomenon, as the unproductive tillers are capable of completing their development if the main shoot is removed. Low productive tiller numbers are clearly an undesirable trait in terms of crop yield potential, although they may have adaptive value in environments where moisture and fertility resources are not sufficient to support many tillers. A search of the germplasm for medium to long-duration cultivars without this trait would appear to be important for long-term yield potential improvement in pearl millet, at least for certain environments.

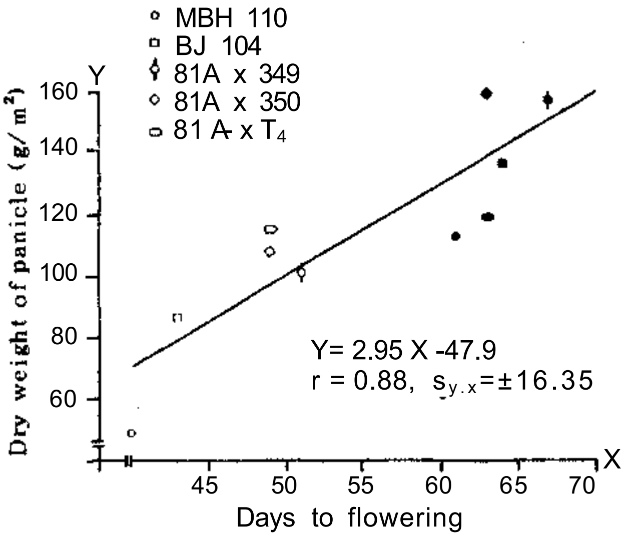


Figure 12. Dry weight (DW) of panicles at flowering (FI) for normal (open symbols) and extended (closed symbols) daylength treatments for five cultivars.

In the dwarf hybrids despite a 17% increase in the yield of individual heads, due to an increase in grain number per head, there was a significant reduction in overall yields in the extended-day treatment. These cultivars suffered from a substantial reduction in grain size in long-day treatments, in addition to the reduction in productive tiller number (Table 16). The grains in the heads of these cultivars were so tightly packed that individual grains appeared to be deformed. Estimates of grain numbers per unit surface area of

Table 16. Effect of day length extension on yield attributes (Mean±SE) in tall and dwarf pearl millet hybrids.[a]

	Tall		Dwarf	
Yield attributes	Normal day length	Extended daylength	Normal daylength	Extended daylength
Productive tiller/m^2	35 ± 4.8	23 ± 2.8	28 ± 1.7	20 ± 0.7
Head length (cm)	20 ± 0.4	25 ±0.2	27 ± 0.2	32 ± 0.4
Grain/head	1350 ± 111	2420 ± 55	2120 ± 175	2950 ± 188
Grain yield g/m^2	320 ± 14.8	354 ± 16.1	299 ± 13.0	255 ± 13.8
100-grain wt(g)	0.81 ± 0.092	0.81 ± 0.088	0.60 ± 0.023	0.51 ±0.020
Grain packing (no./cm^2)	17.4 ± 1.1	19.4 ± 0.92	19.2 ± 0.45	21.5 ± 0.53

a. ICH 412 was excluded from yield calculations because of the extensive ergot infection.

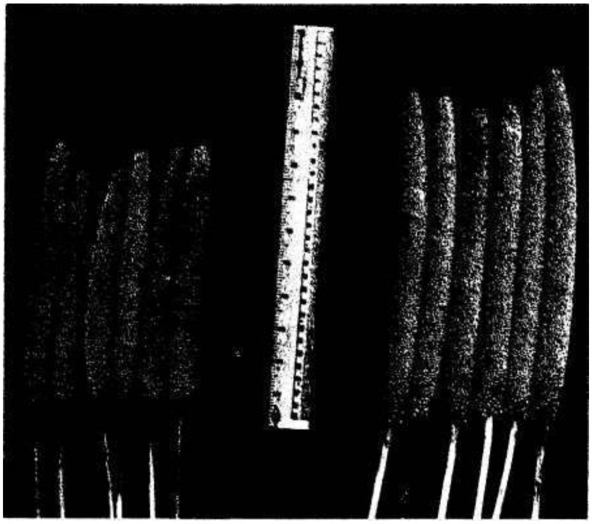


Figure 13. Panicles of hybrid BJ 104 from normal (left) and extended (right) daylength treatments.

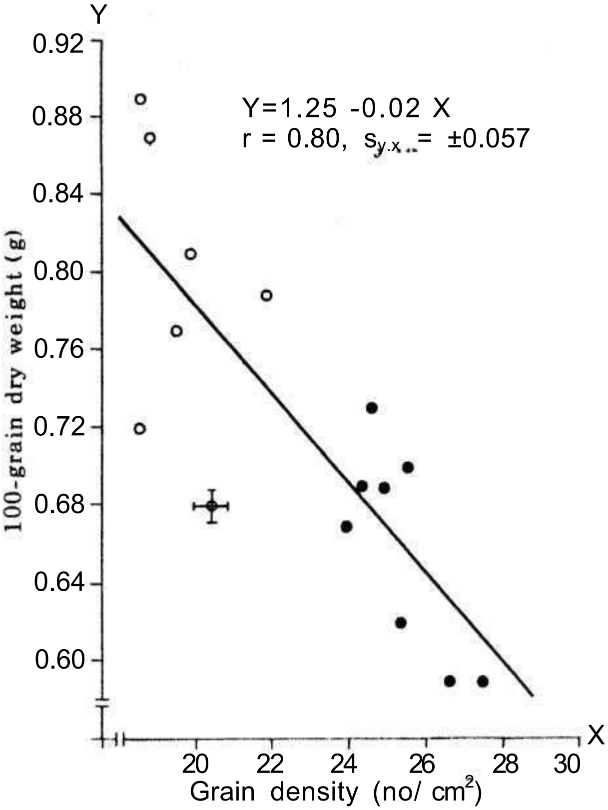


Figure 14. Grain size (100-grain weight) relationship to grain density in the normal (open symbols) and the extended (closed symbols) daylength treatments. Data points are individual head means for hybrid 81Ax350. Means are of three observations for 100-grain weight and seven observations for grain density, taken from the central region of the panicle.

the ear (grain packing) indicated that this parameter increased in all cultivars in the extended daylength treatment, but that the absolute densities were higher in the dwarf than the tall cultivars. Grain packing and grain size appeared to be inversely related in the dwarf cultivars (Fig. 14), which suggested that the smaller grain size in the extended daylength may have been a direct result of the increased grain density. This is the first time we have documented such a relationship and it will need further study, but the results suggest that the use of grain packing as a positive selection criterion in long-duration cultivars should be approached with caution.

Production of New Seed Parents

Only three male-sterile lines (seed parents)—5054A, 5141 A, and 111A—are being extensively used in India to make new hybrids. To widen the genetic base of the seed parent germplasm and enhance the probability of generating hybrids with higher yields and disease resistance, we are paying increased attention to (1) converting new sources of nonrestorers into male-sterile lines, and (2) incorporating resistances, particularly to ergot and smut, into the currently used and promising but otherwise susceptible seed parents. In the meantime, we have successfully used a mutational breeding approach (gamma irradiation) to develop three downy mildew resistant versions of a highly susceptible seed parent ($23D_2A$), which otherwise is a good general combiner. During 1980 the three best pairs of derived $23D_2A$ and $23D_2B$ were multiplied in isolation. One of the versions, ICM ms 81A, which produces superior hybrids, was supplied (along with ICM ms 81B) to many pearl millet breeders in India. A comparison of morphological characters of ICM ms 81A with three common male-sterile lines used in India is given in

Table 17. The other two male-sterile versions will be evaluated for their combining ability in 1982.

Yields in a 25-entry trial of hybrids of ms 81A in 1981 were up to 32% more than BJ 104, coupled with superior downy mildew resistance. Eight out of an additional 275 testcrosses on ms 81A were also retained for reevaluation. A further and possibly the most valuable attribute of ms 81A is the higher rate and certainty with which new male steriles can be discovered using it as a tester. The discovery rate is nearly four times the previous average of 0.63% of verified nonrestorers (mean of 6400 testcrosses using the three standard male-sterile lines), and anthers which are male sterile are clearly recognizable in testcrosses using ms 81A.

Evaluation of 350 testcrosses made on new male-sterile Ex-Bornu lines (at fifth backcross stage in summer 1981) indicated that these seed parents provide the options of developing hybrids for both Indian and African situations. Though many pollinators were good combiners, Togo material and Souna accessions (from Mali) were found to be particularly promising restorers in producing hybrids suitable for India and Africa, respectively. The frequency of non-restorer lines on these male-sterile lines was found to be as high as those on ICM ms 81A.

Another group of 16 potential male-sterile lines—largely African in origin and at the second or third backcross stage—will further broaden the variability in seed parents.

Improvement of Composite Populations

Of 11 composites under recurrent selection, we continued 6 in multilocation S_2 progeny testing and switched 5 in 1981 to a simpler, modified half-sib system. This offers advantages in terms of reduced resource needs, increased phenotype selection on a single selfed-plant basis, and opportunities for progeny testing for stress factors affecting seedling establishment, while maintaining substantial genetic variation in the population.

After 3 years of testing in AICMIP trials, followed by 2 years of yield tests in minikit demonstrations all over the country, our experimental variety WC-C75 was recommended for release by AICMIP at its 1981 annual workshop. Besides being comparable in grain yield (Table 18) to the commercial check, hybrid BJ 104, this variety yields about 20% more fodder and possesses a high level of stable resistance to downy mildew. WC-B77, an experimental variety developed by us from a later cycle of the same World Composite as WC-C75, has compact heads and more tillers than WC-C75 and has done consistently well in the AICMIP trials, yielding about 3% more than BJ 104 and WC-C75. In 1981 it was retained along with IVS-P77 for the 2nd year of testing in AICMIP's Advanced Population Trial (APT). IVC 5454, a progeny variety developed from the Intervarietal Composite,

Table 17. Morphological characteristics of three standard male-sterile lines and ICM ms 81A.[a]

Character	Male-sterile line			
	5054A	5141A	111A	ICM ms 81A
Days to 50% bloom	51 ± 0.2	49 ± 0.1	58 ± 0.1	57 ± 0.2
Plant height (cm)	129 ± 0.7	131 ±0.6	117 ± 0.7	83 ±1.2
Ear length (cm)	17 ± 0.1	17 ± 0.1	28 ± 0.2	15 ± 0.2
Ear girth (cm)	6 ±0.0	5 ±0.0	4 ±0.0	6±0.1
No. of tillers/plant	3 ± 0.1	3 ± 0.1	1 ±0.1	1 ±0.0

a. Recorded in the 1980 rainy season at ICRISAT Center. Observations based on 100 plants for 5054A, 5141A, and 111A, and 72 plants for ICM ms 81A.

Table 18. Performance of ICRISAT pearl millet populations in AICMIP trials.[a]

Population	Grain yield (kg/ha) 1976	1977	1978	1979	1980	Grain yield (%) of[b] BJ 104	PSB 8	Average downy mildew (%)
WC-C75	1490	1630	2070	1760	1850	101	117	2
ICMS 7703			1930	1830	1850	99	114	3
PSB 8[c]	1530	1530	1800	1490		87		5
BJ 104[d]		1790	1970	1810	1810		115	9

a. Source; AICMIP Progress Report 1976-1980.
6. Calculated on the basis of common test years (1978 and 1979).
c. Released synthetic from PAU, Ludhiana.
d. Standard hybrid check.

yielded slightly more than BJ 104 in AICMIP's 1980 Initial Population Trial (IPT) and was promoted for further testing in APT. In 1980, we contributed one more experimental variety, NELC-P79, to AICMIP's IPT. IVC 8004, another progeny variety identified from the Intervarietal Composite, has outyielded WC-C75 by about 15% (at 2820 kg/ ha) in initial yield tests at ICRISAT Center.

Among new experimental varieties tested in the 1981 Elite Varieties Trials (EVT) at ICRISAT Center, we selected, IVS-P78 and DC-P7904 on the basis of yield and uniformity for entry into 1982 AICMIP tests.

Our modest program to assess composites under recurrent selection as sources of hybrid restorer parents has led to the discovery and development of good hybrids. Hybrids ICH 418 developed from the 1R Restorer Composite, ICH 415 from a World Composite restorer, and ICH 423 from an Early Composite restorer have been high yielding with acceptable phenotypic uniformity (see Hybrids and Hybrid Parents section below). Large-scale yield tests in the 1981 EVT again showed ICH 418 as the top ranking entry, yielding about 15% over BJ 104 (2730 kg/ha). ICH 415 ranked sixth in the same trial and yielded 8% over BJ 104, confirming the previous year's hybrid trial results.

The d_2 dwarf F_2/F_4 progenies derived from the third and final backcross of the dwarf sidecar program on seven tall (normal) composites have proved useful in (1) the development of d_2 dwarf hybrids on ICM ms 81Aand medium-to-tall hybrids on 5141A (some of which have been superior to BJ 104 in the initial yield tests), (2) isolation of several progenies with nonrestorer reaction on ICM ms 81A, which will be used in developing a nonrestorer d_2 composite, and (3) the development of d_2 dwarf synthetics. From the first backcross selections, two promising d_2 dwarf synthetics were identified that yielded as much as d_2 dwarf check hybrid GHB 1399 (1830 kg/ha) in 1980 yield trials at four locations in India. These two synthetics have been useful to our millet physiologists to evaluate alternative selection criteria for grain yield improvement. The selected progenies have also been distributed to cooperating millet breeders through the Uniform Progeny Nursery (UPN). Seven d_2 dwarf versions of the respective tall composites were developed during the 1981 postrainy season so a bulk trial in 1982 can be conducted to examine the effects of the d_2 dwarfing gene on yield and yield components.

In our Interpopulation Improvement work on restorer/nonrestorer composites, the slow recovery of agronomically elite nonrestorers from the nonrestorer composite is an impediment to the genetic advance in interpopulation heterosis. Considering the formidable resources required to test reciprocal full-sibs along with respective testcrosses and S_1 progenies in this selection scheme and the value of possible applied results, we are attempting to improve the restorer and nonrestorer Composites independently, using male-sterile testers. This scheme will be simpler in operation, require fewer resources, and possibly be more effective in generating promising restorers in each cycle. With this in view, 1R and 2R composites along with the restorers identified from other composites are being merged to develop a composite called Restorer Composite-1. We are also currently assessing promising hybrids developed at ICRISAT for another composite, ICRISAT Restorer Composite. The B Composite, being developed solely in a d_2 dwarf background, will also be improved using a male-sterile restorer, and will serve as a source of lines for developing d_2 dwarf male-sterile lines that can produce hybrids of various heights depending on the male parent.

Development of Improved Synthetics

Synthetic varieties of various phenotypes are made from progeny generated in the variety cross program and from other sources of new variability, such as the source material project or disease-resistant lines. The better progeny generated in this project are also distributed as source of new variability to national breeders in India and African countries.

In the 1980 Pearl Millet Synthetics Trial (PMST) conducted at seven locations, mean grain yields of four entries (ICMS 7835, 7704, 7857, and 7909) exceeded check hybrid BJ 104 (yield 2260 kg/ha). Synthetic ICMS 8013 (which was top in the 1980 Initial Evaluation Trial) was again highest yielder in the 1981 PMST. We retained three other synthetics for further testing. The synthetics produced in this project have yields and maturities comparable to hybrid checks but have better downy mildew resistance and higher fodder yields.

The synthetics identified earlier as promising in ICRISAT trials continued to perform well in AICMIP trials. After 3 years of testing in AICMIP trials, ICMS 7703 was recommended for minikit testing. This synthetic yields as much as BJ 104 (Table 19) and has superior resistance to downy mildew. In the 1980 AICMIP Initial Population Trial, ICRISAT synthetics ICMS 7704 and ICMS 7805 ranked first and third, yielding 2130 kg/ha and 2000 kg/ha,respectively (BJ 104 yield was 1940 kg/ha), and hence were promoted to the 1981 Advanced Population Trial. Two more synthetics (ICMS 7818 and ICMS 7835) identified from advanced ICRISAT trials were contributed to AICMIPs 1981 Initial Population Trial.

Hybrids and Hybrid Parents

Inbreds derived from other projects but principally from crosses involving existing good hybrid parents are tested for their potential in hybrid combination. This identifies both seed parents and pollen parents.

Two hybrids, ICH 226 [5141 x (1623 x 700490)] and ICH 241 (5141 x S38-142), ranked seventh and eighth in the 27-entry 1980 AICMIP Advanced Hybrid Trial tested at 27 locations. Both showed high levels of downy mildew resistance and were retained for further testing, ICH 220 [5141 x (SD2 x EB 1088)] ranked fourth in the 1980 AICMIP Initial Hybrid Trial, with a mean yield of 2270 kg/ha, 29% more than check BJ 104, and was retained for further testing. With a mean yield of 2020 kg/ha, this hybrid also ranked first in the Sixth International Pearl Millet Adaptation Trial (IPMAT-6) evaluated at 31 locations, mostly in India and African countries (see Cooperative Multilocation Testing, below).

Of our seven restorers contributed to the AICMIP Parental Trial, ICP 382 ranked first with a mean grain yield of 1950 kg/ha, representing a margin of 29% more than the trial mean and 83% more than the check restorer CM 46.

Cooperative Multilocation Testing

In 1980 the Sixth International Pearl Millet Adaptation Trial (IPMAT-6) containing 20 pearl millet test entries and a local check for each location was sent out to 49 locations in 19 coun-

Table 19. Mean yield performance of leading pearl millet hybrids, synthetics, and varieties from populations at six environments[a] in India with yields from two fertility levels at one site.

Entry	Grain yield (kg/ha) Mean	% of BJ 104	PRH	PZF	Downy mildew[b] (%)
ICH 418	3140	115	4020	2290	1
ICH 165	3020	111	4180	1960	0
ICMS 7857	2300	110	4140	1970	0
IVS-P78	2980	109	4080	2130	0
NELC-H79	2980	109	4010	1670	3
ICH 415	2950	108	3470	2280	0
WC-A78	2900	106	3920	1880	0
NELC-A79	2890	106	4190	1940	1
DIC-P7906	2880	106	3740	1890	0
SCI 9064	2810	103	3780	1650	2
ICMS 7909	2790	102	3400	1840	1
ICMS 7919	2760	101	3980	1860	5
DIC-P7904	2730	100	3980	1550	0
SCI 9111	2720	100	3760	1650	0
SSC 9114	2520	92	3410	1690	1
ICH 220	3050	112	4060	1900	0
ICMS 7703	2990	109	3870	2240	1
MBH 110[c]	2850	105	3330	1660	0
WC-C75[d]	2750	101	3640	1950	0
BJ 104[c]	2730	100	2960	1720	1
Mean	2872	105	3825	1886	62[e]
SE ±	80		259	136	

a. Patancheru precision field; Patancheru rainfed fertility strips (three environments—two reported): PRH=high fertility (56 kg P_2O_5/ha; 100 kg N/ha), PZF=zerp fertility (nil P_2O_5; nil N/ha); Bhavanisagar; Hissar.
b. ICRISAT downy mildew disease nursery.
c. Commercial hybrid checks.
d. Variety check.
e. Downy mildew susceptible check NHB 3.

tries. Entries included hybrids, synthetics, experimental varieties, and progeny varieties contributed by ICRISAT and its cooperators. Results were received from 38 locations (including five disease nurseries) in 13 countries representing latitudes from 24°34' S to 30°56'N. Of these, 31 locations reported data on grain yield.

The highest mean grain yield for the test entries was recorded at Serere, Uganda (3290 kg/ha), and the lowest at El'Obeid, Sudan (310 kg/ha). The highest entry yields recorded at these locations ranged from 400 kg/ha (UCH 4 at El'Obeid) to 4080 kg/ha (ICH 162 at Serere), and the lowest were 110 kg/ha (NHB 3 at El' Obeid) and 1670 kg/ha (NHB 3-Serere). Causes of low yields were high levels of downy mildew, *Striga,* insect pests (in West African locations), poor plant stands, bird damage, and inadequate moisture. Rainfall during crop growth ranged from 146 mm (Anantapur, India) to 971 mm (Kaoma, Zambia). At only four locations (three of these in Africa) did the local check yield numerically more than any of the test entries. Mean grain yields of all the trial entries over 31 locations are presented in Table 20. The entries that performed well overall were ICH 220, ICH 211, MBH 127, ICH 162, IVS-P77, UCH 4, ICMS 7818, and ICMS 7704.

Incidence of downy mildew was much more severe at West African locations than in India. Entries ICH 211, ICH 165, and ICMS 7704 exhibited relatively stable levels of downy mildew resistance across locations.

In 1981 we sent IPMAT-7 to 37 locations in 13 countries. Several other multilocational trials (replicated or in the form of observation nurseries) were sent to our breeders in West Africa for evaluation and recording of disease incidence

Table 20. Performance of IPMAT-6(1980) test entries for grain yield (mean over 31 locations) and downy mildew incidence (5 locations).

Entry	Type	Source[a]	Grain yield (kg/ha)	Downy mildew incidence (%)				
				Bambey	Kamboinse	Samaru	Maradi	ICRISAT Center
ICH 220	Hybrid	ICRISAT	2020	0	6	100	45	0
ICH 211	Hybrid	ICRISAT	1960	0	0	11	7	1
MBH 127	Hybrid	MAHYCO	1930	0	19	66	50	2
ICH 162	Hybrid	ICRISAT	1910	0	0	28	13	1
IVS-P77	Exp. var.[c]	ICRISAT	1890	9	8	8	22	1
UCH 4	Hybrid	TNAU	1890	0	5	23	5	6
ICMS 7818	Synthetic	ICRISAT	1860	1	1	20	20	3
ICMS 7704	Synthetic	ICRISAT	1850	1	0	11	10	0
ICH 165	Hybrid	ICRISAT	1820	1	1	8	23	0
GHB 18	Hybrid	GAU	1800	5	56	11	2	5
ICMS 7703	Synthetic	ICRISAT	1780	2	2	37	17	3
SC(1)-W78	Exp. var.	ICRISAT	1780	5	9	30	35	1
WC-C75	Exp. var.	ICRISAT	1780	1	2	22	3	1
WC-B77	Exp. var.	ICRISAT	1760	7	2	15	6	1
IVS 5454	Comp. prog.[d]	ICRISAT	1750	1	18	18	25	2
ICMS 7845	Synthetic	ICRISAT	1700	1	0	2	9	5
LC 7053	Comp. prog.	ICRISAT	1700	2	0	24	8	3
SSC-K78	Exp. var.	ICRISAT	1670	1	2	28	15	1
PHB 47	Hybrid	PAU	1680	7	17	29	37	1
NHB 3[c]	Hybrid	AICMIP	1340	15	88	100	100	62
Mean			1797	2.8	11.8	29.5	22.6	4.8
SE ±			64					

a. AICMIP = All India Coordinated Millet Improvement Project; GAU = Gujarat Agricultural University; MAHYCO = Maharashtra Hybrid Seeds Company; PAU = Punjab Agricultural University; TNAU = Tamil Nadu Agricultural University.

b. At Kamboinse, Samara, and ICRISAT Center, incidence recorded in the downy mildew nursery. Maradi incidence reported as percent of hills infected.

c. Exp. var. = Experimental variety.

d. Comp.prog. = Composite progeny.

e. Withdrawn from commercial cultivation in India, included to assess downy mildew incidence at various locations.

during 1980. Starting in 1981, the number of advanced replicated trials sent from ICRISAT Center to West Africa has been reduced and emphasis is now given to supplying F_1 or F_2 material of appropriate pedigrees. However, some advanced trials like the Elite Varieties Trial, Experimental Varieties Trial, and Synthetics Trials continue to be tested in Senegal and Sudan. Evaluation of the advanced trials for downy mildew, ergot, and smut incidence continues in West Africa.

In 1981 we initiated the International Pearl millet Observation Nursery (IPON) in collaboration with FAO. It comprised five varieties bred at ICRISAT Center that had performed well in multilocational trials in previous years. This observation nursery is primarily intended for distribution in Pakistan, countries of the Arabian Peninsula, Egypt, Sudan, lowland Ethiopia, Somalia, Mauritania, and Morocco.

Looking Ahead

Seedling emergence and establishment. With good progress being made in techniques for screening for emergence ability in pearl millet, we will begin studies to determine the heritability of factors contributing to this ability and the range of genetic variability. If genetic improvement appears possible, selection for emergence ability will gradually be built into the breeding program.

Drought. With work on field methods to screen cultivar performance under stress largely completed, we will place more emphasis on studies of individual cultivars that have performed well under stress. Of particular interest are those lines that show ability to recover rapidly from a stress prior to flowering without significant yield loss.

Low fertility. Our study will concentrate on the relationship between different methods of estimating nitrogenase activity of plants grown in the field and under greenhouse conditions. We will examine the fixation of isotopically labelled nitrogen gas by intact sorghum and pearl millet plants. In field experiments we will follow the response of the plants to inoculation with nitrogen-fixing bacteria.

Diseases. Our large-scale field screening for resistance to downy mildew, ergot, and smut will expand at ICRISAT Center, with the major smut resistance screening work being moved from Hissar to the Center. Multilocation testing for the stability of resistance will continue. More emphasis will be placed on the evaluation of factors affecting the stability and durability of resistance.

Development of ergot- and smut-resistant lines with wider genetic bases will continue, as will utilization of ergot and smut resistance in resistant hybrids and synthetics in cooperation with breeders.

In 1982 we will also examine the feasibility of screening on a large-scale for multiple-disease resistance in multiple-disease nurseries.

Insect pests. We will continue observations on selected cultivars to identify insects with a potential for becoming pests and will initiate studies on the biology and seasonal activity of a few potential pests, such as shoot fly and armyworm. Germplasm lines found to be less susceptible to various insect pests will be retested. Key pests in the major pearl millet growing areas of India will be identified and their economic importance investigated in collaboration with All India Coordinated Millet Improvement Project.

Grain and food quality studies. Protein and lysine analyses will be continued on our germplasm accessions to identify lines with more protein and with reasonable lysine levels.

Work on African food products, such as porridges, will be intensified, and attempts will be made to seek collaboration with institutes in Africa and USA. Physicochemical traits of cultivars will be studied in relation to food quality.

Plant improvement. We will continue to produce elite lines through variety crosses and recurrent selection and will intensify our mobilization of genetic variability from new germplasm accessions into adapted backgrounds of breeding lines. New composites utilizing recently developed source-material progenies will be formed. We will attempt to develop high-protein composite from high-protein lines, some of which have consistently given over 16% protein. The Smut-Resistant Composite will be strengthened by feeding in new and di verse sources of resistance. The incorporation of ergot resistance into restorer and maintainer parents has reached the F_4 stage after initial crossing, and resistant progenies have been identified for utilization in backcrossing. Incorporation of smut resistance into maintainer parents has just begun and will continue. We have also initiated investigations into the genetics of ergot resistance and are developing plans for similar studies on the genetics of smut resistance. We have identified new sources of nonrestorer lines and will continue the conversion of some of the promising ones into new seed parents.

Progeny from a study of various selection techniques designed to directly increase grain numbers will be ready for evaluation in 1982. Traits utilized include head number, head surface area (length x girth), and head weight; these will be compared with visual selection for yield.

Studies on the relationship between time to flowering and plant phenotype will continue, with emphasis on the degree of expression of useful characters in the West African germplasm in a short-season plant habit. Initial studies will involve covering plots to produce short days to trigger flowering in the long-duration types.

Publications

Institute Publications

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CHICKPEA

Contents

CHICKPEA

The principal objectives of the Chickpea Improvement Program are the development of improved cultivars and genetic stocks of desi and kabuli-type chickpeas capable of higher and more stable yields in traditional and nontraditional situations.

Our major activities during the period of this report (June 1980-Dec 1981) were concentrated at three locations: (1) ICRISAT Center at Patancheru (17°N, 78°E), where emphasis is on the development of short-duration desi genotypes suited to peninsular India; (2) our Hissar subcenter (29°N, 75°E) in northern India, for long-duration desi and kabuli genotypes adapted to the northern areas of the Indian subcontinent; and (3) ICARDA, our sister institute at Aleppo (36°N, 37°E) in Syria, for kabuli types adapted to both winter and spring sowing in western Asia and North Africa. Other centers were Gwalior (26°N, 78°E) in central India, Tapperwaripora (34°N, 75°E) in Kashmir, and Terbol (34°N, 36°E) in Lebanon, the last two principally for off-season advancement of breeding materials. In addition, ICRISAT materials were grown by many cooperators at locations in India through the All India Coordinated Pulses Improvement Project (AICPIP), and elsewhere, and their contributions are gratefully acknowledged.

In south and central India the rains ceased early, in September, so the residual soil moisture was depleted earlier than normal, and the shorter growing season tended to reduce the seed yields of all but the shorter duration materials. In the northern areas of the Indian subcontinent, rainfall during the cropping season was much heavier than normal, and diseases such as botrytis gray mold, and ascochyta, phoma, and alternaria blights caused considerable loss to both commercial and experimental crops. As a result, most trial results at Hissar were too variable for effective interpretation, and yield data were not obtained from cooperators at a number of locations in northern India.

Our cooperators in Pakistan reported that the incidence of ascochyta blight was lower this year in the commercial crop, but the area planted by farmers appeared to be much reduced due to the severe crop loss caused by the disease in previous years.

A redeeming feature throughout the Indian subcontinent was the lower incidence of *Heliothis* and reduced pest damage, especially in peninsular India.

In western Asia, crop conditions were fairly normal, but low rainfall may have contributed to the reduced yields in North Africa, although, as a result, the incidence of ascochyta blight was lower than normal.

Diseases

Surveys

We conducted surveys in Nepal, Bangladesh, and parts of India. In Nepal, wilt was widespread and serious, and stunt diseases was common. In Bangladesh, collar rot (*Sclerotium rolfsii*) and rhizoctonia root rot (*Rhizoctonia solani*) were observed, but the most serious problem in farmers' fields was botrytis gray mold (*Botrytis cinerea*). Because of excessive rains throughout the season in northern India, the crop suffered heavy damage from botrytis gray mold and ascochyta blight (*Ascochyta rabiei*). Other commonly observed diseases were stem rot (*Sclerotinia sclerotiorum*), phoma blight (*Phoma medicagiois*), and alternaria blight (*Alternaria attentat a*).

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

Breeding for resistance. Over 4500 new germplasm accessions were screened in wilt-sick plots, and 62 additional lines were identified as promising (less than 20% mortality). These will be tested again. The 133 germplasm selections identified in wilt-sick plots last season (1979/80) were screened this year, and 18 were found resistant (less than 10% mortality). Four lines (ICCC-10, NEC-472, Coll.238, and GNG-85) that were found promising against stunt were also promising against wilt. Five lines (ICC-1403, -1981, -5800, 7320-11-1-HB, and 7320-11-2-HB) that were identified as low pod borer lines by our entomologists were also found promising against wilt.

So far we have confirmed wilt resistance in 50 lines through field, greenhouse, and laboratory screening. These are available on request from ICRISAT's Genetic Resources Unit. We also helped scientists of several other research organizations by screening their breeding materials in wilt-sick plots at ICRISAT Center and Hissar and communicating the results.

We made 52 crosses involving wilt and root rot resistant parents. Seventy-three F_2 and F_3 populations and 1935 F_4 and more advanced progenies were tested for wilt resistance at Hissar, and 8 F_2 populations and 5546 F_3 and more-advanced progenies were tested at ICRISAT Center. A total of 314 single plants were selected at Hissar and 2016 at ICRISAT Center. Forty-three uniformly resistant lines at Hissar and 88 at ICRISAT Center were bulked for testing in replicated trials.

In replicated tests in wilt-sick plots of lines bulked in the previous season, two entries at Hyderabad and 11 at Hissar yielded significantly more than WR-315, the wilt-resistant parent, but the Hissar trial was highly variable. The yields of the three highest yielding lines in each trial are compared with that of WR-315 in Table 1. Sixteen lines will be included in international screening nurseries and 20 in the 1981/82 Root Rots and Wilt Nursery. A new resistant kabuli type has also been identified.

Table 1. Performance of wilt-resistant lines at ICRISAT Center and Hissar, 1980/81.

IC No./Name	Seed yield (kg/ha)	DFF[a]
ICRISAT Center		
74729-2P-1P-1P-BP	1251	66
73105-14-2-2P-1P-1P-BP	1194	60
74513-3P-1P-2P-1P-BP	1092	79
WR-315	845	55
SE±	124.6	1.1
CV(%)	27.9	3.2
Hissar		
741663-3P-1P-1P-2P-BP	1949	90
74132-B-4H-1H-1P-BP	1882	97
741663-6P-1P-1P-2P-BP	1827	89
WR-315	653	91
SE±	258.2	3.9
CV(%)	42.7	3.6

a. DFF = Days to 50% flowering.

Biology and Epidemiology. In continuing studies on the survival of F. *oxysporum* f. sp. *ciceri,* we buried infected roots of wilted chickpea plants in soil in pots and removed them every 3 months to attempt fungus isolations. The fungus survived in the host roots for 33 months, at which point the root tissue had decomposed almost fully. Therefore, to check on further survival of the pathogen, we planted seeds collected from healthy plants of the wilt-susceptible cultivar JG-62 in the pots in which infected roots had been buried, and observed wilt in seedlings even 39 months after the experiment was initiated. This experiment is continuing.

In another experiment we found that the fungus survived for 24 months in infected roots buried 60 cm deep in the soil. This experiment is also continuing.

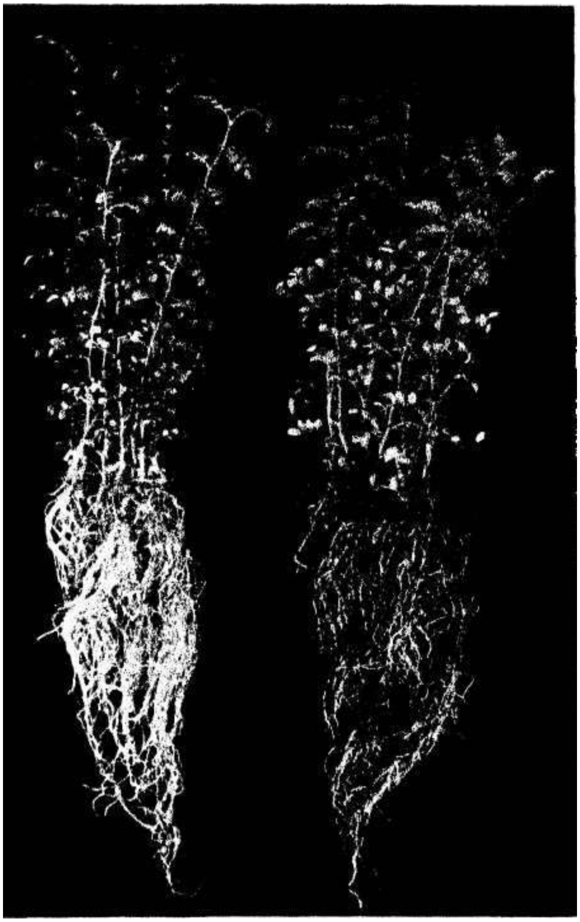
Influence of crop rotation and intercropping. In collaboration with our agronomists, a 4-year experiment to study the effect of crop rotation and intercropping on the incidence of wilt was initiated this year in a sick plot. Treatments included rotation of chickpea with fallow, sorghum, or maize in the rainy season, followed by sole chickpea or chickpea intercropped with wheat. The first-year results indicate that none of the treatments influenced wilt incidence in the susceptible cultivar, JG-62, which showed nearly 100% incidence.

Eradication of the fungus from the seed. Early work at ICRISAT has established that the wilt fungus can be internally seedborne and that seed dressing with Benlate-T (30% benomyl + 30% thiram) can completely eradicate the fungus. All our seed samples sent to cooperators are now routinely treated with Benlate-T. This year we established that the seed dressed with Benlate-T can remain free of fungus even when planted 1 year later. Thus seed dressing with Benlate-T should eliminate chances of moving the fungus from ICRISAT to cooperating locations since all cooperators plant the seed within a year after treatment.

Dry Root Rot (*Rhizoctonia bataticola*)

Screening for resistance. Dry root rot is one of the important diseases of chickpea in the semi-arid tropics. Last year we reported a "blotting paper technique" to routinely screen germplasm and breeding material for resistance to dry root rot. Of 50 fusarium wilt resistant lines screened by this method for additional resistance to dry root rot, ICC-554 and ICC-6926 were highly resistant (rating of 2 on 1-9 scale), and ICC-1443, -1910, -1913, -2086, and -7681 were resistant (rating of 3).

Survival. As in the case of the wilt fungus, we have been carrying out studies on the survival of *R. bataticola* in infected roots. Results obtained so far indicate that the fungus can survive up to 36 months.



Chickpea genotypes resistant (*ICC-7111, left*) *and susceptible* (*ICC-6494*) *to black root rot* (Fusarium solani).

Black Root Rot (*Fusarium solani*)

Screening for resistance. In several chickpea growing countries, the black root rot caused by *F. solani* results in substantial plant mortality. We have now developed and standardized a simple pot technique to screen for resistance to this disease: a 5-ml-inoculum suspension is poured around the base of each 7- to 10-day-old seedling. The seedling roots are examined for damage 25 days after inoculation and scored on a 1 -9 scale, where 1 means no visible infection and 9 means complete rotting and seedling death. So far all 50 known wilt-resistant lines have been screened for resistance to black root rot. Of these, ICC-7111 showed 1.5 rating; ICC-554, -1450, -3593, and -11088 showed 2.5 rating; and ICC-519, -658, -1611, -1891, -1913,-2089,-2660, -6098, -7248, -8982, -9001, -10104, and -11531 showed a rating of 3. It is worth mentioning that ICC-554 is resistant to wilt and dry root rot, as well as to black root rot.

Multiple Soilborne Disease Screening

ICRISAT Center has a multiple-disease sick plot. The fungi present in this plot, in order of prevalence, are *F. oxysporum* f. sp. *ciceri, R. bataticola, Sclerotium rolfsii, R. solani, F.*

solani, and a sterile seed/seedling-rotting fungus. This plot was used to retest 195 promising lines that had been selected in 1979/80. Of these, 95 showed multiple resistance (less than 10% mortality), and 40 have been selected for inclusion in the 1981 / 82 International Chickpea Root Rots/ Wilt Nursery. We screened several lines at ICRISAT Center for cooperators from Delhi, Kanpur, and Gurdaspur and communicated the results to them, A large amount of breeding material generated at ICRISAT Center was also screened, and promising materials were further advanced.

Ascochyta Blight (*Ascochyta rabiei*)

Screening for resistance. Screening of germplasm was continued at ICRISAT Center, using the Isolation Plant Propagator procedure, and 33 additional lines were identified as promising. Over 30 desi lines that were found resistant in field screening at ICARDA showed susceptibility to the fungus isolate we use at ICRISAT Center. It is not uncommon to see differences in performance of lines at different locations. Of the 60 wilt-resistant lines screened for resistance to ascochyta blight, ICC-519 was found most promising. Also six of the 151 F_3 progenies screened were found wilt resistant.

Ascochyta blight nursery at Islamabad, Pakistan. The resistant ICARDA germplasm accession ILC-195 can be seen directly behind the rows of susceptible genotypes in the foreground.

A large amount of desi and kabuli germplasm as well as breeding material was screened, and four lines were found resistant. This completes the screening of our entire kabuli germplasm collection (over 3500 lines) at ICARDA, and 23 lines have been identified as resistant. A total of 3954 additional desi germplasm lines were screened at ICARDA, and 34 lines with resistance at both vegetative and pod stages were identified.

We made 132 crosses between 31 desi germplasm accessions that had been resistant to ascochyta blight at Tel Hadya in 1979/80 and north Indian lines. The F_{1s} will be advanced in Kashmir and Terbol, and F_2 populations of crosses involving parents that maintained resistance in Pakistan in 1980/81 will be screened at Tel Hadya, Islamabad, and Ludhiana in 1981/82.

Biology and epidemiology. At ICARDA, an isolate of *A. rabiei* capable of killing a resistant line, ILC-482, was discovered. There are indications that races of *A. rabiei* exist, but firm evidence is needed. *A. rabiei* is seedborne, and we confirmed that seed dressing with fungicide Calixin M (30% calixin + 30% maneb) eradicates the fungus. Deep sowing of chickpea seed was found to reduce seed transmisson of ascochyta blight. The age of the plant had no effect on blight incidence. Pods of many lines that were resistant at the vegetative stage were found infected. We noted that the pH of pod exudates was more acidic than that of vegetative parts. Pod resistance vs vegetative-stage resistance will be studied in more detail.

ICRISAT is posting a pathologist at ICARDA to carry out work on diseases and support the chickpea breeding work in that region.

Stunt (Pea Leaf Roll Virus)

Work on screening for resistance to stunt was carried out at Hissar. A nursery was planted on 25 September 1980, 1 month in advance of normal planting, to ensure high disease incidence. A mixture of the hosts of pea leaf roll virus (e.g., alfalfa, broadbean) was planted around as well as throughout the nursery to augment the disease pressure. One row of a susceptible cultivar, WR-315, was planted after every two test rows as an indicator and spreader row. The average of disease incidence in WR-315 was 74% (range 43 to 100% in different rows).

Lines ICC-6433 and ICC-10495 were found promising (less than 10% infection) again this year; these had been found promising in the previous four seasons. Lines ICC-403, -591, -685, and -2546 were promising for the third consecutive season. Eight crosses were made between ICC-10596, which has maintained a high level of stunt resistance, and adapted desi and kabuli lines, F_3 populations of previous crosses were screened at Hissar, but the screening was confounded by other disease problems and the populations were bulked for further testing in the coming season.

Mosaics

This year we initiated studies on identifying and characterizing different viruses associated with mosaic symptoms in chickpea. In addition to alfalfa mosaic virus, reported by us earlier, we recorded cucumber mosaic virus (CMV) and bean yellow mosaic virus (BYMV) in chickpea under natural field conditions. While CMV was reported earlier from India, our report on the occurrence of BYMV is the first one for India. However, incidence of mosaics is normally very low in farmers' fields.

Botrytis Gray Mold (*Botrytis cinerea*)

This disease occurred in severe form in northern India in the 1980/81 chickpea season. Since Pantnagar is an endemic location for this disease, we sought help from the scientists of G.B. Pant University of Agriculture and Technology at Pantnagar to initiate screening for resistance. About 1000 germplasm accessions were planted and steps were taken to augment natural incidence by spraying spore suspensions. At the end of the season, only four lines—ICC-1069, -6250, -7574, -10302—survived, and produced almost normal yield. This work will be further strengthened.

Bean yellow mosaic results in very small distorted leaves, as seen at the top of this chickpea plant.

Genotypes that showed resistance in epidemic conditions this season will be used as parents in crosses to incorporate resistance into improved genetic backgrounds next season.

Combined Disease Resistance

Crosses have been made to combine fusarium wilt and root rots resistance with resistance to ascochyta blight and stunt.

Inheritance Studies

Fusarium wilt resistance. In crosses involving C-104 as the susceptible parent, resistance appeared to be inherited as a single recessive gene, but where JG-62 was used as the susceptible parent, an excess of susceptible plants was produced. The basis for this difference is being investigated.

Insect Pests

Surveys

Over the years since our first report in 1973 we have recorded very few insect pest problems on chickpea. In some locations and years, however, we have recorded severe pest damage on this crop. In India, *Heliothis armigera* is by far the most damaging pest, but in a few areas termites and cutworms can greatly reduce plant stands. A few other Lepidoptera larvae, including species of *Spodoptera* and *Autographa* feed upon foliage and pods and can cause severe damage in some areas. Aphids, particularly *Aphis craccivora,* are of some importance on chickpea, largely because they transmit stunt disease, which is caused by pea leaf roll virus.

This year at ICRISAT Center the *Heliothis* attack on chickpea, both at the vegetative and podding stages of the crop, was much less than in past years (Fig. 2 in pigeonpea section). At Hissar, however, *Heliothis* larvae built up to large populations during the late podding stage, and some of the entries in our trials suffered more than 50% pod damage.

We surveyed farmers' chickpea fields in several states across India during the past 4 years. The pod damage percentages in the major chickpea-growing states are shown in Table 2. Although the damage varied greatly from year to year and state to state, it was generally low. In our surveys we also asked the farmers if they used pesticides. The data (Table 3) showed that most farmers used no pesticides on this crop.

Natural Enemies of Heliothis

We collected *Heliothis* larvae from pesticide-treated and pesticide-free fields through the season at ICRISAT Center and recorded the rates of parasitism (Table 4).

The rate of parasitism was very low this year, probably a result of the relatively low populations of *Heliothis.* There was an apparent suppression of parasitism on the pesticide-treated fields during the treatment period (Nov-Dec) but subsequent recovery in January. In November

Table 3. Survey of pesticide use in major chickpea-growing states of India.

Year	No. of farmers surveyed	Farmers using pesticide (%)
1977/78	101	14 (14.9)
1978/79	270	12 (4.4)
1979/80	115	5 (4.4)
1980/81	121	15 (12.4)

Table 2. Damage to chickpea pods caused by insect pests in samples collected from farmers' fields in the major chickpea-producing states in India.

State	Percent pods damaged by pests			
	1977/78	1978/79	1979/80	1980/81
Andhra Pradesh	16.2	14.2	3.6	27.2
Gujarat	3.9	NR	NR	7.8
Haryana	0.4	3.2	6.4	NR
Karnataka	1.7	2.7	4.5	NR
Madhya Pradesh	8.3	22.0	NR	10.4
Maharashtra	7.1	4.1	3.2	9.0
Punjab	10.1	2.1	9.8	NR
Rajasthan	0.4	1.9	19.6	8.2
Uttar Pradesh	30.5	7.5	9.0	8.5

NR = Not recorded.

Table 4. Parasitism in *Heliothis* larvae at ICRISAT Center, 1980/81.

Month	Percent larvae parasitized (No. examined) Pesticide-treated fields	Pesticide-free fields
November	0.5 (185)	0.9 (220)
December	1.0 (300)	3.1 (450)
January	4.4 (270)	4.3 (421)

the hymenopteran parasite *Campoletis chloridae* was the most common, but later in the season the Diptera, particularly *Carcelia illota,* became the dominant parasites. Collection of larvae from chickpea in local farmers' fields showed a much greater rate of parasitism, rising to more than 30% in January; again the Hymenoptera were most common in November and the Diptera in January.

We know little about the predators of *Heliothis* larvae on chickpea, but from our field observations it is evident that insectivorous birds eat many of the large larvae feeding on this crop. Most of the large larvae found on chickpea are green, probably because larvae of other colors are easily noticed by the birds and eaten. Further evidence for this was obtained from counts of larvae on normal green chickpea plants and on a cultivar with red foliage. The number of eggs and young larvae on both plant types was almost the same, but the large green larvae were far fewer on the red plants. The green larvae may be more easily seen on the red plants by predatory birds.

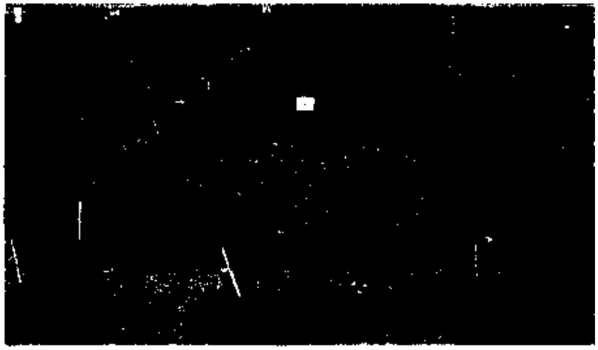
Plant Density and Pesticide Use

Last year we reported that the populations of *Heliothis* larvae per unit area increase greatly in closer spaced chickpea in pesticide-free trials. This year we tested two cultivars, our resistant selection ICC-506 and the susceptible but high-yielding cultivar Annigeri, at wide (17 plants/m^2) and close (33 plants/m^2) spacing in pesticide-free and pesticide-protected conditions at ICRISAT Center (Table 5). The *Heliothis* populations increased with closer spacing, but this had little or no effect on the percentage of pod damage or the yields. As expected, pesticide

Table 5. Data from pesticide-protected and unprotected spacing trials of two chickpea cultivate, ICC-506 (pest-resistant) and Annigeri (pest-susceptible) at ICRISAT Center.

Cultivar	Spacing	*Heliothis* larvae/m^2 A	B	% pods damaged A	B	Grain yield/m^2 A	B
ICC-506	S_1	7.1	9.0	0.02	3.9	142	133
	S_2	9.1	13.0	0.14	2.1	142	140
	Mean	8.1	11.0	0.78	3.0	143	137
Annigeri	S_1	7.6	13.0	2.3	13.8	150	114
	S_2	16.2	26.0	1.4	15.4	154	120
	Mean	11.9	19.5	1.8	14.6	152	117
Overall	S_1	7.4	11.1	1.2	8.8	146	124
	S_2	12.6	20.0	0.8	8.7	149	130
SE ± Cultivar		0.79	2.09	0.30	1.02	6.24	3.02
Spacing		0.79	2.09	0.30	1.02	6.24	3.02
Cultivar x Spacing		1.12	2.96	0.42	1.44	8.82	4.27

S_1 = 60 x 10 cm; S_2 = 30 x 10 cm;
A = sprayed; B = unsprayed.



These spacing trials are being conducted on ICRISAT Center fields. Our studies indicate that pest problems are greater in closer spaced chickpea.

use gave greater increase in yield on the susceptible cultivar than on the resistant selection.

In our comparisons of large plots of pesticide-treated and pesticide-free desi- and kabuli-type chickpeas we split each plot between more and less susceptible cultivars. Here the less susceptible kabuli type (ICC-5264) substantially outyielded the susceptible (L-550) in both protected and unprotected conditions. The susceptible desi type (Annigeri) gave marginally greater yields than the less susceptible (ICC-506) in both sprayed and unsprayed plots in spite of much greater damage by *Heliothis.* Overall, the use of pesticides increased yields from 1100 kg/ha to 1278 kg/ha. This year, when there were low *Heliothis* populations, pesticide use on this crop would have been a relatively poor investment.

Resistance to *Heliothis*

Screening for resistance. We have been screening all available chickpea materials for resistance to *Heliothis armigera* in open field tests, with the natural populations of the pests supplemented by laboratory-bred insects where needed. We screened 571 new germplasm accessions this year, bringing the total screened since 1975 to over 12 000, and have had considerable success in identifying selections that differ greatly in their susceptibility to *Heliothis* attack. One selection, ICC-506, has performed consistently well over years and tests. This year we compared ICC-506 with entries in the Indian national Gram Coordinated Variety Trial (GCVT) and found that it outyielded all other entries and also gave the lowest percentage of pod damage (Table 6). We have other selections that look equally promising. The best of these selections are now being used in the breeding program in an attempt to further intensify *Heliothis* resistance and to incorporate this resistance into materials that have other desirable characteristics.

It is now evident that ICC-506 and some of our other *Heliothis*-resisiant selections are very susceptible to wilt disease, caused by *Fusarium oxysporum.* Our breeders have been making crosses that should give progeny with combined wilt and *Heliothis* resistance. In cooperation with ICRISAT biochemists and the Max-Planck Institute of Biochemistry at Munich, we have been attempting to identify the mechanisms involved in the resistance of chickpea selections to *Heliothis.* Last year we reported that polyphenol contents are particularly high in the seed

Table 6. Data from a trial of chickpea cultivars grown in pesticide-free conditions at ICRISAT Center, 1980/81.

Cultivars	Days to flowering	Mean pod damage(%)	Yield (kg/ha)
ICC-506[a]	47	5	1909
Phule-4	47	14	1639
BDN-9-3	42	9	1594
Annigeri-1 (Check)	47	23	1499
H-73-10	57	15	1461
ICCC-4	65	18	1433
ICCC-13	57	16	1395
BG-405	65	11	1276
BG-401	75	11	1272
C-235 (Check)	75	9	1204
SE±		2.2	108.8
CV (%)		34.7	14.8

a. Selected in previous years' tests as being resistant to *Heliothis.*

coat of ICC-506. This year Dr. H. Rembold of the Max-Planck Institute has reported that our more resistant selections tend to exude greater concentrations of malic acid from the many glandular hairs that cover the plants from the seedling stage.

Our attempts to extend the testing of our selections to other locations were again largely frustrated. At our Hissar subcenter the trials looked good until the flowering stage when cold, wet weather encouraged buildup of diseases, particularly *Botrytis* sp, which greatly affected the podding on most plots. Pod damage caused by *Heliothis* was very common, particularly on plants and plots that had been affected by disease. This association masked the differences that might have resulted from genetic differences in susceptibility to the pest. We supplied the seeds of our selections to entomologists at 13 different locations in cooperation with AICPIP. The data received from some of these centers showed great variation. The results were encouraging from Coimbatore in Tamil Nadu, where ICC-506 had the lowest percentage of pod damage and gave the highest yield. Results from locations in the main chickpea-growing areas in northern India were much less encouraging, for our most promising selections looked no better than our most susceptible checks. These results provide further evidence of the need to intensify our selection and testing at Hissar, as the data and selections obtained there are more likely to be of direct utility in the major chickpea-growing areas.

Breeding for resistance. Our efforts to incorporate *Heliothis* resistance into adapted backgrounds increased. Diallel sets of crosses were made among six desi and four kabuli parents resistant to *Heliothis,* and 29 further crosses were made between adapted and resistant selections. A replicated test of parents and F_{1s} of a 4 x 4 diallel among susceptible and resistant lines made in 1979/80 indicated that variation in pod borer damage is predominantly additive but there are significant non-additive effects for pod number and seed yield in insecticide-free conditions.

We selected 1170 single plants for low and high borer damage in 42 F_{2s} of crosses made in 1978/79 and 1979/80 to be grown as nonreplicated F_3 progenies for further screening in 1981/82. In addition, 121 F_3 progenies of 7 crosses made in 1978/79 were grown as nonreplicated rows. There was a small but significant positive correlation ($r = 0.27$, $P<0.01$) for percentage of borer damage between the F_2 plants in 1979/80 and their F_3 progenies. In both sets there were good correlations between field assessment of borer damage and percentage damage determined in the laboratory confirming the effectiveness of visual assessment of borer damage for selection purposes.

Breeders' materials selected under insecticide protection were compared with resistant selections under protected and insecticide-free conditions at Hyderabad (short and medium duration) and at Hissar (long duration) to assess the magnitude of interactions between genotypes and insecticide application.

At Hyderabad, ICC-506 and IC-738-8-01-IP-BP were killed by wilt in the unprotected, short-duration trial and were excluded from the analysis. In both duration groups (Table 7) seed yields and borer damage were higher in the unprotected than in the protected trials, indicating the influence of factors other than borer damage on seed yields. However, there were significant interactions between insecticides and genotypes for seed yields, the resistant lines giving relatively higher yields than the breeders' lines under unprotected conditions.

Response to Inputs

Fertilizer Placement

The possibility that the failure to obtain response to nitrogen and phosphorus in chickpea is due to the absence of nutrients in the active root zone was examined by spot placement of fertilizer. Single superphosphate (40 kg P_2O_5/ha) was placed alone and in combination with urea (20 kg N/ ha) at depths of 20,45, and 70 cm, both with and without irrigation on a deep Vertisol low in available nitrogen (60 ppm),

Table 7. Seed yields (kg/ha) of *Heliothis*-resistant and breeders' lines in insecticide-free and protected trials at ICRISAT Center, 1980/81.

	Short duration		Medium duration	
	Unprotected	Protected	Unprotected	Protected
Heliothis-resistant lines	2022	1332	1668	931
Breeders' lines	1646	1393	1558	936
Annigeri	1828	1650	1839	1308
SE±	71.0		62.0	
Mean	1833	1412	1638	975
SE ±	51.1		24.8	

Table 8. Mean grain yield (kg/ha) as affected by fertilizer application and irrigation.

	No fertilizer	Superphosphate	Urea + superphosphate	Mean for irrigation	SE ±
Unirrigated	1416	1557	1864	1612	38.7
Irrigated	2718	2907	2843	2823	
SE ± at an irrigation level		87.3			
SE± at a fertilizer level		75.7			
Mean for fertilizer	2067	2252	2354		
SE±		53.5			

medium in available phosphorus (7 ppm), and moderately saline (0.6 m mho/cm).

The mean grain yield increased by 75% due to irrigation, by 9% due to phosphorus alone, and by 13.9% when nitrogen and phosphorus were applied together (Table 8). Grain yield increased by 32% in response to placement of nitrogen and phosphorus together in the nonirrigated treatment, probably because the nodules ceased to be active earlier in this treatment than when irrigation was applied.

These results suggest that deep and spot placement of phosphorus could result in a marginal increase in grain yield, whereas nitrogen is effective only in a receding soil moisture situation.

Yield Potential

We demonstrated in 1978/79 that the yields of chickpea at ICRISAT Center (in peninsular India) are low, compared with yields in northern India, due to moisture stress. Irrigation increased yields more than twofold (ICRISAT Annual Report 1978/79, Table 5, p 125).

Potential yields of three chickpea cultivars were assessed for the first time in big plots (675 m^2) to confirm earlier results. The crops were grown in nonreplicated plots under nonlimited nutrient and water conditions. Yields were estimated from sample areas to assess crop "uniformity.

Growth duration (sowing to maturity) ranged between 105 and 110 days and grain yield between 2800 and 3200 kg/ha. Daily productivity was high, around 26 to 30 kg grain/ ha per day (Table 9); in a crop growing on receding moisture it was around 15 kg grain/ ha per day (ICRISAT Annual Report, 1978/79, Table 5, p 125).

These results indicate that total yield and daily productivity of chickpea in peninsular India can be increased substantially by irrigation.

Table 9. Yield, days to maturity, and grain yield per day of irrigated chickpea at ICRISAT, 1980/81.

Variable	K-850	Annigeri	CPS-1
Yield (kg/ha)	2757	3172	2924
Days to maturity	107	109	105
Grain yield (kg/ha per day)	25.8	29.1	27.8

Biological Nitrogen Fixation

Rhizobium Strains

We are transferring our *Rhizobium* collection to storage in freeze-dried ampoules. The collection continues to be expanded, and isolates are available to any interested scientist. We also accept requests to store any strains of nodulating chickpea or other *Cicer* species.

Success of Inoculation and its Evaluation

At ICRISAT Center, significant responses in chickpea yield to inoculation with rhizobia have only been obtained when natural *Rhizobium* populations are low, supporting the limited evidence we have at the moment that the naturalized rhizobia in ICRISAT fields are generally effective in fixation. However, failure to obtain a yield response in any situation does not necessarily indicate that the inoculum has failed to benefit the plant. Thus, successful establishment of inoculum may be reflected in superior nitrogen fixation with greater input of fixed nitrogen into the host and hence a saving of soil nitrogen for use by subsequent crops. Establishment of the inoculum is measured by determining the proportion of nodules due to the inoculum.

One of the techniques employed is to use a strain with a particular recognizable attribute, such as antibiotic resistance. Two methods of inoculant application—normal seed inoculation and inoculant in liquid poured onto the furrow below the seed—were used in three different fields with varying numbers of rhizobia.

With both methods of inoculation, the inoculant strain was most successful with the lowest level of native rhizobia (Table 10). Liquid inoculation increased the success rate, possibly due to closer proximity of the rhizobia to the roots.

Field testing of *Rhizobium* strains was continued at ICRISAT Center as part of AICPIP, but no significant responses were obtained, apparently because of the adequate number and efficiency of local *Rhizobium* populations. However, intensive collection of nodules was made at ICRISAT Center and in collaboration with Dr. A.L. Khurana at Haryana Agricultural University, Hissar, on an experiment testing two hosts and 14 strains of *Rhizobium.* With the development of antisera now in progress at ICRISAT Center in recently completed rabbit housing facilities, we expect to be able to examine the competitive ability of the inoculant strains and improve our selection criteria. The potential of inherent antibiotic resistance as an identification tool has not yet been realized, and further studies are in progress under a collaborative project with the Rothamsted Experimental Station at Harpenden, U.K.

Nitrogen Fixation

In previous annual reports we reported on the poor nodulation and nitrogen fixation by chickpea at ICRISAT Center under rainfed conditions and its improvement with irrigation. Limited data also suggest site differences within

Table 10. Success of inoculation in relation to the natural population of rhizobia in the soil and methods of inoculation.

Field	Mean no. of native rhizobia	Method of inoculation: Seed pelleting	Method of inoculation: Liquid inoculation
		Nodules due to inoculum (%)	
1	<1	98	100
2	40	36	80
3	8000	1	12

a cultivar, as nodulation and fixation were superior at Hissar in northern India. During 1980/81 an intensive set of measurements by the acetylene reduction technique was made of both nodulation and nitrogen fixation. The measurements at ICRISAT Center were made weekly, while those at Haryana Agricultural University, Hissar, were made fortnightly in collaboration with Dr. F.C. Garg.

In our study of four varieties at both sites, K-850 (previously named 850-3/27) behaved quite differently from the other three, which were similar. The data in Figure 1 are for K-850 and G-130 at both sites.

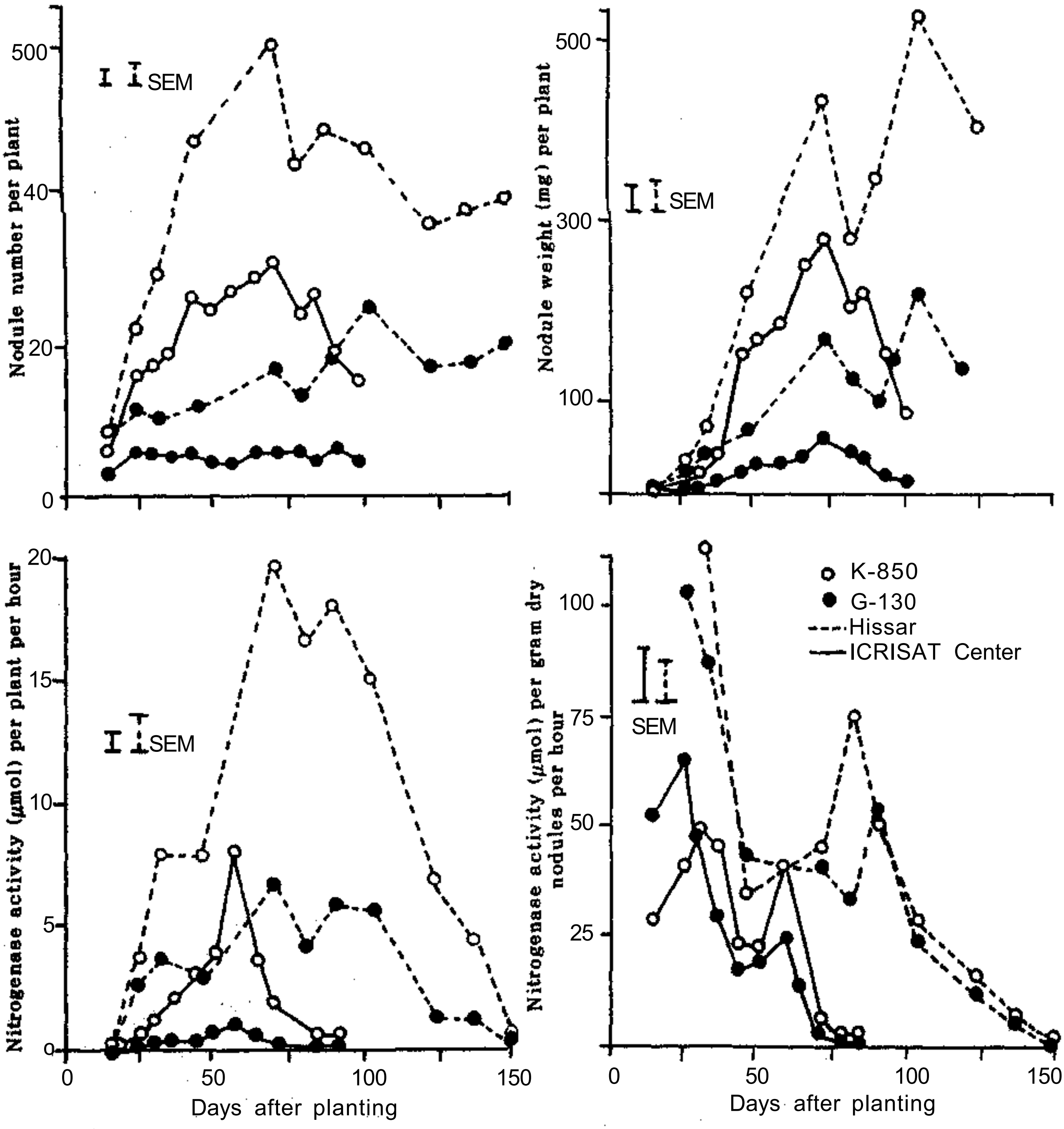


Figure 1. Seasonal profile of nitrogen fixation at Hissar and ICRISAT Center, 1980/81.

Major differences between the sites within a cultivar and superiority of K-850 at both sites observed by us earlier were confirmed. At Hissar, nodule numbers and weights were higher; nitrogenase activity per gram of nodule was also higher and continued longer. Nodule size increased up to 70 days at ICRISAT Center and 100 days at Hissar. Nitrogenase activity ceased by 80 days at ICRISAT Center but stopped only after about 135 days at Hissar, Even this lengthy activity at Hissar was probably terminated prematurely due to the incidence of ascochyta blight, observed at 100 days, and botrytis gray mold, which was confirmed at 140 days but was probably present earlier. These diseases almost certainly reduced the grain yields at Hissar, but they were still greater than at ICRISAT Center (cv K-850, 2.0 and 1.6 tonnes/ha and G-130,2.0 and 0.9 tonnes/ ha at Hissar and ICRISAT Center, respectively).

At ICRISAT Center the yield and seasonal patterns of nodulation and nitrogenase activity were similar to those in previous years, while at Hissar the yields and duration of nodule activity were probably less than normal. However, there is little doubt that the Hissar environment is more favorable to the nitrogen-fixation process, probably because of favorable temperature and moisture conditions. At ICRISAT Center (ICRISAT Annual Report 1979/80, p 93) the rate of nitrogen fixation responded dramatically to irrigation, and examination of the rainfall records of the two sites during the crop growth period (see ICRISAT Center's Research Environment section of this Annual Report) reveals superior moisture input at Hissar. Published data by other workers show that nodulation and nitrogen-fixation activities of chickpea are sensitive to temperatures above 30°C in controlled environments. One of the striking differences we observed this past season was that, during the first 60 days after sowing (late Oct to late Dec), at ICRISAT Center the soil temperature at 10-cm depth exceeded 30°C for a mean of 6 hr/day, while at Hissar the soil at this depth did not exceed this temperature until 160 days after planting. The relative contributions of moisture and temperature limitations to nitrogen fixation are difficult to separate, and further studies are proposed for the coming year.

Screening for Nodulation

As described in our previous annual reports, there is wide variation among chickpea lines in nodulation and nitrogen-fixing ability. Studies of the nature of this variation require the development of methods of reducing plant-to-plant variability and obtaining reproducible results, and ways of establishing suitable controlled environmental conditions are being investigated.

Also for breeding and inheritance studies it may be necessary to recover desirable plants for seed production following rating for nodulation. Plants growing in pots may be removed and examined for nodulation at 40-50 days and repotted with 93-97% survival to the seed production stages. Plants from the field may also be salvaged in the early stages of growth by transplanting into pots containing sand:vermiculite: grit (1:2:2), covering with polythene bags for 1 or 2 days and retaining in a glasshouse at about 25°C and 70-75% relative humidity. Although it is more difficult to revive field-grown plants than potted ones, we have obtained up to 90% survival to seed production in this way.

Inheritance Studies

In a study of the inheritance of nodulation ability the parents and F_1, F_2, and F_3 generations of the cross between K-850 (good nodulator) and 12-071-04244 (poor nodulator) were examined for nodulation in pots in the screenhouse. In these conditions, 12-071-04244 nodulated as well as K-850, and the means and variances of the different generations were similar, emphasizing the need to refine our screening techniques.

Food Quality

Cooking Quality

We evaluated 18 cultivars, including some of our breeding lines, for cooking quality. The cooking time ranged between 60 and 98 min, with a mean of 79 min for whole seeds, and between 29 and 41 min, with a mean of 35 min for dhal samples. No significant correlation was observed between cooking time of whole-seed and dhal samples. The cooking quality of whole-seed and dhal samples of ICCC-4 was better than Annigeri. Total phosphorus, phytic acid, calcium, magnesium, and pectic substances were determined on these samples, and some of them were highly correlated with the cooking time of chickpea dhal (Table 11).

Studies of the effect of processing practices (dehulling of chickpea) on the cooking quality of chickpea dhal showed that wet processing increased the cooking time of dhal over that of the dry processing method. Whole-seed and dhal samples presoaked in salt solutions took less cooking time than those presoaked in water, Presoaking in water produced a variable response in the cooking time of the four cultivars tested (Table 12).

Protein Quality

Using rapid colorimetric methods, we analyzed

Table 11. Ranges and means for cooking time, phytic acid, calcium, magnesium, and pectic substances of chickpea dhal and correlations (r) with cooking time.

Constituent	Range	Mean	r
Cooking time (min)	29 - 41	34.6	
Total phosphorus (mg/g)	2.3- 3.7	3.0	-0.549
Phytic acid (mg/g)	9.5- 13.4	11.1	-0.729**
Calcium (mg/100 g)	41.7- 70.9	53.1	0.357
Magnesium (mg/100 g)	112 -136	121.7	-0.652**
Pectic substances (mg/g)	55 - 97	77.6	0.108
Texture (Instron force, kg)	145 -325	214.3	0.965**

** Significant at 1% level.

Table 12. Effect of presoaking in different salt solutions[a] on cooking time of chickpea cultivars.

Preparation/ cultivar	Control	Cooking time (min)				
		Water	NaCl	Na_2CO_3	$NaHCO_3$	$Na_5P_3O_{10}$
Whole seed						
Annigeri	76	38	26	10	14	12
850-3/27	80	18	16	10	10	10
L-550	60	20	18	10	12	10
Rabat	72	16	12	8	8	8
Dhal						
Annigeri	38	28	16	8	10	8
850-3/27	48	24	20	8	12	10
L-550	46	20	14	6	10	10
Rabat	40	16	12	8	8	8

a. Soaked in 1% solution at room temperature for 16 hr.

40 cultivars for sulphur amino acids and tryptophan and compared the values with those obtained by standard amino acid analyzer procedure. The colorimetric methods appeared to be satisfactory for screening germplasm accessions for these amino acids.

To study environmental influences, we determined the seed protein and amino acid contents of 107 chickpea germplasm accessions grown at ICRISAT Center during 1979/80 and 1980/81. The protein content in dhal samples showed large variability, while methionine, cystine, and tryptophan values showed little variation (Table 13).

In our studies of the effects of irrigation and fertilizer application on the seed protein and amino acid contents of chickpea, we found that irrigation increased protein content but application of nitrogen and phosphorus fertilizers did not change protein values much. Slightly higher levels of sulphur amino acids (as percent of protein) were observed in samples obtained from the nonirrigated field, probably because of the reduced levels of protein in them.

We completed protein analysis for 595 chickpea breeding lines included in ICSN-DS, GCVT, and GIET trials grown at ICRISAT Center in 1980/81, and ICSN-DS, ICSN-DL, and ICCT-DL trials grown at Gwalior in 1980/81, to monitor their seed protein contents in relation to existing cultivars and to examine the effect of locations. In general, the seed from Gwalior appeared to have slightly higher protein content than that from ICRISAT Center. In all trials some entries showed as high seed protein contents as the standard checks and correlations between seed protein content and yield were low and nonsignificant.

Six F_3 and 23 F_4 populations of crosses involving high protein and high-yielding strains were grown at Hissar and two at ICRISAT Center, and were bulk harvested for selection for high protein in 1981/82. F_3 plants with high protein content will be selected from four crosses for progeny rows in the coming season.

Seed Coat Content of Desi and Kabuli Cultivars

Seed coat samples of eight desi and seven kabuli cultivars of chickpea were analyzed for crude fiber, acid detergent fiber, and neutral detergent fiber. Striking differences were observed between desi and kabuli cultivars in the levels of different fibers (Table 14). Lignin content (calculated by difference) was higher in kabuli, while desi had higher cellulose content. Seed coat accounted for about 90 and 70% of the total crude fiber content of whole seed of desi and kabuli cultivars, respectively.

In order to learn the relationship between seed coat percentage and thickness, 21 desi and 19 kabuli cultivars were studied. Seed coat percentage varied from 9.7 to 17.3 with a mean of 14.2 in desi, and from 3.7 to 7.0 with a mean of 4.9 in kabuli cultivars. The thickness of seed coat varied from 115 to 205 μ (mean 144 μ) for desi and from 37 to 106 μ (mean 58.5 μ) for kabuli cultiv-

Table 13. Comparison of protein and amino acids of defatted chickpea dhal samples grown on Vertisols during 1979/80 and 1980/81.[a]

	1979/80		1980/81	
	Range	Mean	Range	Mean
Protein (%)	19.6-29.2	24.10	15.7-25.60	20.90
Methionine (g/16g N)	0.9- 1.46	1.13	0.8- 1.52	1.14
Cystine (g/16g N)	0.8- 1.40	1.08	0.9- 1.42	1.17
Tryptophan (g/16g N)	0.7- 1.20	0.96	0,8- 1.27	1.05

a. Based on 107 cultivars.

Table 14. Means and ranges of crude fiber, acid detergent fiber, and neutral detergent fiber contents of seed coats of desi and kabuli cultivars.[a]

Fiber	Desi		Kabuli	
	Range	Mean	Range	Mean
Crude fiber (%) (cellulose)	52.3-58.0	54.9	31.1-46.4	36.6
Acid detergent fiber (%) (cellulose + lignin)	68.1-72.8	70.0	51.2-62.4	55.0
Neutral-detergent fiber (%) (cellulose + lignin + hemicellulose)	72.0-75.3	73.2	52.6-63.7	57.2

a. Based on eight desi and seven kabuli cultivars.

ars. A positive and highly significant correlation (r=0.923) between seed coat percentage and thickness was recorded. Seed coat thickness was not significantly correlated with seed weight (r= -0.13 for desi, 0.16 for kabuli, and -0.19 for overall). This observation requires further study but indicates that it may not be possible to reduce the thickness of the seed coat by selecting for increased seed weight, although the proportion of seed coat is lower in cultivars possessing larger seeds.

Plant Improvement

Breeding Methodology

Various plant improvement studies are in progress in the Chickpea Improvement Program.

Breeding methods. This year single-plant selections were made in F_4 space-planted bulks of six crosses (Caina x Ponaflar, JG-221 x F-404, P-324 x ICCC-5, B-106 x NEC-989, P-790 x P-1798, and F-496 x F404) advanced by pedigree, bulk, or single-pod *descent methods.*

Multiple crossing. Twenty-one F_2 bulks of single and three- and four-way crosses among Annigeri, ICCC-1, ICCC-2, and 850-3/27 were advanced in continuation of a study of the variability generated by multiple crosses.

D x K introgression. F_2 bulks of crosses among three desi (CPS-1, Pant G-114, BG-203) and three kabuli (C-104, K-4, P-9800) genotypes were grown as space-planted bulks for single-plant selection and classification according to seed type. Crosses involving C-104 exhibited a much higher proportion of kabuli- and near-kabuli-type seeds than those involving the other kabuli parents.

Off-season nurseries. We again advanced F_1s and other materials in off-season nurseries at Tapperwaripora in Kashmir and under rain shelters at ICRISAT Center. Procedures are now standardized to ensure production of sufficient quantities of good quality seed for sowing at ICRISAT Center in the following main season.

At ICRISAT Center, we advanced 103 F_1s from various crossing programs and 290 Ft bulks of crosses for erect plant type.

At Tapperwaripora, we sowed 757 F_1s, which included: (1) diallel and line x tester series of both desi and kabuli projects, (2) material for breeding method and introgression studies, and (3) crosses to incorporate wilt, stunt, *Ascochyta* and *Heliothis* resistance into improved backgrounds. In addition, we multiplied 353 F_3 progenies and 315 F_4 to F_9 bulked lines.

Male sterility. Our efforts to select for greater stability of the male-sterile characteristic continued, and we crossed male-sterile plants with adapted lines to introduce the character into improved backgrounds.

Breeding Desi Types

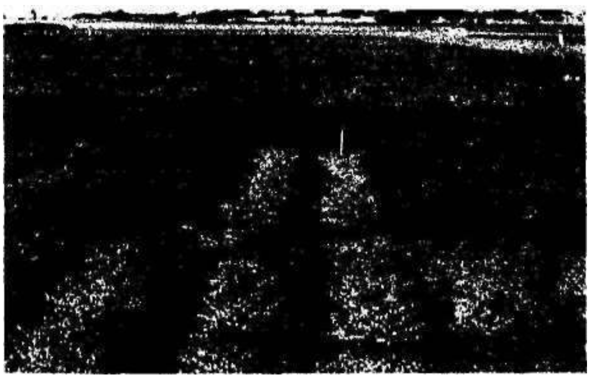
We made 228 further crosses among genotypes that had performed consistently well in India and elsewhere, including materials developed by ICRISAT and other centers. Nearly 5500 populations and progenies of earlier crosses were advanced at ICRISAT Center and Hissar (Table 15). F_1, F_2, and F_3 populations were compared in replicated trials at one or more locations. F_1 and F_2 tests of diallel and line x tester sets at ICRISAT Center or Hissar confirmed previous indications that genetic variation in chickpea is predominantly additive. We included 145 F_3 populations from crosses made in 1977/78 in replicated trials at ICRISAT Center , Gwalior, and Hissar, and the best of these are being advnaced for further selection in 1981/82.

Over 3000 single plants were selected in 80 F_4 bulks. These, together with 2000 plants selected in F_5 and F_6 progenies will be examined further in non-replicated progeny rows in 1981/82. Promising uniform progenies in F5 and more advanced generations were bulked for inclusion in international screening nurseries in 1981/82.

Two preliminary trials of short-duration materials were conducted at ICRISAT Center and Gwalior, each comprising 47 promising F_5 to F_7 lines bulked in the previous season or ICCC lines and the checks, Annigeri and G-130. At ICRISAT Center several entries gave significantly higher seed yields than Annigeri, the highest yield (3372 kg/ha, IC-75788-39H-BH-BP) being 73% more than the check. At Gwalior, there were no significant differences among entries. The highest yield was 1330 kg/ha (IC-75674-28P-BP-BP) compared with 955 kg/ha from G-130. One entry (IC-74685-9P-LB-IH-IP-IP-BP) has been submitted for AICPIP trials in 1981/82, and several will be included in international trials and nurseries.

Table 15. Desi populations and progenies grown at ICRISAT Center and Hissar, 1980/81.

Generation	ICRISAT Center	Hissar	Total
F_1	95	95	190
F_2	317	342	659
F_3	144	194	338
F_4	80	110	190
F_5	1911	282	2193
F_6	520	437	957
F_7	226	183	409
F_8	351	210	561
Total	3644	1853	5497



Progeny rows of desi-type chickpea. Early maturity is an important feature of adaptation in peninsular India.

Breeding Kabuli Types

The kabuli program was expanded, but because of serious disease problems encountered at Hissar most data were incomplete. We made 97 crosses involving kabuli genotypes to combine high yield and other desirable agronomic characteristics.

Of the 226 F_1 to F_3 populations tested in replicated trials, five yielded significantly higher than the check L-550. Further selection will be confined to the best populations.

We made around 1100 single-plant selections in 2551 F_2 to F_7 populations and progenies on the basis of yield and seed characteristics for progeny rows in 1981/82. In addition, 164 rows were selected for nonreplicated bulks and 90 for replicated trials in the coming season.

In trials of advanced breeding lines, 32 entries gave significantly higher seed yields than L-550 (Table 16) and were similar in duration. Seeds tended to be small but several entries combined good yields with acceptable seed size.

Table 16. Characteristics of kabuli lines at Hissar, 1980/81.

IC No.	Seed yield (kg/ha)	Weight of 100 seeds (g)
Trial-1		
74670-9H-1H-2H-BH	2228	22.0
75485-11H-2H-1H-BH	2197	32.3
74454-10H-1H-3P-1H-BH	2190	23.7
L-550 [a]	1435	23.1
SE ±	290.7	0.9
Trial-2		
7379-BH-2-1P-1H-1H-BH	2167	22.6
74433-7P-1P-3P-BP	2152	18.0
7369-2-1-1P-1P-BP	2112	20.7
L-550	1279	23.0
SE±	264.3	0.8
Trial-3		
7385-15-1-1H-1P-BP	2654	18.8
7385-15-1-1P-2H-BH	2547	18.6
7358-3-2-BP-1P-BP	2500	22.3
L-550 [b]	1062	22.6
SE ±	233.5	1.1
Trial-4		
75406-6P-1H-BH	2501	20.7
75485-11H-1H-BH	2144	25.5
7558-4-3-1P-1P-BP	2116	24.9
L-550 [a]	1633	21.8
SE±	233.1	0.9

a. Means of two entries.
b. Means of three entries.

Extending Adaptation of Chickpea

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

Early sowing. Screening of genotypes for early sowing in peninsular India was again carried out at ICRISAT Center.

Forty-seven genotypes that had performed consistently well in early-sown trials at ICRISAT Center in previous seasons were included in replicated tests sown early (mid-Sept) and at the normal time (mid-Oct), together with Annigeri and G-130 as standard checks. The early sowing established satisfactorily under rainfed conditions, but early cessation of the rains made it necessary to give a presowing irrigation to the normal sowing to ensure emergence. During this season, when rains stopped very early and no winter rains occurred, early sowing did not extend crop duration and yields were significantly lower than in the normal-sown crop. However, a number of genotypes, which had given consistently higher yields than Annigeri over two to three seasons, were identified (Table 17) and 20 crosses were made between these and other genotypes to initiate an improvement program for early sowing.

We also tested 248 germplasm accessions in four trials grouped according to growth duration. In the two trials of shorter duration materials, several lines gave higher yields than Annigeri. Their seed yield was positively correlated with plant stand. These trials will be repeated.

High-input conditions. We evaluated 500 germplasm accessions at Hissar for performance under high-input conditions. They were sown in an augmented design, received 40 kg N, 60 kg P_2O_5, and 50 kg $ZnSO_4$/ha and were irrigated twice. As with other investigations the trial suffered severe disease problems, so we plan to repeat it in 1981/82.

Late sowing in north India. Interest continues to increase in genotypes that maintain yield levels when sown late following the rainy-season

Table 17. Seed yields In kg/ha and as percent increase over the check Annigeri in early-sown trials at ICRISAT Center, 1978-81.

Entry	1978/79 Yield	1978/79 Percent increase	1979/80 Yield	1979/80 Percent increase	1980/81 Yield	1980/81 Percent increase	Mean Yield	Mean Percent increase
P-1329			1635±126	65	1461 ±121	58	1548	61
P-1067-1	1008±118	88	1696+126	67	1282±121	39	1329	61
P-4089-1	1137±118	113	1559±126	57	1057±121	14	1251	53
P-18	870± 66	18	1519+126	52	1053+121	14	1147	29

Table 18. Days to 50% flowering, seed yield, and total dry matter (kg/ha) of 10 desi and 5 kabuli cultivars of chickpea sown on 11 November and 21 December 1979 at Hissar.

	Days to 50% flowering		Yield			Total dry matter		
	Nov	Dec	Nov	Dec	Dec as % of Nov	Nov	Dec	Dec as % of Nov
Desi	82	74	1510	605	40	3069	1447	47
Kabuli	75	60	1133	759	67	2701	2387	83
SE ±	3.3	3.8	84.9	114.3		173.3	231.6	

crops—sorghum, pearl millet, maize, or paddy—as an alternative to wheat in north India.

In our study of this cropping system in 1979/80, the performances of 10 desi and 5 kabuli cultivars were compared at two different sowing dates—early November and late December.

The time to flowering was shorter in the December than in the November sowings, particularly in kabuli cultivars, most of which flowered earlier than the desis (Table 18). Seed yields were low from the November sowing, which was later than the optimum normal sowings in the region (late October). However, the December sowing yield was less than half that of the November sowing. In the late December planting, kabuli cultivars in general produced higher dry matter and seed yields than the desis, the best yields being obtained from L-550 and GL-645, suggesting that kabulis may be better adapted to late planting. Low temperatures in the early stages of vegetative growth in late plantings may explain better adaptation of kabulis, since they evolved in similar environmental conditions in the Middle East. This could be an important consideration in breeding for late plantings in northern India.

We included 21 F_1s and F_2s of crosses made in 1979/80 in a replicated test and single plants were selected in bulks of the best F_2s for progeny rows in 1981/82. In addition, desi and kabuli genotypes that had performed consistently well in late sown trials during the previous 3 years were included in tests under normal and late-sown conditions and the trial of 12 contrasting genotypes was repeated. Coefficients of variation were high due to disease and the trials will be repeated in the coming season.

Plant Type

Tall erect habit. The development of improved, tall erect plant types suited to mechanical harvesting and with possible improved yield potential continued at ICRISAT Center and Hissar.

The crosses made included a diallel set of six derivatives of previous crosses that had given yields similar to conventional types in trials at ICRISAT Center or Hissar; and a line x tester set of eight adapted lines and five original tall types.

From the progenies bulked in the F_6 and F_7 generations, we included eight lines at ICRISAT Center and six lines at Hissar in a preliminary plant type x density interaction trial. One trial comprising three tall lines and three checks (Annigeri, K-850, ICCC-4), was evaluated with and -without irrigation at ICRISAT Center to assess yield potential. In 2 years of testing, yields of the midtall types did not significantly exceed the best yielding conventional bushy cultivars (Table 19). There was no interaction of plant types with different planting densities (8,33, and 67 plants/m^2), but the derived lines in the F_6 and F_7 generations yielded as well as the conventional types. As the original tall types are very poor yielding (ICRISAT Annual Report 1976/77, Table 36, p 99), the incorporation of improved yielding ability (by means of early flowering and increased pod number) in the first cycle of crossing offers promise for further improvement. The more open canopy also contributed to reduced disease development, which will be an added advantage in more humid environments.

Double-podded and multiseeded types. Genotypes with two pods at each node have shown a yield advantage of up to 11% over normal, single-podded cultivars. Increasing the number of seeds per pod also offers the opportunity of improved yield potential.

Around 25 lines stable for the double-podded character have been identified. Among 30 multiseeded lines evaluated at ICRISAT Center, ovule number per pod ranged from 1.8 to 4.0 and seeds per pod from 1.1 to 2.2, with a mean of 1.6

Iron chlorosis causes yellowing, growth reduction, and yield loss in susceptible genotypes (*NP-62 in photograph*).

Table 19. Yields (kg/ha) of conventional and tall chickpea genotypes at ICRISAT Center and Hissar in 1979/80 and 1980/81.

	ICRISAT Center			Hissar	
Cultivar/IC No.	1979/80	1980/81	Cultivar/IC No.	1979/80	1980/81
Conventional					
Annigeri	877	2223	H-208	2645	2071
K-850	657	2048	G-130	1863	2299
Tall					
7573-4-1P-1P-BP	811	1607	7512-52-1P-3H-BH	1876	1622
7573-74-1P-3P-BP	888	1574	75123-37-2P-1H-BH	1908	2173
7573-14-1P-2P-BP	655	1360	7570-10-1P-2H-BH	1771	1809
SE ±	158.2	64.7		556.3	452.5
CV(%)	94	16		75	65

compared with 1.2 in other lines. Six lines with more seeds per pod were used in the crosses. Five lines (HMS-4,-5, -6,-13, and-23)were crossed in a diallel series to consolidate genes for the multi-seeded character, and five others were crossed with six double-podded genotypes to combine the two characters. In addition, selection was practised for the double-podded and multi-seeded characters in 61 F_2 populations and 351 F_3 progenies (ICRISAT Center) and 166 F_3 progenies (Hissar) of earlier crosses to combine the two characteristics.

Inheritance Studies

Crosses have been made to examine the inheritance of susceptibility to iron chlorosis. F_{1s} will be grown off-season and the F_2 populations will be grown in the 1981/82 season.

Cooperative Activities

International cooperative work continued through the distribution of genetic material in the form of trials and nurseries and increased contact with other programs. We are tending to tailor materials supplied for specific situations as we have learned more about problems and research capacities in chickpea-producing areas, particularly in Bangladesh and Pakistan.

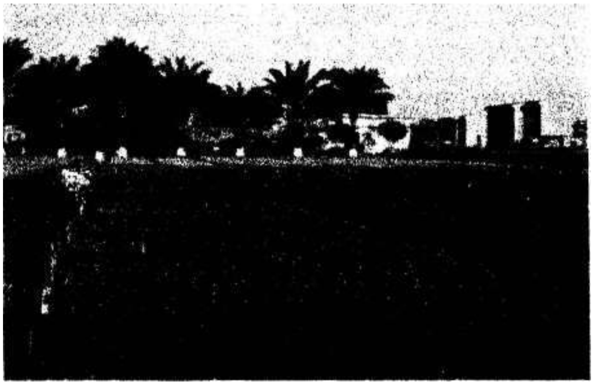
International Trials and Nurseries

We sent 132 sets of trials and nurseries to 57 cooperators in 24 countries, mainly India (Table 20).

Table 20. International chickpea trials and nurseries distributed by ICRISAT in 1980/81.

Country	F_2MLT	F_3MLT	ICSN-DS	ICSN-DL	ICCT-DS	ICCT-DL	ICAT	ICRRWN	Total
Argentina								1	1
Australia								2	2
Bangladesh	2	1	3		3			1	10
Bulgaria							1		1
Burma			1		1				2
Chile								1	1
Egypt								1	1
Ethiopia			1		2			2	5
Honduras			1						1
India	10	12	12	16	5	5	2	14	76
Iraq								1	1
Japan							1		1
Malawi							1		1
Mexico			1		1	1		1	4
Muscat							2		2
Nepal								1	1
Pakistan	1	3		2		2		1	9
Peru								1	1
Philippines					1				1
Sudan							1	1	2
Tanzania					1				1
USA							1	4	5
YAR					1			1	2
Zambia							1		1
Total	13	16	19	18	15	8	10	33	132

Trials of F_2 (F_2-MLT) and F_3 (F-MLT) populations were continued to identify crosses exhibiting stable performance across environments and to make available segregating materials for selection for local adaptation. The mean seed yields of populations of crosses common to 1979/80 and 1980/81 are shown in Table 21. Crosses IC-771084 and -77429 performed well in both seasons. The results were more consistent than reported last year, but the yields of some crosses varied considerably between years, confirming the need for tests in more than one season. International chickpea screening nurseries of short- (ICSN-DS) and long- (ICSN-DL) duration desi genotypes were sown as augmented designs with 60 and 80 test entries, respectively. At most sites there were entries giving significantly higher seed yields than the best checks. Among the short-duration group, ICCL-80074 gave the highest yield and appeared among the top 10 entries at 8 of the 10 locations. In the long-duration trial, ICCL-80082 was the highest yielder and ranked in the top 10 in 5 out of 9 locations. The best entries will be included in international and coordinated trials in 1981/82.



ICRISAT 1980/81 chickpea trials and nurseries at Ishurdi in Bangladesh.

The International Chickpea Cooperative Trials tested 16 lines of short- (ICCT-DS) and long- (ICCT-DL) duration desi types. Two long-duration entries, ICCL-79065 and -79090, will be submitted for coordinated trials, and others will be repeated in international trials in the coming season.

Table 21. Seed yields (kg/ha) and ranks of F_2 (1979/80) and F_3 (1980/81) populations in trials at several locations in India.

IC/ICC No.	Pedigree	F_2MLT[a]		F_3MLT[b]	
		Yield	Rank	Yield	Rank
77429	T-3xH-223	1303	2	1566	3
77441	H-208xH-223	1155	8	1556	4
77474	Pant G-114xK-4	1284	4	1375	12
77768	Annigerix (JG-71xP-45)	361	14	1518	6
77794	ICCC-1x(P-36xNEC-550)	1228	6	1571	2
77865	ICCC-2x(7332-7-2-3xP-2713-1)	1241	5	1383	11
77867	Pant G-114x(73111 -8-2-B-BHx JM-482)	1117	10	1550	7
77882	BG-203x(P-1198-1xOfra)	1065	11	1299	14
77892	Pant G-115x(P-82xp-9800)	1175	7	1386	10
771079	Pant G-115 P-1353	1291	3	1554	5
771084	ICCC-4XP-1353	1426	1	1666	1
771135	F_2(12-071-05093xP-2974)-2xF_2(P-1231xp-1214)-2	1141	9	1461	9
4918	Annigeri	900	13	1481	8
4948	G-130	1059	12	1331	13

a. Means of seven environments.
b. Means of six environments.

International disease nursery. Detailed results of the International Chickpea Root Rots and Wilt Nursery (ICRRWN) for 1979/80 are available separately (Pulse Pathology Progress Report No.11). We sent 56 entries originating in four countries and in ICRISAT Center to 35 locations in 19 countries. Data were returned from 21 locations in 19 countries. Three entries (ICC-2072, ICC-7248, and GG-588) performed well across 10 locations, and eight entries (ICC-102, -267, -3099, -3439, -7254, -7681, ICCC-10, and GG-669) did well across nine locations. All other entries also did well across several locations.

Distribution of Breeders' Material

In addition to the nursery and trial sets, we supplied 1655 samples of parental lines and segregating populations to breeders in India and elsewhere during the year.

Cooperation with ICARDA

This year one of our entomologists again spent several weeks with ICARDA at Aleppo, Syria, where he cooperated in pest management studies. He reported that the leaf miner, *Liriomyza cicerioa,* was much more damaging than during the previous year, both on the ICARDA research farm and in local farmers' fields. There was also a higher incidence of *Heliothis* spp on the crop this year. *H viriplaca* was more common than *H. armigera.* The former has a very marked pupal diapause. Several of the pupae that were collected as larvae from the fields in May 1980 and pupated at that time did not produce moths until March 1981. Two species of braconid parasites were recorded from the *Heliothis* larvae, one of which appears to be a new record for that region.

Nearly 4000 desi germplasm accessions were screened for ascochyta blight resistance at Tel Hadya. F_1s of crosses between north Indian lines and seven lines resistant to *Ascochyta* in Pakistan were supplied for off-season multiplication at Terbol and screening for resistance in 1981/82. We also supplied seed of 101 advanced kabuli lines for inclusion in ICARDA nurseries. See the "International Cooperation" section of this Annual Report for a fuller review of our cooperative work at ICARDA.

Cooperation with AICPIP

We contributed three new entries (P-324, ICCC-23, and ICCC-24) to the Gram Initial Evaluation Trial, and ICCC-4 and ICCC-13 continued in the Gram Coordinated Variety Trial in peninsular and central India for the 3rd year. In the relatively dry season, the two entries, which are medium duration, performed poorly in the peninsular trials, but reports from central India indicate that they have maintained previous years' performance in that region. Three kabuli lines (ICCC-24, -25, and -26) were included in the kabuli coordinated trial. One set each of the desi coordinated trials was grown at ICRISAT Center. For 1981/82 we are submitting five new desi and three kabuli lines for inclusion in the coordinated trials.

Looking Ahead

The quantitative breeding methods utilized during the past 3 years will be evaluated. Characterization of environments will permit us to focus on more specific objectives with regard to physiological adaptation and disease resistance, particularly in nontraditional situations such as early sowing in south India, late sowing with increased inputs in north India, and winter plantings in the Mediterranean and Middle East areas. We will give greater emphasis to incorporating resistance to ascochyta blight and botrytis gray mold into adapted backgrounds and to breeding for combined resistance to the major pathogens. The incorporation of *Heliothis* resistance into high-yielding backgrounds and the improvement of existing levels of resistance will also receive increased attention. Work on identification of efficient strains of *Rhizobium* will continue.

Publications

Institute Publications

ICRISAT. 1980. Proceedings, International Workshop on Chickpea Improvement, ICRISAT, 28 Feb-2 Mar 1979, Patancheru, India (Eds. Green, J.M., Nene, Y.L., Smithson, J.B., and Garver, Cynthia). 298 pp.

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PIGEONPEA

Contents

PIGEONPEA

The pigeonpea improvement program continued pursuit of its basic objective: the development of cultivars and broad-based populations of early-, medium-, and late-maturity pigeonpeas capable of providing higher and more stable yields in traditional and nontraditional cropping systems. This report covers the data for the 1980 rainy-season crop plus some of the 1981 data for the early-maturity pigeonpeas at our Hissar cooperative research station; the remaining data for the 1981 rainy season are still being processed and will be presented in next year's Annual Report.

Our major activities were concentrated at four locations: (1) ICRISAT Center at Patancheru (17°N; 760 mm rainfall), where emphasis is on the development of medium-maturity types for intercropping with major cereals in central and peninsular India; (2) Hissar station (29°N; 350 mm rainfall) for development of early-maturity pigeonpeas suited as sole crop with limited irrigation in pigeonpea-wheat rotations, a new cropping system of northwestern India; (3) Gwalior station (26°N; 900 mm rainfall) for long-duration types suited to intercropping systems in the northeastern region; and (4), through contract research, at the University of Queensland, Brisbane, Australia, (27°S; 1092 mm rainfall), where the primary objective has been the development of short-season pigeonpeas and mechanized production systems in extensive dryland agriculture.

During the 1980 season, northwestern India, with a short rainy season and few disease and insect problems, remained the most productive environment for early-maturity pigeonpea crops. Time of maturity is very critical in this region, as late maturity would delay the wheat sowings and could result in frost damage to the pigeonpea crop.

In central and peninsular India the medium-duration crop again suffered from wilt and sterility mosaic diseases and from pod borer attack. The lack of genotypic stability across years was further affected by the early cessation of rains.

In the northeastern region, sterility mosaic, wilt, and podfly were the major yield reducers. Heavy rainfall in July delayed the plantings in farmers' fields and also resulted in considerable damage to the earlier sown material in trials at most of the experiment stations. Thus, no results on the multilocation tests were obtained from our cooperators in this region. The postrainy-season pigeonpea crop, which is gaining rapid acceptance by farmers, suffered badly from leaf diseases.

Diseases

Surveys

Since 1974 we have conducted roving surveys to identify important pigeonpea diseases, in most of the Indian states. This year we surveyed the two remaining Indian states (Orissa and West Bengal) and four African countries: Kenya, Malawi, Tanzania, and Zambia. In Orissa macrophomina stem canker and sterility mosaic were important, while in West Bengal phytophthora blight and wilt were common. Wilt was found to be a serious disease in Kenya, Malawi, and Tanzania. Cercospora leaf spot was common in Kenya and Malawi and powdery mildew was important in Kenya, Tanzania, and Zambia.

Wilt

Our major effort against wilt, which causes serious losses worldwide, has been to identify sources of resistance and use them in the breeding program.

Screening for resistance. Of the 13 early-maturity pigeonpeas selected at Hissar, 4 were found to have promising resistance and will be tested again. An additional 2000 germplasm accessions were screened, and only 48 were identified as promising. Of the wild relatives of pigeonpea, *Atylosia volubilis* was found resistant.

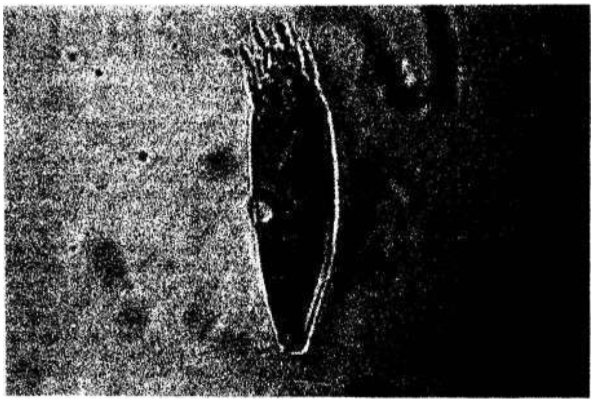
In our efforts to develop high-yielding, wilt-resistant material, we evaluated 105 medium-maturity lines in a preliminary yield observation nursery. Of these, six lines gave higher yields than the check cultivar, C-11; these will be re-evaluated in a replicated yield trial. ICPL-270—a wilt-resistant, high-yielding selection from AS-71-37, which remained resistant for three consecutive years in the wilt-sick nursery—was entered in the 1981 Arhar Coordinated Trial-2 (ACT-2).

Having obtained true-breeding, wilt-resistant lines, we made crosses between resistant and susceptible parents to determine the inheritance of resistance.

Influence of crop rotation and intercropping. In cooperation with ICRISAT's cropping systems scientists, a 4-year experiment to study the effect of crop rotation and intercropping of pigeonpea was started in the 1978/79 season. In the 2nd year, pigeonpea intercropped with sorghum had 24% wilt, in contrast to 85% in the continuous sole crop treatment. We also observed that 1 year's break between pigeonpea crops by fallowing, or by growing crops like sorghum or tobacco, reduced the wilt to 22%, 20%, and 44%, respectively.

Sterility Mosaic

Causal agent. The causal agent of sterility mosaic is not known; it is believed to be a virus. The causal agent is transmitted by an eriophyid mite, *Aceria cajani* Channabasavanna. Because it is not possible to transmit the causal agent mechanically, it has been difficult to establish its viral nature. This year we intensified our efforts to purify the causal agent, and we obtained at various times four different viruslike particles (short, stiff rods; long, thin stiff rods; long, thin flexuous rods; and rhabdovirus). Our efforts to establish the cause will continue.



Aceria cajani, *the vector of sterility mosaic of pigeonpea.*

Biology of the vector. We continued our study of this subject. Viruliferous mites retained their infectivity up to 72 hr without access to a susceptible host. The mites' eggs, detectable on the vegetative tips of a number of plants, are oval, milky white and transluscent, and slightly smaller than the trichome glands. The eggs measure 30 x 40 μ and are loosely fastened, usually to a trichome. They usually hatch after 4 to 5 days. The female mites exhibited a short preoviposition period of between 24 and 27 hr, then laid 1 to 3 eggs almost daily. Further studies will continue.

The mites, which are carried by wind, were able to spread the disease up to at least 450 m in the windward direction. However, against the wind, the mites did not spread the disease even to 25 m. Studies will continue to determine the maximum distance to which mites can spread the disease.

Infector-hedge technique. In previous years we used the spreader-row technique in which several intermittent rows of a susceptible line were planted 4 to 6 months in advance of planting the test material. The spreader rows were staple-inoculated in the seedling stage with viruliferous mites and maintained by irrigating them through

Screening for sterility mosaic of pigeonpea by the infector-hedge technique. The hedge of infected plants is to the right of the test lines.

the summer season (see "ICRISAT Center's Research Environment" at the front of this Annual Report). This year we modified this technique and developed the infector-hedge technique. This consisted of advance planting of only four rows of a susceptible cultivar at one side of the field. The direction of the rows was across the usual wind direction. Plants in these four rows were staple-inoculated and mites were allowed to multiply. By the time the normal planting date approached, these rows had developed into a hedge. The disease spread was excellent (indicator rows had 99.4 to 100% infection), and we were able to screen 2 ha of breeding material downwind from the infector hedge. This technique is much simpler than the spreader-row technique.

Screening for resistance. We screened 433 new germplasm lines and found one line, ICP-10819 (PI397630), to be resistant. Selecting and rescreening resistant plants from segregating germplasm lines enabled us to purify 40 additional germplasm lines for resistance. The large amount of breeding material screened this year included 41 F_2 bulks involving resistant and agronomically good lines, backcross progenies of male-sterile and resistant lines, inbred lines, F_7 progenies, and short-duration material for Hissar. Nine of the F_7 progenies of the cross C-11 x ICP-6997 were found uniformly resistant and agronomically acceptable. Eighty-one lines, which were found to be less susceptible to pod borer or podfly, were screened against sterility mosaic. Four lines (MLT-28, ICPL-100-EB, ICP-8583-E1-EB-EB, and ICP-7176-5-E1) showed less than 10% sterility mosaic. Of the 16 entries in an All India Coordinated varietal trial, ICRISAT's early-maturity entry, ICPL-86, was the only one to have a promising level of resistance to sterility mosaic.

Several sterility mosaic resistant lines of medium maturity outyielded the standard adapted cultivar C-11, even without disease pressure. A multilocation sterility mosaic resistant lines test is being conducted in 1981 with 22 of our most promising lines, along with a tolerant check (ICP-2376) and a susceptible check (C-11). In addition, a multilocation yield nursery of sterility mosaic lines was planted in 1981 with 20 F_8 progeny bulks, which showed less than 10% sterility mosaic incidence, from a highly promising cross C-11 x ICP-6997.

Phytophthora Blight

Epidemiology. How the fungus *Phytophthora drechsleri* f.sp. *cajani* survives from one season to another is not known. In our studies to answer this question, we collected 5-cm-long stem pieces with lesions from field-infected plants. In one experiment the infected stem pieces were planted both on the surface and 2.5 cm below the surface in two soil types (Alfisol and Vertisol) in 20-cm pots, which were kept in the open. Two sets of pots were prepared; one set was watered every 15 days and the other was not. In another experiment the infected stem pieces were kept in gunny bags; one set of gunny bags was kept in a storeroom (21-44°C) and the other in a cold room (18-20°C). In stage 2 of both experiments, the survival of the fungus was tested every month by placing the infected stem pieces from each set on the surface and 2.5 cm below the surface in the two soil types in earthen pots. The blight-susceptible cutivar Hy-3C was sown (2 cm deep) in all treatments every month immediately after placing the infected pieces in the pots. Survival of the fungus was indicated by the appearance of blight disease on the plants.

The results indicated that the fungus could survive in the infected pieces only up to 3 months (Table 1). Normally there is more than a 3-month gap between the harvest of pigeonpea and the next season's planting. It is therefore doubtful whether the survival of the fungus on infected stem pieces plays any role in bringing about primary infection in the field.

Screening for resistance. We pot-screened breeders' lines for *Phytophthora* (P_2 isolate) and identified 14 resistant inbred lines of ICP-1, 1 of ICP-7120,5 of ICP-102, and 44 of ICP-7065. Of the 138 *Phytophthora*-resistant F_5 progenies evaluated in unreplicated plots, 8 gave higher yields than the standard adapted cultivar, C-11. These lines will be reevaluated in a replicated yield test during the 1981 rainy season.

Fungicidal control. Metalaxyl (Ridomil), an acylalanine compound, has been reported to be very effective in controlling diseases caused by Phycomycete fungi, of which *Phytophthora* is a member. We therefore initiated studies to explore the possibility of using metalaxyl to control phytophthora blight. Although foliar sprays were effective, we did not pursue work on this method of application because the pigeonpea farmers usually have limited resources. Instead, we concentrated on seed dressings with metalaxyl (5 g/ kg seed) and obtained excellent control of blight in greenhouse conditions. However, seed dressing did not give sufficient protection under conditions where the disease developed in the field.

Multiple-Disease Resistance

For yield stability and wide adaptability of genotypes it is essential to develop cultivars with combined resistance to all the above three diseases. We made 119 crosses exclusively to incor-

Table 1. Survival of *Phytophthora drechsleri* f.sp. *cajani* in infected stem pieces stored under different conditions, as shown by the appearance of blight on susceptible cultivar Hy-3C.

Tested pathogenicity periods (months)	Placement of blight-infected stem pieces[a]	Soil type	Percent seedlings blighted: Stored in soil, With watering	Stored in soil, Without watering	Stored in bags, Storeroom (21-44°C)	Stored in bags, Cold room (18-20°C)
1	Surface	Alfisol	43.7	33.3	31.2	10.5
		Vertisol	25.0	7.7	5.0	13.6
	2,5 cm deep	Alfisol	29.4	31.2	33.3	7.1
		Vertisol	4.3	0.0	11.0	20.8
2	Surface	Alfisol	4.2	34.8	0.0	4.3
		Vertisol	0.0	3.8	7.4	3.8
	2.5 cm deep	Alfisol	17.8	0.0	26.9	7.1
		Vertisol	29.4	6.2	4.8	12.0
3	Surface	Alfisol	0.0	0.0	0.0	0.0
		Vertisol	0.0	0.0	0.0	0.0
	2.5 cm deep	Alfisol	5.0	0.0	4.2	56.0
		Vertisol	0.0	0.0	.0.0	19.3
4 to 12	No blight incidence in any treatment.					

a. Twenty-five infected stem pieces were used for each treatment.

porate all three disease resistances into good agronomic backgrounds. We will advance these crosses in our multiple-disease nursery. A backcross program is also in progress to incorporate sterility mosaic resistance into BDN-1, an adapted cultivar resistant to wilt and *Phytophthora.* Similarly, backcrosses were made using sterility mosaic resistant advanced lines from the cross C-11 x ICP-6997 and as the recurrent parent ICP-11292, a wilt-resistant selection from the standard adapted cultivar C-11.

Four F_6 and F_7 lines from the cross ICP-6997 x ICP-7065, three from the cross ICP-7035 x ICP-7065, and one F_6 line from the cross Hy-3C x ICP-7065, which were all originally selected for *Phytophthora* resistance, were found to possess combined resistance to all three diseases in the multiple disease nursery. These lines will be yield-tested in a replicated test and rescreened in the multiple-disease nursery during the 1981 rainy season.

In addition we made 36 F_7 single-plant selections of late maturity showing resistance to all three diseases. These selections will be evaluated at Gwalior for their yield potential.

Promising short-season lines were also screened for their resistance to the three diseases. A wilt-tolerant (3.6% wilt) line, ICPL-95, was the second top yielder in peninsular India. Thirteen early maturing, advanced lines were found to have less than 5% sterility mosaic in the disease nursery and several lines showed less than 5% phytophthora blight in pot culture screening. Three promising lines with less than 5% sterility mosaic and blight incidence were selected for further evaluation of their yield and disease resistance.

Insect Pests

Surveys

Since 1975 we have been surveying farmers' fields in the 15 states which cover the major pigeonpea-growing areas of India. These surveys, completed in 1981, have covered 1460 fields. We timed our visits to farmers' fields so that we could collect nearly mature pod samples for examination. Some of our observations are discussed below; we will publish the detailed data from these surveys separately.

Sorting pigeonpea pods into various pest damage categories is a skilled and time-consuming task.

Table 2 gives a summary of the data from the pod samples collected by us during our surveys. For convenience, we classified the 15 Indian states covered in our survey into four broad zones (Fig. 1). The damage caused by pod borers, the most important of these being *Heliothis armigera,* was most severe in the south zone. The podfly, *Melanagromyza obtusa,* was most damaging in the late-maturing crops, which are mainly grown in the north zone. Of the 100 or more minor pests of this crop, only the damage caused by bruchids and Hymenoptera was separately assessed (Table 2). It is evident that bruchids can cause substantial damage to seeds in pods in the south zone, particularly if the pods are not harvested soon after ripening. They then infest the stored crop and are capable of destroying it completely within 6 months, unless suitable precautions are taken. The hymenopteran pest, *Tanaostigmodes* sp appeared to cause little harm in farmers' fields, but can build up to very damaging populations on research stations where selective pesticides are used.

Table 2. Insect pest damage to pigeonpea pods in various zones in India, 1975-81.

Zones	Borers	Percent pod damage			Total
		Podfly	Bruchids	Hymenoptera	
I Northwest Zone (Early-maturing pigeonpea) (n=49)	29.7	14.5	0.05	0.03	44.0
II North Zone Above 23°N (Late-maturing pigeonpea) (n=359)	13.2	20.8	0.2	0.5	33.8
III Central Zone 20°-23°N (Mid- and late-maturing pigeonpea) (n=446)	24.3	22.3	2.2	1.6	48.0
IV South Zone Below 20°N (Early- and mid-maturing pigeonpea) (n=443)	36.4	11.1	6.7	2.2	49.9

n=No. of samples analyzed for pest damage.

In the northwestern states of Haryana and Punjab there has been a rapid expansion of early-maturing pigeonpeas. The crop matures just before the winter and escapes much of the podfly damage that caused severe damage to the late-maturing crops previously grown in these states. The damage caused by borers to the early-maturing crops is variable, but of obvious concern. We will monitor the pest problems on the early-maturing pigeonpea at Hissar in Haryana and will work on their management.

The pod damage due to insects amounts to a loss of more than 30% of the crop over much of India, and the loss in southern India is much higher. Besides this, the pests also cause the drop of flowers and young pods. We often treble the yields at ICRISAT Center by using pesticides on pigeonpea. Only 6% of the surveyed farmers' crops had been treated with pesticides, and on almost all of these the organochlorines DDT and/or BHC had been used.

In the 1980/81 cropping season the *Heliothis* populations, both at ICRISAT Center and across most of southern and central India, were much lower than in previous years, but another borer, *Maruca testulalis,* caused extensive damage in some parts of central India.

We take every available opportunity to learn more about the pests of pigeonpea in the many countries in which it is an important crop, not only through tours and visits but also by correspondence with entomologists in those countries. It appears that in most of these countries little attention is paid to the insect problems on pigeonpea, for the entomologists there mainly concentrate on the cash crops and major cereals. Our visits this year to several countries in southern and eastern Africa confirmed our earlier observations that *H. armigera* is the major pest of pigeonpea in that region but that several other pests, including sucking bugs, can also be very damaging. The podfly commonly found on

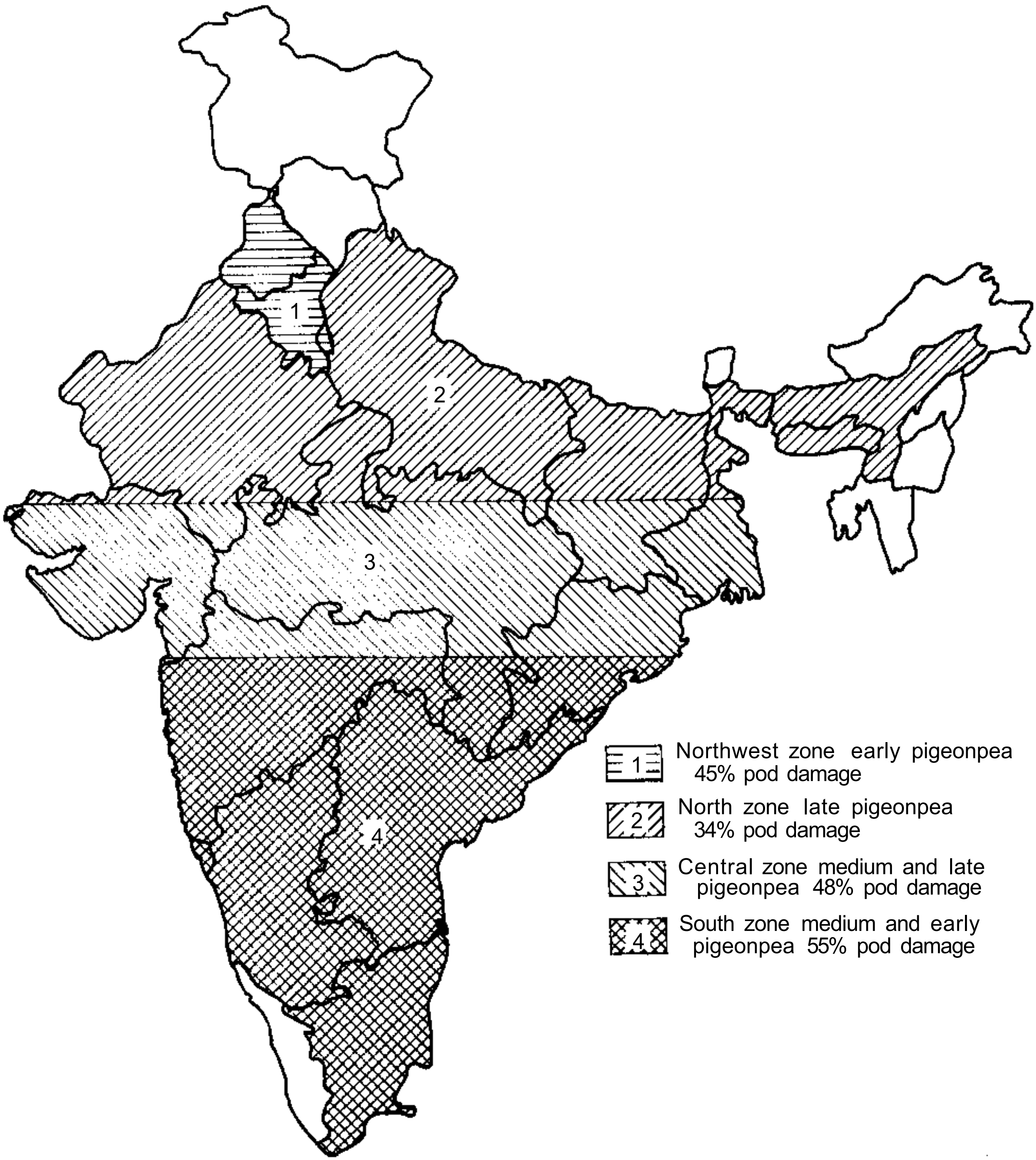


Figure 1. Pigeonpea-growing zones in India based on pest damage assessments, 1975-81.

crops in that region was identified as *Melanagromyza chalcosoma.*

Heliothis

Populations. *H. armigera* is the most important pest of pigeonpea in virtually all countries in which this crop is grown, except in the Americas, where other species of this genus are the dominant pests. *Heliothis* attacks not only pigeonpea but also a wide range of other crops and weeds. It can be damaging on all the mandate crops of ICRISAT, Therefore, to understand and manage *Heliothis* populations we need to study the pest not only on pigeonpea but also on its alternative hosts throughout the year. This year we formulated a new project in which we will monitor *Heliothis* populations across host plants and areas of India with the eventual objective of predicting the sizes and timing of the populations. Preliminary data were calculated from the records compiled by our pest control surveillance unit over the past 2 years (Fig. 2). A surprising feature of these data was the large populations of larvae on groundnuts early in the season. Although we found relatively few larvae per groundnut plant, the large numbers of plants per unit area resulted in many *Heliothis* per unit area. The larvae probably cause little loss to the groundnut crop, for they feed mostly upon the leaves and this loss is rapidly compensated by the plants. The moths resulting from the larvae feeding on groundnuts, sorghum, and millet in August and September may then disperse and lay eggs upon pigeonpea crops in October and November. However, we also suspect that moth migration may have an effect on the populations of *Heliothis* both at ICRISAT Center and across India.

The obvious vulnerable period for this pest at and around ICRISAT Center is during the end of the hot dry season (May) when very few larvae are found, particularly on our farm where we observe a closed season and destroy all plants that can act as hosts for *Heliothis* during that period. Our observations in the district surrounding ICRISAT Center indicate that irrigated tomatoes act as the major host for *Heliothis* larvae through this period. Thus, intensive pest control on the tomato crop in May-June should greatly reduce infestations on the more important crops later in the season, but only if diapause or migration are not important factors in determining local populations. Our preliminary observations indicate that *Heliothis* does not survive the dry season as diapause (quiescent) pupae in any measurable numbers.

To help monitor the populations of *Heliothis* across India, we have placed a series of light traps at several locations in cooperation with the ICRISAT cropping systems entomologist and the entomologists in various Indian Universities and Institutes. Light traps are, however, expensive both in terms of equipment and recording time, and we are now investigating the possibility of substituting these with pheromone traps, which are less expensive, attract only *Heliothis* moths, and can be used in locations where there is no electric power supply.

However, before we can utilize pheromone traps in our pest monitoring studies, we must standardize their design and correlate their catches with both light trap catches and field records of *Heliothis* larvae populations. We have this year initiated such an exercise both at ICRISAT Center and at several of the locations where *Heliothis* is being recorded from light traps. To be of use in monitoring populations, the trap catches must be well correlated with field populations. Up to now we have not been satisfied with the light trap catch data vs field population correlations. The greatest correlations ($r = 0.6$) were those associated with counts of larvae on crops 2 weeks before the trap catches, and correlations of catches with field counts 2 weeks later have been no greater than $r = 0.4$. Such data indicate that our light traps are of limited value in warning us of impending infestations, but rather better in telling us that there has been an infestation.

We are testing pheromone traps in cooperation with the Tropical Products Institute, London, which supplied us with rubber septa impregnated with synthetic pheromone. The traps that we are currently using are modified from a design supplied by the Center for Over-

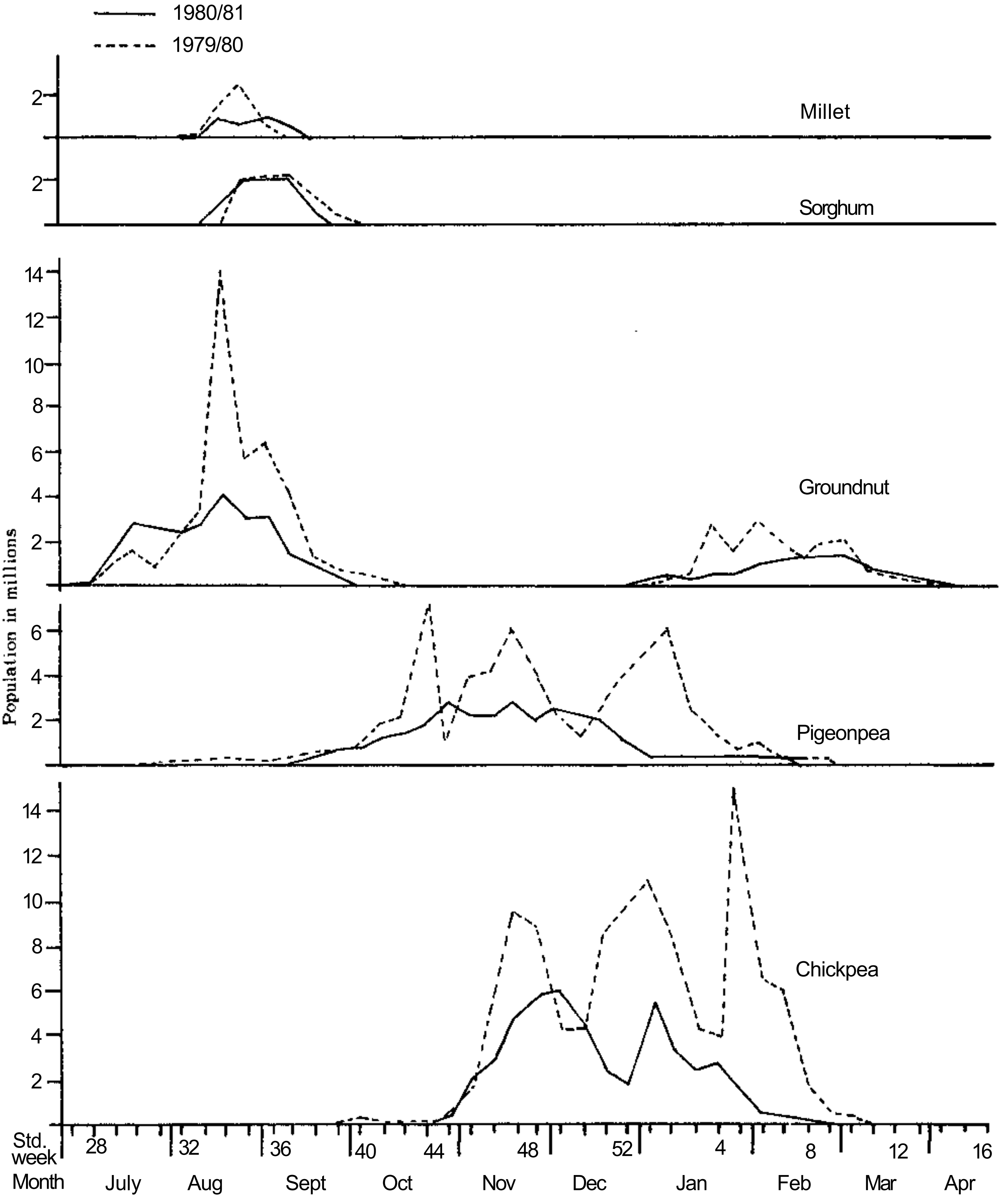


Figure 2. Populations of *Heliothis armigera* larvae on crops in the pesticide -protected area at ICRISAT Center.

seas Pest Research and made from locally obtained cheap material.

Plant spacing and *Heliothis* damage. In previous years (ICRISAT Annual Report 1978/79, p 103) we found that close spacing of pigeonpea crop tends to give high populations of *Heliothis* larvae per unit area. This year we tested two midmaturity cultivars, ICP-2223-1 (a selection with relatively low susceptibiity to *Heliothis* attack) and PPE-50-1 (a selection with high susceptibility) at two spacings in trials in pesticide-free fields on both Alfisol and Vertisol areas at ICRISAT Center. As in previous years, the number of *Heliothis* larvae per unit area was greater in the close spacing, but this year this difference was not reflected in increased percentage of pod damage. The yields from the close-spaced crop were much greater than from the wide-spaced one, particularly on the Alfisol area (Table 3).

We obtained similar results from another trial in which two other selections were tested at two intrarow spacings. In previous years the close-spaced crops were more heavily damaged than those at wide spacings, but not this year, probably because the *Heliothis* populations were unusually low.

Resistance to *Heliothis.* As we previously noted in our Annual Report 1979/80, p 109, the development of *Heliothis*-resistant plants is particularly difficult in pigeonpea. However, we have made steady progress in this project and now have several selections that have shown consistently less pod damage than the common checks of the same maturity class in each year of test. The level of resistance so far obtained has been inadequate, so our breeders are now crossing our best selections in an attempt to increase resistance levels. We also made further progress in selecting from among the derivatives of crosses between pigeonpea and its wild relative *Atylosia scarabaeoides,* which is markedly resistant to *Heliothis.*

This year we screened 440 new germplasm accessions, bringing the total screened so far to nearly 8000. The most promising of these have been carried forward to replicated testing in the 1981 season. Our most promising advanced materials were sent to 13 cooperators for testing in 1980 under the All India Coordinated Pulses Improvement Project (AICPIP), but data from these tests were incomplete, for many trials were ruined by drought or floods. The percentages of borer damage in pods harvested from our early-maturing selections are shown in Table 4. Though it is evident that the data were quite variable, PPE-45-2 was consistently less damaged than the check. This selection has also been less damaged than the checks in each of the past 4 years of test at ICRISAT Center.

In our midmaturity trials some selections, including ICP-2223-1, performed well over all locations and gave good results over several tests and years at ICRISAT Center. We filled requests for our best materials from several cooperators both within and outside India.

Table 3. Effect of plant spacing on insect-caused damage and yield in two pigeonpea cultivars grown on Alfisol and Vertisol at ICRISAT Center, 1980/81.

Selection	Spacing	Percent pods damaged		Grain yields (g/m^2)	
		Alfisol	Vertisol	Alfisol	Vertisol
ICP-2223-1	75x30 cm	24.2	21.8	120	114
	37.5x20 cm	19.9	22.6	255	122
PPE-50-1	75x30 cm	24.3	26.1	108	93
	37.5x20 cm	23.0	27.7	256	108

Biological control. We continued to monitor the natural enemies of *Heliothis* in our fields with a view to augmenting the biological control of this pest either by the introduction of exotic natural enemies, or through the encouragement of the natural control by changing cultural practices.

The previous ICRISAT Annual Report (1979/80, p 113-114) described our progress and success in laboratory rearing of *Eucelatoria* sp, a tachinid parasite of *Heliothis* from the USA. This year we conducted preliminary trials on the best means of releasing this parasite in our fields. We compared the field emergence of parasites from freshly parasitized *Heliothis* larvae and from parasite puparia that were obtained from *Heliothis* larvae kept in the laboratory. The parasite emergence was very low from the parasitized *Heliothis* larvae placed in containers in the fields, possibly because the temperatures were too high or the humidity levels too low.

Heliothis larvae collected from pigeonpea and chickpea crops were exposed to *Eucelatoria* in our laboratory. Both groups were highly susceptible, with 83% of the larvae from pigeonpea and 86% from chickpea being parasitized. However, in field cages we obtained a very different result. We fixed large cages over pigeonpea and chickpea crops in the field, placed 200 *Heliothis* larvae on the plants inside each cage, and then released 40 *Eucelatoria* flies into each cage. Three days later we collected all the larvae that we could find in each cage and brought them into our laboratory for observation. Two such trials were conducted and the data are reported in Table 5.

The parasitism rate in larvae on pigeonpea was reasonable in both tests, but was very low in

Table 4. Borer damage assessment in early-maturing pigeonpea selections tested at various locations in India during the 1980/81 rainy season.

Selections tested	Percentage of pods damaged by borers			
	ICRISAT Center	ICRISAT Subcenter, Hissar	AICP1P Centers	
			Jabalpur	Pantnagar
PPE-45-2	18.1	8.0	12.2	15.9
Sehore-197	29.8	22.0	14.5	24.6
T-21 (check)	33.3	15.2	20.2	16.6
ICP-7349-1-S4	28.2	8.2	19.5	19.8
ICP-7203-E1	28.2	11.8	31.2	14.4
ICP-1914-E2	17.2	28.4	17.0	25.8
SE ±	3.30	1.93	5.21	4.09
CV (%)	25.7	26.2	56.6	42.0

Table 5. Susceptibility of *Heliothis* larvae feeding on pigeonpea and chickpea to *Eucelatoria* parasitism in field cage tests at ICRISAT Center.

	Test 1		Test 2	
	Pigeonpea	Chickpea	Pigeonpea	Chickpea
Heliothis larvae released	200	200	200	200
Heliothis larvae recovered	31	61	135	78
Parasitism in recovered larvae (%)	32.3	4.9	23	0

chickpea. It is possible that the parasite, like many potential pests, was deterred by the acid exudate on chickpea.

Podfly

Populations. The podfly, *Melanagromyza obtusa,* is the second most damaging pest of pigeonpea in India (see Table 2). In 1981 we embarked upon a more intensive study of this pest and its management. In most areas this pest builds up through the season to become most damaging upon the late-maturing cultivars but is then reduced to low populations by the hot, dry summer season. At ICRISAT Center we find that the pest can survive on pigeonpea throughout the year in irrigated experimental plots, but for most of each year there are no pigeonpea pods available in farmers' fields in most areas. We had previously identified some alternative hosts of this pest including *Atylosia* spp, two species of *Rhynchosia,* and one of *Tephrosia.* This year we found that a few more species of *Rhynchosia* could act as host for this pest: *R. rothii, R. bracteata, R. suaveolens,* and *R. cana.* We are now attempting to quantify the populations of the podfly through the year on pigeonpea and on its alternative hosts at ICRISAT Center.

Rhyncosia bracteata *pods showing black shriveled seeds damaged by podfly. This and other wild legumes can play an important role in maintaining populations of this major pest of pigeonpea for experimental work.*

Resistance to podfly. Our screening of plants for resistance to podfly has given us more consistent progress than the search for resistance to *Heliothis.* We have now several selections that have consistently shown less podfly damage than the relevant check cultivars. Some of these lines are now being utilized in a breeding program designed to intensify resistance and to determine its inheritance.

Entomologists and biochemists at ICRISAT and the Max-Planck Institute for Biochemistry at Munich are attempting to determine the mechanisms responsible for resistance. We earlier showed that when the young pods of some cultivars are washed with water, they become more susceptible to egg laying by podfly, so we have been analyzing the pod wall exudates of our susceptible and resistant selections.The washed and unwashed pod wall tissue and washings were analyzed for soluble nitrogen, total nitrogen, total soluble sugars, and total phenolic compounds.

Total soluble sugars of tender pods were found to be inversely related to the susceptibility of the pigeonpea lines to podfly. This observation indicates that tender pods of less susceptible lines may have more soluble sugars. In some tests, more phenolic compounds were found in the pod washings of less susceptible lines than in those of the highly susceptible lines. These observations are based on our past 2 years' data, but further in-depth study is needed to confirm these results.

Natural control. All stages of the podfly, with the exception of the adult, are concealed within the pod, where they are protected from natural enemies and most pesticides. There are some parasites of this pest, however, and *Euderus* spp have earlier been reported in podfly pupae. Our studies of podfly pupae collected from several locations across India have now revealed two more genera of parasites, *Ormyrus* and *Eurytoma.* We are now cooperating with national scientists in a survey of the parasitism of podfly at several locations across India.

Other Pests

Pigeonpea plants are host to very many insect species, several of which can assume pest status in particular seasons and locations. From the early seedling stage, pigeonpea provides food for insects, which in turn are hosts for a complex of natural enemies, including parasites and predators. We monitor the minor pests and their natural enemies partly in the hope that pests of the young plants, such as *Eucosma critica,* will act as hosts to parasites that will transfer to *Heliothis* larvae. Our studies, however, now indicate that few, if any, of the many species of parasites that we have recorded on the minor pests are also recorded on *Heliothis.*

Nodule-damaging fly. Our studies of the nodule-damaging fly *Rivellia angulata* have led to a better understanding of the timing of adult populations, through records of catches from the traps that we have developed. From May 1981 we placed cages over soils that were cropped in the previous season with pigeonpea, sorghum, and the intercrop of these two crops. We found that flies emerged from the soil in the period between June and September. More flies emerged from the soil that had been cropped with pigeonpea (8.4/trap per week) than from soil that had the intercrop (2.7) or had grown sorghum (1.2). We suspect that these pests are carried over in the soil from one season to the next as diapause pupae. The few flies emerging from soil that had been cropped with sorghum may have been associated with nodules on leguminous weeds in that crop.

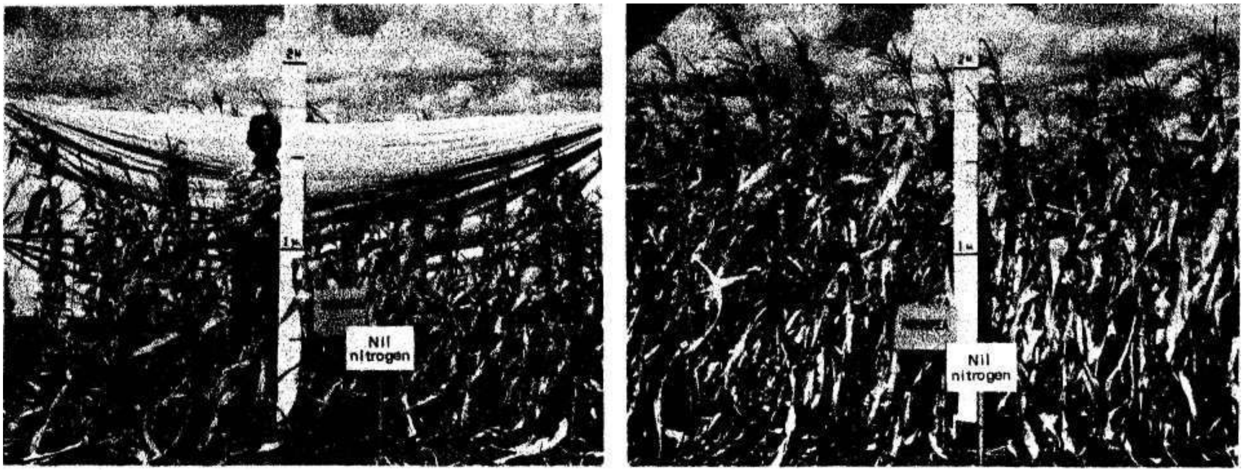
Biological Nitrogen Fixation

Residual Effect of Pigeonpea

Very little information is available on the residual effect of pigeonpea grown either as sole or intercrop on a subsequent cereal crop. An experiment was therefore conducted on a Vertisol field at ICRISAT during the rainy seasons of 1979 and 1980 to test the response of a maize crop when grown after sole pigeonpea, sole sorghum fertilized with 0 and 80 kg N/ha, sorghum/pigeonpea intercrop with 0 and 80 kg N/ha, and fallow. Before planting, a basal dressing of single superphosphate was applied to supply 40 kg P_2O_5/ha. Pigeonpea seeds were inoculated with *Rhizobium* in a peat carrier. In the intercrop, sorghum cv CSH-6 (3-1/2 months duration) and pigeonpea cv ICP-1 (6 months duration) were sown in a constant arrangement of 2 rows of sorghum/1 row of pigeonpea on 1.5-m-wide broadbeds. The crops were grown under rainfed conditions. At harvest, grain yields and total dry-matter yields were measured. All the above-ground plant parts were removed at the end of the season except for fallen parts of pigeonpea. The yields were normal for the cultivars in this environment. The total land equivalent ratios for intercrops clearly showed a yield advantage of 47% and 37% in grain and total top dry-matter yields, respectively, over the sole crops (Table 6).

The total nitrogen uptake by the sole crop of sorghum was the same as that by the sole crop of pigeonpea. In the sorghum/pigeonpea intercrop, the nitrogen uptake by sorghum was the same as in the sole crop of sorghum, but was markedly reduced for the intercropped pigeonpea. This reflects the poor ability of pigeonpea to compete with sorghum as an intercrop.

During the 1980 rainy season the maize cv Deccan Hybrid 101 was planted uniformly over the experimental area. Each of the former main treatments was split into five subplots receiving the following nitrogen treatments: 0, 20,40, 60, and 80 kg N/ha, At maturity, observations on final grain yield and total dry-matter yield were recorded. The effects of previous crops on grain



Maize grown the year following sorghum (*left*), *which had received 80kg N/ha, and pigeonpea* (*right*), *which had received no nitrogen. No additional nitrogen was applied to the maize crop in both situations.*

Table 6. Yield of seed, total top dry matter, and nitrogen uptake of sorghum and pigeonpea grown in the first year (rainy season, 1979).

	Seed yield		Total top dry matter		N uptake	
Treatment	Sole (kg/ha)	LER[a]	Sole (kg/ha)	LER[a]	Total/kg/ha by species	Total for treatment
Pigeonpea	1630	1.0	6 040	1.0	83.2	83.2
Sorghum at 0 N	3950	1.0	9 870	1.0	80.0	80.0
Sorghum at 80 N	5000	1.0	12 610	1.0	121.8	121.8
Sorghum/pigeonpea[b] at 0 N						
S	3800	0.96	9 035	0.92	80.1	
P	840	0.51	2 690	0.45	38.0	
S + P		1.47		1.37		118.1
Sorghum/pigeonpea[b] at 80 N						
S	4730	0.95	11 550	0.92	111.3	
P	680	0.42	2 460	0.41	36.5	
S + P		1.37		1.33		147.8
Fallow						
SE ±						6.78
CV (%)						28

a. LER = Land Equivalent Ratio: the relative land area required for sole crop(s) to produce the yield(s) achieved in intercropping. An LER of 0.5 for a given crop indicates that it has produced in intercropping the equivalent of 50% of its sole crop yield.

b. 2 rows sorghum/1 row pigeonpea.

yields of maize were significantly different (Fig. 3), with the most beneficial effect coming from a previous crop of sole pigeonpea. Maize after a sole crop of pigeonpea significantly outyielded maize following fallow, sole sorghum, and sorghum/pigeopea intercrop with or without nitrogen applied to the previous crop. This superiority was maintained in the treatments with nitrogen applied to the maize crop, although the magnitude of the yield differences varied.

In terms of total dry-matter yields, pigeonpea as sole crop also had the maximum beneficial effect. No significant interaction was noted between the effects of previous crops and the rates of nitrogen applied to maize. The relationships between total dry-matter yield of maize and rate of nitrogen applied to the maize crop following each of the previous crops have been calculated. The relationships were linear and provide a useful means of estimating nitrogen requirements following each crop. The intercept

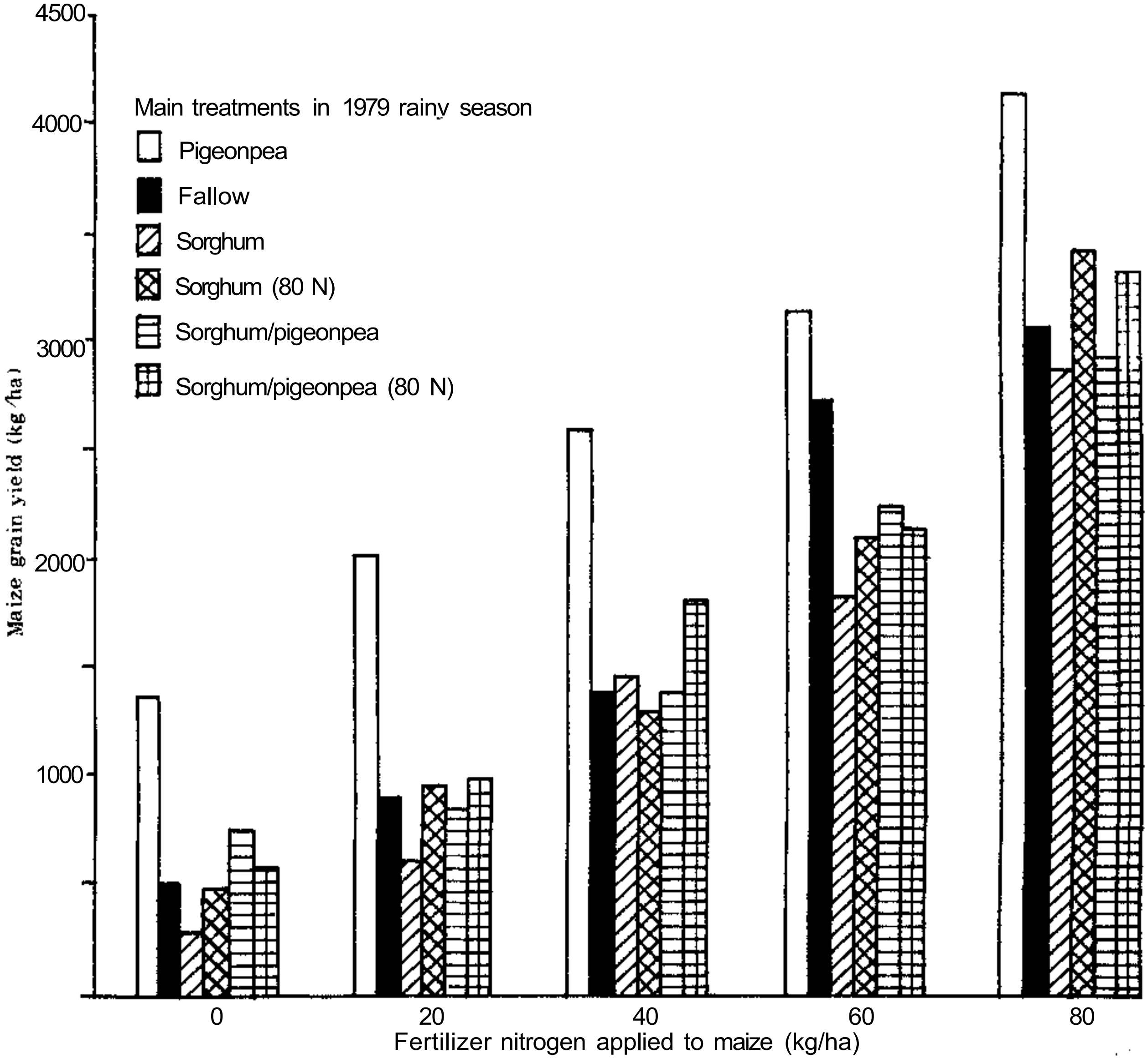


Figure 3. Residual effect of pigeonpea on grain yields of maize in the 1980 rainy season.

of the nitrogen response line of the sole pigeonpea crop corresponded to 6260 kg/ha total dry matter. To achieve the same total dry matter production of maize from the other treatments it was calculated that between 38 and 49 kg N/ ha would have been required. It is assumed that sorghum would have derived most of its nitrogen requirements from soil, thereby depleting the soil nitrogen pool, while pigeonpea would have derived, in addition, nitrogen from symbiosis with *Rhizobium.* Although the mechanism of the beneficial effect is not yet clearly understood, the considerable amount of leaf fall, which has been reported to provide 30-40 kg N/ha, could be one of the factors contributing to the higher residual effect of sole pigeonpea. Intercropped pigeonpea could not add as much nitrogen because its growth was adversely affected by competition from the sorghum in the intercrop.

Rhizobium Collection

During the year we isolated rhizobia from pigeonpea nodules collected from pigeonpea fields in the Indian states of Maharashtra and Gujarat, bringing the culture collection at ICRISAT to a total of 510 *Rhizobium* strains. We are now concentrating on freeze-drying the collection. Selected strains were supplied to scientists in India, USA, Puerto Rico, Canada, South Africa, and Swaziland.

Rhizobium Strain Selection

As in previous years, we field-tested *Rhizobium* strains from our own collection and from other centers in India as a part of AICPIP.

At ICRISAT Center no significant responses to inoculation were observed, apparently because of the existing population of rhizobia, but we are particularly interested to know whether the inoculant strains formed nodules. With such identification we expect to determine whether certain strains are more competitive than others in a range of sites.

In order to identify these strains, we have a collaborative program with Rothamsted Experiment Station at Harpenden, U.K., to reexamine the use of inherent antibiotic resistance as an identification tool. The promise shown by this technique has not yet been fully realized. Meanwhile, facilities for housing rabbits have been completed at ICRISAT Center, antiserum production is in progress, and serological identification techniques are being developed.

Selection of Pigeonpea for Nitrogen Fixation

While our previous testing has clearly shown that lines differ in their amount of nodulation and nitrogen fixation, it is equally evident that intraline variation is also high. This variation is presumably associated with the outcrossing that is seen in the species. Emphasis has therefore been placed on selection of individual plants with superior nodulating ability, accompanied by repeated self-fertilization to provide plants with consistent performance. Once these are available they will then be used for heritability studies and breeding purposes.

Physical Environment

Soil

Tolerance to salinity. Screening for salt tolerance was continued both in brick chambers and in the field. These techniques have been described in earlier reports (ICRISAT Annual Report 1976/77, p 86; 1977/78, p 105; 1979/80, p 108).

Soil used in the brick chambers was salinized with 15 meq salt/kg of soil with a mixture of NaCl, Na_2SO_4, and $CaCl_2$ in the proportion 7:1:2. Judged on the basis of percent survival and growth, 13 lines were found to be tolerant.

Twenty-seven advanced breeding lines and 20 cultivars were planted in a naturally saline field with an electrical conductivity of 2.5 mmho/cm in the 0-30 cm and 5.5 mmho/cm in the 30-60 cm layer. A tolerant check (C-11) and a susceptible check (Hy-3C) were grown on either side of each line. Scoring was done on a 1 to 5 scale relative to the tolerant check, and the surviving plants were counted. Thirteen advanced breeding lines and four cultivars were found to be tolerant. More advanced breeding lines are being screened in the field.

Tolerance to Waterlogging

We continued screening pigeonpea lines for tolerance to waterlogging, using the techniques developed earlier at ICRISAT (Annual Report 1976/77, p 85). In a test of 83 advanced breeding lines, including those resistant to *Phytophthora,* each test row was bordered by a susceptible (Hy-3C) and a tolerant (BDN-1) check. Nineteen lines were found to be more tolerant than BDN-1. New breeding material is being screened.

Postrainy Season

Seeding date and irrigation effects. Postrainy-season pigeonpeas use moisture stored in the soil profile, which is progressively depleted as the crop grows. The response of postrainy-season pigeonpeas to sowing date (ICRISAT Annual Report 1977/78, p 103) and to irrigation (ICRISAT Annual Report 1979/80, p 107) has already been demonstrated. This year we studied the interaction between sowing date (16 Sept, 16 Oct, 17 Nov) and irrigation frequency in a medium (C-11) and a late-maturing [NP(WR)-15] cultivar.

C-11, which matures 2 to 3 weeks earlier than NP(WR)-15, outyielded it. The yield of both cultivars decreased with delayed sowing, as reported earlier (ICRISAT Annual Report 1977/78, p 103). The response to irrigation also decreased with delayed seeding (Fig. 4). The medium-duration cultivar C-11 consistently gave a good response to irrigation; planted in September the two treatments with the most frequent irrigation outyielded the control by 160%. The late cultivar NP(WR)-15 gave no significant response to irrigation, except in the earliest planting. The maximum yield of 1500 kg/ha, which was obtained by C-11 in this test, was comparable to the yield of the main-season nonirrigated crop. Further work on water-use efficiency of rainy and postrainy pigeonpeas is now in progress.

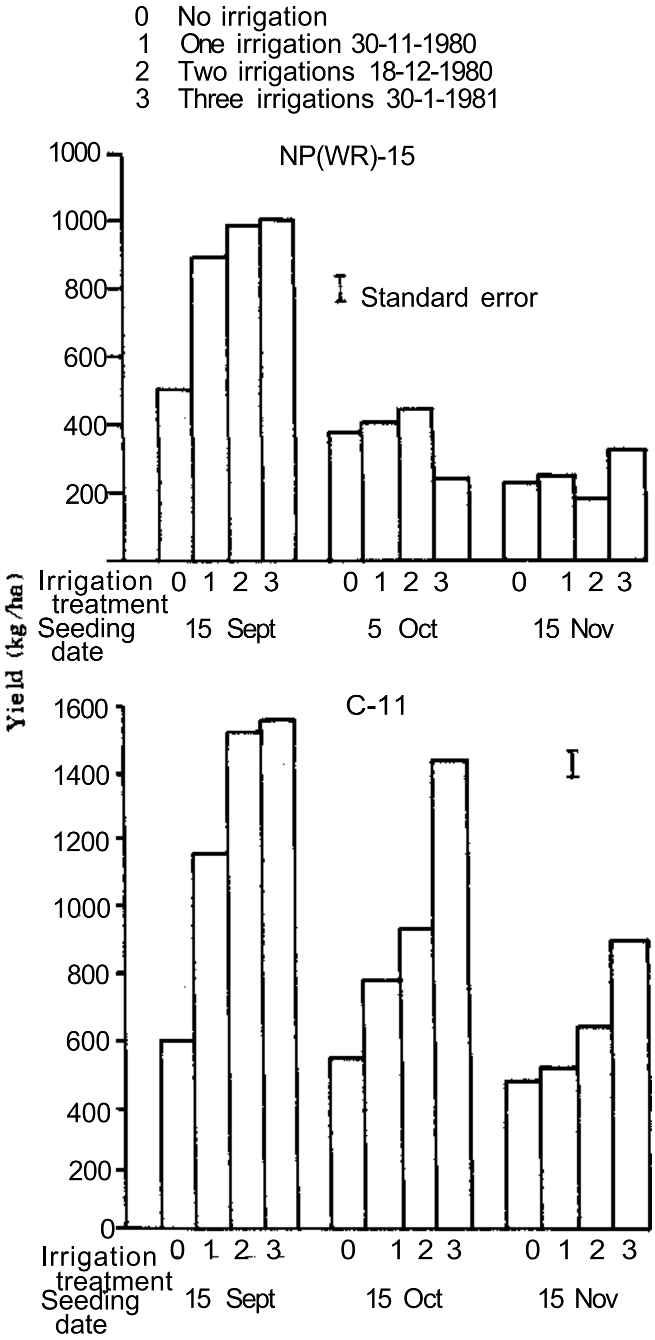


Figure 4. Response to irrigation of two cultivars of pigeonpea seeded at ICRISAT Center on three dates in the 1980 postrainy season.

Fertilizer and irrigation effects. The lack of responsiveness in pigeonpea to soil-applied fertilizers could be due to failure of these fertilizers to reach the active root zone. This possibility was examined by deep and spot (concentrated) placement of fertilizer at ICRISAT Center in postrainy-season pigeonpea. Single superphosphate (40 kg P_2O_5 /ha) was placed alone and in combination with urea (20 kg N/ha) at depths of 20,45, and 70 cm both with and without irrigations on a Vertisol low in available nitrogen (60 ppm), medium in available phosphorus (7 ppm), and moderately saline (0.6 mmho/cm of 1:2 soil water extract).

The yields without irrigation were high (1940 kg/ha) and the response to irrigation, though significant, was of smaller magnitude (19% over control), probably due to adequate groundwater conditions in the subsoil. Application of urea with single superphosphate (SSP) stimulated straw yield and increased grain yield by 5.7%, irrespective of irrigation and depth of placement. However, there was no response to SSP alone. In contrast to this, with the same level of applied SSP, chickpea showed 8% increase in grain yield (see Chickpea section, this Annual Report). These results suggest that pigeonpeas are more efficient in phosphorus absorption and therefore do not respond to SSP. The deep placement of urea in combination with SSP had only a marginal effect on yield.

Second harvest yields. Pigeonpeas are intrinsically perennial, and produce a second flush of pods after the first flush is harvested by pod-picking or ratooning. The deep root system enables the plants to exploit moisture stored in the deeper layers of the soil profile. Thus a second harvest becomes feasible from the same crop during the late postrainy season when it would normally be difficult to plant another crop without irrigation.

We investigated the ability of pigeonpea to produce a second harvest yield both in Alfisols and Vertisols over the past 5 years. The second harvest yields were consistently higher in Alfisols than in Vertisols (Table 7), the averages being 659 and 193 kg/ha, respectively. These results are surprising in as much as higher yields were expected on Vertisols than on Alfisols because of the greater water-holding capacity of the former.

Nutrient deficiency or toxicity studies have not provided any clue to this phenomenon. The possibility that the second harvest yields of pigeonpeas in Vertisols are reduced by soil cracking severing the pigeonpea roots is currently under investigation.

Food Quality

Cooking Quality

The effect of various kinds of pretreatments of whole seed of pigeonpea before subjecting it to dehulling was examined. The cooking time of dhal obtained from the pretreated samples was

Table 7. First and second harvest yields (kg/ha) of medium-duration pigeonpeas on Alfisols and Vertisols at ICRISAT Center, 1976-81.[a]

	First harvest yield		Second harvest yield	
	Alfisol	Vertisol	Alfisol	Vertisol
1976/77	1235	715	1024	338
1977/78	1581	1769	704	334
1978/79	1129	1607	531	152
1979/80	1315	1102	252	56
1080/81	759	574	785	84
Mean	1204	1153	659	193

a. For 1976/77, means of cvs No. 148 and AS-71-37 are shown; in other years data are for cv BDN-1. The first harvest was obtained by pod-picking.

Does soil cracking in Vertisols reduce pigeonpea yields? The question is being investigated at ICRISA T Center.

determined. It was observed that while soaking the whole seed in water increased the cooking time of dhal, soaking in 1% solution of sodium carbonate decreased it considerably (Table 8). In another study using the same five cultivars, whole untreated seed and dhal samples prepared using the standard water pretreatment were soaked in 1% solutions of NaCl, Na_2CO_3, $NaHCO_3$ and Na_5PaO_{10} (sodium tripolyphosphate) at room temperature for 8 hours. The cooking time of these samples was determined. The Na_2CO_3 treatment was the most effective in reducing the cooking time (Table 9).

We also compared the cooking quality of 14 pigeonpea cultivars grown during both the rainy and postrainy seasons of 1980/81 at ICRISAT Center. Dhal samples were evaluated for cooking time, water absorption, percent solids dispersed, and texture using the back extrusion cell technique in an Instron food testing machine. Results showed that cultivars grown during the rainy season exhibited better cooking quality than those grown in the postrainy season. A comparison of the cooking quality of several germplasm accessions belonging to the early-, medium-, and late-maturity groups revealed no clearcut differences. These are only preliminary observations and we are continuing our work on the cooking quality of pigeonpea by analyzing more cultivars.

Protein Quality

To compare the accuracy of rapid colorimetric methods for methionine (McCarthy and Sullivan) and cystine (Goa) against results obtained using the amino acid analyzer (Beckman 120) we analyzed 65 defatted dhal samples. The amino acid contents of these cultivars ranged between

Table 8. The cooking time (min) of pigeonpea dhal obtained by various pretreatments before dehulling.

	Pretreatment procedures[a]				
Cultivar	None	Oil (1% w/w)	Water (1% w/v)[b]	NaCl (1% w/v)[b]	Na_2CO_3
BDN-1	20	20	26	20	16
C-11	16	20	24	20	16
No. 148	16	16	20	14	12
LRG-30	16	18	22	18	14
LRG-36	14	18	24	14	12

a. After pretreatment samples were dried at 65°C overnight before dehulling. b. Soaked for 8 hr.

Table 9. Cooking time of pigeonpea as influenced by soaking in different salt solutions.[a]

	Control	Cooking time (min)				
		Water	NaCl	Na_2CO_3	$NaHCO_3$	$Na_5P_3O_{10}$
Whole seed						
BDN-1	70	43	38	26	30	32
C-11	56	44	40	24	28	30
No. 148	48	42	37	24	26	27
LRG-30	54	43	38	28	30	30
LRG-36	56	40	38	30	30	29
Dhal						
BDN-1	26	12	8	5	6	6
C-11	24	14	10	8	8	6
No. 148	20	12	8	6	8	7
LRG-30	22	15	10	5	6	5
LRG-36	24	14	10	5	6	6

a. Soaked in 1% solution at room temperature for 8 hr.

0.70 and 1.58 g/16 g N for methionine, with a mean of 1.05, and between 0.70 and 1.34 g/16 g N for cystine, with a mean of 0.99 when analyzed on the amino acid analyzer. These values were highly correlated ($P \leq 0.01$) with the colorimetric procedures (methionine, $r = 0.934$, cystine, $r = 0.853$). This work further confirmed that methionine and cystine are positively correlated ($r = 0.849$, $P \leq 0.01$) with each other and that screening for either of these two amino acids should be sufficient for protein quality improvement work in a pigeonpea breeding program.

In another study two rapid colorimetric procedures (Spies and Chambers, and Concon) for the estimation of tryptophan were compared with the procedure using alkaline hydrolysates in the amino acid analyzer. We analyzed 60 pigeonpea dhal samples for tryptophan by these three procedures. Tryptophan content (g/ 16g N) as determined by the amino acid analyzer varied between 0.73 and 1.64 with a mean of 1.15. A similar range was obtained by the colorimetric procedures. A statistical comparison of the methods revealed that the Spies and Chambers method was simple, rapid, and satisfactory for the large-scale screening of tryptophan levels in dhal samples.

Antinutritional Factors

We assayed the developing green seed and mature seed samples of one grain-type (C-11) and eight vegetable-type pigeonpeas for protease inhibitors, in vitro protein digestibility, and oligosaccharides. Data obtained for the developing green seed samples are shown in Table 10. Protein digestibility of some of the vegetable types was found to be higher than that of C-11. The trypsin inhibitor activities (units inhibited per mg of meal) of vegetable types ranged from 2.32 to 3.86 and that for chymotrypsin from 1.91 to 3.05. The total soluble sugar content of the vegetable types varied from 4.70 to 5.54%, while C-11 contained 4.91%. No large differences were observed in the concentration of starch content of these lines when compared with C-11. Developing green seed samples of the vegetable types and of C-11 had lower amounts of raffinose and stachyose than did samples of their mature seed. We found that another sugar, verbascose, was absent in developing green pigeonpeas, although it was present in considerable amounts in mature seeds. Our results thus indicate that these three sugars, which are reported to cause flatulence, are low in developing green pigeonpeas.

Table 10. The levels of protease inhibitors and soluble sugars in developing green seed samples of vegetable-type pigeonpeas.

Cultivar	Trypsin inhibitor[a]	Chymotrypsin inhibitor[a]	Soluble sugars (%)	Sucrose[b]	Raffinose[b]	Stachyose[b]
ICPL-102	2.94	3.05	5.32	60.1	9.0	11.0
ICPL-114	2.67	2.87	4.85	57.2	9.5	6.2
ICPL-119	3.86	2.65	4.70	65.4	9.4	3.1
ICPL-122	2.40	2.29	4.92	46.9	6.1	3.2
ICPL-128	2.32	2.65	5.54	44.0	6.2	2.5
ICPL-212	2.67	2.40	5.40	65.7	7.7	2.4
ICP-6997	2.76	2.17	5.23	49.2	5.0	2.8
ICP-7035	3.23	1.91	4.96	29.0	1.4	2.5
C-11	2.58	2.90	4.91	55.7	1.2	2.0

a. Units inhibited per mg meal.
b. Expressed as percent of total soluble sugars in freeze-dried, whole-seed samples that were collected at 144 days after planting during the 1980/81 rainy season.

Table 11. The distribution of polyphenolic compounds in the seed components of pigeonpea cultivars.

Cultivar	Testa color	Seed coat (% w/w)	Polyphenols (mg/g sample)		
			Seed coat	Dhal	Whole seed
BDN-1	Dark red	15.2	106.9	1.9	15.1
C-11	Light red	15.7	92.3	'I.7	14.2
NP(WR)-15	White	16.4	37.2	1.4	6.0
Hy-3C	White	13.0	27.0	1.6	3.7

We also studied the levels of polyphenolic compounds (loosely termed tannins) of pigeonpea. Analyses of four pigeonpea cultivars with different seed coat colors showed that the seed coat contained the highest proportion of polyphenols, and the red seed types appeared to have higher concentration of polyphenols than the white ones (Table 11). However, when pigeonpeas are processed into dhal, most of the polyphenolic compounds are removed with the seed coat. Preliminary in vitro assays indicated that polyphenolic compounds of pigeonpea adversely affect the activities of digestive enzymes. Further studies are required to investigate the role of polyphenolic compounds in the bioavailability of nutrients of pigeonpea seeds. This information is particularly important for areas where the pigeonpea is consumed as whole mature seed.

Plant Improvement

Extra-early and Early Pigeonpeas

With the increasing availability of high-yielding, short-season pigeonpea types, new cropping patterns are gaining popularity in northwestern India. The pigeonpea-wheat rotation is fast replacing some of the rainy-season cereal crops, such as maize, rice, sorghum, or millet, especially under conditions of limited irrigation. Therefore, at our Hissar station development of high-yielding, short-duration pigeonpea genotypes continues, with emphasis on (1) increasing yield levels by the incorporation of long pods containing many seeds into an early-maturity background, and (2) developing lines resistant to sterility mosaic, phytophthora blight, and wilt diseases and with low levels of susceptibility to pod borers. To fulfill some of these objectives we made at Hissar 124 crosses in the 1980 and 200 in the 1981 rainy season, involving diverse parentage.

Several promising lines that matured in less than 105 days were identified. The high yielding lines we identified in 1981 are earlier than those reported in the 1980 test (Table 12). These lines can provide more time to farmers to prepare their fields for wheat. Most of these lines are about 120 to 150 cm tall, which makes them easy to manage and spray.

In a newly developed cropping system in western Uttar Pradesh and parts of Haryana, short-duration pigeonpeas are planted in April, intercropped with summer mung bean (*Vigna mungo*). By this practice, farmers harvest a full grain crop of both mung bean and pigeonpea and about double the amount of dried pigeonpea stalk with a reduced cost of cultivation compared to growing the two crops separately. The performance of some promising ICRISAT lines under this system is given in Table 13.

Late Pigeonpeas

The breeding program for developing improved, late-maturing genotypes adapted to traditional production systems is in progress at Gwalior. The major breeding objectives are the incorporation of disease resistance, low susceptibility to pod borer and podfly, increased pod and seed size, profuse secondary and tertiary branching, and dwarf stature. To meet these objectives, we made 61 crosses during the 1980 rainy season.

Thirteen late-maturing cultivars and eight promising germplasm selections are being purified and maintained by plant-to-progeny selfing.

Table 12. Performance of some very early pigeonpea lines at Hissar (1980 and 1981 rainy seasons).

Pedigree	Days to flower	Days to mature	100-seed weight (g)	Yield (kg/ha)
		1980 SEASON		
ICPL-179	57	101	7.8	2558
ICPL-267	58	95	7.4	2239
ICPL-268	58	101	8.1	2158
ICPL-287	58	101	8.0	2122
Prabhat (check)	68	105	6.2	1971
SE ±	1.2	1.0	0.18	90.3
CV (%)	3.8	2.0	4.5	10.0
		1981 SEASON		
Comp. 1 ODT-H14-HB	56	97	8.8	2513
Comp. 1 ODT-H13-HB	55	98	7.6	2450
Comp. 1 ODT-H 7-HB	54	90	7.7	2429
Comp. 1 ODT-H15-HB	58	93	7.3	2306
Prabhat (check)	74	118	6.1	2321
ICPL-287 (check)	58	106	7.6	2039
SE ±	0.7	6.3	0.2	108.1
CV (%)	1.9	9.8	4.5	8.9

Table 13. Performance of some advanced pigeonpea lines in April plantings intercropped with mung bean at Hissar in 1980 rainy season.

Pedigree	Days to flower	Days to mature	100-seed weight (g)	Yield (kg/ha) Grain	Yield (kg/ha) Dried stalks
			1980 SEASON		
ICPL-189	134	196	8.8	2692	19 184
ICPL-81	123	165	7.6	2400	14 857
ICPL-2	130	174	7.6	2050	13 617
ICPL-142	144	187	8.2	1991	14 964
T-21 (check)	151	192	7.8	1863	12 198
SE ±	2.2	1.9	0.24	93.1	983
CV (%)	2.7	1.8	4.8	8.2	11
			1981 SEASON		
ICPL-87	75	202	10.1	2821	11 853
ICPL-148	117	196	9.4	2764	11 720
ICPL-155	118	203	7.8	2666	9 976
ICPL-1	134	186	7.9	2653	10 698
T-21 (check)	152	197	7.6	2439	14 022
SE ±	2.3	1.7	0.28	176.1	896.3
CV (%)	4.3	2.0	4.3	16.9	18.7

On the basis of yield performance, two pure lines from each of 13 cultivars and 8 germplasm selections were identified for further testing during the 1981 rainy season.

The performance of 10 promising late-maturity lines is presented in Table 14. Two of these, ICPL-310 and ICPL-311, were entered in the ACT-3 of the AICPIP during the 1981 rainy season.

Medium-Maturity Pigeonpeas

The development of locally adapted, medium-maturity pigeonpeas with high yield, disease resistance, low pod borer susceptibility, acceptable grain quality, and suited to intercropping has been the major objective of our breeding program at ICRISAT Center.

In all, 423 crosses were made during the 1980 rainy season to pursue the above objectives. Major emphasis was on the incorporation of multiple disease resistance into good agronomic backgrounds.

At ICRISAT Center, in addition to the attempts to breed specifically for medium-duration types, the potential of various breeding procedures is also being assessed.

Line Development

We continued to purify and maintain popular pigeonpea cultivars. Some of the purified lines gave higher yields than their respective open-pollinated cultivars and their yield potential will be further assessed in station trials and multilocation tests. One promising pure line of ST-1 (ICPL-234) was submitted for testing in the ACT-2 in 1981.

Several advanced, medium-duration lines derived from single, triple, and double crosses outyielded the standard check, C-11, at ICRISAT Center. These lines will be further evalu-

Table 14. Performance of some promising late-maturity pigeonpea lines at Gwalior during the 1980 rainy season.

Line	Days to flower	Days to mature	100-seed weight (g)	Yield (kg/ha)
Test 17				
4754-6-GB*-GB	144	263	9.3	2105
7176-5-GB-GB*-GB	144	258	9.3	2100
4745-8-GB-GB*-GB	142	258	9.3	1957
ICPL-310[a]	144	256	9.3	1905
6426-9-GB-GB*-GB	142	256	10.5	1866
4779-75*-3*-B*-GB-GB	147	263	11.8	1833
4745-3-GB-GB*-GB	144	262	9.3	1804
Gwalior-3 (check)	141	259	8.0	1781
SE ±	2.5	2.6	0.66	309.1
CV (%)	3.5	2.0	13.6	40.1
Test 18				
ICPL-311[a]	140	252	9.5	2158
74367-W9*-1-GB-GB*-GB	154	254	8.4	1952
74428-W8*-2-G2-GB-GB	140	256	10.3	1952
Gwalior-3 (check)	152	252	7.8	682
SE ±	13.2	3.6	0.51	333.0
CV (%)	14.7	2.4	9.1	50.7

a. Entered in the ACT-3 during the 1981 rainy season.
* from selfed plants.

ated. Thirty-six of the most promising lines will be multiplied for multilocation testing.

Population Development

We advance a large number of populations every year by growing 4000 to 5000 plants of each cross and harvesting a single pod from each plant. This enables us to handle a large number of hybrid populations, which is necessary because of our broad-based breeding objectives and the limited information that we have on the parents. In 1980 we had 47 F_2, 181 F_3, 139 F_5, and 33 F_6 populations of crosses involving parents from all three maturity groups. The performance of unselected bulk populations advanced by this single-pod descent method is being assessed in 1981 in multilocation tests.

During 1980 we again supplied two unselected bulk population tests to various cooperators in India. The medium-maturity bulk populations test was conducted at Akola, Gulbarga, Badnapur, Kanpur, Sardar Krishinagar, and at ICRISAT Center, and the late-maturity bulk populations test was conducted at Varanasi, Berhampur, Dholi, and Gwalior. Three of the 19 medium-maturity populations (BDN-1 x 1258, BDN-1 x ICP-102, and C-11 x 7186) along with the check C-11 were consistently among the top yielders at each location.

We planted the F_3 population of the cross BDN-1 x 7977, advanced by single-pod descent, in our multiple-disease nursery at ICRISAT Center and isolated 50 plants showing resistance to all three major diseases. The progenies of these plants will be screened again and those showing resistance will be evaluated for their yield potential.

Development of composite populations using male sterility and dual population breeding schemes is under way. We advanced these populations by open pollination for three generations. We have now drawn random individual plants from each population and are evaluating their progenies in 1981.

Hybrids

New hybrids. Our pigeonpea breeding work at ICRISAT Center and in cooperation with the University of Queensland, at Brisbane, Australia, has enabled us to identify several sources of genetic male sterility as well as cytoplasmic-genetic male sterility. The main thrust in our hybrid program has been based on the genetic male steriles, MS-3A and MS-4A, which have given excellent seed set when exposed to a pollen source. In our fourth hybrid yield test involving 10 male parents, each crossed with MS-3A and MS-4A, the top hybrid MS-3A x ICPL-227 yielded 1822 kg/ha at ICRISAT Center in 1980, an increase of 33% over the yield of the best adapted cultivar (C-11). We will produce seed for this hybrid in sufficient quantities in isolation for multilocation testing by AICPIP. The yield performance of our hybrids in the 1980 All India Coordinated Trials was impressive (see below All India Coordinated Trials section).

One of our first early-maturing hybrids yielded 3900 kg/ha at our Hissar station in the 1981 rainy season (Table 15). This yield was 33% higher than that of the adapted check T-21. In addition the hybrid matured 10 days earlier. The hybrid was one of four produced from two early-maturing cultivars in our male-sterility conversion program (see below).

Seed production. The hybrid seed production system involving 6 female rows of MS-3A to 1 pollinator row of AS-71-37 gave us an excellent set of hybrid seed on a large production plot. This year we obtained 1101 kg/ha of hybrid seed

Table 15. Performance of some short-duration pigeonpea hybrids at Hissar during the 1981 rainy season.

Pedigree	Days to flower	Days to mature	100-seed weight (g)	Yield (kg/ha)
Prabhat (MS-3A) x ICPL-161	70	135	7.8	3901
ICPL-161	88	141	9.2	2612
T-21 (MS-3A) x ICPL-87	95	140	7.9	3548
ICPL-87	80	140	11.1	2196[a]
Prabhat (MS-3A) x ICPL-81	80	128	7.6	2906
ICPL-81	75	120	7.4	1895
Prabhat (MS-3A) x ICPL-4	68	119	7.3	2286
ICPL-4	70	117	6.5	1801
T-21 (check)	95	145	7.0	2929
UPAS-120 (check)	80	123	7.3	2224
SE ±	0.1	1.1	0.2	102.2
CV (%)	0.3	1.7	5.3	7.8

a. Plant stand was poor.

in two pickings using this system at ICRISAT Center.

Male-sterile conversion. In our male-sterile conversion program we completed the fifth backcross this year on ICP-1, -6978, -7035, Prabhat, and T-21. The new male-sterile lines in these diverse backgrounds enhance the chances of identifying outstanding hybrids suited to different agroecological situations. In addition, some of these new male-sterile lines are known to carry disease resistance. We will use the new male-sterile lines to produce the large number of combinations that are essential for identifying outstanding hybrids.

Cytoplasmic-genetic male-sterile. Studies on cytoplasmic-genetic male sterility revealed that in addition to C-11, *Atylosia scarabaeoides* also restores fertility. Unfortunately, this male sterility is associated with varying degrees of female sterility, which in turn results in poor pod setting on the male-sterile plants. Crosses have been made to transfer the sterile cytoplasm into different nuclear backgrounds with the hope of recovering male-sterile genotypes with good pod setting.

Response to spacings. In southern and parts of western India, our medium-maturity hybrids were top yielders (Table 16). However, the advantage of the hybrids over the most adapted cultivar is yet to be conclusively demonstrated at ICRISAT Center. It is possible that the hybrids may have a specific spacing requirement to realize their full genetic potential at ICRISAT Center.

To test this hypothesis the hybrid ICPH-5 (MS-3A x C-11) and its parents were grown at two row spacings and, within each row, four plant spacings both in an Alfisol and a Vertisol (Table 17).

The hybrid showed heterosis but it was not sufficient to make the hybrid's yield significantly higher than that of the adapted parent C-11 (Table 17). There was no significant interaction between spacings and entries. These results show that at ICRISAT Center the yield potential of this hybrid was not masked at any specific plant spacing in 1980.

Intergeneric Hybridization

This year at ICRISAT Center we successfully crossed *Atylosia grandifolia,* a hardy and fire-tolerant Australian species, with two pigeonpea cultivars, Pant A-2 and C-l 1.

Different levels of *Atylosia* germplasm were obtained in five pigeonpea cultivars by 0-4 backcrosses to the cultivars. F_2 bulks derived from selfed F_1 plants are being tested in 1981 along with the recurrent pigeonpea parents to determine the level of backcrossing required to generate transgressive segregants.

We identified a new translucent-anthered, male-sterile line among the BC_1 F_3 progenies of the cross (ICP-6915 x *A. scarabaeoides)* x ICP-6915. In addition to sibbing, we have crossed these male-sterile plants with MS-3A, MS-4A, and two normal pigeonpea cultivars to study the nature of male sterility.

Natural Outcrossing

At ICRISAT Center, our attempts to estimate the extent of natural outcrossing continued. We observed 26% outcrossing in contiguous pigeonpea blocks sprayed with insecticide; in sprayed and unsprayed isolation blocks the outcrossing was 22 and 33%, respectively. These results indicate that the percentage of outcrossing in this crop varies with location and amount of pesticide application.

Isolation distances required for the maintenance of genetic purity of pigeonpea varieties vary from location to location, depending on the extent of outcrossing that occurs in a particular location. During the 1980 rainy season we conducted a study at ICRISAT Center to determine the isolation requirements for maintaining genetic purity. Using green and purple stem color marker stocks, average outcrossing percentage on the green stem plants was estimated at 3% at a distance of 100 m from the dominant purple stem plants block; an average of 15, 7, and 4% outcrossing was observed at distances of

Table 16. Yield performance (kg/ha) of ICRISAT entries vis-a-vis standard checks in ACT-2 north plains east and peninsular zones of India (1980 rainy season).

	North plains east zone		Peninsular zone										Overall average (7 common locations)
	Sabour	Kanke	Coimbatore	Badnapur	Akola	Rahuri	Bangalore	Gulbarga	Jalna	ICRISAT Center	Rajendranagar	Paithan	
No. of entries	11	10	17	17	16	16	12	16	14	15	12	25	
						STANDARD CHECKS							
No. 148	NR[a]	NR	1090 (11)[b]	730 (8)	320 (12)	330 (6)	NR	520 (9)	780 (5)	1390 (2)	1010 (5)	720 (6)	737
C-11	NR	NR	1040 (13)	580 (14)	430 (7)	290 (7)	NR	410 (13)	700 (8)	1090 (12)	NR	840 (1)	649
						ICRISAT ENTRIES							
ICPH-2	1370 (1)	300 (1)	1330 (4)	770 (6)	730 (2)	160 (9)	570 (1)	590 (5)	890 (1)	1140 (10)	1190 (1)	710 (7)	801
ICPH-5	1190 (2)	230 (2)	1270 (5)	670 (11)	730 (2)	130 (11)	250 (7)	690 (1)	850 (3)	1310 (5)	710 (8)	NR	807
ICPL-42	780 (4)	130 (5)	1190 (10)	730 (7)	440 (6)	90 (13)	180 (10)	550 (6)	640 (10)	1210 (8)	940 (7)	700 (9)	680
Top of test	1370	300	1560	990	820	460	570	690	890	1430	1190	840	977
Mean (location)	607	142	1144	709	437	229	288	518	706	1211	876	653	749
SE ±	76.2	10.2	160.2	41.0	83.0	63.0	13.2	103.2	40.5	75.8	55.1	66.8	
CV(%)	25.1	14.3	28.0	11.7	40.0	55.0	9.2	39.9	11.5	12.5	10.9	20.5	

a. NR = Not reported.
b. Figures in parentheses are yield ranks.

Table 17. Effect of spacing on the yield (kg/ha) of pigeonpea hybrid MS-3A x C-11 and its parents grown on a Vertisol and an Alfisol at ICRISAT Center, rainy season 1980.

	Vertisol				Alfisol			
Spacings	C-11	MS-3A	MS-3AxC-11	Mean	C-11	MS-3A	MS-3AxC-11	Mean
75x15 cm	1437	746	1411	1198	1160	1037	1214	1137
75x30 cm	1363	1041	1548	1317	1179	996	1329	1168
75x60 cm	1518	1040	1205	1254	1411	1120	1350	1294
75x120 cm	1339	682	1263	1095	1230	743	871	948
150x7.5 cm	1480	1008	1315	1268	1071	1013	1148	1077
150x15 cm	1508	980	1193	1227	1004	1081	1161	1082
150x30 cm	1386	1016	1389	1264	1093	886	1133	1037
150x60 cm	1479	966	1296	1247	837	887	1210	978
SE ±		120.4			111.7			
Mean	1439	935	1328		1123	970	1177	
SE±		42.5		73.7		39.5		68.4
CV (%)		16.9			17.7			

0,20, and 50 m from the dominant marker block, respectively. We are repeating this experiment in the 1981 rainy season.

Identification and incorporation of mechanisms that ensure complete self-pollination in pigeonpeas would greatly reduce the labor and material costs involved in artificial selfing. The "free stamen" flower modification that we described in last year's annual report (p 102) has been observed to ensure complete self-fertilization for five seasons. This character is being transferred to the popular pigeonpea cultivars C-11 and BDN-1.

New Plant Types

The extension of pigeonpea to new systems of production might be possible through the development of new plant types. Dwarf plants have several advantages, including easier application of insecticides, better partitioning of photosynthate to pods, and suitability for mechanical harvest. We are attempting to combine high yield and dwarf stature in the various maturity groups. Twenty-three semidwarf progenies derived from crosses between the D_2 dwarf and normal types were tested in a replicated yield trial. We found 13 progenies that yielded better than the standard adapted cultivar C-11 and will reevaluate them to confirm their superiority.

Cooperative Activities

International Trials

During 1980/81, we sent an early-maturity pigeonpea international trial with 28 elite ICRISAT lines to 10 locations in eight countries and a medium-maturity pigeonpea international trial with 14 elite lines, including one hybrid, to 10 locations in 10 countries. We continued testing our most promising vegetable-type advanced lines in two international trials (Vegetable-type Pigeonpea International Trials): VPPIT-1 (early maturity) at five locations and VPPIT-2 (medium maturity) at seven locations in five countries other than India.

All India Coordinated Trials

Our excellent cooperation with the All India Coordinated Pulses Improvement Project continued. Several ICRISAT lines and hybrids were tested in extra-early (EACT), early- (ACT-1), and medium- (ACT-2) duration Arhar Coordinated Trials.

Five ICRISAT lines were entered in the EACT during the 1980 rainy season and the performance of three promising lines in the trials conducted in the area defined by the AICPIP as the north plains west zone is given in Table 18. On the basis of the zonal average, ICPL-1 and ICPL-81 outyielded both the standard adapted cultivars, Prabhat and UPAS-120, while the performance of ICPL-87 at certain locations was excellent. ICPL-1, ICPL-81 and -87, and ICPL-151 and -179 have been submitted for the 3rd, 2nd, and 1st year of testing, respectively, in the EACT during 1981. With the third successful year of testing, ICPL-1 could enter the minikit trial (prerelease on-farm trial) in 1982.

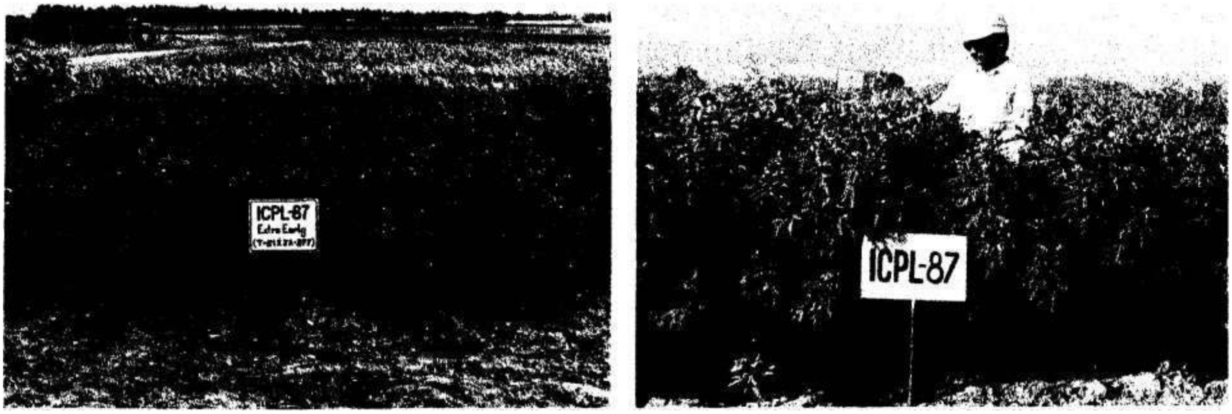
Of the three ICRISAT lines in ACT-1, ICPL-6 performed well for the 2nd year; it ranked first in the north plains west zone with a zonal average yield of 1839 kg/ha during 1980 (Table 19). ICPL-95 did well in the peninsular zone. ICPL-6 is being retested for the 3rd year, along with two other promising new lines, ICPL-150 and -189, during the 1981 rainy season. ICPL-6 will be a probable candidate for minikit trials in 1982.

In ACT-2, three ICRISAT lines, ICPL-42, -192, and -227, and two hybrids, ICPH-2 and -5, were tested during 1980. In the north plains east and peninsular zones of India, the performance of the ICRISAT hybrids was outstanding. ICPH-2 ranked 1st at five locations and 2nd at one, and ICPH-5 ranked 1st at one location and 2nd at 3 out of 12 locations (Table 16). On the basis of the zonal average they both outyielded the standard checks, No. 148 and C-11. One new hybrid, ICPH-6, and two new lines, ICPL-234 and -270, along with three old entries have been entered in the 1981 ACT-2. ICPH-2 and ICPL-42 are possible entries for the minikit trials in 1982.

Table 18. Yield performance (kg/ha) of ICRISAT entries vis-a-vis standard checks in EACT conducted in north plains west zone (1980 rainy season).

	Pantnagar	Ludhiana	Faridkot	Delhi	Bulandshahr	Hissar (HAU)	Hissar (ICRISAT)	Sriganganagar	Hanumangarh	Zonal average (6 locs.)
No. of entries	12	13	13	13	6	13	13	13	13	NA[a]
Prabhat (check)	NR[b]	980(4)[c]	1170(2)	1420(7)	NR	1650(13)	1480(12)	1770(5)	1300(13)	1430
UPAS-120 (check)	2910(2)	940(8)	1110(3)	950(12)	1300(4)	1880(9)	2080(8)	2000(2)	2230(3)	1680
ICPL-87	1860(12)	960(6)	490(11)	590(13)	1580(1)	2390(1)	3160(1)	1800(4)	2200(4)	1680
ICPL-81	2600(5)	1120(2)	NR	1350(10)	1100(5)	2100(5)	2180(5)	1490(11)	2010(8)	1710
ICPL-1	2700(4)	780(12)	800(9)	1480(6)	NR	1960(7)	2710(2)	1590(10)	2490(2)	1840
Top of test	2960	1390	1200	2000	1580	2390	3160	2050	2500	2250
Mean (location)	2510	970	930	1540	1270	2040	2070	1700	1990	1720
SE ±	199.5	152.7	30.7	85.5	73.7	74.5	116.9	83.3	82.6	
CV (%)	15.9	31.5	6.6	11.1	11.6	7.3	11.3	9.8	8.3	

a. NA = Not applicable. b. NR = Not reported. c. Figures in parentheses refer to yield rankings.



Our advanced early-maturing pigeonpea line, ICPL-87, at podding stage at ICRISAT Center (left) and at Hissar. The difference in growth is due to daylength and temperature at these two sites.

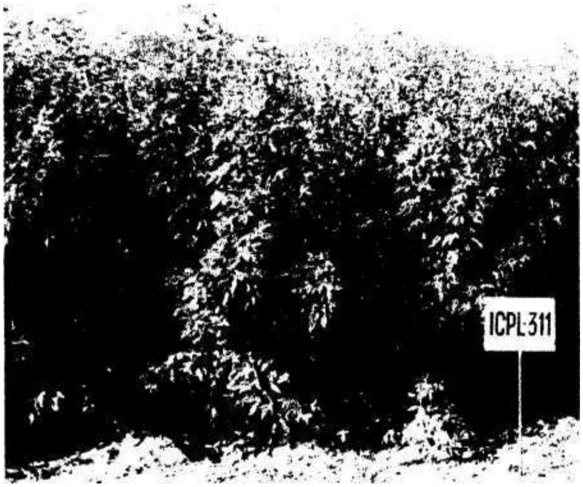
Table 19. Yield performance (kg/ha) of ICPL-6 and T-21 (check) in ACT-1 conducted in north plains west zone (1980 rainy season).

Location	Pant-nagar	Hissar (HAU)	Hissar (ICRISAT)	Delhi	Srigan-ganagar	Loonka-ransar	Zone mean (5 locs.)
No. of entries	13	13	15	9	11	9	
T-21 (cheek)	1220(4)[a]	2460(2)	1560(2)	1610(6)	1880(2)	NR[b]	1750
ICPL-6	1390(1)	2620(1)	1550(3)	1690(5)	1900(1)	990(1)	1830
Top of test	1390	2620	1890	2310	1900	990	2060
Mean (location)	1010	1910	1280	1680	1300	831	1440
SE ±	79.0	47.9	81.9	102.6	60.8	49.8	
CV (%)	9.8	5.2	12.7	11.2	13.5	13.9	

a. NA = Not applicable.
b. Figures in parentheses refer to yield rankings.
c. NR = Not reported.

For the first time, late-maturity ICRISAT lines (ICPL-310 and -311) have been entered in ACT-3 in the 1981 rainy season.

In addition to the materials entered in the regular All India Coordinated Trials, several ICRISAT pigeonpea trials consisting of ICRISAT elite lines and unselected bulk populations and disease-resistant material were supplied to Indian national breeders. These included Preliminary Multilocation Trials (PMT-1 for early-maturity pigeonpeas went to nine locations and PMT-2 for medium maturity to eight), Inbred Lines Test (ILT to three locations), Advanced Population Tests (APT-1 for medium maturity went to six locations and APT-2 for late maturity to three), Sterility Mosaic Resistant Lines Test (SMRLT went to three), and Vegetable-type Pigeonpea International Trials (VPPIT-1 for early maturity went to nine locations and VPPIT-2 for medium maturity to seven).



ICPL-311, a wilt-resistant pigeonpea line developed at our Gwalior substation, is one of the first two lines we have entered in the AICPIP trial for late-maturing lines. This trial is grown throughout northeastern and central India.

ICAR-ICRISAT Disease Nurseries

A cooperative Indian Council of Agricultural Research (ICAR) and ICRISAT Uniform Trial for Pigeonpea Wilt Resistance was initiated in 1980. The trial consisted of 20 entries, of which 16 were contributed by ICRISAT. Two entries contributed by ICRISAT, ICP-10958 and -11299, were found promising at all nine locations—Annigeri, Badnapur, Berhampore, Dholi, IARI (New Delhi), ICRISAT Center (two locations), Jabalpur, and Ranchi—and two additional entries, ICP-7182 and -8863, did well across eight locations. AICPIP has recommended ICP-8863 for use by breeders, as this line had also been tested and found good in previous years.

Similarly, a cooperative ICAR and ICRISAT Uniform Trial for Pigeonpea Sterility Mosaic Resistance was initiated in 1980. The trial, consisting of 20 entries, of which 16 were contributed by ICRISAT, was grown at six locations (Badnapur, Bangalore, Dholi, ICRISAT Center, Pantnagar, and Vamban). Lines that were found resistant at ICRISAT Center held their resistance at Badnapur and Pantnagar. Some of them were susceptible at Dholi, Bangalore, and Vamban. ICP-8854 held its resistance at all locations except at Bangalore, and AICPIP recommended it for use by breeders. Possibly there are different strains of the virus or its vector that cause variation in the performance of lines at different locations.

University of Queensland

Our work at the University of Queensland during the year continued to be funded by ICRISAT and a Commonwealth Special Research Grant from the Australian Government. A pigeonpea breeder from ICRISAT continued his assignment there, returning to ICRISAT Center in October 1981.

Seasonal conditions in southeastern Queensland were unfavorably wet immediately prior to harvest of many of the early-maturing lines. Seed damage occurred on these lines, so ratoon crops were taken to ensure continuity of germplasm. In general, however, crop growth was excellent.

Inheritance of photoperiod-insensitivity. The studies initiated by us in 1979 were extended by growing selected lines derived in the F_2 in natural and 16-hr photoperiods in the field. We are still analyzing the data. Preliminary indications are that three major genes are involved in the expression of photoperiod-insensitivity. These genes act in a hierarchial order. Single plants from the F_3 progeny rows have been selected in an attempt to isolate pure breeding lines containing the individual photoperiod-sensitive genes or the genes in specific combinations. Further evaluation of this material is planned in 1982.

Diallel analyses. The data derived from diallel mating designs (both from the University of Queensland and ICRISAT) were analyzed and are being interpreted. Hybridizations for a new, six-parent diallel are almost complete and we hope to be able to grow both the F_1 and F_2 generations at the University of Queensland at two sowing dates and two plant populations in order to assess the importance of method of evaluation on the genetic parameters estimated.

Yield tests. We recorded promising results this year in a range of yield tests conducted at Redland Bay and elsewhere in Queensland (Table 20). The data indicate that with the appropriate agronomic management (particularly plant population and insect control) high yields are possible in early-maturing pigeonpeas.

Fast-ratooning lines. Four sister lines were identified in 1980 from an ICRISAT introduction (Prabhat x Baigani). These lines produce a new canopy below pod level prior to seed maturity of the main crop. When compared to a similar maturing check these lines were no different in main crop maturity, but after the main crop was harvested the ratoon crop matured 3 weeks earlier than the checks. It is postulated that the earlier formed canopy on these fast-ratooning lines enabled an immediate supply of photosynthate to be available when they were ratooned and thus allowed them to regrow more quickly.

These studies will be continued in 1982 with detailed growth analysis of this character. Hybrids between the fast-ratooning lines and elite material of the same maturity have been developed to study the inheritance of this character.

Halo blight disease. We recorded a leaf disease caused by *Pseudomonas phaseolicola* at Redland Bay in 1981. It appeared to have been transferred from leguminous weed species during a period of unseasonably heavy rainfall in April. Affected leaves developed halo spots due to toxin production by the bacteria. The disease is known to be seedborne in *Phaseolus vulgaris,* and care is being exercised to harvest noncontaminated material.

This disease is not expected to be of importance in the grain-producing areas away from the humid coastal strip.

Prerelease of lines. Three lines were chosen for final prerelease testing in 1982. These lines have been tested over a number of locations and seasons and are all photoperiod-insensitive, determinate, and early flowering (60 days). Seed weights range from 7 to 12 g/100 seeds. We anticipate that one of these lines will be released after final testing. Two of the lines are introductions from ICRISAT and the third, a selection made at the University of Queensland.

Table 20. Performance of some advanced pigeonpea breeding lines in a replicated test at Redland Bay, Queensland, Australia.

Entry	Parentage	Days to 50% f1.	g/100 seeds	Yield kg/ha	Yield % of check	Remarks
QPL-37	Triple cross	64	11.3	4570	163	ICRISAT introduction
QPL-38	Triple cross	66	10.0	4220	151	ICRISAT introduction
QPL-17	HAU Line	61	8.0	3710	133	HAU introduction
QPL-34	Triple cross	65	9.6	3550	127	ICRISAT introduction
QPL-20	Pant A-2 x Baigani	56	12.3	2900	104	ICRISAT introduction
Check-1	QPL-3	54	6.8	2030	73	UQ. INS.
Check-2	Prabhat	59	7.6	2800	100	
Mean (location)				2750		
SE ±				275		
CV (%)				20		

Distribution of Breeders' Material

In addition to our entries in the All India Trials, we supplied 1288 pigeonpea samples to various breeders on request: 28 scientists in 25 countries (other than India) received 610 samples. In India, 678 samples were supplied to 40 scientists at 34 locations. The materials despatched included F_{1s}, F_{2s}, segregating progenies, advanced lines, disease-resistant lines, male-sterile stocks, and new plant types.

Looking Ahead

With the availability of a large number of advanced lines and populations of early-, medium-, and late-maturity, we will intensify multilocation testing in India and other pigeonpea-growing countries. In the hybrid program, the new male-sterile lines will be utilized to produce a large number of hybrid combinations in order to identify hybrids suitable for different agroecological situations. Continued emphasis will be placed on transfer of multiple-disease resistance into good agronomic types. We will also explore development of new plant types and their utility in new production systems. With the completion of pest surveys, we can now test various elements of pest management. Screening for tolerance to salinity and waterlogging and identification of efficient strains of *Rhizobium* will continue.

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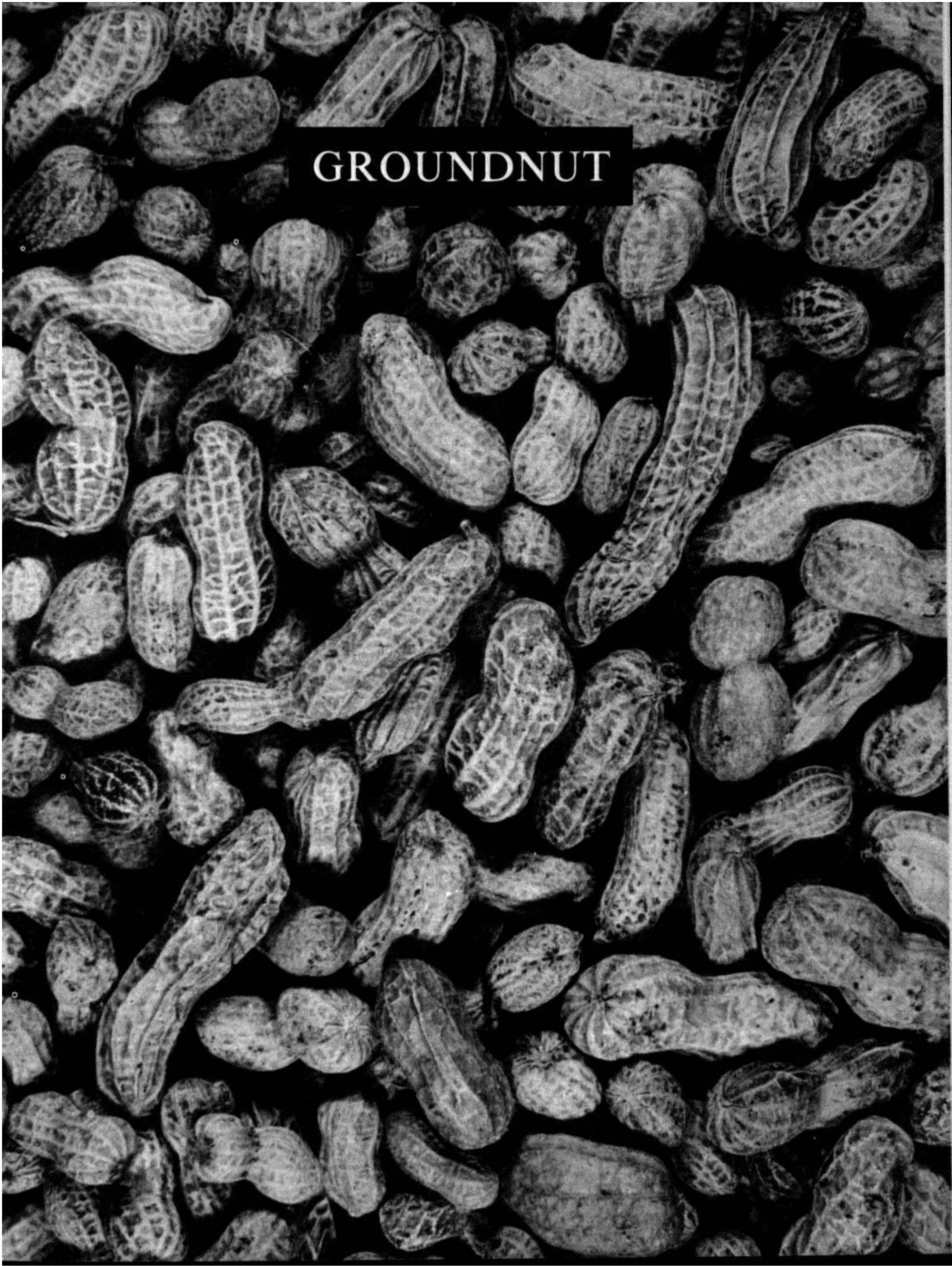

GROUNDNUT

Contents

GROUNDNUT

Groundnut is an important food and cash crop in the semi-arid tropics (SAT), but its average yield of around 800 kg/ ha is low in comparison with the 3000 kg/ ha or higher obtained in developed countries. The low yields are largely due to disease and pest attacks and drought stress.

In the Groundnut Improvement Program we have been working on disease and pest problems, as well as on problems of nitrogen fixation and yield potential, for the past 5 years, but significant research on drought and other physiological stresses has become possible only in the past year with the establishment of our Physiology Subprogram. Our management strategy remains unchanged: to utilize the genetic diversity in groundnut and its wild relatives and breed into the crop stable resistance or tolerance to the major yield reducers.

Diseases

Fungi cause serious diseases of groundnut in the SAT, the most important being the leaf spots caused by *Cercospora arachidicola* and *Cercosporidium personatum,* and rust caused by *Puccinia arachidis.* Virus diseases are also important, some being of widespread occurrence (e.g., peanut mottle virus disease), while others, such as groundnut rosette, are of restricted distribution. The problem of food contamination by mycotoxins is receiving much attention worldwide, and the particular problem of aflatoxin contamination of groundnuts is receiving high priority in most groundnut-growing countries.

Foliar Fungal Diseases

Screening for resistance. In the 1980 and 1981 rainy seasons we continued field screening of selected resistant lines and new accessions for resistance to rust and late leaf spot diseases. Three new sources of resistance were identified: U4-47-7 (MB) and U4-47-7 (LB) for resistance to rust and USA-63 to late leaf spot. U4-47-7 (MB) and U4-47-7 (LB) were also resistant to colonization of dried seeds by *Aspergillus flavus.*

All germplasm lines that have been found resistant at ICRISAT Center to rust and to late leaf spot are listed in Tables 1 and 2, respectively. Cultivars resistant to both pathogens are listed

Table 1. Rust reactions of some groundnut cultivars in field screening trials at ICRISAT Center, 1980 and 1981 rainy seasons.

Cultivars	Mean rust scores[a]
NC Ac 17090, PI 341879, PI 390593, PI 393646, PI 405132, PI 407454, PI 414331	2.5
EC 76446 (292), PI 259747, PI 360680, PI 314817, PI 315608, PI 381622, PI 393527-B, PI 393646, PI 414332, U4-47-7 (MB), U4-47-7 (LB)	3.0
NC Ac 17129, NC Ac 17132, NC Ac 17133 RF, PI 215696, PI 390595, PI 393517, PI 393531	3.5
NC Ac 927, PI 298115, PI 393516	4.0
NC Ac 17130, NC Ac 17135, NC Ac 17124, PI 393526, PI 393641	4.5
NC Ac 17127	5.0
TMV 2[b], Robut 33-1[b], J 11[b]	9.0

a. Scored on a 9-point disease scale; 1 = no disease and 9 = 50 to 100% foliage destroyed.
b. Standard susceptible cultivars.

Table 2. Late leaf spot reactions of some groundnut cultivars in field screening trials at ICRISAT Center, 1980 and 1981 rainy seasons.

Cultivars	Mean late leaf spot scores[a]
EC 76446 (292), PI 259747, PI 350680, PI 215696, PI 341879, PI 381622, PI 405132, USA 63	3.0
NC Ac 17133 RF, NC Ac 17506	3.5
NC Ac 17132, NC Ac 17135, NC Ac 15989, NC Ac 927, Krap. St. 16, RMP 91, PI 390595, PI 393516	4.0
NC Ac 17124, PI 393526, PI 393641	4.5
NC Ac 17130, NC Ac 17142, PI 390593	5.0
TMV 2[b], Robut 33-1[b], J 11[b]	9.0

a. Scored on a 9-point disease scale (See Table 1, fn a).
b. Standard susceptible cultivars.

Table 3. Groundnut cultivars with resistance to both rust and late leaf spot diseases at ICRIS AT Center, 1980 and 1981 rainy seasons.

	Main field disease scores[a]	
Cultivars	Rust	Late leaf spot
PI 341879, PI 405132	2.5	3.0
EC 76446 (292), PI 259747, PI 350680, PI 381622	3.0	3.0
NC Ac 17132, PI 390595	3.0	4.0
PI 215696	3.5	3.0
NC Ac 17133 RF	3.5	3.5
NC Ac 927, PI 393516	4.0	4.0
NC Ac 17135	4.5	4.0
PI 393526, PI 393641	4.5	4.5
NC Ac 17130	4.5	5.0
PI 390593	2.5	5.0
TMV 2[b], Robut 33-1[b], J 11[b]	9.0	9.0

a. Mean of field disease scores on a 9-point scale (see Table 1, fn a) over several seasons.
b. Standard susceptible cultivars.

in Table 3. (For further information on multiple resistance see ICRISAT Annual Report 1979/80, p 153.)

Yield losses from foliar diseases. We carried out a replicated field trial at ICRISAT Center in the 1979, 1980, and 1981 rainy seasons, using 19 germplasm lines and cultivars with and without fungicide application for control of foliar diseases. The entries represented a wide range of resistance to the two diseases. The best disease control was achieved with eight applications of a chlorothalonil preparation. Field disease scores, pod yields from untreated plots, and estimated yield losses from foliar diseases are given in Table 4. Estimated yield losses were lower in resistant than in susceptible lines. Some of the resistant lines outyielded the released Indian cultivars TMV 2, M 13, and Robut 33-1 under the severe rust and late leaf spot epidemics expe-

Table 4. Pod yields of foliar-disease-resistant and susceptible groundnut cultivars and estimated yield losses from disease.

Cultivars	Field disease scores[a]		Yields of dried pods in rainy-season crops (kg/ha)			Estimated yield losses from foliar diseases (%)			Mean loss
	Rust	Late leaf spot	1979	1980	1981	1979	1980	1981	
FESR 5-P2-B1	2.0	3.0	1244	987	1250	26.6	19.9	14.8	20.4
NC Ac 17090	2.2	5.2	2389	2137	2500	29.3	22.1	27.5	26.3
FESR 12-P6-B1	2.7	3.7	1525	1202	1383	32.7	35.0	29.1	32.3
FESR 11-P11-B2	3.0	3.2	1661	1669	2267	23.1	17.6	11.1	17.3
PI 259747	3.0	3.3	1265	960	2150	37.3	45.0	3.8	28.7
NC Ac 17133 RF	3.2	3.5	1682	1508	2484	46.5	21.9	17.2	28.5
NC Ac 17127	3.8	4.6	1778	1473	1900	19.8	27.1	28.8	25.2
NC Ac 17132	3.8	4.6	1850	1307	2334	43.2	51.2	25.9	40.1
NC Ac 17135	4.0	4.6	1991	1350	2700	33.2	31.0	8.5	24.2
PI 298115	4.0	6.8	578	1057	1600	26.6	46.7	34.3	35.9
K rap St 16	4.8	4.2	1311	1667	2384	23.4	17.3	28.5	23.1
NC Ac 17142	5.0	4.8	2161	1480	2117	28.2	37.0	31.4	32.2
NC Ac 15989	7.3	4.7	1078	719	1200	41.0	57.9	55.6	51.5
NC Ac 1301	8.4	8.0	788	902	1833	62.0	58.8	32.5	51.1
NC Ac 17133 YF	8.5	7.7	955	520	1150	43.9	75.6	46.9	55.5
M 13	8.8	6.6	1778	1287	1533	50.1	55.5	34.8	46.8
Robut 33-1	9.0	9.0	1456	862	1517	69.8	80.4	53.6	67.9
TMV 2	9.0	9.0	1122	604	1067	46.0	72.2	56.8	58.3
SE ±			38.7	29.4	77.0				
CV (%)			13.6	14.4	19.0				

a. Mean of field disease scores on a 9-point scale (see Table 1, fn a) over several seasons.

rienced at ICRISAT Center in the three seasons.

Diseased-crop physiology. A physiological analysis of the data from the yield loss trials for 1979 and 1980 seasons indicated that none of the lines investigated had both high foliar disease resistance and high yield potential (Fig. 1). Lines known to combine these characters appear to be compromises betwen these two extremes. Therefore, response to chemical disease control varied considerably with the yield potential of the genotype (Fig. 2). The response to fungicide application increased markedly only when yield potentials of 3 tonnes were exceeded.

Growth analysis of some resistant and some susceptible lines with and without chemical foliar disease control was conducted to examine the effects of the diseases on growth and growth distribution. We found that disease control did not markedly improve the yields of certain susceptible lines. The low yield potential of these lines allowed them to regenerate the leaves lost to disease, and so provided them with a disease tolerance mechanism.

Foliar diseases in intercrops. In a replicated field trial in the 1980 rainy season at ICRISAT Center, six groundnut lines with different

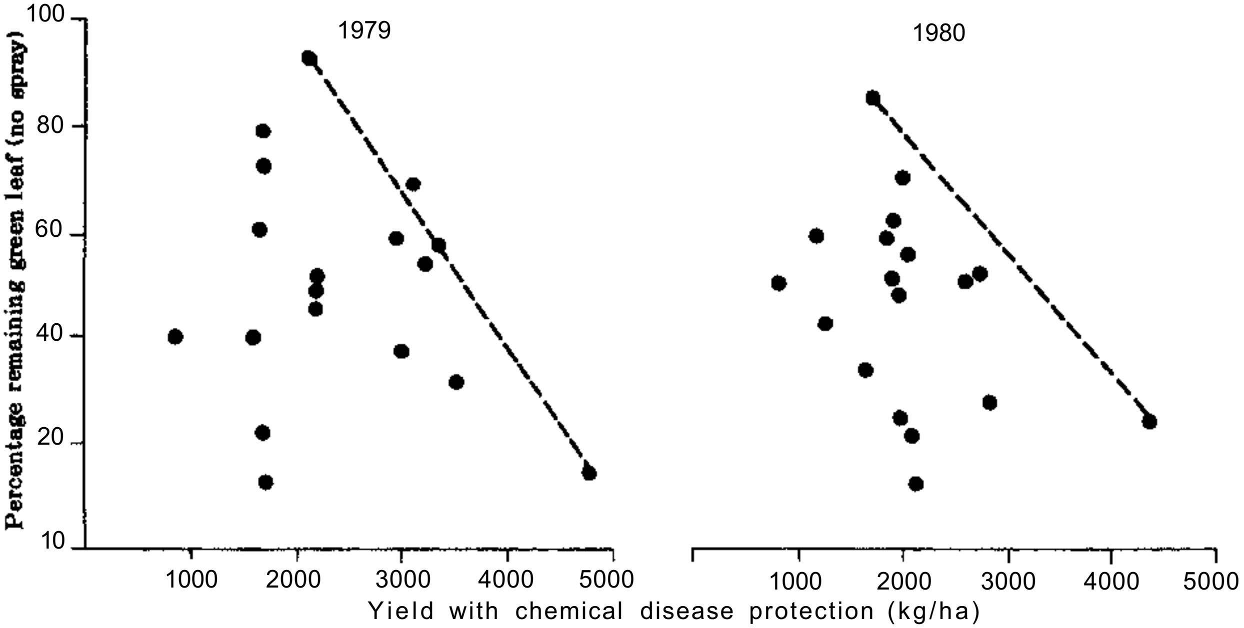


Figure 1. Resistance to foliar disease as measured by percentage of remaining green leaf plotted against leaf potential for 18 groundnut cultivars. The most resistant cultivars and the cultivars with the greatest yield potential are joined by the broken line.

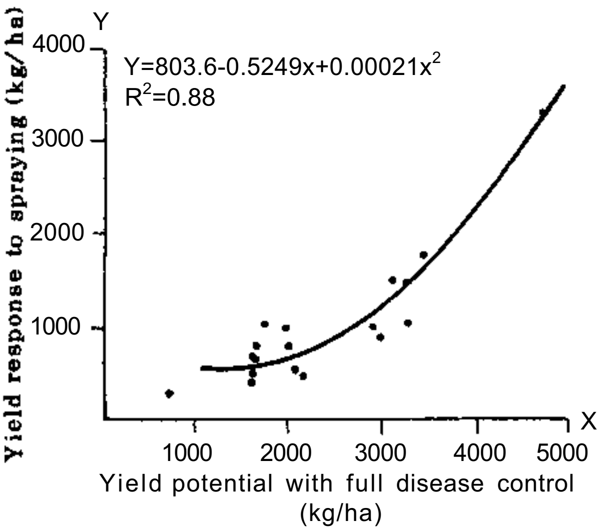


Figure 2. Relationship between response to disease control and yield potential of groundnut.

degrees of resistance to rust and leaf spot diseases were grown as sole crops and as intercrops with pearl millet (1 row of millet: 3 rows of groundnut). The damage caused by rust and leaf spots was less in the intercropped than in the sole cropped groundnuts.

In another trial in the 1981 rainy season, we grew three groundnut lines as sole crops and as intercrops with pearl millet and with sorghum. Intercrop ratios were 1 row of cereal: 1 and 3 rows of groundnut. There was no difference in leaf spot damage between the intercrop treatments, but rust caused significantly less damage in intercropped than in the sole cropped groundnuts.

Reaction of genotypes to rust. We tested 25 rust-resistant and 5 rust-susceptible genotypes for reaction to rust in a glasshouse inoculation trial. Plants were inoculated when 40 days old, and in the resulting single cycle of infection, measurement was made of several disease characters (Table 5). These characters correlated significantly with one another and with the mean of field disease scores from previous trials. They could therefore be used for resistance screening of inoculated plants in the glasshouse, a useful facility in areas where rust disease pressure is

Table 5. Varietal reaction of groundnut *to* inoculation with rust: comparison of disease characters with one another and with field disease scores.

Cultivars	Field disease scores[a]	Incubation period (days)	Infection frequency (lesions/ cm^2)	Pustule diameter (mm) at 30 DAI	% pustules ruptured at 20 DAI	% pustules ruptured at 30 DAI	% leaf area damaged
NC Ac 17090	2.0	19.3	5.9	0.68	0.3	0.5	3.6
PI 405132	2.3	18.3	8.1	0.63	1.3	5.6	3.9
PI 414332	2.3	14.7	4.1	0.86	1.4	0.5	2.7
PI 393646	2.7	18.1	6.7	0.57	0.6	2.4	2.3
PI 407454	3.0	18.5	4.7	0.57	1.1	4.7	1.7
EC 76446 (292)	3.0	17.5	6.2	0.59	5.1	13.5	5.1
PI 393527-B	3.0	15.9	4.2	0.51	14.4	38.8	5.0
PI 314817	3.0	15.2	3.2	0.49	2.4	15.5	2.8
PI 393643	3.0	14.7	5.5	0.73	3.0	9.2	4.8
PI 381622	3.0	13.0	6.9	0.94	2.4	7.5	2.3
PI 414331	3.0	11.9	1.4	0.57	3.8	0.0	0.9
PI 350680	3.0	11.3	3.6	0.79	0.3	0.5	1.9
PI 393517	3.3	13.8	6.7	0.49	1.2	4.5	1.9
PI 393531	3.7	11.4	4.5	0.51	0.0	2.0	1.3
NC Ac 17127	3.8	9.5	29.5	0.95	96.0	100.0	12.3
NC Ac 17129	4.0	11.4	21.0	1.29	95.5	100.0	13.9
NC Ac 17130	4.0	10.1	10.2	1.29	97.1	100.0	8.0
NC Ac 17132	4.0	9.9	12.3	1.12	96.0	100.0	20.0
PI 393526	4.0	9.8	6.1	1.04	94.8	100.0	6.3
NC Ac 17124	4.0	9.7	23.0	1.24	97.0	100.0	25.0
NC Ac 17135	4.0	9.3	22.5	1.31	95.7	100.0	21.0
PI 298115	4.0	9.2	11.3	1.16	90.5	100.0	16.2
NC Ac 17142	5.0	9.6	11.8	1.10	95.5	100.0	12.3
C. No. 45-23	5.2	10.2	9.2	1.07	100.0	100.0	15.8
PI 270806	6.3	9.3	15.8	1.35	100.0	100.0	24.2
J 11	9.0	9.7	16.4	1.15	100.0	100.0	27.5
TMV 2	9.0	9.3	13.5	1.12	100.0	100.0	18 1
NC 3033	9.0	9.1	10.8	1.01	100.0	100.0	15.3
EC 76446 (SP)	9.0	9.0	14.9	1.26	99.6	100.0	24.5
Robut 33-1	9.0	9.0	15.5	1.08	99.8	100.0	19.5
SE ±		0.45	1.38	0.042			
CV (%)		8.1	29.2	10.2			

a. Mean of field disease scores on a 9-point scale (see Table 1, fn a) over several seasons.
DAI= Days after inoculation.

insufficient to permit reliable field screening, where field screening is prohibited, or where the presence of other foliar diseases complicates field screening.

Reaction of wild *Arachis* spp to rust. Rooted detached leaves or branches of 64 wild *Arachis* species accessions arranged in replicated layouts in sterilized sand in plastic trays were inoculated with the rust pathogen. They were then incubated in growth chambers at high relative humidity at 25°C, and with 12-hr photoperiods. The susceptible cultivar TMV 2 was included as a check. After 30 days the leaves or branches were examined for development of rust. *A. monticola* (HLK 104) was highly susceptible, *A. rigonii* (GKP 10034) was susceptible, *Arachis* sp 30063 was moderately susceptible, six accessions (five from Section *Arachis)* were highly resistant, and the remaining 55 accessions were immune (Table 6).

Breeding for rust resistance. We grew 140 new F_1 crosses in the period from the 1980 to the 1981 rainy season. Of the material carried forward from previous seasons, 303 single plant selections and 5913 bulk selections were made from F_2 to F_{10} populations. No selection was made for rust resistance in the postrainy season due to low disease pressure, but selections were made for desirable agronomic characters. The postrainy season also gives us an opportunity to compare yields of our resistant lines against the susceptible checks in a virtually disease-free environment.

Yield trials: the FESR rust-resistant selections, originating as F3 progenies from the USDA nursery in Puerto Rico, have been advanced and yield tested at ICRISAT Center for several seasons now (ICRISAT Annual Report 1977/78,1978/79,1979/80). Some of the most resistant of these lines have also been used as parents in our hybridization program. The lines that emerged from this program as most promising were yield tested in the 1980 and 1981 rainy seasons and also in the 1980/81 postrainy season. The results of the 1981 rainy-season trial are given in Table 7. Generally the FESR selections do not have the yield potential and desirable agronomic characters of some of the more promising hybrids being developed at ICRISAT from such parents as NC Ac 17090, PI 259747, and EC 76446 (292). In addition, the FESR lines did not significantly outyield the susceptible released standard cultivar Robut 33-1, which is similar to FESR lines in its season length and plant habit. Therefore, testing of the FESR lines at ICRISAT Center will now cease, although we will continue to use them as parents and distribute them to cooperators.

During the 1980 rainy season and 1980/81 postrainy season, rust-resistant lines developed at ICRISAT Center were selected and advanced. Many new hybrid combinations were also made during this period from material tested by ICRISAT pathologists. In the 1981 rainy season we yield tested many hybrids (F_6 to F_8 populations) at ICRISAT Center and conducted one trial at our Dharwar station in Karnataka State. Most of the trials were conducted on broadbeds in fields where supplementary irrigation and insect control measures could be provided, if required (Tables 8-12). One trial was sown under low-fertility conditions without supplementary irrigation (Table 13). Many of the entries significantly outyielded the susceptible controls, including Robut 33-1. Some of the high-yielding lines derived from resistant x susceptible crosses that were rated as susceptible to rust last year (ICRISAT Annual Report 1979/80, p 129) also yielded well in these trials. Also, some lines with good resistance to rust (ratings of 2-3 on the 9-point scale) had good ratings (4-5) for late leaf spot resistance as well. These entries were from crosses of HG 1 x NC Ac 17090, SM 1 x EC 76446 (292), Shantung Ku No.203 x EC 76446 (292), and JH 89 x EC 76446 (292).

Reaction to late leaf spot. We tested 11 resistant and two susceptible cultivars for reaction to late leaf spot in a glasshouse inoculation trial. The plants were inoculated when 50 days old, and in the resulting single cycle of infection, measurement of several disease characters was made at two intervals (Table 14). Correlations were highly significant between percentage defoliation, lesion diameter, and sporulation measured in the glasshouse test and mean field disease scores from previous trials, indicating that the characters could be used for separating resistant from susceptible genotypes in glasshouse screening.

Breeding for resistance to leaf spots. Sources

Table 6. Reaction of wild *Arachis* species to rust at ICRISAT Center.

Section and series	Species	Collection No.	PI No.	ICG No.	Synonyms[a]	Rust reaction
Section: *Arachis*						
Series *Annuae:*	A. *batizocoi*	K 9484	298639	8124	207/338312	I
	A. duranensis[b]	K 7988	219823	8123		
	A. spegazzinii[b]	GKP 10038[c]	262133			
Series *Perenne:*	*A. correntina*[b]	HL 176	331194	4984	9584	I
	A. correntina[b]	K 7897	262134	8134	298635	I
	A. correntina[b]	GKP 9530	262808			I
	A. correntina[b]	GKP		8140	9530/9531	I
	A. stenosperma.[b]	HLK 410	338280	8126	411/337309	HR
		HLK 408	338279	8125	409/ 337308	HR
		HLK 409	337308	8137	408/ 338279	HR
	A. cardenasii[b]	GKP 10017	262141	8216		I
	A. chacoense[b]	GKP 10602	276235	4983		I
	A. villosa		210554	8144		I
	Arachis sp				Manfredi-5	I
Series *Amphiploides:*	A. *monticola*	HLK 104	331338	8135	219824/263393	HS
Series Not known:	*Arachis* sp	30006		8190		I
	Arachis sp	30011		8193		I
	Arachis sp	30031				HR
	Arachis sp	30035				HR
Section: *Erectoides*						
Series *Procumbense*:	A. *rigonii*	GKP 100 34	262278		326/331190	S
Series *Tetrafoliate:*	A. *apressipila*[b]	GKP 10002		8129		I
	A. paraguariensis	KCF 11462		8130	331/ 337358	I
	Arachis sp	GKP 9990	262877	8127		I
	Arachis sp	GKP 9993	261878	8128		I
Section: *Triseminale*						
	A. *pusilla*	GKP 12922	338449	8131		I
Section: *Extranervosae*						
	A. villosulicarpa	Ex. Coimbatore		8142		I
Section: *Rhizomatosae*						
Series *Eurhizomatosae*:	A. *hagenbeckii*	HLKO 349	338305			I
	A. *hagenbeckii*	HL 486	338267	361		I
	A. *glabrata*	HLKHe 552	338261			I
	A. glabrata	HLKHe 553	338262			I
	A. *glabrata*	HLKHe 560	338263			I
	A. *glabrata*	HLKHe 571	338265			I
	A. glabrata	GKP 9827	262796			I
	A. *glabrata*	GKP 9830	262797			I
	A. *glabrata*	Ex. Coimbatore				I

Continued

Table 6, *continued*

Section and series	Species	Collection No.	PI No.	ICG No.	Synonyms[a]	Rust reaction
	Arachis sp	HLO 333	338316			I
	Arachis sp	HL 492	338284			I
	Arachis sp	HLKHe 567	338299			I
	Arachis sp	K 7934	201856		298638	I
17 accessions with GKP Nos. and PI Nos: 9566/262812, 9567/262818, 9580/262825, 9591/262827, 9592/262828, 9618, 9634/262836, 9645/262841, 9649/262844, 9667/262848, 9797/262807, 9806/262792, 9813/262793, 9834/262798, 9882/262286, 9935/262301, 10596/276233.						I
	Arachis sp	GKP 9893			9893 PL1/8 4-79	HR
Section: Not known:	*Arachis* sp	1960		8172	1960 100/15 11-78	I
	Arachis sp	30063		8198		MS
	Arachis sp	30085				I
	Arachis sp				245 11-78	I

a. Accessions that have been reported to be identical for taxonomic, morphological, or other reasons.
b. Nomen nudum,
c. Accessions with small and large leaflets (ICG 8138 and 8139,respectively) have same reaction.
I = Immune
HR = Highly resistant
S = Susceptible
HS = Highly susceptible
MS = Moderately susceptible

Table 7. F_{10} FESR rust-resistant yield trial, ICRISAT Center, 1981 rainy season.

Selection	Days to harvest	Yield (kg/ha)	Shelling (%)	Reaction[a] Rust	Leaf spot
FESR 8-P13-B1-B2-B1-B1-B1-B1	108	3857	63	3	6
FESR 11-P7-B1-B2-B1-B1-B1-B1	109	3780	71	2	8
FESR 11-P8-B2-B1-B1-B1-B1-B1	109	3752	69	2	6
FESR 8-P2-B1-B1-B1-B1-B1-B1	109	3687	68	2	4
FESR 11-P13-B1-B2-B1-B1-B1-B1	109	3632	69	2	5
NC Ac 17090[b]	109	4250	74	2	6
Robut 33-1[c]	109	5000	68	9	9
J 11[c]	109	4348	67	9	9
M 13[c]	109	2672	65	9	9
SE±		218.3			
CV(%)		11,5			

a. Scored on a 9-point scale (see Table 1, fn a).
b. Rust-resistant germplasm line.
c. Standard susceptible checks.

Table 8. Breading groundnut for rust resistance; F_6 yield trial at ICRISAT Center, 1981 rainy season.

Selection	Days to harvest	Yield (kg/ha)	Shelling (%)	Reaction[a]	
				Rust	Leaf spot
(Faizpur 1-5xNC Ac 17090) F2-B1-B2-B1-B1	99	5033	63	3	9
(NC Ac 400 xNC Ac 17090) F2-B2-B2-B2-B4	111	4666	68	3	9
(JH 89xEC 76446 (292)) F2-B1-B1-B2-B1	111	4468	66	3	4
(Argentine xNC Ac 17090) F2-B2-B1-B2-B1	111	4468	64	3	7
(NC-Fla-14xNC Ac 17090) F2-B1-B2-B2-B1	107	4450	60	3	7
NC Ac 17090[b]	111	4863	68	2	5
J 11[c]	107	4090	62	9	9
Robut 33-1[c]	99	3984	58	9	9
SE ±		205.1			
CV(%)		8.8			

a. Scored on a 9-point disease scale (see Table 1, fn a).

b. Rust-resistant check.

c. Standard susceptible checks.

Table 9. Breeding groundnut for rust resistance; F_7 yield trial at ICRISAT Center, 1981 rainy season.

Selection	Days to harvest	Yield (kg/ha)	Shelling (%)	Reaction[a]	
				Rust	Leaf spot
(NC Ac 2768 x NC Ac 17090) F2-B2-B1-B2-B1-B1	107	5280	69	9	9
(TG 14 x NC Ac 17090) F2-B1-B1-B2-B1-B1	107	5010	62	3	7
(Dh 3-20 x NC Ac 17090) F2-B1-B1-B2-B1-B1	107	4947	66	3	9
(HG 1 x NC Ac 17090) F2-B2-B1-B2-B1-B1	107	4891	60	3	5
(NC Ac 400 x EC 76446 (292)) F2-B1-B1-B2-B1-B1	114	4880	60	3	7
(SM 1 x EC 76446 (292)) F2-B2-B1-B2-B1-B1	107	4873	64	2	5
NC Ac 17090[b]	107	4098	72	2	6
Robut33-1[c]	103	4074	70	9	9
JL 24[c]	103	3836	63	9	9
J 11[c]	107	3322	68	9	9
SE ±		340.5			
CV (%)		14.1			

a. Scored on a 9-point disease scale (see Table 1., fn a).

b. Rust-resistant check.

c. Standard susceptible checks.

Table 10. Breeding groundnut for rust resistance; F_7 and F_8 yield trial at ICRISAT Center, 1981 rainy season.

Selection	Days to harvest	Yield (kg/ha)	Shelling (%)	Reaction[a]	
				Rust	Leaf spot
(Dh 3-20 x PI 259747) F2-P75-P1-B1-B2-B2-B1	107	4625	66	2	6
(Comet x NC Ac 17090) F2-B2-B1-B2-B1-B1	103	4296	66	3	9
(Starr x NC Ac 17090) F2-B1-B1-B2-B1-B1	102	4187	60	3	9
(Shantung Ku No. 203 x EC 76446 (292)) F2-B1-B1-B2-B1-B1	111	4175	70	3	4
(NG 268 x NC Ac 17090) F2-B1-B1-B2-B3-B1	107	4116	63	9	9
NC Ac 17090[b]	114	4129	65	3	6
Robut 33-1[b]	110	4067	60	9	9
JL 24[c]	107	3962	66	9	9
J 11[c]	107	3780	64	9	9
SE±		716.9			
CV(%)		12.0			

a. Scored on a 9-point disease scale (see Table 1, fn a).
b. Rust-resistant check.
c. Standard susceptible checks.

Table 11. Breeding groundnut for rust resistance; F_8 yield trial at ICRISAT Center, 1981 rainy season.

Selection	Days to harvest	Yield (kg/ha)	Shelling (%)	Reaction[a]	
				Rust	Leaf spot
(NC-Fla-14 x PI 259747) F2-PP-B1-B2-B3-B1	99	4826	64	9	9
(FSB 7-2 x PI 259747) F2-B3-P3-B1-P1-B1-B1	99	4820	57	9	9
(Argentine x PI 259747) F2-B3-P1-B1-B2-B1-B1	103	4468	58	9	9
(TG 17 x PI 259747) F2-PP-B1-B1-B2-B1-B1	111	4352	68	3	9
(Var. 2-2 x PI 259747) F2-P3-P1-B1-B2-B1-B1	103	4336	66	9	9
NC Ac 17090[6]	114	4611	70	2	7
Robut 33-1[c]	99	3697	52	9	9
J 11[c]	106	3370	62	9	9
SE±		256.0			
CV(%)		12.0			

a. Scored on a 9-point disease scale (see Table 1, fn a).
b. Rust-resistant check.
c. Standard susceptible checks.

Table 12. Breeding groundnut for rust resistance; F_7 and F_8 yield trial at Dharwar, 1981 rainy season.

Selection	Yield (kg/ha)
(GAUG 1 x PI 259747)	
F2-B2-B1-B2-B1-B1	2401
(99-5 x PI 259747)	
F2-P108-P1-B1-B2-B3-B1	2217
(NG 268 x NC Ac 17090)	
F2-B1-B1-B2-B3-B1	1959
NC Ac 17090[a]	1738
Dh 3-30[6]	1955
J 11[b]	2010
Robut 33-1[b]	1957
SE ±	146.4
CV (%)	17.6

a. Rust-resistant check.
b. Standard susceptible cultivars.

of resistance to late leaf spot are listed in Table 2 and genotypes resistant to both rust and late leaf spot, in Table 3. Since the two diseases occur together in the field, we are screening segregating populations simultaneously for resistance to them. Advanced breeding lines are being intercrossed to increase the level of resistance.

The genotype NC 3033 is being utilized as a source of resistance to early leaf spot. We grew this genotype in the 1981 rainy season together with nine F_2 and six F_3 populations; selections from these will be tested in the 1982 rainy season.

Soilborne Fungal Diseases

Seed and seedling diseases. In collaboration with the Punjab Agricultural University, Ludhiana, India, we screened 64 genotypes for resistance to *Aspergillus niger* seedling collar rot on Ludhiana farm, where there is high inoculum

Table 13. Breeding groundnut for rust resistance; F_7 and F_8 yield trial (low fertility) at ICRISAT Center, 1981 rainy season.

Selection	Growth habit	Days to harvest	Yield (kg/ha)
(Var. 2750 x PI 259747)			
F2-PP-B1-B1-B2-B3-B1	SB	108	1616
(JH 60 x PI 259747)			
F2-B1-B1-B1-B2-B1-B1	SB	105	1611
(AH 6279 x PI 259747)			
F2-B1-B4-B1-B2-B1-B1	SB	105	1579
(X14-4-B-19-B x NC Ac 17090)			
F2-B2-B1-B2-B1-B1	SB-IB/VB	105	1512
(AH 8254 x PI 259747)			
F2-P4-P1-B1-B2-B1-B1	SB	108	1510
NC Ac 17090[a]	Val	109	1169
JL 24[b]	SB	108	1382
J 11[b]	SB	108	1141
Robut 33-1[b]	VB	105	1070
SE ±			81.0
CV (%)			11.3

SB = Spanish Bunch; IB = Irregular branching; VB = Virginia Bunch; Val = Valencia.

a. Rust-resistant check.
b. Standard susceptible checks.

Table 14. Reaction of resistant and susceptible groundnut cultivars to inoculation with late leaf spot: comparison of disease characters with one another and with field disease scores.

Cultivars	Field disease scores[a]	Disease characters: Percentage defoliation 20 DAI	40 DAI	Percentage leaf area damaged 20 DAI	40 DAI	Mean lesion dia(mm) 20 DAI	40 DAI	Lesion number/ cm^2 20 DAI	Sporulation index[b] 40 DAI
PI 215696	3.0	0.0	15.3	2.9	7.2	1.3	2.0	2.4	2.2
PI 259747	3.0	0.6	25.6	3.2	13.4	0.9	2.0	1.7	2.0
PI 341879	3.0	3.5	18.5	3.8	10.2	0.9	2.3	.3.9	2.7
PI 350680	3.0	1.0	39.3	7.7	15.5	0.9	2.3	2.5	2.5
PI 381622	3.0	1.0	17.2	2.4	10.7	0.8	2.0	2.3	2.2
PI 405132	3.0	0.5	13.0	2.6	11.7	1.2	1.9	2.0	2.0
PI 390595	4.0	8.0	42.1	4.6	14.6	1.3	3.5	2.3	2.0
PI 393516	4.0	13.7	46.9	5.3	11.5	1.4	2.2	3.2	2.1
PI 393526	4.5	20.1	60.9	14.4	16.9	2.1	3.2	3.9	3.0
PI 393641	4.5	1.3	36.4	0.9	16.7	1.4	2.9	0.8	2.4
PI 390593	5.0	11.8	54.3	3.1	12.9	1.6	2.9	2.2	2.3
TMV 2[c]	9.0	39.9	87.3	14.9	6.3	3.8	6.7	3.8	5.0
Robut 33-1[c]	9.0	36.4	87.2	21.8	5.4	2.1	3.9	2.7	5.0
SE ±		1.56	2.26	0.75	1.19	0.08	0.11	0.30	0.09
CV (%)		46.5	17.0	35.2	32.0	16.8	12.0	37.1	10.5

a. Mean of field disease scores on a 9-point scale (see Table 1, fn *a)* over several seasons.
b. Extent of sporulation scored on a 5-point scale where 1 = no sporulation, and 5 = extensive sporulation.
c. Standard susceptible cultivars.

DAI= Days after inoculation.

pressure. In both 1980 and 1981 rainy seasons the genotypes J 11, U-4-47-7, and U-2-1-26 showed good resistance. All three genotypes had shown resistance to *A. niger* collar rot in our earlier trials at ICRISAT Center (ICRISAT Annual Report 1979/80).

Pod rot disease. In 1980/81 we recorded pod rot diseases similar to that found at ICRISAT Center (ICRISAT Annual Report 1978/79, 1979/80) in coastal Andhra Pradesh, Tamil Nadu, and Punjab states of India. Preliminary studies indicate that the same fungi—*Fusarium* spp, *Macrophomina phaseolina,* and *Rhizoctonia solani*—are the most important components of the disease complex in all these areas.

In 1980/81 we confirmed the resistance of seven of the genotypes that previously showed less than 10% of pods rotted at ICRISAT Center (ICRISAT Annual Report 1979/80), and identified four new sources. Five of these genotypes were also found to be resistant to *A. flavus* colonization of dried seeds (Table 15).

In a preliminary drought screening trial (see Drought Screening section below) with 81 genotypes in the 1980/81 postrainy season at ICRISAT Center, we found that rapid and severe pod rotting occurred in many genotypes where stress had occurred in the preceding 30 days, when the crop was watered to facilitate lifting. Eleven genotypes with below-average damage were selected for further testing.

Table 15. Incidence of pod rot in selected groundnut cultivars in field trials at ICRISAT Center, 1980/81.

Cultivars	Percentage of pods rotted: Rainy-season crops 1980	Rainy-season crops 1981	Postrainy-season crop 1980/81
Sources of pod rot resistance reported in 1979/80:			
J 11[a]	5.1	7.9	7.4
NC Ac 841[a]	8.7	12.8	4.5
NG 387[a]	5.2	9.7	7.8
Sir of Bizapur	6.9	11.7	4.2
Exotic 2	6.3	9.5	6.5
Var. 27[a]	5.6	9.1	6.1
U-1-2-1	6.9	11.3	6.7
New sources of pod rot resistance:			
C.No. 677	4.9	8.4	4.9
Ah 7223[a]	7.1	8.6	7.8
C.No. 55-437	8.0	9.7	6.9
U-4-4-1	4.6	7.7	3.8
Commonly grown cultivars:			
TMV 2	15.6	19.0	16.7
Robut 33-1	18.1	30.4	17.9
SE ±	1.80	1.99	2.06
CV (%)	29.7	15.4	30.1

a. Also resistant to A.flavus colonization of dried seeds.

The aflatoxin problem. We continued screening germplasm for resistance of dried seeds to invasion by *A. flavus,* using techniques previously described (ICRISAT Annual Report 1979/80; ICRISAT Groundnut Program Occasional Paper 2). Some test data are presented in Table 16. In these tests more colonization occurred in seed from postrainy-season crops than in seed from rainy-season crops.

Seeds of several genotypes were also tested to determine the levels of natural infection with *A. flavus.* Three replicates of 100 seed samples were taken from undamaged, field-dried mature pods of each genotype. The seeds were surface-sterilized for 3 min in 0.1% aqueous solution of mercuric chloride, rinsed in sterile water, then plated aseptically onto Czapek Dox Rose Bengal Streptomycin Agar medium in 9 cm dia petri dishes, five seeds per dish. The plates were incubated at 25°C, and colonies of *A.flavus* growing from infected seeds were recorded (Table 17). Natural *A. flavus* seed infection was lower in genotypes whose dried seeds were resistant to colonization by the fungus than in susceptible genotypes.

We tested 95 genotypes for resistance to aflatoxin production following invasion of seeds by toxigenic strains of *A.flavus.* Aflatoxin was produced in all genotypes tested, but varietal differences in rate of accumulation and total toxin produced were found (Fig, 3).

The mycotoxin citrinin was found occurring naturally in seed of several genotypes grown at ICRISAT Center.

Table 16. Groundnut seed resistance to colonization by *Aspergillus flavus* in tests at ICRISAT Center, 1980/81.

	Percent seeds colonized by A. *flavus*			
	Postrainy--season crops		Rainy-season crops	
Genotypes	1979/80	1980/81	1980	1981
UF 71513	13.1	14.2	6.6	9.5
PI 337394 F	19.9	19.5	8.1	12.6
PI 337409	20.8	21.0	9.4	13.3
J 11	21.8	17.5	12.0	12.5
Ah 7223	15.7	15.8	4.5	10.4
Monir 240-30	16.1	14.3	9.0	10.3
Var. 27	21.2	19.9	9.7	11.5
Faizpur	19.7	19.1	9.8	12.9
TMV 2[a]	49.4	41.5	36.7	36.2
OG 43-4-1 [b]	96.9	98.2	91.2	93.2
SE±	1.08	1.43	1.36	1.22
CV(%)	6.4	8.8	11.9	9.5

a. Susceptible check.
b. Highly susceptible check.

Table 17. Natural *Aspergillus flavus* infection of seeds from field-dried pods of groundnut genotypes resistant and susceptible to seed colonization.

	Percent seeds naturally infected by A. *flavus*			
	Postrainy-season crops		Rainy-season crops	
Genotypes	1979/80	1980/81	1980	1981
UF 71513[a]	0.6[b]	1.3	0.0	0.3
PI 337394 F[a]	0.3	1.0	0.3	0.6
PI 337409[a]	0.6	1.6	0.3	0.6
J 11[a]	0.3	0.3	0.6	0.3
TMV 2	1.3	2.6	1.6	1.3
EC 76446 (292)	1.3	3.3	2.0	
Krapovickas Str. 16	1.6	2.3	2.0	
OG 43-4-1	1.6	2.3	1.3	
Robut 33-1	1.3	2.3	1.3	
M 13	2.0	3.0	2.0	
Gangapuri				2.0
SE±	0.68	0.90	0.59	0.55
CV (%)	28.2	27.9	31.4	25.7

a. Genotypes with dry seed resistance.
b. Means of three replications.

Breeding for resistance to *Aspergillus flavus*. Cultivars with resistance to seed colonization by *A.flavus* (PI 337409, PI 337394F) were involved in a crossing program with diverse and elite germplasm and breeding lines derived from the high yield and quality project, and useful early-generation breeding material was developed.

Some F_4 and F_5-generation breeding popula-

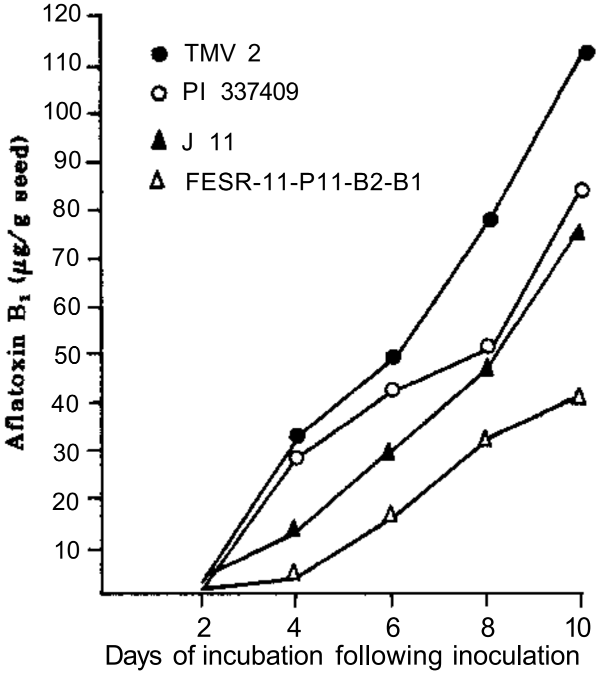


Figure 3. Aflatoxin B_1 accumulation in seeds of four groundnut cultivars inoculated with toxigenic *A.flavus* strain AF8-3-2A and incubated at 25±3°C.

tions were screened for seed resistance to colonization by *A.flavus,* and those with less than 15% seed colonization were selected for further testing and yield evaluation. (Table 18),

All possible crosses involving three resistant (PI 337394F, PI 337409, and UF 71513-1) and one susceptible (FESR 12-P6-B1-B1) cultivars have been attempted. Screening F_0 and F_1 seeds of these crosses for resistance to colonization by *A.flavus* will help us to understand the nature of resistance and to formulate breeding strategies.

Virus Diseases

Bud Necrosis Disease

Causal agent. In 1980/81 we developed an improved method for purifying tomato spotted wilt virus (TSWV), the causal agent of bud necrosis disease. This involves clarification of groundnut leaf extracts, concentration by high speed centrifugation, and treatment with antisera prepared against healthy groundnut leaf extracts. Further purification is achieved by one cycle of rate zonal centrifugation and two cycles of quasi-equilibrium zonal density gradient centrifugation in sucrose solutions. We have produced an antiserum for TSWV, which facilitates detection of the virus serologically, employing an enzyme-linked immunosorbent assay (ELISA) in plant extracts.

Screening for sources of resistance. In the 1980 rainy season we screened 239 germplasm lines in a replicated field trial for resistance to bud necrosis disease. The entries NC Ac 343, NC Ac 2230, NC Ac 2242, and NC Ac 2277 had significantly lower disease incidence than all other entries. Of these, NC Ac 2242, NC Ac 343, and NC Ac 2230 were found tolerant to jassid and thrips attack in our earlier studies (ICRISAT Annual Report 1979/80).

We also screened 42 accessions of wild *Arachis* species in the glasshouse by mechanical sap inoculation and grafting techniques for resistance to infection with the virus. All accessions tested became infected with TSWV following graft inoculation. However, the accessions A. *chacoense* (10602), *A. correntina* (9580), and *A. cardenasii* did not become infected following mechanical sap inoculation.

Vector studies. Previous research at ICRISAT showed massive invasion by *Frankliniella schultzei* (the thrips vector of TSWV) occurring on rainy-season crops from mid-August to early September, and on postrainy-season crops from January to mid-February (ICRISAT Annual Report 1979/80). Our observations in the 1980 rainy and 1980/81 postrainy seasons confirmed these findings and suggested that wind velocity and maximum day temperatures were important factors influencing population buildup and migration of *F. schultzei* Of the mass flights recorded between June 1980 and April 1981, most occurred when wind velocity at 1400 hr was below 10 km/hr and the remainder when the velocity was between 10 and 15 km/hr. Most

Table 18. Groundnut selections promising for resistance to *Aspergillus flaws* (with less than 15% seed colonization).

Pedigree	Seed colonized (%)
(Faizpur 1-5 x PI 337394 F) F2-B1-SPB1	11.10
(HG 1 x PI 337394 F) F2-B1-SPB1	10.74
(J 11 x PI 337394 F) F2-B1-SPB1	15.06
(Tifspan x PI 337394 F) F2-B1-SPB1	12.00
(Chico x PI 337394 F) F2-B1-SPB1	14.23
(Faizpur 1-5 x PI 337409) F2-B1-SPB1	13.45
(J 11 x PI 337409) F2-B1-SPB1	6.27
(66-437 x PI 337394 F) F2-B1-SPB1	14.16
(NC.Fla 14 x PI 337394 F) F3-B1-SPB1	13.68
(Robut 33-1 x PI 337394 F) F2-B1-P2	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P3	11.10
(Robut 33-1 x PI 337394 F) F2-B1-P5	11.10
(Robut 33-1 x PI 337394 F) F2-B1-P7	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P8	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P9	11.11
(Robut 33-1 x PI 337394 F) F2-B1-P15	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P16	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P23	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P31	10.00
(Robut 33-1 x PI 337394 F) F2-B1-P33	10.00
J 11[a]	14.00
OG 43-4-1[b]	96.00

a. Resistant check.
b. Susceptible check.

flights occurred when the maximum day temperature was between 20 and 35°C.

Plant population and disease incidence. In a replicated field trial at ICRISAT in 1980, TMV 2, Robut 33-1, and M 13 were sown at two within-row and two between-row spacings. As previously found (ICRISAT Annual Report 1979/80), bud necrosis disease incidence was lower at the higher population than at the lower population. This difference was more marked in cultivars TMV 2 and M 13 than in Robut 33-1.

In another field trial in 1980 we planted TMV 2 and Robut 33-1 on two dates (June and July) and at two plant populations (Tables 19 and 20). Planting date and genotype had a greater effect than plant spacing on disease incidence and yield.

Management of bud necrosis disease. At ICRISAT Center two cultural practices have been found effective in reducing incidence of bud necrosis disease—growing the crop at high plant population, and sowing the rainy-season crop in mid-June and the postrainy-season crop in November. Before these practices can be recommended for other localities it will be necessary to carry out the basic studies on vector populations and migrations and on effects of plant population in the specific localities.

In areas where the disease is severe, highly

Table 19. Effect of date of sowing and plant spacing on incidence of bud necrosis disease (BND) on groundnut cultivars TMV 2 and Robut 33-1 at ICRISAT Center, 1980 rainy season.

Sowing dates	Bud necrosis disease incidence (%) in TMV 2 50th day	TMV 2 100th day	Robut 33-1 50th day	Robut 33-1 100th day	Bud necrosis (%) (mean) 50th day	Bud necrosis (%) (mean) 100th day
15 June	12.9	70.5	4.0	30.7	8.4	50.6
	(20.8)[a]	(58.1)	(11.2)	(33.5)	(16.0)	(45.8)
15 July	69.1	94.1	32.3	58.5	50.7	76.3
	(56.3)	(76.2)	(34.6)	(49.9)	(45.4)	(63.0)
Mean	41.0	82.3	18.1	44.6		
	(38.5)	(67.2)	(22.9)	(41.7)		

SE±	Sowing date:	BND	
		50th day	(1.90)
		100th day	(1.20)
SE±	Cultivars:	BND	
		50th day	(0.84)
		100 th day	(1.13)

Percent BND in relation to plant spacing:

		SE±
75 x 10 cm - 50th day	28.4	
	(29.7)	(0.50)
75 x 15 cm - 100th day	30.7	
	(31.7)	
75 x 10 cm - 50th day	59.7	
	(51.8)	(0.96)
75 x 15 cm - 100th day	67.2	
	(57.0)	

a. Figures in parentheses are transformed values.

Table 20. Effect of date of sowing and plant spacing on pod yield of groundnut cultivars TMV-2 and Robut 33-1 at ICRISAT Center, 1980 rainy season.

Sowing date	Pod yield (kg/ha) TMV 2	Pod yield (kg/ha) Robut 33-1	Mean pod yield (kg/ha)	SE±
15 June	942	1455	1198	
15 July	75	255	165	27.7
Mean	508	855	681	
SE ±	17.0			

Mean yield for plant spacing:
75 x 10 - 755 kg/ha SE ± 25.0
75 x 15 - 609 kg/ha

susceptible cultivars such as TMV 2 should not be grown.

Peanut Mottle Virus Disease

Causal agent. In our disease surveys during 1976-81 we recorded peanut mottle virus (PMV) disease in Karnataka, Tamil Nadu, and Andhra Pradesh states of India.

In 1980/81 our purification method has been further refined to yield 40 mg of PMV from 1 kg of pea tissue. A sample of antiserum has been produced with a titre of 1/600, as determined by the precipitin ring test. We have now successfully adopted the ELISA technique for detection of PMV in seed. Using this technique we detected the viral antigen in embryos and cotyledons of infected seeds. By use of ELISA, small portions of tissues can be tested without destroying the seed. Over 5000 seeds from PMV-infected plants have now been tested simultaneously by ELISA and by "growing-on" tests, with good correlation between results from the two methods.

Screening for sources of resistance. In the 1980 rainy and 1980/81 postrainy seasons we screened 150 germplasm lines for resistance to PMV. Yield reduction following infection was estimated, and the percentage of seed transmission of the virus was determined. All lines were susceptible. Yield losses of infected plants ranged from 11 to 65%. Seed transmission was positive in all but two lines—NC Ac 17133 (RF) and PI 393643.

Over 5000 seeds of each of lines PI 259747, EC 76446 (292), and NC Ac 1826 from PMV-infected plants were tested by ELISA and by growing-on tests for presence of PMV. EC 76446 (292) showed no seed transmission, but PI 259747 showed 0.003% and NC Ac 1826, 0.007%. These three lines had shown no transmission in our earlier preliminary tests with smaller numbers *of* seeds.

A few plants each of 26 wild *Arachis* species were tested for resistance to PMV by mechanical sap inoculation and by grafting. Only two them, *A. chacoense* (10602) and *A.pusilla* could not be infected by either method.

Peanut Clump Virus Disease

Causal agent. In our disease surveys during 1976-81 we have recorded the peanut clump virus (PCV) disease in Tamil Nadu, Rajasthan, Punjab, Gujarat, and Andhra Pradesh states of India. We have purified the virus; the particles are rod-shaped, 24-26 nm wide, with a modal length of 165 and 230 nm, as determined in crude plant extracts (Figs. 4 and 5). An antiserum has been produced with a titre of 1/800, as determined by the precipitin ring test. Serological tests have shown that this virus is not related to tobacco rattle and pea early browning viruses. The virus contains a single polypeptide of molecular weight 24 000 daltons, and has similarities (soilborne nature, symptoms on peanut, wide host range, particle morphology, and density in CsCl) to peanut clump virus reported from West Africa.

Screening for sources of resistance. In collaboration with the Punjab Agricultural University, we carried out screening for resistance at Ludhiana, India, where the disease has been recurring in the same positions in fields for several years. Of 1200 germplasm lines screened, all were susceptible, but NC Ac 17840, NC Ac 17847, NC Ac 17866, and EC 21887 showed tolerance to PCV. Their growth and yield were only slightly affected by the presence of the virus.

Cowpea Mild Mottle Virus Disease

In a collaborative study with the University of Agricultural Sciences, Bangalore, India, we investigated the virus-vector relationship in 1980/81. The virus was found to be transmitted in a nonpersistent manner by the vector *Bemisia tabaci.* The virus causes an economically important disease in soybean. Out tests indicate that the isolate occurring in India is not seed transmitted in soybean or in groundnut, unlike the West African isolate of the virus.

An antiserum for cowpea mild mottle virus has been produced. We have found that the Indian strain is serologically related to the isolate reported on cowpeas in West Africa. The antiserum has also been used to identify the virus on soybeans in Thailand.

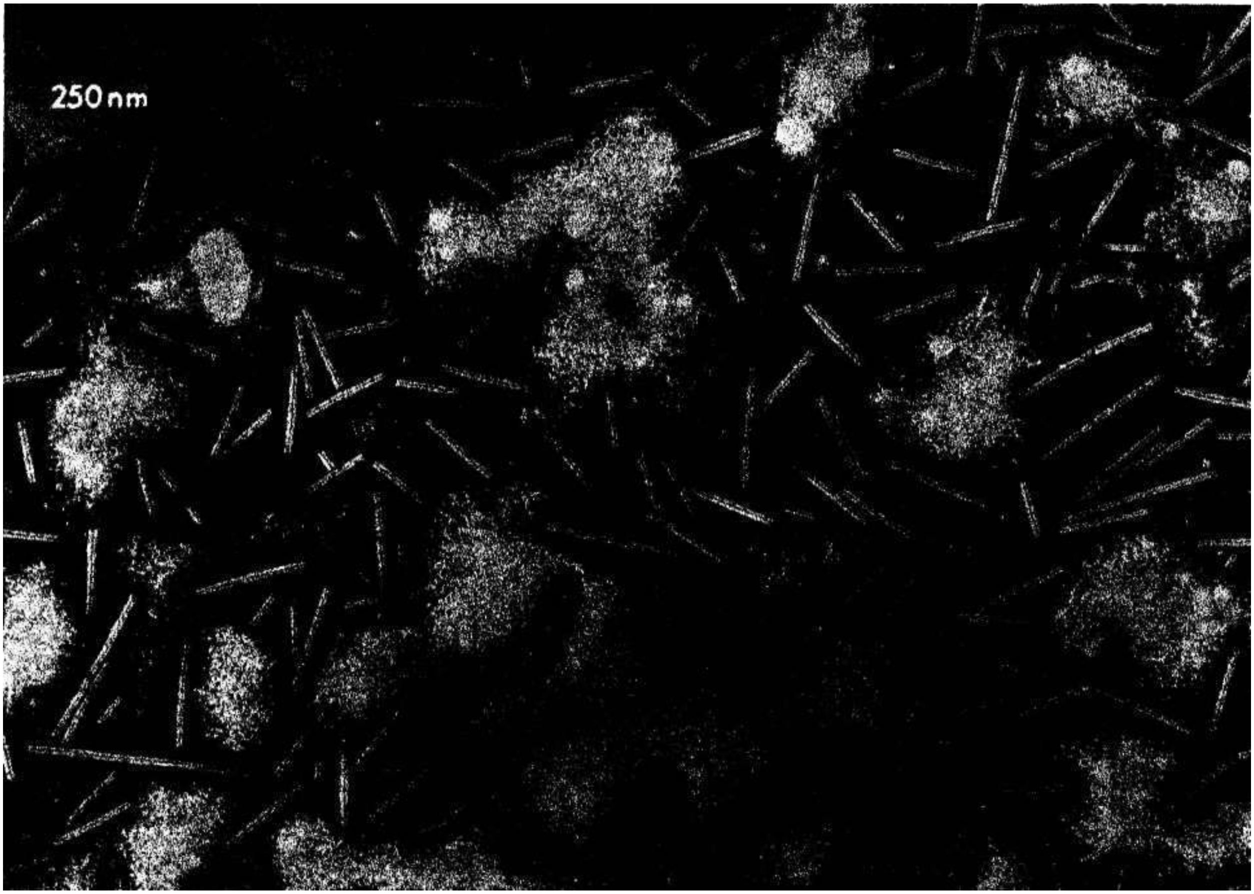


Figure 4. Purified peanut clump virus particles stained with phosphotungstic acid.

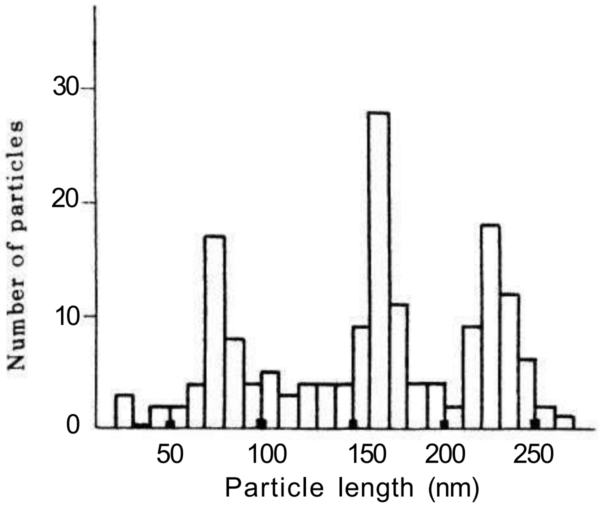


Figure 5. Clump virus particle length distribution in crude groundnut leaf extracts.

Pests

Incidence at ICRISAT Center

During the 1980 rainy season, a thrips (*Scirtothrips dorsalis*), a jassid (*Empoasca kerri*), and a leafminer (*Aproaerema modicella*) were the major pests; populations of leafminer built up during August and September, possibly because of low rainfall in July and August. There was a major attack by this insect in the 1980/81 postrainy season. In addition, armyworm (*Spodoptera litura*) caused severe damage in some fields during March and April. In the 1981 rainy season, the rainfall was heavy and well distributed throughout the growing season, and pest damage was generally low. Jassids, armyworm, white grub (*Lachnosterna fissa*), and termites were of moderate importance in restricted areas on ICRISAT Center farm.

Pest Surveys in India

We made field trips during the report period to the states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, and Uttar Pradesh. The leafminer *A. modicella* and the thrips *Caliothrips indicus* were serious pests in drought-affected areas of south India, This leafminer, which was endemic to south India, has now become a serious pest in Maharashtra and Gujarat in central India, particularly where there is large-scale cultivation of irrigated summer groundnuts. In sandy soils of Gujarat, Rajasthan, and Uttar Pradesh, white grubs and termites (*Odontotermes obesus*) were serious pests. Armyworm caused large-scale defoliation in parts of Andhra Pradesh, Karnataka, and Tamil Nadu; this insect was a minor pest of groundnuts until recent years. Jassid damage in Gujarat and Tamil Nadu was serious. Red hairy caterpillar (*Amsacta albistriga*) was an important pest in parts of Tamil Nadu, Karnataka, and Andhra Pradesh.

Assessment of Yield Losses from Thrips Attack

We conducted an experiment in the 1980/81 postrainy season to assess yield loss from thrips on the cultivar TMV 2. This season was suitable for such a trial because of high incidence of thrips (S. *dorsalis* and *Frankliniella schultzei*), and low incidence of fungal and virus diseases and sucking pests such as aphids and jassids, which occur simultaneously with thrips in the rainy season and affect yields.

Several plots of groundnut were exposed to insect pests for different periods to relate yield loss with pest attack at different stages of crop growth. Detailed weekly observations on pest populations and virus diseases were recorded. After the thrips population declined in March, all plots were sprayed with endosulfan (0.1%) to protect against leafminer and armyworm and bavistin + dithane M-45 to protect against fungal diseases.

Table 21. Assessment of groundnut yield loss from thrips[a] attack on the TMV 2 cultivar at ICRISAT Center, 1980/81 postrainy season.

Insecticide protection	Pod yield (kg/ha)
All season	1368
From 15 days after emergence	1438
From 30 days after emergence	1206
From 60 days after emergence	1092
No treatment	1051
SE ±	72.4
CV (%)	13.5

a. *Scirtothrips dorsalis* and *Frankliniella schultzei* were the major thrips pests at ICRISAT Center during this period.

The total crop protection increased yield by 30% (Table 21). The majority of the yield increase was from protection given during days 15-60 of crop growth, when only the thrips were major pests and differences in thrips populations were significant. Damage from other insect pests, including the leafminer, and from fungal and virus diseases was small and their effects on yield in various plots were nonsignificant. Therefore, the yield loss could be attributed only to thrips.

Assessment of Yield Losses from All Pests

We conducted a replicated trial in the 1980/81 postrainy season to assess the total yield loss from insect pests on the cultivar TMV 2 at ICRISAT Center. Test plots were protected with monocrotophos sprays (0.2%) at fortnightly intervals, and untreated plots served as controls. The major early-season pests were thrips, and in late-season, the leafminer. The yield differences were statistically significant; the mean yield of treated plots was 1477 kg/ha, while that of untreated plots was 1028 kg/ha, indicating a loss of 30.4% due to insect pests.

Biology of Major Pests and Host-Plant Resistance

Jassids. Of the several species of jassids that infested groundnuts at ICRISAT Center in 1980/81, *Empoasca kerri* was the most prevalent. The jassids infested the crop in July, but large populations gradually built up from late August till October. Cowpea was found to be a preferred host. We undertook mass rearing of jassids in the laboratory to augment field populations for resistance screening trials.

For advanced resistance tests, 41 groundnut cultivars were sown in a pesticide-free area in 4-m x 4-row plots in the 1st week of July. Two rows of cowpea came after every two test plots. Three releases, each of 500, 5000, and 10 000 laboratory-bred jassids, were made on the cowpeas. The cowpeas were harvested in August to encourage jassids to move to the groundnuts. Percent yellowing of foliage (typical jassid injury) and number of nymphs per five plants in the central two rows were recorded. Several lines had low levels of jassid injury, and most of them had low jassid infestation (Table 22). Laboratory tests using restricted numbers of insects in multiple choice or no-choice experiments showed that jassids were less fecund on the first nine lines in Table 22, than on the susceptible TMV 2 and Robut 33-1 cultivars.

Preliminary screening of another 300 cultivars resulted in identification of 12 lines that showed very little jassid injury. These are: NC Ac 2123, 785, 1140, 17011, 16940, 2154, 2798, 7481, and 2679; EC 36892 and 27446; and K-4 (a hybrid from *A. hypogaea* and *A. cardenasii*).

Table 22. Groundnut sources of resistance to jassids[a] at ICRISAT Center, 1980 rainy season.

Cultivar	Yellowing caused by jassids (%)[b]	No. of nymphs/5 plants
NC Ac 2232	0.0	1.3
NC Ac 2230	0.1	2.0
NC Ac 2243 (DP)	0.1	2.0
NC Ac 2242	0.2	1.3
NC Ac 2243 (T)	0.2	1.3
NC Ac 2214	0.2	1.7
NC Ac 2240	0.7	1.7
NC Ac 1705	1.0	5.7
NC Ac 343	1.9	2.7
NC Ac 2244	0.8	10.3
NC Ac 489	1.0	5.0
NC Ac 2666	1.5	8.7
M 13[c]	10.0	9.0
TMV 2[c]	40.0	20.3
Robut 33-1[c]	33.3	14.3
FESR 1, P9-B3-B2-B1[d]	53.3	17.0
Mean (41 cultivars)	18.55	9.8
SE ±		2.17
CV (%)		38.3

a. Empoasca kerri was the major jassid pest at ICRISAT Center during this period.

b. Arc sin transformation was used for analysis.

c. Standard check.

d. Susceptible check.

DP = Deep purple tests; T = Tan testa.

Thrips. Sources of resistance to thrips were sought because of their importance as pests and vectors worldwide. More emphasis was laid on *F. schultzei,* which, in addition to being a pest, is also a vector of tomato spotted wilt virus which causes bud necrosis disease of groundnuts. The objective was to combine vector resistance with high-yielding cultivars such as Robut 33-1. Most of the jassid-resistant cultivars were also promising against thrips, and therefore our observations were taken in a combined trial for jassids and thrips. The resistance, judged from low thrips injury, was observed in several lines (Table 23). Some of these lines were tested in USA, where they also showed high resistance to *F. fusca.* Also laboratory tests showed that thrips were less fecund on NC Ac 2242, 2214, 2240, 2232, and 2243 than on TMV 2. Further tests with other cultivars are in progress.

Aphids. Field screening to identify sources of resistance to the aphid, *Aphis craccivora,* at

Table 23. Groundnut sources of resistance to the thrips *Frankliniella schultzei* at ICRISAT Center, 1980 rainy season.

Cultivar	Injury rating (1-9 scale)
NC Ac 2243 (T)	1.9[a]
NC Ac 2243 (DP)	2.1[a]
NC Ac 2242	2.2[a]
NC Ac 2214	2.3
NC Ac 2230	2.3[a]
NC Ac 1705	2.4
NC Ac 2240	2.4[a]
NC Ac 343	2.8
NC Ac 2232	2.8[a]
NC Ac 2462	3.0
NC Ac 2142	3.2
NC Ac 2144	3.7
NC Ac 2199[b]	5.6
Mean (41 cultivars)	4.2
SE ±	0.62
CV(%)	26.7

a. Least damaged cultivars by F. fusca at Tifton, Georgia, USA, with injury rating of 3.3-3.8. Susceptible check PI 339974 had injury rating of 5.8.
b. Susceptible check.
T = Tan seed coat.
DP = Deep purple seed coat.

ICRISAT farm was not possible because of inadequate buildup of this insect pest. Testing was therefore done in the screenhouse by artificially infesting plants with aphids. Out of 1600 *A. hypogaea* sources screened, none was found promising. However, two wild species, *A. chacoense* and *A. batizocoi,* were highly resistant. Some progenies of *A. chacoense* x *A. hypogaea* were also promising (Table 24). However, in tests of over 100 progenies of *A. batizocoi* x *A. hypogaea* none was found resistant.

We are attempting to improve field screening by artificial release of aphids at ICRISAT Center and by searching for a location with a known history of high aphid infestation.

Table 24. Multiplication of the aphid, *Aphis craccivora,* on some wild *Arachis* spp and their derivatives at ICRISAT Center, 1980/81.

Species/derivatives	No. of nymphs released	No. of nymphs after 2 weeks
A. glabrata	40	0
A. *chacoense*	40	2
A. marginata	40	2
A. duranensis	40	43
A. cardenasii	40	44
A. chacoense x *A. hypogaea*		
HP 431 A	50	6
HIC 6-1	50	12
Arachis hypogaea (TMV 2)	10	619

Leafminer. We initiated investigations on this insect, *A. modicella,* in the 1980 rainy season. The insect completed three generations during the rainy season and four in the postrainy season, with peak populations occurring in September and April. Screening work in the rainy season cannot be relied on, as population buildup is low in years with heavy and well distributed rains, such as in 1981. Therefore, major screening work must be done in the postrainy season. Preliminary observations indicated occurrence of a sex pheromone in females; virgin female traps attracted high numbers of males (Table 25).

Of 180 lines that we screened for resistance to the leafminer, a few were found promising and will be further tested in the 1981/82 postrainy season.

The insect was easily controlled by monocrotophos @ 600 g.a.i./ha, and the application at the emergence of the second generation of moths caused the greatest reduction in population.

Armyworm. We initiated work on the biology of this insect in 1980. Several thousand larvae and pupae of S. *litura* were collected and reared in the laboratory to investigate the mortality factors. We found that viruses were an important mortality factor in both rainy and postrainy

Table 25. Numbers of leafminer moths (*Aproaerema modicella*) caught in traps with and without virgin female moths at ICRISAT Center, 1980/81 postrainy season.

	Average number of moths per trap per day					
	Trap pair 1		Trap pair 2		Trap pair 3	
Period[a]	With females	Control	With females	Control	With females	Control
9-17 February	108*	2	34*	2	70	4
15-24 March	128*	6	105*	10	71	14
8-13 April	247*	57	272*	70	229*	55

a. Trapping periods correspond to adult emergences of three generations of the leafminer.
* 't' value significant ($P < 0.05$).

Table 26. Natural mortality of army worm (*Spodoptera litura*) at ICRISAT Center following outbreaks in March and September 1981.

Host stage attacked	Mortality factor	Mortality[a] (%) Mar 1981	Sept 1981
Larva	Tachinid parasites	7.5	7.8
	Fungi	0.0	21.4
	Virus	31.3	47.9
Pupa	Unknown	26.3	8.0

a. Based on samples of over 1000 larvae each.

seasons and fungi in the rainy season. The parasitism level was usually low, and mortality was caused mainly by tachinid parasites (Table 26).

Termites. Two replicated trials were laid out in termite-infested, pesticide-free Alfisols at ICRISAT Center. The crops were lifted in November (about a month later than normal maturity date) to allow extra time for damage to pods. Pods were carefully harvested, and percentages of damaged pods were recorded (Table 27). Several lines showed low termite damage. Of these NC Ac 343 and RMP-40 gave good yield under low fertility pesticide-free conditions. Some FESR lines also had low pod damage.

Multiple resistance. A few germplasm lines were found to have various degrees of resistance to several insect pests (Table 28). While most of the lines were poor yielders, NC Ac 343 in addition to having multiple pest resistance was also high yielding. This line was reported to have a high degree of resistance at North Carolina State University (USA) to the pod borer *Diabrotica undecimpunctata howardi,* the jassid *Empoasca fabae,* and *Frankliniella fusca.*

Breeding for Pest Resistance

Jassids. At ICRISAT Center the jassid-resistant parents NC Ac 2214, 2232,2242,1705,

Table 27. Sources of resistance to termites causing pod scarification in groundnut at ICRISAT Center, 1980 rainy season.

Trial 1		Trial 2	
Cultivar	Scarified pods (%)	Cultivar	Scarified pods(%)
FESR 1, P9-B3-B2-B1	1.5	NC Ac 10033	2.7
NC Ac 2243 (T)	2.4	NC Ac 1113	2.9
NC Ac 2243 (DP)	3.1	NC Ac 2897	3.5
NC Ac 343	3.1	NC Ac 7481	5.8
NC Ac 2240	4.9	NC Ac 7236	5.3
RMP 40	5.0	Ah 7663	5.4
NC Ac 2214	5.3	FESR 2, P9-P1-B3-B1	5.7
NC Ac 2230	8.8	FESR 1, P3-B1-B3-B1	6.3
NC Ac 2744	58.3	NC Ac 2723	58.3
Mean (41 cultivars)	26.0	Mean (75 cultivars)	23.8

Table 28. Groundnut genotypes with resistance to several pests at ICRISAT Center, 1980 rainy season.

Cultivar	Jassid injury: yellowed foliage (%)	Thrips injury (1-9 scale)	Termite damaged pode(%)	Yield (kg/ha)
NC Ac 2243	0.1	2.1	3.4	100.0
NC Ac 2242	0.2	2.2	17.7[a]	339.2
NC Ac 1705	1.0	2.4	12.9[a]	410.8
NC Ac 2240	0.7	2.4	4.9	162.5
NC Ac 2214	0.2	2.3	5.3	602.2
NC Ac 343	1.9	2.8	3.0	1055.8
TMV 2	40.0	5.8	32.6	500.0

a. Moderate level of resistance.

343,10247, and 15729 were crossed with Robut 33-1, a high-yielding but susceptible cultivar, and M 13, a high-yielding cultivar with moderate jassid resistance. The progenies of these are in various filial generations, and selection of high-yielding, jassid-resistant progenies is in progress.

One of the resistant parents, NC Ac 2214, is hairy, and some of the progenies from the crosses of this and less pubescent parents showed transgressive segregation for hairiness. They were selected for this character, but since they are poor yielders, a backcrossing program was started to incorporate high yield characters.

Thrips. In 1980/81 we started work on breeding for resistance to thrips, using resistant parents NC Ac 2214,2232,2242,1705, and 343 and high-yielding parents Robut 33-1 and M 13. Additionally, two resistant parents, NC Ac 2243 and NC Ac 2230, have been introduced into our crossing program. The progenies resulting from these crosses are being screened for thrips resistance and high yield.

Nitrogen Fixation

Response to *Rhizobium* Inoculation

Cultivar/*Rhizobium* compatibility. Experiments conducted at ICRISAT Center during the 1980 and 1981 rainy seasons confirmed earlier findings (ICRISAT Annual Report 1978/79, 1979/80) that inoculating with superior *Rhizobium* strains increases groundnut yields, even in fields where the crop is nodulated by an effective native population. The cultivar Robut 33-1 inoculated with *Rhizobium* strain NC 92 by liquid application outyielded the uninoculated controls in 1980 and 1981 by 21% and 17%, respectively (Table 29 and 30). Similar results were obtained when the experiment was conducted at Dharwar (550 km from ICRISAT Center), the yield increase there being 40% (Table 31). Robut 33-1 inoculated with *Rhizobium* strain 5a/70

Table 29. Effect of different methods of inoculation on groundnut (CV Robut 33-1) yield (kg/ha) at ICRISAT Center, 1980 rainy season.

	Method of inoculation	
Treatment	Granular	Liquid
5a/70	1290	1770
NC 92	1020	1640
IC 6006	1000	1630
Mixture (5a/70 +NC 92 + IC 6006)	1050	1520
Uninoculated[a]	1350	
CV (%)	15	

a. Standard error for comparing uninoculated treatment with any *Rhizobium* strain treatment is ± 77.4 and for comparing method of inoculation within strains is ±133.8.

Table 30. Response of groundnut yield (kg/ha) to *Rhizobium* inoculation at ICRISAT Center, 1981 rainy season.

	Cultivar		
Treatment[a]	Robut 33-1	J 11	ICGS 15
5a/70	2440	1710	1800
NC 92	2760	1870	2390
IC 6006	2070	1680	1920
Mixture (5a/70 +NC 92 + IC 6006)	2710	1600	1940
Uninoculated	2350	1950	1970
CV (%), main plots: 13			

a. Standard error for comparing *Rhizobium* treatments within cultivars is ± 177.8.

Table 31. Response of groundnut yield (kg/ha) to *Rhizobium* inoculation at Dharwar, 1981 rainy season.

	Cultivar		
Treatment[a]	Robut 33-1	J 11	TMV 2
NC 92	2150	1850	1640
5a/70	1630	1920	1460
Uninoculated	1530	1710	1270
CV (%)	23.0		

a. Standard error for comparing *Rhizobium* treatments within cultivars is ± 176.5.

also had increased yields in the 1980 rainy season (Table 29). No effect of inoculation was observed in several other cultivar/strain combinations tested. However, during the 1981 rainy season, ICG 15, a progeny of Robut 33-1 x TMV 7, also showed improved yield when inoculated with the strain NC 92 (Table 30). These results suggest a *genetic* association between cultivar Robut 33-1 and strain NC 92.

Method of inoculation. The conventional method of inoculating a legume with *Rhizobium* is by application to the seed. However, groundnut seeds are fragile. Direct treatment with the inoculum may harm germination. Also, there are problems of compatibility with seed protectant chemicals. We have observed that under moisture-stress conditions seed inoculation can inhibit germination. Alternatively, *Rhizobium* can be used in varous granular formulations or as peat/water suspension (liquid). Peat-coated sand placed below the seed (granular form) inhibited germination (Table 32). At ICRISAT we obtained the best results by adding *Rhizobium* directly to the soil, as a liquid formulation (Table 29). This can be done by mixing the peat containing rhizobia in water and pouring the mixture into the furrow before sowing (Fig. 6).

Effects of *Rhizobium* population. In an experiment conducted in the glasshouse, we studied the number of rhizobia required to produce maximum nodulation and nitrogen fixation. We found that groundnut required a minimum of 10^6 rhizobia/ seed for maximum nodulation and nitrogen fixation (Table 33, Fig. 7). We are currently determining the minimum *Rhizobium* population required for inoculation under field conditions.

Table 32. Effect of method of inoculation on percentage germination of groundnut, 1980/81.

Method of inoculation	Germination (%) Site 1	Site 2
Control (uninoculated)	83	77
Seed slurry inoculated	46	71
Liquid inoculant in furrow	98	79
Granular inoculant	73	57
SE ±	3.2	3.1
CV (%)	8	13

Figure 6. A simple procedure to inoculate groundnut. The peat containing rhizobia is mixed with water and added in the furrows before sowing.

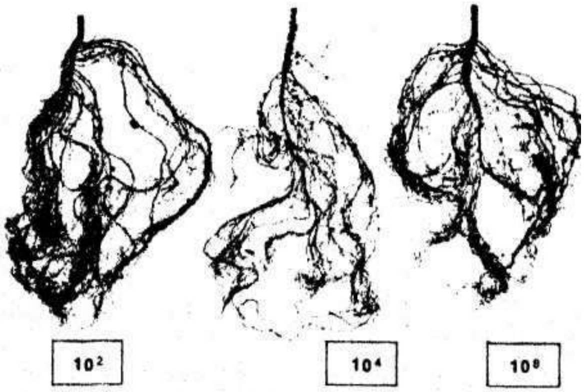


Figure 7. More nodules were formed as the number of rhizobia was increased (10^2, 10^4,10^6 cells/seed in the specimens shown above).

Table 33. Effect *of Rhizobium* population on nitrogen fixation (mg N/plant) in glasshouse at ICRISAT Center.

Inoculation level (*Rhizobium* cells/ seed)[a]	Robut 33-1		TMV 2	
	Strain		Strain	
	5a/70	NC 92	5a/70	NC 92
2.7 x 10^2	23	25	19	17
2.7 x 10^4	41	23	28	29
2.7 x 10^6	60	45	63	37
2.7 x 10^8	61		64	46
CV (%)		30		

a. Standard error for comparing inoculation levels within a cultivar and Rhizobium strain is ± 5.9.

Table 34. Nitrogenase activity (μ mol/plant per hr) of 15 groundnut germplasm lines during two rainy and two postrainy seasons at ICRISAT Center.

Cultivar	Rainy season		Postrainy season		Mean
	1978	1979	1977/78	1978/79	
NC Ac 2821	117	67	44	86	87
Ah 5144	114	66	28	77	71
NC Ac 2654	85	55	52	117	70
Polachi 1	101	51	32	84	67
Ah 8254	91	47	39	84	65
NC Ac 1303	97	62	29	69	65
JH 171	89	46	43	73	63
NC Ac 2600	97	51	34	61	61
Ah 3277	91	46	27	77	60
TG 17	86	53	31	66	59
Ah 3275	87	48	25	66	58
Argentine	73	47	41	61	56
NC Ac 888	78	37	32	69	54
NC Ac 495	76	43	28	63	53
NC Ac 516	69	37	33	65	49
SE ±	9.4	5.6	6.8	3.8	
CV (%)	18	19	20	11	

Screening Germplasm for Nitrogenase Activity

We screened several germplasm lines for nitrogenase activity during two rainy (1978 and 1979) and two postrainy (1977/78 and 1978/79) seasons. These experiments were conducted at 75 cm between-row and 15 cm within-row plant spacings. Large differences in nodulation and nitrogenase activity (as measured by acetylene reduction) were observed among the lines. A Virginia cultivar, NC Ac 2821, ranked highest in mean nitrogenase activity (Table 34). Interestingly, a cross between NC Ac 2821 and Robut 33-1 has resulted in high-yielding progenies (see Hybrids in Plant Improvement section below). This suggests the possibility of increasing yield potential by incorporating high nitrogen-fixing lines in the breeding program.

Effect of Depth of Sowing

In our field surveys we observed that many farmers practice deep sowing to make use of residual moisture for germination. This results in the development of an elongated hypocotyl and poor rooting, and therefore poor nodulation. Though the deep-sowing saves some irrigation water, the resulting loss of nitrogen fixation may be substantial, especially among Spanish cultivars. Hypocotyl nodulation contributes substantially to the nitrogen fixation of the deep-sown crop. For example, in a deep-sown Virginia cultivar, Kadiri 71-1, hypocotyl nodules contributed around 50% of the nitrogenase activity at 70 days after planting (Fig. 8). We

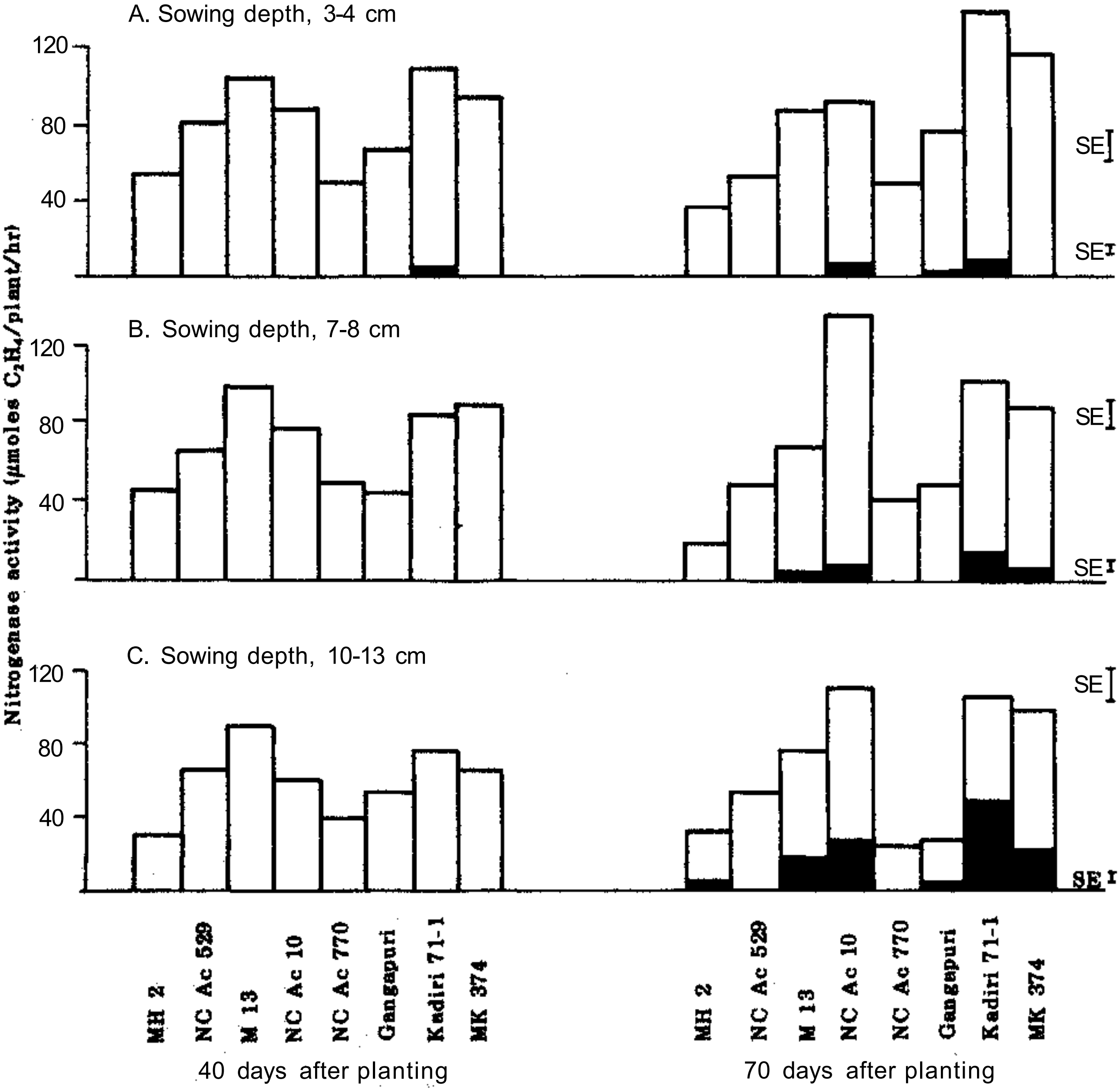


Figure 8. Effect of sowing depth on nitrogen fixation of groundnut. Shaded areas represent nitrogenase activity of hypocotyl nodules.

observed, however, that most of the Spanish types lack the ability to nodulate on the hypocotyl. As indicated in Figure 8, the Spanish (NC Ac 529, NC Ac 770) and the Valencia (MH 2 and Gangapuri) types were more severely affected by increased depths than were the Virginia types (M 13, NC Ac 10, and Kadiri 71-1). If hypocotyl nodulation were incorporated into Spanish types, this could be beneficial where deep sowing is practiced.

Studies on Nonnodulating Groundnut

Response to fertilizer nitrogen and estimation of nitrogen fixation. During the 1980/81 postrainy and 1981 rainy seasons, we studied the response of a nonnodulating groundnut line to fertilizer nitrogen application. This line exhibited poor efficiency in utilizing soil nitrogen (Figs. 9 and 10). The dry matter and seed yield of

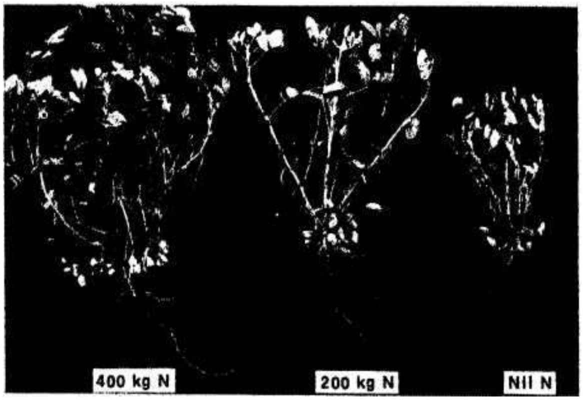


Figure 10. Response of a nonnodulating line to fertilizer nitrogen.

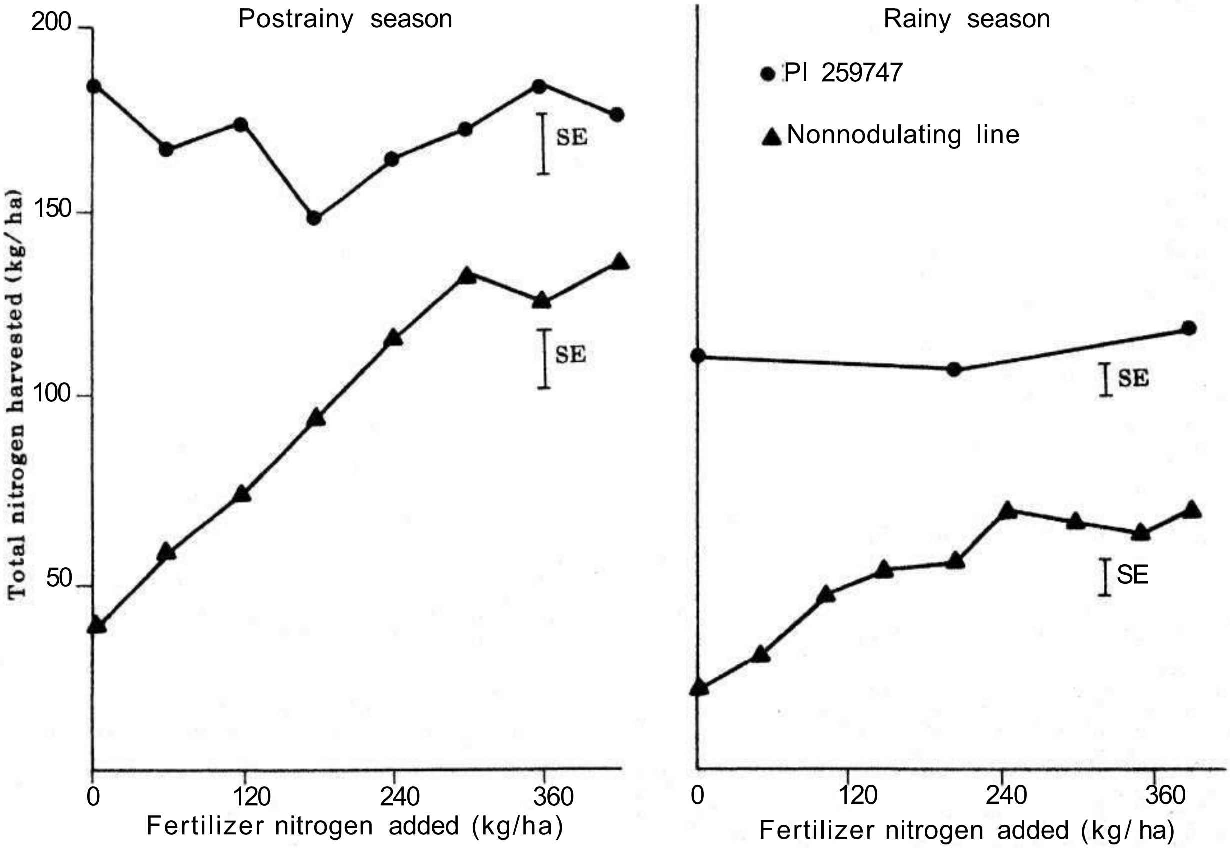


Figure 9. Response of a nodulating (PI 259747) and a nonnodulating line to fertiliser nitrogen.

such lines did not equal that of a nodulating crop even when 400 kg N/ha was applied. A nodulated crop meets most of its nitrogen requirements from the atmosphere by virtue of its nitrogen-fixing ability and the rest from the soil nitrogen. The nonnodulating crop depends solely on soil nitrogen. Thus nonnodulating lines can serve as a useful tool for estimating the nitrogen fixed by a nodulated crop.

The nitrogen fixed by different cultivars, as estimated by this differential method, is shown in Table 35. PI 259747 fixed more nitrogen during the postrainy season (145 kg N/ha) than in the rainy season (89 kg N/ ha). This is probably due to the longer growing period in the postrainy season. Unlike PI 259747, Robut 33-1 and NC 17 are susceptible to rust (for details see ICRISAT Annual Report 1979/80, pp 152-153); hence the estimated nitrogen fixed by these two cultivars in the rainy season was lower than what would be expected under disease-free conditions.

Grafting studies. Reciprocal grafts were made on nodulating and nonnodulating stocks. A nonnodulating scion growing on a nodulating stock was induced to form roots. These roots failed to nodulate in spite of the presence of a nodulated root on the stock (Fig. 11). On the other hand when the nodulating scion growing on a nonnodulating stock produced roots, they formed nodules. This indicates that translocated compounds do not influence nodule formation and the ability to nodulate is governed by the genome of the root cells (for details of genetics of

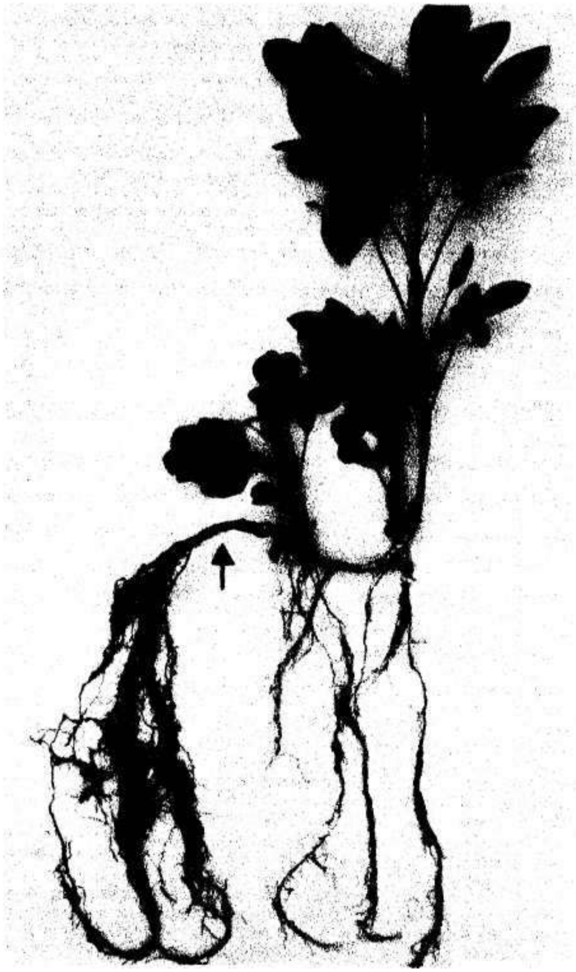


Figure 11. Nodulating and nonnodulating roots on the same plant. Roots originating from the nonnodulating scion did not bear any nodules, while original stock (NC 17) was nodulating. Arrow indicates position of the graft.

Table 35. Estimated nitrogen fixed by groundnut cultivars at ICRISAT Center, 1980/81.

Season	Nitrogen harvested (kg/ha)				Nitrogen fixed (kg/ha)		
	PI 259747	Robut 33-1	NC 17	Nonnodulating line	PI 259747	Robut 33-1	NC 17
Postrainy(1980/81)	184			39	145		
Rainy (1981)	110	88	89	21	89	67	68

a. The crop was harvested 140 days after planting during the postrainy season and 96 days after planting during the rainy season.

nonnodulation see Nigam et al., 1980, listed in "Publications").

Root hairs: presence and absence. In groundnut, root hairs and nodules occur only when there are lateral roots. The rhizobia enter the root at the base of the root hair. Our preliminary observations have shown that nonnodulating lines lack root hairs (Fig. 12). We are confirming this observation by crossing PI 259747 and NC 17, but it seems likely that the absence of root hair is the cause of nonnodulation in groundnuts.

Genetics of nonnodulation. This year we confirmed our earlier observations on the genetics of nonnodulation (ICRISAT Annual Report

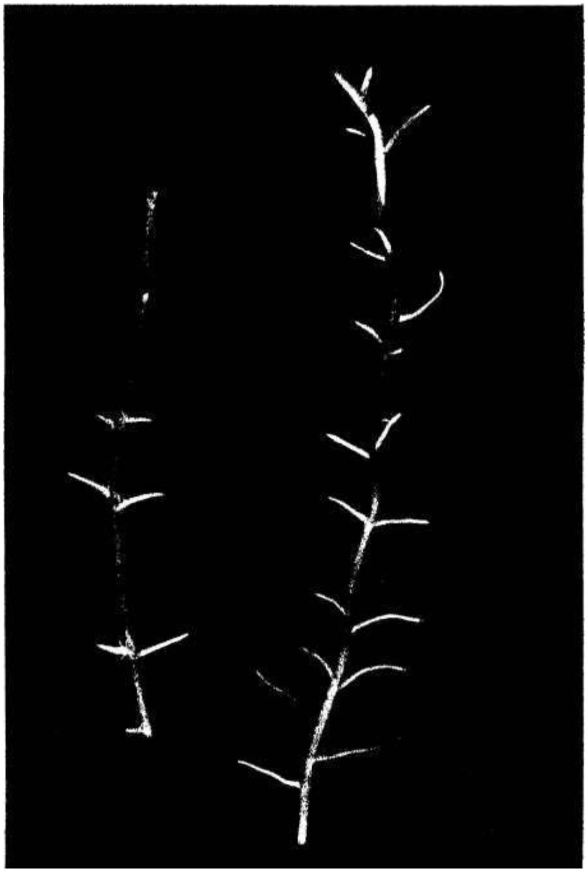


Figure 12. Root hairs on the junction of lateral roots of a nodulating cultivar (PI 259747). The nonnodulating line (right) grown under similar conditions did not produce root hairs.

1979/80). The cross NC 17 x PI 259747 was repeated and the final experiment consisted of parents, F_1 reciprocals, F_2 reciprocals, and BO and BG reciprocals. Based on the segregation in the F_2 generation and the behavior of backcross progenies, it was confirmed that the expression of nonnodulation is governed by two duplicate recessive genes.

Development of isogenic lines. We are developing nonnodulating near-isogenic lines of the parent line NC 17 in a backcrossing program. At present we have 87.5% of the NC 17 gene complement and have identified nonnodulating plants similar to NC 17.

Nonnodulating groundnut lines. So far, we have stabilized 34 nonnodulating lines (26 from NC 17 x PI 259747 and 8 from Shantung Ku No.203 x PI 259747). These lines vary in branching habit and seed and pod characteristics.

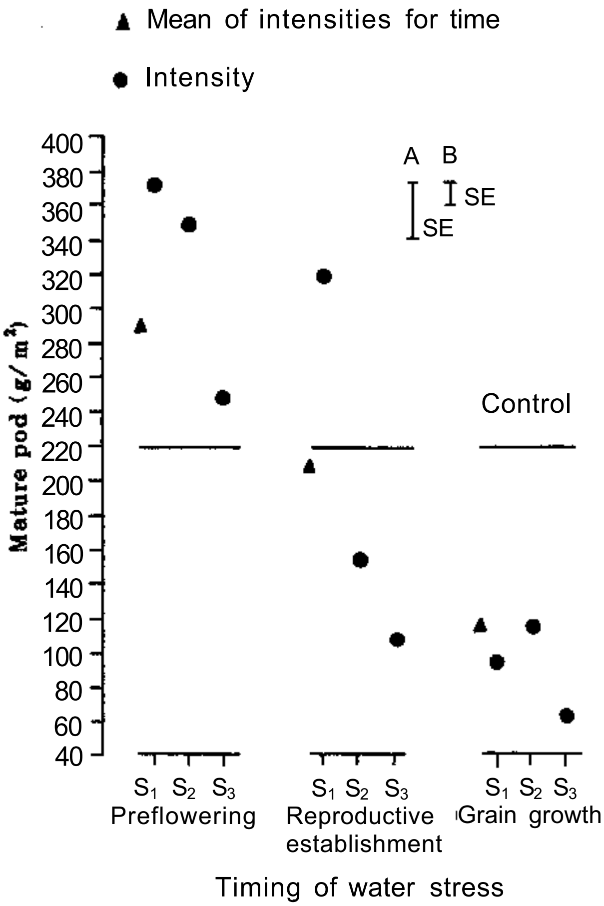
Drought

Timing and Intensity of Drought

In a cooperative experiment with the agroclimatology, soil physics, and land and water management sections of our Farming Systems Research Program, we examined the effects of timing and intensity of drought on the growth and development of the variety Robut 33-1. Growth and development were recorded by growth analysis. The final yields were greatest where the crop had experienced water stress during the preflowering stage (Fig. 13). This increased yield occurred because of a change in the distribution of growth between vegetative and reproductive components in response to the early stress.

Effects of Drought on Populations

We grew groundnuts in a wide range of populations in a square pattern arrangement of a systematic design. Drought was created by withholding water at different stages of crop growth (Table 36).



S_1=mild stress, S_2 = intermediate stress, S_3=severe stress.
A = SE for comparison of stress intensity within times of stress.
B = SE for the comparison of time of stress means.

Figure 13. The effect of time and intensity of drought on the yield of Robut 33-1.

Yields were not obtained in treatment D3 because the drought stress induced very severe pod rotting. The yields achieved by Robut 33-1 in different populations for treatments, D0, D1, and D2 are shown in Fig. 14. In the well watered treatment (DO) yield increased rapidly at populations between 2 and 8 plants/m^2, after which the data from each population were too variable to allow any definite conclusion. However, there was little change in yield at populations between 10 and 26 plants/m^2. In the DI and D2 treatments high populations resulted in decreased yield; the optimum populations were between 10 and 16 plants/m^2 for D2.

These stress conditions were extreme, and further experiments are under way to study the responses under less severe conditions.

Drought Screening

In a preliminary screening exercise we subjected 81 lines of groundnuts to the same patterns of stress as our systematic population trials (Table 36).

During stress and after the release of stress, crop canopy temperatures, leaf damage, and regrowth were recorded. When the crop was watered to allow harvesting, extremely rapid pod rotting occurred in many of the lines where stress had occurred only in the preceding 30 days (treatment D3). The extent of pod rot was recorded by the pathologists and the 11 lines showing least damage were noted. Generally,

Table 36. Timing and duration of drought stress in groundnut at ICRISAT Center, 1980/81.

Treatment No.	Pre flowering	Flowering	Pod setting[a]	Grain growth
D_0 (control)	W	W	W	W
D_1	W	D	D	D
D_2	W	W	D	D
D_3	W	W	W	D
Calendar date of start	11 Dec 1980	24 Jan 1981	23 Feb 1981	22 Mar 1981

a. 70 mm of rain prevented full development of stress.
W = Irrigated every 7-10 days to replenish water.
D = Irrigated with 70 mm water every 30 days.

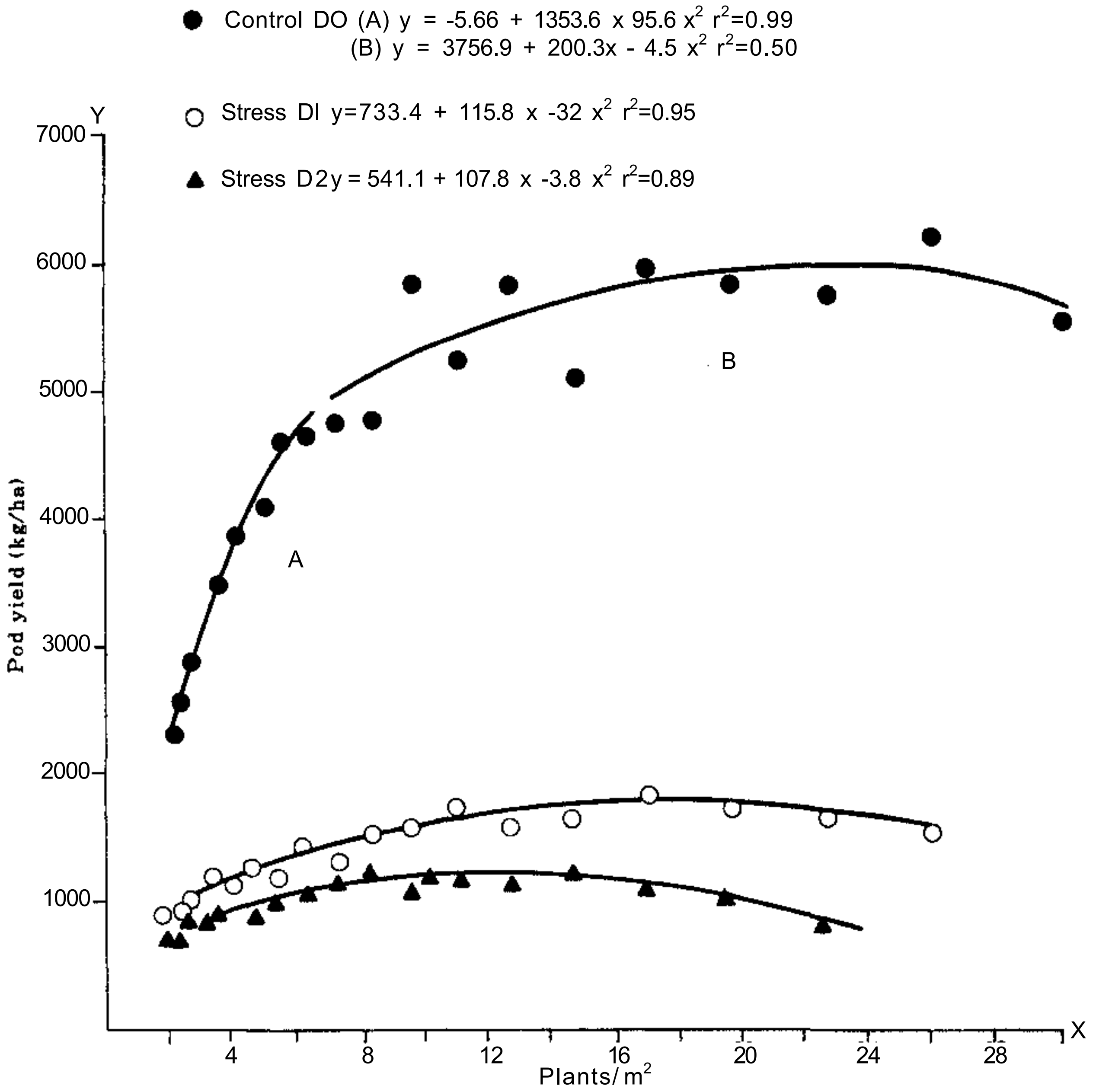


Figure 14. The effects of droughts on the yield achieved by cv Robut 33-1 grown at different densities.

lines with a runner habit and those of the Valencia subspecies were most susceptible to this damage.

A severe infestation of tobacco caterpillar (*Spodoptera litura*) occurred and proved difficult to control. This confounded the effects of drought by causing differential defoliation. Lines that were not severely damaged by the caterpillar attack were: NC Ac 2692, S-1, EC 109271 (53-437), PI 259747, JH-335 x Robut 33-1, and Robut 33-1.

Water stress at all stages significantly reduced yield; however, the varieties responded differently to different types of stress, indicating that time of stress should be given greater attention in future screening exercises. The pod yields achieved by the best five lines in each drought treatment are shown in Table 37.

Shelling percentage varied considerably from cultivar to cultivar in the dry treatments. Some varieties were able to achieve nearly normal pod filling in the drought, while the average of all 81 cultivars was 45% of the control (Table 38).

The kernel yields resulting from the varying responses of pod effects and shelling percentages result in different cultivars emerging as best (Table 39).

Plant Improvement

Breeding for High Yield and Quality

We continued our efforts to generate base material with high yield potential for pest and disease resistance breeding programs and for areas of the world where these and other constraints are not prevalent, or where protective measures are routinely taken. We yield tested large quantities of breeding material carried over from previous seasons; only selected results are presented here. New crosses were also made during 1980/81, and promising selections were advanced—largely by bulk pedigree methods, though some single-plant selections were also made. Yield trials were conducted in the rainy season under protected high-fertility conditions and also under nonprotected low-fertility conditions at ICRISAT Center. Off-station trials were conducted at Dharwar (Karnataka) and Anantapur (Andhra Pradesh) in India. In the 1980/81 postrainy season many of the trials were conducted on 150-cm broadbeds, instead of on 60-cm or 75-cm ridges. The broadbed-and-furrow system allowed us to reduce the interrow spacing and plant four rows per bed. In general, yields were considerably improved under this system.

Table 37. Pod yields of the best five cultivars in drought treatments at ICRISAT Center, 1980/81.

D0		D1		D2		D3[a]	
Cultivar	Total pod wt (g)/pl.	Cultivar	Total pod wt (g)/pl.	Cultivar	Total pod wt (g)/pl.	Cultivar[b]	Total pod wt (g)/pl.
Virginia bunch ex-uranle	40.0	GA 207-3 x Robut 33-1	9.5	JH 335 x Robut 33-1	12.6	JH 335 x Robut 33-1	20.6
Ah 7702	39.2	NC Ac 5	8.8	28-206 x Robut 33-1	11.8	NC Ac 23	19.5
S-7-2-8	35.2	NC Ac 23	8.4	Manifredi x M-13	11.3	Robut 33-1	17.3
NC Ac 4	34.9	EC-109271 (55-437)	8.3	JH 113	11.2	X40-X-X-3-B x Robut 33-1	15.9
JH 335 x Robut 33-1	34.8	Shulamit	8.1	TMV 2	11.2	28-206 x Robut 33-1	15.7
SE ±			1.67				
Mean of 81 cultivars	24.7		4.4		4.7		5.9
SE ±			0.49				

a. Data incomplete due to pod rotting, so statistical analysis was not attempted.
b. Cultivars that survived the pod rot and water stress.

Table 38. Shelling percentage of the best five cultivars from each of four drought treatments at ICRISAT Center, 1980/81.

D0		D1		D2		D3[a]	
Cultivar	Shelling percentage	Cultivar	Shelling percentage	Cultivar	Shelling percentage	Cultivar	Shelling percentage
JH 107	76.6	PI 25947	69.4	JH 107	67.9	JH 113	69.6
Argentine	75.2	Shulamith	64.7	28-206 x Robut 33-1	66.0	NC Ac 2692	68.8
Tifspan	74.9	X40-X-X-3-B	60.8	JH 113	65.9	GA-207-3 x Robut 33-1	66.6
Ah 7289	74.2	RS-1	60.8	Argentine	65.7	USA 20 x TMV 10	65.5
EC 109271	74.9	S-1	57.4	USA 20 x TMV 10	62.1	28-206 x Robut 33-1	62.4
SE±			13.06				
Mean of 81 cultivars	67.2		33.6		36.3		28.7
SE±			2.78				

a. Data incomplete due to pod rotting, so statistical analysis was not attempted.

Table 39. Seed yield from the best five cultivars in each of four drought treatments at ICRISAT Center, 1980/81.

D0		D1		D2		D3[a]	
Cultivar	Seed wt (g/plant)	Cultivar	Seed wt (g/plant)	Cultivar	Seed wt (g/plant)	Cultivar	Seed wt (g/plant)
Ah 7702	27.2	Shulamith	5.2	JH 335 x Robut 33-1	7.7	JH 335 x Robut 33-1	12.4
USA 20 x TMV 10	25.4	GA 207-3 x Robut 33-1	5.1	TMV 7	7.3	Robut 33-1	10.6
59-127	25.3	NC Ac 1672	4.8	Manfredi x M 13	6.9	28-206 x Robut 33-1	10.0
NC Ac 4	24.6	USA 20 x TMV-10	3.7	Argentine	6.9	X40-X-X-3-B x Robut 33-1	9.4
S-7-2-8	24.9	NC Ac 23	3.6	28-206 x Robut 33-1	6.4	Tifspan	9.1
SE±			3.14				
Mean of 81 cultivars	16.4		1.7		2.4		3.4
SE±			0.69				

a. Severe pod rot damaged the treatment, so statistical analysis was not attempted.

Natural hybrids. The high-yielding cultivar Robut 33-1, which probably originated as a natural cross, shows considerable variation. Promising selections have been made from this cultivar (ICRISAT Annual Report 1979/80, p 131) and entered into national trials. Under high-fertility conditions at ICRISAT Center in the 1980 rainy season, selection 18-8-B1-B1-B1 was the highest yielder and was superior to Robut 33-1 and the national Spanish check, J 11. Fourteen other selections also outyielded J 11. Under low-fertility conditions, with no supplementary irrigation, yields were much lower, and selection 7-4-B1-B1-B1 significantly outyielded both Robut 33-1 and J 11. At Dharwar another selection, 7-6-BI-BI-BI, significantly outyielded Robut 33-1 and J 11, The top seven selections in each trial are listed in Table 40. Selection 7-4-B1 - B1-B1, which yielded well at ICRISAT Center under high-fertility conditions, did not perform well under low-fertility rainfed conditions either at Dharwar or at ICRISAT Center. On the other hand, selection 7-6-B1-B1-B1 appeared promising in all of the 1980 rainy-season trials.

In the 1980/81 postrainy season this trial was conducted on broadbeds, and selection 24-16-B1 -B1 -B1 -B1 significantly outyielded all checks (Table 41). The two top selections in the trial

Table 41. Robut 33-1 natural hybrid trial at ICRISAT Center, 1980/81 postrainy season.

Selection	Yield (kg/ha)
24-16-B1-B1-B1-B1	6498
18-8-B1-B1-B1-B1	6066
1-5-B1-B1-B1-B1	5963
18-17-B1-B1-B1-B1	5935
21-11-B1-B1-B1-B1	5808
11-15-B1-B1-B1-B1	57 20
27-20-B1-B1-B1-B1	5699
1-1-B1-B1-B1-B1	5329
10-3-B1-B1-B1-B1	5255
50-1-B1-B1-B1-B1	5250
J 11 (check)	4422
Robut 33-1 (check)	5346
M 13 (check)	2948
SE ±	355.5
CV(%)	16.7

Table 40. Robut 334 natural hybrid trials at ICRISAT Center and Dharwar, 1980 rainy season.

ICRISAT Center				Dharwar (Rainfed)	
High fertility		Low fertility			
Selection	Yield (kg/ha)	Selection	Yield (kg/ha)	Selection	Yield (kg/ha)
18-8-B1-B1-B1	2163	7-4-B1-B1-B1	916	7-6-B1-B1-B1	2366
24-16-B1-B1-B1	2025	13-6-R1-B1-B1	905	13-6-B1-B1-B1	2079
7-6-B1-B1-B1	2005	11-7-B1-B1-B1	887	7-4-B1-B1-B1	1997
18-17-B1-B1-B1	2004	11-15-B1-B1-B1	878	50-1-B1-B1-B1	1994
1-1-B1-B1-B1	1992	10-3-B1-B1-B1	871	24-16-B1-B1-B1	1990
50-1-B1-B1-B1	1991	7-6-B1-B1-B1	865	11-7-B1-B1-B1	1980
27-20-B1-B1-B1	1972	1-1-B1-B1-B1	859	27-20-B1-B1-B1	1759
J 11(check)	1002		357		1492
Robut 33-1 (check)	1764		783		1577
SE ±	109.7		43.2		179.1
CV (%)	12.7		11.6		19.8

were also the highest yielders in the 1980 rainy-season trial under high-fertility conditions.

The trials were repeated in the 1981 rainy season at ICRISAT Center (high and low fertility), Dharwar, and Anantapur (Table 42). Yields were again high (over 5000 kg/ha) under high-fertility conditions at ICRISAT Center. At Anantapur the check Spanish cultivar, J 11, was the highest yielder. Four selections were among the top five in yield across sites, and many had yielded well in previous trials.

Hybrids. The material derived from the hybridization program at ICRISAT was also yield tested after several years of selection and advancement. Trials were conducted in all three seasons under report. In the 1980/81 postrainy season we again used the broadbed-and-furrow system and obtained the highest yields so far achieved at ICRISAT Center, over 7000 kg/ha (Table 43). The first seven advanced breeding lines in this trial had Robut 33-1 as one of the parents, and six of the seven had an exotic cultivar, NC Ac 2821, as the other parent. The parent NC Ac 2821 has been identified as having a very good ability to fix nitrogen. All of the top eight cultivars had previpusly performed well in the 1980 rainy season in a 7x7 lattice yield trial conducted at ICRISAT Center and Dharwar.

In the 1981 rainy season we tested some more selections at ICRISAT Center (high and low fertility) and Dharwar. Under high fertility (MGS 8 x Robut 33-1) F2-B2-B1N1-B1-B1-B1-B1 significantly outyielded (4972 kg/ha) all the checks (Robut 33-1,3505 kg/ha). Under rainfed conditions M 13, a long-season cultivar, was the highest yielder (1609 kg/ha), followed by (Argentine x Chico) F2-P2-B1N1-B1-B1-B1-B1. Both these cultivars significantly outyielded Robut 33-1. At Dharwar J 11 had the highest yield (1854 kg/ha), followed by (MK 374 x Robut 33-1) F2-P1-B1-B1-B2N1-B1-B1, which was among one of the top five yielders at all locations.

The best selections from the many trials conducted were assigned ICGS numbers before entering into national and international trials.

Table 42. Robut 33-1 natural hybrid trials at ICRISAT Center, Dharwar, and Anantapur, 1981 rainy season.

ICRISAT Center				Dharwar (Rainfed)		Anantapur (Rainfed)	
High fertility		Low fertility					
Pedigree	Yield (kg/ha)	Pedigree	Yield (kg/ha)	Pedigree	Yield (kg/ha)	Pedigree	Yield (kg/ha)
1-5-B1-B1-B1-B1	5736	18-17—B1-B1-B1-B1-B1	1641	7-4-B1-B1-B1-B1-B1	2252	21-11-B1-B1-B1-B1-B1	1974
18-8-B1-B1-B1-B1-B1	5646	1-5-B1-B1-B1-B1-B1	1602	18-8-B1-B1-B1-B1-B1	1956	7-6-B1-B1-B1-B1-B1	1800
50-1-B1-B1-B1-B1-B1	5595	24-16-B1-B1-B1-B1-B1-B1	1487	13-6-B1-B1-B1-B1-B1	1908	1-1-B1-B1-B1-B1-B1	1757
24-16-B1-B1-B1-B1-B1-B1	5384	1-1-B1-B1-B1-B1-B1	1469	27-20-B1-B1-B1-B1-B1	1844	1-5-B1-B1-B1-B1-B1	1640
7-6-B1-B1-B1-B1-B1	5380	10-3-B1-B1-B1-B1-B1	1436	21-11-B1-B1-B1-B1-B1	1780	7-4-B1-B1-B1-B1-B1	1629
21-11-B1-B1-B1-B1-B1-B1	5325	18-8-B1-B1-B1-B1-B1	1433	7-6-B1-B1-B1-B1-B1	1772	10-3-B1-B1-B1-B1-B1	1590
J 11 (check)	4478		1296		1780		1978
Robut 33-1 (check)	4409		1248		1507		1700
M 13 (check)	3138		1295		1180		1160
Dh 3-30 (check)					1721		
SE ±	322.6		64.9		158.1		154.7
CV (%)	13.1		9.5		18.8		20.4

Table 43. High yield and quality yield trial at ICRISAT Center, 1980/81 postrainy season.

Selection	Days to maturity	Yield (kg/ha)
(Robut 33-1 x NC Ac 2698) F2-B1-B1-B1-B1-B1	144	7128
(Robut 33-1 x NC Ac 2821) F2-P1-B1-B1-B1-B1-B1	148	7127
(Robut 33-1 x NC Ac 2821) EF2-B1-B1-B1-B1-B1-B1	148	7054
(Robut 33-1 x NC Ac 2821) F2-B3-B1-B1-B1-B1-B1	141	6671
(Robut 33-1 x NC Ac 2821) F2-P4-B1-B1-B1-B1-B1	148	6600
(Robut 33-1 x NC Ac 2821) EF-2-P2-B1-B1-B1-B1-B1	141	6194
(Robut 33-1 x NC Ac 2821) F2-B4-B1-B1-B1-B1-B1	147	6176
(Goldin 1 x Faizpur 1-5) F2-P1-B2-B1-B1-B1-B1	132	6079
(Goldin 1 x Faizpur 1-5) F2-P5-B1-B1-B1-B1-B1	132	6044
(MGS 9 x 2-5) F2-B1-B3-B1-B1-B1-B1	132	6006
(NC Ac 2741 x TMV 2) F2-P3-B1-B1-B1-B1-B1	132	5947
(Robut 33-1 x NC Ac 2821) EF2-P5-B1-B1-B1-B1-B1	137	5927
(Argentine x NC Ac 2158.) F2-B2-B2-B1-B1-B1-B1	132	5891
(Tifspan x NC Ac 2944) F2-B1-B1-B1-B1-B1-B1	132	5831
(J 11 x TG 3) F2-B4-B2-B1-B1-B1-B1	132	5764
(USA 20 x TMV 10) F2-P3-B2-B1-B1-B1-B1	148	5724
J 11(check)	132	5254
Robut 33-1 (check)	148	5067
SE ±		184.9
CV (%)		7.8

Earliness and Dormancy

We are developing early-maturing cultivars for areas where the rainy season is of short duration, and also for areas where there is sufficient residual moisture (after a rice crop for example) to grow a short-duration legume crop. Two short-duration Spanish cultivars, Chico and 91176, are being used extensively in our breeding program. Both are typical Spanish cultivars and lack seed dormancy. They will sprout in the ground if there is sufficient soil moisture when they reach maturity. In conjunction with ICRISAT physiologists, we are examining early-maturing, sequentially branched (i.e., Spanish-type) progenies of Spanish x Virginia crosses for the presence of seed dormancy. Virginia cultivars show a marked seed dormancy period after physiological maturity.

Breeding for earliness. During the period 1980 to 1981 we advanced 16 single-plant selections and over 3000 bulk selections. Our main selection criterion was early flowering, and we identified a number of crosses that flowered earlier than the Spanish or Virginia parent. Other materials that showed early-maturing characteristics, particularly from the project dealing with high yield and quality, were also transferred to this project. Similarly, breeding lines from the earliness project that were high yielding but not early were transferred to the high yield and quality project.

In the 1981 rainy season we yield tested 10 breeding lines and four checks under high-fertility conditions at ICRISAT Center, and the results of some of these are shown in Table 44. Yields were not significantly different, but there were significant differences between maturity dates (Table 44). Although Chico is early maturing, it is very small seeded and commercially unacceptable. From the results it appears, however, that lines can be selected that are approximately equal to Chico in maturity but have a seed size equal to, or exceeding, the commercial checks JL 24 and J 11. The selection (Dh 3-20 x Chico) F2-B1-B1-B1-EB1-B1 appears promising in this respect.

Dormancy screening. The strategy of breeding for earlier maturity of varieties to improve the coincidence of crop life with greater probabilities of rainfall has been a traditional approach

Table 44. Yield trial of early-maturing breeding lines at ICRISAT Center, 1981 rainy season.

Selections	Yield (kg/ha)	Days to maturity	Shelling (%)	100-kernel weight (g)
(TMV 7 x Chico) F2-P8-B1-B1-EB1-B2-B1	4497	88	74	34.0
JL 24[a]	4423	88	76	37.4
(JH 89 x Chico) F2-B1-N1B1-B1-B2-B1	4356	90	78	36.2
(Dh 3-20 x Chico) F2-B1-B1-B1-EB1-B1	4293	84	76	38.2
(75-24 x Chico) F2-EB2-EB2-EB1 (R)	3725	84	80	28.4
91176[a]	4185	86	78	36.3
Chico[a]	4176	86	76	27.8
J 11 (Spanish check)	4296	90	78	32.8
SE ±	313.9	1.4		
CV(%)	12.5	2.8		

a. Early-maturing Spanish parents.

for increasing yield and yield stability. However, this strategy also increases the probabilities of rain on the crop at or after maturity, and since the current known sources of early maturity also have nondormant seeds, this policy can result in increased spoilage of the crop. Therefore we initiated a program to identify methods of screening for dormancy and, if possible, identify dormancy from within populations derived from early nondormant types crossed with dormant long-season types.

We collected 180 lines from the F_6, F_7, and F_8 populations. Using only seed from sequentially branching plants (i.e., Spanish types) we tested this material for germination after drying it for 1 week. To test seed viability and dormancy, a comparison was made between germination of seeds watered with distilled water or with a 0.001% ethrel solution. Ethrel breaks dormancy in groundnuts by the release of ethylene gas.

Of the material tested, seed from four lines did not germinate in water after 15 days, while in all cases the ethrel-treated seed achieved 100% germination within 2-3 days. The four lines that did not germinate in water were Dh 3-20 x Robut 33-1 (F_6), Kadiri 71-1 x Gangapuri(F_7),TMV 10 x Chico (F_6), and Shulamit x Chico (F_7).

To evaluate the test method and confirm the results obtained, we sowed seeds from the four lines and from the standard dormant and nondormant lines in the 1981 rainy season and tested for dormancy of fresh and cured seed at weekly intervals from maturity. The test lines showed segregation for branching habit, and these types were separately tested.

A low level of fresh seed dormancy, which was broken by seed drying, was found in the nondormant control variety TMV 2, indicating the confusion that can arise from testing uncured seed.

When cured seed from the four lines was tested, some 20% of seeds showed good germination, while the remaining seeds did not germinate for 20 days. This variation may be due to continued segregation for dormancy, and single-plant selections will have to be made for further investigation.

Utilization of Wild Species

We continued to assemble wild species germplasm, to screen it for characters that could be of use to breeders, and to cross selected species with *A. hypogaea.* Some species can be crossed readily and genes transferred to *A. hypogaea* by a number of routes. These species, and their hybrids, were analyzed cytologically to determine the best routes for transfer of genes. Other species cannot be readily crossed with *A. hypogaea,* and we continued our efforts to cross these incompatible species, using phytohormones and tissue culture techniques.

Accessions

The Indian Plant Quarantine Service released 99 new accessions to us between June 1980 and December 1981, when our stocks consisted of 41 accessions of 17 named species, 53 accessions of 41 unnamed species, and 69 accessions whose taxonomic status is not known. Wild species records are maintained in the computer, listing relevant accession data, taxonomic data, collection data, and all known code numbers and synonyms for the accession: Copies of this file, which has been sorted by Collector Number, Plant Introduction Number, and by latitude and longitude, have been provided to collaborators.

We grew the wild species in the field for multiplication and disease assessment in the 1980 and 1981 rainy seasons. Accessions with few seeds were sown in trays for out-of-season increase to build up stocks. Rhizomatous wild species were grown in large concrete containers.

Seed of wild species (138 samples) was supplied to 10 scientists in 7 countries, and 7 scientists in India. Rhizomatous cuttings were supplied to two scientists in two countries.

The species of the section *Rhizomatosae* grown in concrete containers flowered profusely in February 1981 and produced many pegs and some pods; pegs and pods in this section had not been observed previously at ICRISAT, and pegs and immature pods had been observed only rarely elsewhere. Pegs were observed in 30 accessions, and mature pods were harvested from 22 of these.

Interspecific Breeding

Triploid Route

Hybridization. All eight available diploid species in section *Arachis* have now been crossed with at least four cultivars of *A. hypogaea.* Seeds were obtained in 39 combinations using *A. hypogaea* as female parent (Table 45). Triploid hybrids representing 11 different combinations were analyzed cytologically (Tables 46 and 47). The chromosome association in the different triploid hybrids did not differ significantly with regard to number of bivalents formed. *A. hypogaea* x *A. batizocoi* hybrids had a lower univalent frequency and a higher trivalent frequency (Table 46), indicating a close genetic affinity between *A. hypogaea* and *A. batizocoi,* compared to other diploid species of section *Arachis.*

Colchicine treatment. We treated triploid hybrid seedlings with colchicine solution (0.25% or 0.35%). The hexaploids were fertile and gave up to 200 pods per plant. We will screen these hexaploids and backcross the selected ones to *A. hypogaea.*

Backcrossing. The hexaploids, and the progenies with variable numbers of chromosomes (50-60) obtained from the selfed seeds of some triploids, were backcrossed to different early-maturing and productive cultivars. In all, we carried out 3385 pollinations in BC_1, BC_2, and BC_3 generations and obtained 424 pods. Crossability ranged from 6 to 21 pegs per 100 pollinations. The resultant progenies had from 40 to 50 chromosomes. The pentaploids and the plants with chromosome numbers between 40 and 50 had variable pollen and pod fertility and some of them did not flower.

Greater emphasis was given to the derivatives of *A. cardenasii* because of its resistance potential to late leaf spot, and a few tetraploid derivatives were obtained and are being multiplied. One of these tetraploid derivatives has shown good jassid resistance in preliminary trials.

Table 45. Pod set (per 100 pollinations) in hybrids of different *A. hypogaea* (4 x) botanical varieties crossed with wild species (2 x).

Female parent	Male parent							
	A. villosa	*A. correntina*	*A. chacoense*	*A.* sp HLK-410	*A.* sp 10038	*A. duranensis*	*A. cardenasii*	*A. batizocoi*
A. hypogaea hypogaea (Virginia):								
Robut 33-1	20.88	26.25		31.81	15.62	24.13		15.24
Makulu Red			20.00	13.51	9.52	21.05	13.50	10.01
A. hypogaea fastigiata (Spanish):								
ICG 1472	11.66	11.11	22.41	17.15	10.88	4.50	4.39	12.90
Tifspan	14.70	4.34			6.84	11.57	18.18	20.83
Chico	19.60	16.50	18.51	20.00	2.04	9.17	23.80	
A. hypogaea fastigiata (Valencia):								
Gangapuri	25.00		7.69	5.55	20.00	11.52		20.00

Autotetraploid Route

This route has the advantage of doubling the gene dose of a desired character, and enabling hybridisation with *A. hypogaea* at the same ploidy level.

We have produced autotetraploids by colchicine treatment of all eight diploid species of section *Arachis.* The autotetraploids have larger leaves and flowers and an irregular meiotic cycle, with a high frequency of multivalents and a variable number of univalents. The means for different autotetraploids ranged from 2.4 to 4.7 quadrivalents and 1.8 to 4.5 univalents/The majority of the autotetraploids had reduced fertility. Pollen fertility was poor (8.1% - 16.0%), except in *A.batizocoi* (37%).

Hybridization. Six autotetraploids were successfully crossed with different cultivars of *A. hypogaea.* The progenies obtained were vigorous in growth with intermediate leaf size, and with many similarities to *A. hypogaea.*

Cytology. We observed that meiosis was irregular in two progenies, but *A. hypogaea* subsp *fastigiata* x *A. batizocoi (*4x) formed many bivalents (a mean of 14.08) and showed regular distribution of chromosomes at AI and AII. Pollen, pod, and seed fertility were good. Six progenies have been established to date. These were tested in the field, and all-of them were found immune to rust. Two progenies were also tested in the laboratory and the field test results were confirmed (Table 48).

Backcrossing. The autotetraploid derivatives of *A. hypogaea* crossed with five different species were backcrossed with different *A. hypogaea* cultivars, and 93 pods were obtained. They will be further backcrossed, to stabilize them cytologically and genetically, and selected for desirable characters.

Amphiploid Route

This route has the advantage of combining desirable characters from two different species in an

Table 46. Mean chromosomal associations and pollen fertility in hybrids of *A. hypogaea* (4 x) x wild species (2 x) of section *Arachis*.

Crops	Means of different chromosome associations I	II	III	IV	V	Pollen fertility (%)
A. *hypogaea* x A. *villosa*	9.12	8.6	1.04	0.16		19
A. *hypogaea* x A. *correntina*	8.29	9.8	0.56	0.04		20
A. *hypogaea* x A. *chacoense*	9.72	8.6	0.80	0.10		17
A. *hypogaea* x *Arachis* sp HLK-410	9.30	9.5	0.50	0.30		13
A. *hypogaea* x A. *cardenasii*	8.44	9.64	0.56	0.16		8
A. *hypogaea* x *Arachis* sp 10038	10.64	7.56	1.32	0.08		11
A. *hypogaea* x A. *duranensis*	7.56	9.25	0.95	0.05		18
A. *hypogaea* x A. *batizocoi*	4.65	8.90	2.13	0.16	0.04	4

Table 47. Mean chromosome associations and pollen fertility in hybrids of *A. hypogaea* (4x) x *A. cardenasii* (2x) of section *Arachis*,

Cross	Means of different chromosome associations I	II	III	IV	Pollen fertility (%)
A.hypogaea x A. *cardenasii* (F. 452.4, Florida)	9.8	9.52	0.36	0	5
A. *hypogaea* x A. *cardenasii* (Samaru-38, Nigeria)	7.28	10.68	0.40	0.40	4
A. *hypogaea* x A. *cardenasii* (G. 153, Nigeria)	8.40	9.40	0.96	0.13	13
A. *hypogaea* x A. *cardenasii* (Robut 33-1, India)	8.44	9.64	0.56	0.16	9

Table 48, Reaction to rust (*Puccinia arachidis*) of some A. *hypogaea* autotetraploids and amphiploids involving *A. batizocoi* and their F_1 hybrids.

Genotype	Disease reaction
A. *hypogaea* Robut 33-1 Tifspan Tifspan (2 x) Chico	Susceptible
A. batizocoi	No visible symptoms
A. batizocoi (4 x)	No visible symptoms
A. *villosa*x A. *batizocoi*(4x)	No visible symptoms
Tifspan x A. *batizocoi* (2 x)	No visible symptoms
Chico x A. *batizocoi* (4 x)	No visible symptoms
Robut 33-1 x A. *villosa* x A, *batizocoi* (4 x)	No visible symptoms
Chico x A. *villosa* x A. *batizocoi* (4 x)	No visible symptoms

F_1 hybrid, which, by doubling the chromosome number, can be crossed with *A. hypogaea* at the tetraploid level. With an appropriate combination of species it can provide more potential for recombination between wild and cultivated species genomes than the autotetraploid route. All eight available diploid species were crossed. Interspecific hybrids from the species of the same cluster revealed a near-normal chromosome association with a high mean frequency of bivalents, ranging from 8.96 to 9.80 per pollen mother cell (PMC) (Tables 49 and 50). When *A. batizocoi,* the only member of the other cluster, was one of the parents, the hybrid showed highly irregular chromosome association and a high mean frequency of univalents, ranging from 6.0

Table 49. Mean chromosome associations and pollen fertility in intracluster hybrids of diploid species of section *Arachis*.

Cross	Means of different chromosome associations I	II	III	IV	Pollen fertility (%)
A. *villosa* x A. *correntina*	0.40	9.72		0.04	85
A. *villosa* x *Arachis* sp 10038	0.29	9.70		0.07	71
A. *villosa* x A. *duranensis*	0.64	9.52		0.08	75
A. villosa x A. *cardenasii*	0.73	9.52		0.05	75
A. *correntina* x A. *chacoense*	0.81	9.59			74
A. correntina x *Arachis* sp HLK-410	0.40	9.80			71
A. *correntina* x A. *cardenasii*	0.70	9.55	0.55		77
Arachis spHLK-410 x A. *chacoense*	0.63	9.37			91
Arachis sp 10038 x A. *chacoense*	0.68	8.96	0.04	0.12	67
A. *duranensis* x A. *chacoense*	0.23	9.46	0.20	0.03	60
Arachis sp HLK-410 x *Arachis* sp 10038	0.06	9.70		0.13	80
A. *duranensis* x *Arachis* sp HLK-410	0.52	9.26	0.04	0.02	70
Arachis sp HLK-410 x A. *cardenasii*	0.63	9.50	0.06	0.03	70
Arachis sp 10038 x A. *duranensis*		9.76		0.12	74
Arachis sp 10038 x A. *cardenasii*	0.96	9.28	0.12		79
A. *duranensis* x A. *cardenasii*	0.40	9.44		0.24	81

Table 50. Mean chromosome associations and pollen fertility in reciprocal hybrids of diploid species of section *Arachis*.

Cross	Means of different chromosome associations I	II	III	IV	Pollen fertility (%)
A. *villosa* x A. *correntina*	0.40	9.72		0.04	85
Reciprocal	0.40	9.80			84
A. *villosa* x A. *duranensis*	0.64	9.52		0.08	75
Reciprocal	0.72	9.64			81
A. *correntina* x *Arachis* sp HLK-410	0.40	9.80			74
Reciprocal	0.30	9.65	0.38	0.02	71
Arachis sp HLK-410 *x Arachis sp* 10038	0.06	9.70		0.13	80
Reciprocal	0.52	9.10	0.21	0.05	68
A. *batizocoi* x A. *villosa*	9.84	5.08			4
Reciprocal	7.22	5.54	0.40		4

to 10.6 per PMC (Table 51). This was reflected in pollen stainability. Some F_1 seedlings of the 46 diploid hybrid combinations obtained were treated with colchicine. Amphiploid plants were established in 34 combinations, with the number of plants per combination varying from 1 to 19.

The majority of the amphiploids had large, dark green leaves, prolonged stunted growth, and irregular meiotic cycle, like the autotetraploids. Only a few combinations produced a limited number of pods and seeds. The exception was the amphiploid of *A. villosa* x *A. hatizocoi* (Table 52), which showed the highst frequency of bivalents (18.2) and regular distribution of chromosomes in subsequent stages of the meiotic cycle. It had a pollen fertility of 60% (Table 52), along with moderate pod and seed fertility.

Hybridization with *A. hypogaea.* Of the 31 different amphiploids established, 22 were successfully crossed with different cultivars of *A. hypogaea* (Table 53). Amphiploids of *A. villosa* x *A. batizocoi, A. correntina* x *A. batizocoi,* and *A. duranensis* x *Arachis* sp GkP 10038 had good crossability with *A. hypogaea.*

The majority of the progenies were vigorous and similar in habit and leaf morphology to *A. hypogaea.* Most of them had a high degree of pollen and pod sterility (Table 52). A detailed cytological analysis of nine combinations revealed that *A. hypogaea* x (amphiploid *A. villosa* x *A. batizocoi*) had a high degree of bivalent association (14.88) and resulted in a pollen fertility of 63.4% (Table 52). A high degree of regular distribution of chromosomes was observed at AI and AII (38% and 96% of cells, respectively). These progenies have shown immunity to rust under field and laboratory conditions, a feature of both the wild parents (Table 48). The rest of the A. *hypogaea* x amphiploid progenies showed varying degrees of irregularity in chromosome association (see Table 52).

Backcrossing. Twelve *A. hypogaea* x amphiploid F_1 progenies have been backcrossed with different cultivars of *A. hypogaea* and produced 197 pods. Two BC1 progenies have been further backcrossed with *A. hypogaea* to produce 15 and 36 BC2 pods. In the backcrossing program priority has been given to cross combinations that combine resistance to all major pathogens of groundnut; for example one BC2 amphiploid derivative involves *A. correntina, A. chacoense,* and *A. cardenasii* parents, which contain resistance for almost all pathogens, and another involves *A. chacoense* and *A. duranensis,* which combines resistances to early leaf spot and TSWV (bud necrosis) with that to rust.

Intersectional Hybridization

Our previous investigations on incompatibility between tetraploid species of section *Arachis* and of section *Rhizomatosae* revealed that in some crosses pegs were formed in fewer than 20% of the pollinations but did not develop any pods. Application of gibberellic acid (GA3), kinetin (Kn), or naphthyl acetic acid (NAA) not

Table 51. Mean chromosome association and pollen fertility in intercluster hybrids of diploid species of section *Arachis.*

Cross	Means of different chromosome association				Pollen fertility (%)
	I	II	III	IV	
A. *batizocoi* x A. *villosa*	7.22	5.54	0.40		4
A. *batizocoi* x A. *correntina*	8.88	5.38	0.11		3
A. batizocoi x A. *chacoense*	8.66	5.63	0.10	0.26	4
A. *batizocoi* x *Arachis sp* HLK-410		Seedlings died			
A. *batizocoi* x A. *duranenais*	10.60	4.72	0.04		4
A. batizocoi x A. *cardenasii*	6.00	6.88	0.08		7

Table 52. Chromosome associations in amphiploids of some diploid species and in some F_1 hybrids *of A. hypogaea x* amphiploids.

Cross	Means of different chromosome associations I	II	III	IV	VI or VII	Pollen fertility (%)
Amphiploids:						
A. *villosa x Arachis* sp HLK-410	2.36	13.6	0.68	2.0		
Arachis sp HLK-410 x *A. villosa*	1.04	14.30	0.434	2.17		36
A. correntina x A. chacoense	3.5	14.5	0.75	1.37		
Arachis sp HLK-410 x *A. correntina*	2.96	15.2	0.32	1.4		
A duranensis x A. villosa	2.0	13.55	0.05	2.55		
A. duranensis x A. correntina	0.56	12.24	0.2	3.68		
Arachis sp HLK-410 x *Arachis* sp 10038	3.45	13.96	0.41	1.80		
Arachis sp 10038 x *Arachis* sp HLK-410	1.75	15.12	0.37	1.62		
Arachis sp 10038 x A. *duranensis*	0.92	13.04	0.2	3.04	0.04	41
A. duranensis x Arachis sp 10038	0.84	11.69	0.07	3.61	0.04	71
A. *duranensis x* A. *cardenasii*	1.66	13.0	0.23	2.6	0.066	
Arachis sp HLK-410 x (*A. chacoense x A. cardenasii*)	2.52	13.30	0.69	2.13		
A. *correntina x* (*A.chacoense x* A. *cardenasii*)	2.4	14.9	0.5	1.5		
A. *batizocoi x* A. *villosa*	6.32	14.92	0.32	0.72		
A. *villosa x* A. *batizocoi*	1.52	18.2	0.4	0.16	0.04	60
A. *batizocoi x* A. *correntina*	4.5	16.6	0.5	0.2		
A. *batizocoi x* A. *duranensis*	2.47	16.68	0.473	0.68		8
A. hypogaea x amphiploid *A.hypogaea* x (A. *villosa x Arachis* sp HLK-410)	9.72	12.45	1.36	0.27		
A. *hypogaea x* (*A. villosa x* A. *duranensis*)	10.0	13.0		0.66		
A. *hypogaea x* (A. *villosa x A. batizocoi*)	4.52	14.88	0.68	0.88		63
A. hypogaea x (*A. correntina x* A. *villosa*)	11.6	11.41	0.416	1.25		51
A. *hypogaea* x (*Arachis* sp HLK-410 x A. *chacoense*	11.26	10.93	1.26	0.8		37
A. *hypogaea x* (*Arachis* sp HLK-410 x *Arachis* sp 10038)	10.04	12.0	0.8	0.88		35
A. *hypogaea x* (*A.duranensis x* A. *chacoense*)	11.8	7.2	2.4	1.4		
A. *hypogaea x* (*A. duranensis x Arachis* sp 10038)	9.65	10.6	1.1	1.4		42
A. *hypogaea x* (*A batizocoi x A. correntina*)	7.90	13.27	1.45	0.27		

only stimulated the production of more pegs, but also sustained their subsequent growth to a stage when pods were formed (ICRISAT Annual Report 1979/80). This report presents the results of subsequent experiments using all three kinds of hormones independently or in combination.

These experiments were aimed at the consistent production of hybrid pegs and pods in large numbers.

Effect of auxins. Three concentrations (5.00 x 10^{-5} M, 1.25 x 10^{-4} *M*, and 2.50x 10^{-4} *M*) of two auxins, indole acetic acid (IAA) and naphthyl acetic acid (NAA), were used. Use of IAA did not induce more pegs than in the controls in both crosses (Tables 54 and 55), but IAA seems to have a role in pod induction in *A. hypogaea* (Table 54). Two concentrations of NAA (5.00 x 10^{-5} M, 1.25 x 10^{-4} *M*) produced more pegs in *A. hypogaea* only, and many of these formed pods also (Table 54). However, they were not effective in the cross *A. monticola* x *Arachis* sp PI No. 276233.

Table 53. Crossability between *A. hypogaea* and amphiploids of section *Arachis*.

Cross	No. of polli-nations	No. of pegs raised	No. of pods	Pods (%)	No. of plants
A *hypogaea* (4)[a] x (*A. villosa* x *Arachis* sp HLK-410)	281	44	35	12.45	35
A. *hypogaea* (2) x (*A. villosa* x A. *duranensis*)	131	31	25	19.08	9
A. *hypogaea* (4) x (A. *villosa* x A. *batizocoi*)	290	92	76	26.20	42
A. *hypogaea* (5) x (A. *correntina* x A. *villosa*)	465	129	104	22.36	35
A. *hypogaea* (4) x (A. *correntina* x A. *chacoense*)	218	55	46	21.10	27
A *hypogaea* (2) x (A. *correntina* x *Arachis* sp HLK-410)	168	22	15	8.92	8
A. *hypogaea*(2) x (A. *correntina* x *Arachis* sp 10038)	71	19	13	18.30	5
A. *hypogaea* (3) x (A. *correntina* x A. *batizocoi*)	198	80	58	29.29	41
A. *hypogaea* (2) x (*Arachis* sp HLK-410 x A. *correntina*)	116	17	12	10.34	2
A. *hypogaea* (2) x (*Arachis* sp HLK-410 x A. *chacoense*)	91	24	8	8.79	4
A. *hypogaea* (3) x (*Arachis* sp HLK-410 x *Arachis* sp 10038)	222	34	21	9.45	9
A. *hypogaea* (1) x (*Arachis* sp 10038 x A. *chacoense*)	15	3	2	13.33[b]	2
A. *hypogaea* (2) x (*Arachis* sp 10038 x *Arachis* sp HLK-410)	114	26	14	11.11	14
A. *hypogaea* (2) x (A. *duranensis* x A. *chacoense*)	130	18	17	13.07	17
A. *hypogaea* (2) x (*A. duranensis* x *Arachis* sp HLK-410)	89	14	12	13.48	17
A. *hypogaea* (3) x (A. *duranensis* x *Arachis* sp 10038)	151	39	40	26.49	40
A *hypogaea* (2) x (*A. duranensis* x *A. cardenasii*)	92	27	22	23.91	8

Continued

Table 53, *continued*

Crops	No. of polli-nations	No. of pegs raised	No. of pods	Pods (%)	No. of plants
A. *hypogaea* (1) x (*A. batizocoi* x A. *correntina*)	11	2	2	18.18[b]	3
A, hypogaea (3) x (*A. batizocoi* x A. *chacoense*)	166	51	43	25.90	43
A. hypogaea (1) x (*A. batizocoi* x A. *duranensis*)	10	5	5	50.0[b]	5
A *hypogaea* (3) x (A. *correntina* x (A. *chacoense* x A. *cardenasii*)	275	54	46	16.72	46
A hypogaea (2) x *Arachis* sp HLK-410 x (A. *chacoense* x A. *cardenasii*)	181	47	37	20.44	34
Total	3519	836	655	18.61	456

a. Number of A. *hypogaea* cultivars used.
b. Result based on few pollinations.

Table 54. Effect of two auxins on pegs and pod formation in an incompatible cross, *A. hypogaea* cv Robut 334 x *Arachis* sp PI No. 276233.

Concentration	IAA			NAA		
	No. of polli-nations	No. of pegs formed	No. of pods formed	No. of polli-nations	No. of pegs formed	No. of pods formed
5.00 x 10-5M	95	8	2	52	12	8
1.25 x 10-4M	102	10	1	75	18	6
2.50 x 10-4M	100	5	2	52	2	2
Control	152	24	8	152	24	8

Table 55. Effect of two auxins on peg and pod numbers in an incompatible intersectional cross, *A. monticola x Arachis* sp PI No. 276233.

Concentration	IAA			NAA		
	No. of polli-nations	No. of pegs formed	No. of pods formed	No. of polli-nations	No. of pegs formed	No. of pods formed
5.00 x 10-5M	82	5	0	98	7	0
1.25 x 10-4M	134	12	0	138	21	0
2.50 x 10-4M	80	8	1	110	15	1
Control	364	57	2	364	57	2

Effect of gibberellic acid. Four concentrations of gibberellic acid (GA3) were applied to flowers of *A. monticola* pollinated with *Arachis* sp PI No.'276233. Even at the lowest concentration, GA3 was found to stimulate pegs in 56% of pollinations. With increase in the GA3 concentration the peg numbers increased up to 87% of pollinations (Table 56). Subsequently a few pods were obtained from these pegs (Table 57), but there was no consistency in response, and the pods developed rather slowly and rarely matured fully. One GA3 concentration (2.50 x 10^{-4} *M*)was tried in *A. hypogaea* crosses with three other incompatible male parents and was found to be effective (Table 58).

Table 56. Effect of gibberellic acid on peg and pod numbers in an incompatible cross, *A. monticola* x *Arachis* sp PI No. 276233.

GA3 concentration (mg/ liter)	No. of polli-nations	No. of pegs formed
3.13 x 10-5M	27	14 (56%)
6.25 x 10-5M	26	19 (73%)
1.25 x 10-4M	21	18 (87%)
2.50 x 10-4M	45	36 (80%)

Table 57. Effect of hormones and their combinations on pegs and pod numbers in incompatible cross *A. monticola* x *Arachis* sp PI No. 276233.

Treatment	No. of pollinations	No. of pegs formed	No. of pods formed	No. of embryos cultured
Kn 10-7M + GA 2.50 x 10-4M	280	125	18	1 (mature)
Kn 10-7M + NAA 1.25 X 10-4M	92	18	0	0
Kn 10-7M	38	0	0	0
NAA 1.25 x 10-4M	28	0	0	0
GA3 2.50 X 10-4M	142	72	6	0

Table 58. Effect of some plant hormones, individually and in combination, on peg and pod number in incompatible crosses in *A. hypogaea* cv Robut 33-1.

	Section *Rhizomatosae*												Section *Triseminale*			
	PI No. 276233				Coll. No. 9649				A. *glabrata*				*A. pusilla*			
Treatment	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Nil	469	75	33	0	42	7	5	0	61	12	8	0	28	0	0	0
Kn 10-7M + GA2.5 x 10-4M	102	16	5	5	41	16	6	1	78	43	23	8				
Kn 10-7M + NAA1.25 x 10-4M	76	1	0	0	34	3	3	0	29	20	11	0				
NAA 1.25 x 10-4M	22	2	0	0	37	8	3	0	15	3	0	0				
GA3 2.50 X 10-4M	262	134	34	23	54	32	11	1(gl)	55	33	7	2(gl)	49	20	2	0

A = No. of pollinations.
B = No. of pegs formed.
C = No. of pods formed.
D = No. of embryos cultured.
gl = Globular embryos.

Effect of cytokinins. Two cytokinins were investigated earlier for their role in peg and pod formation in incompatible crosses. It was found that both cytokinins (kinetin and BAP) stimulated peg initiation and elongation, but their most significant effect was to stimulate pod and seed development (ICRISAT Annual Report 1979/80). Subsequent experiments were therefore conducted to combine the effects of GA3, kinetin, and auxins.

Effect of combinations of hormones. The following two treatments were tried:

(a) Single treatment: a mixture of kinetin or auxin with gibberellic acid. The mixture of hormones was prepared in such a way that it contained the hormones at their individually effective concentrations. Kinetin (10^{-7} *M)* plus GA3 (2.50 x 10^{-4} *M*) produced fewer pegs than GA3 alone might have produced, but a greater proportion of these pegs formed pods from which embryos were obtained and cultured (Tables 57 and 58). These observations indicate that kinetin is desirable for pod, seed, and embryo development.

A mixture of kinetin and NAA was not beneficial (Tables 57 and 58).

(b) Multiple treatments: gibberellic acid (2.50 x 10^{-4}M) was used as an initial treatment at pollination because of its ability to produce pegs in large numbers. In both the crosses, *A. hypogaea* x *Arachis* sp PI No. 276233 and *A. monticola* x *Arachis* sp PI No. 276233, the GA3 treatment induced pegs in most pollinations—close to or up to 100% in many cases (Fig. 15). Most of these pegs were already formed by the time another treatment with kinetin or IAA was administered 10, 15, 20, or 25 days later:

(1) Kinetin following GA3. The number of pegs producing pods due to kinetin varied from none to 100%, depending on the treatment. In some cases the embryos could be dissected and cultured. In the cross *A. hypogaea* x *Arachis* sp PI No. 276233 kinetin gave the most dissectable embryos per pollination when applied on the 25th day after pollination, followed closely by three kinetin treatments: on the 10th, 17th, and 24th days after pollination (Fig. 15). In the cross *A. monticola* x *Arachis* sp PI No. 276233 kinetin treatments resulted in formation of pods, but only some treatments (15, 22D; 20D; 25D) had dissectable embryos. Among these, one treatment on the 20th day after pollination was better than any other (Fig. 15).

(2) IAA following GA3. The number of pegs forming pods was less than that formed after kinetin treatment in both crosses. In *A. hypogaea* crosses maximum embryos per pod, per peg, and per pollination were obtained after IAA treatment on either the 10th, or 15th, or 25th day after pollination. Most IAA treatments yielded embryos for culture (Fig. 15). In *A. monticola* crosses only the treatment 10 days after pollination resulted in four embryos.

These results are tentative and need to be repeated.

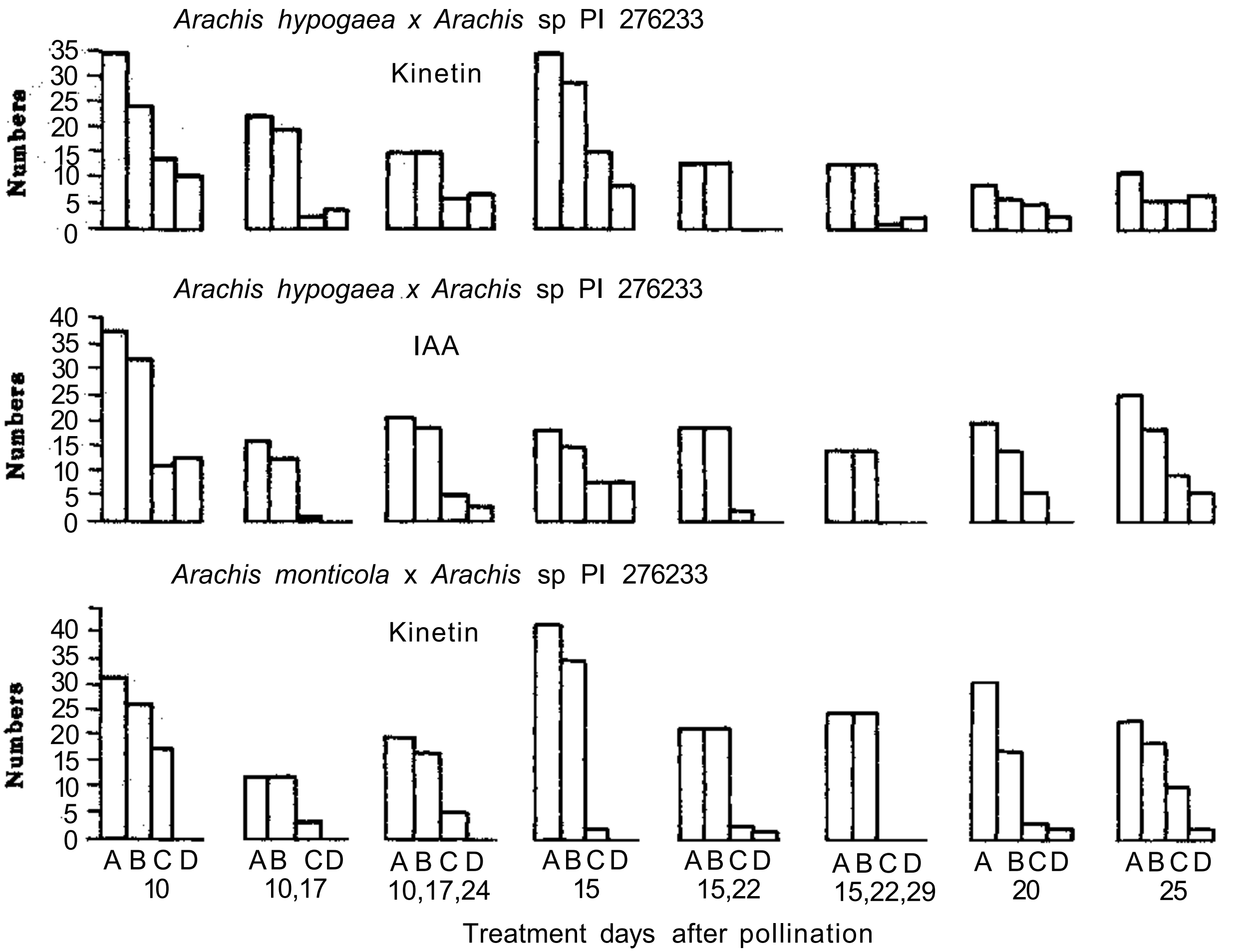
Hybrid production from incompatible crosses. Pods formed after single or multiple hormone treatments do not consistently harbor embryos mature enough to be easily cultured, and there is a need for a method to culture very young embryos.

Embryo culture: Embryos at early cotyledonary stages were easily dissected and cultured successfully to raise plants. The smallest embryos that we could dissect were 0.1 mm long proembryos from 1 mm long ovules. However, culture requirements for very young embryos are known to be complex and are being investigated.

Tissue Culture

Regeneration of plants. In addition to plant regeneration from organs and tissues reported earlier (ICRISAT Annual Report 1979/80, Groundnut Figs. 2, 3, 16, and 17), we successfully cultured a few other explants in 1980/81 (Figs. 16 and 17), not only from *A. hypogaea* but also from wild species (*A. pusilla* and *A. correntina*).

Gynophore tips: Pods and callus (which produces shoot buds and shoots) were formed when gynophores from two species, *A. hypogaea* and *A. pusilla,* were cultured (Table 59).



A,B,C,D: Number of pollinations, pegs, pods, and embroys, respectively.

Figure 15. Effect of kinetin and IAA (on different days after pollination) on pod and embryo production on GA3-Induced pegs in two incompatible crosses in *Arachis.*

Disease-free plants: Disease-free plants can be obtained through tissue culture. A.*hypogaea* shoot meristems were cultured in sufficient numbers for production of disease-free *A.hypogaea* plants to be practical. Shoot meristems were also cultured from a plant of *A. correntina* showing witches' broom disease; the plantlets obtained in vitro showed no morphological symptoms of this disease (Fig. 17c).

Wild Species Derivatives

The wild species derivatives received from North Carolina State University (USA) were grown as spaced plants in our Postentry Quarantine Isolation Area. There was variation within lines, and single-plant selections were made and grown in progeny rows. From one to eight plants were selected, and progeny rows or bulks were grown in the 1980 rainy season (ICRISAT Annual Report 1979/80). These were scored for rust and leaf spots incidence, habit, and number of pods produced per plant. The selected progenies (including bulks from uniform single-plant progenies) were increased in the 1980/81 postrainy season and assessed for productivity, pod size,

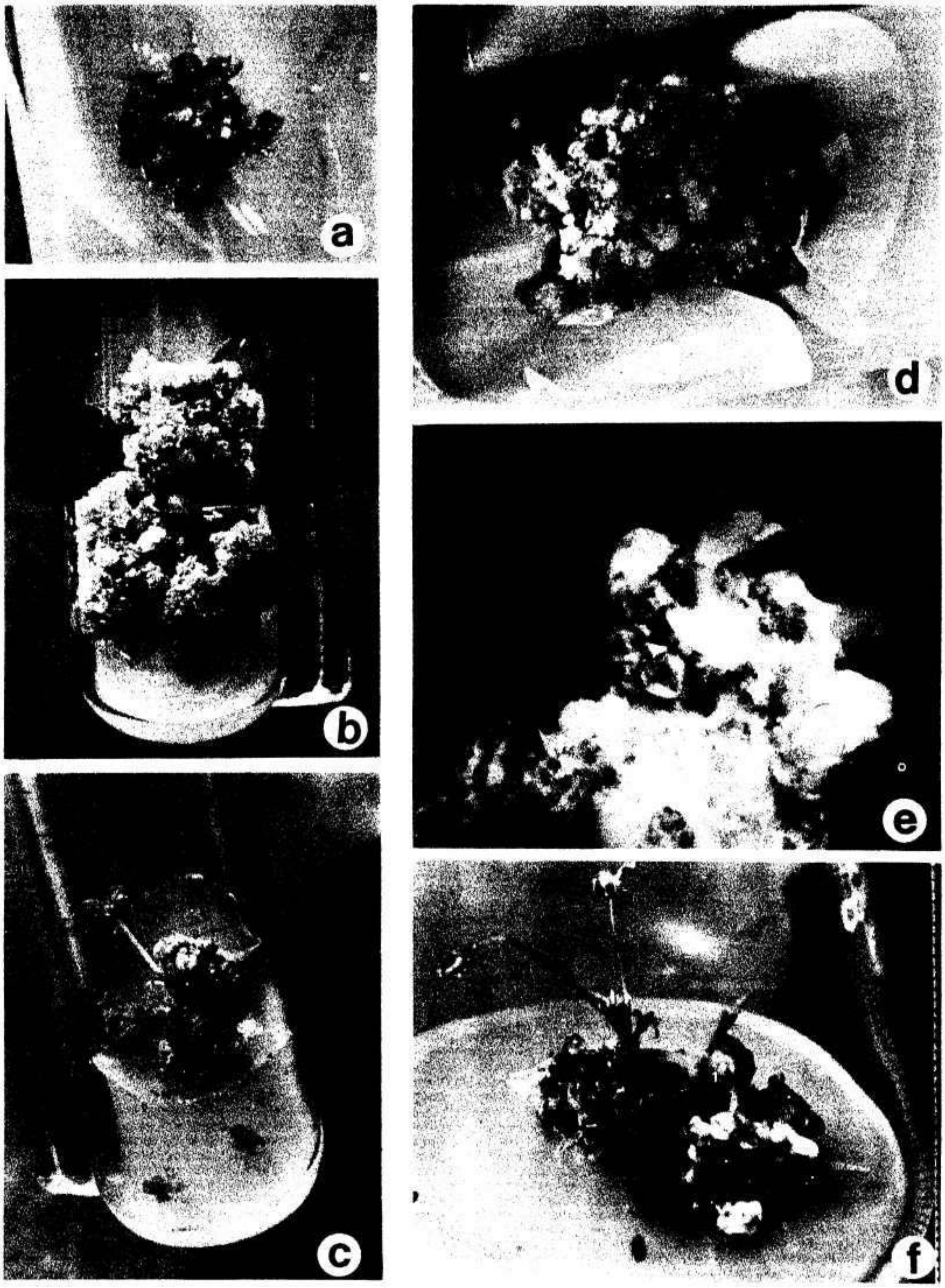


Figure 16. Shoot differentiation in *Arachis* tissue culture:

a, b. *Arachis hypogaea* cv. Robut 33-1 young leaflet segments cultured on MS NAA 1mg/liter and MS NAA 2mg/liter BAP 0.5 mg/liter, respectively. Note shoot buds in (a) and callus and shoot in (b). (a)3.3x,(b) 1.5x.

c. *A. pusilla* young leaflet segments cultured on MS NAA 2 mg/liter BAP 0.5 mg/liter. Note shoot buds and a shoot. 1.67x.

d, e, f. *A. pusilla* root segments from 6-day-old seedlings,—(d) on MS NAA 2 BAP 0.5 mg/liter, 3.2x; (e) on MS NAA 0.5 mg/liter Kn 0.01 mg/liter, 3x; (f) on MS Kn 2 mg/liter GA 1 mg/liter, 2x.

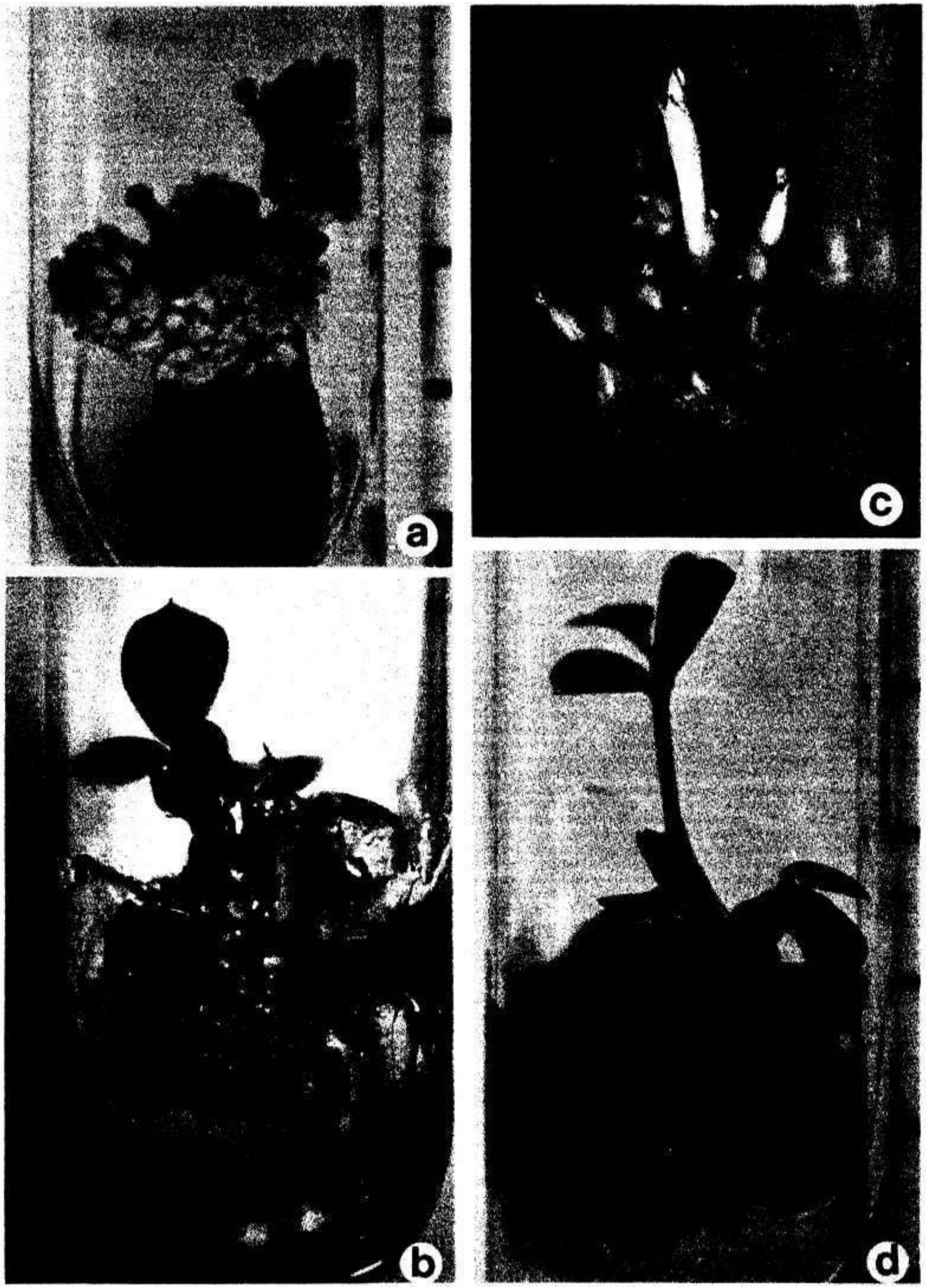


Figure 17. Shoot differentiation in *Arachis* tissue culture:

a. *A. hypogaea* deembryonated cotyledon, note proliferation and shoot buds on nodal end; MS Kn 4 mg/liter, 2.64x.

b. *A. hypogaea* deembryonated cotyledon, note multiple shoots; MS N A A 2 mg/liter BAP 0.5 mg/liter, 3.2x.

c. *A.correntina* shoot tip from witches' broom disease; callus and shoots on MS NAA 2 mg/liter BAP 0.5 mg/liter, 3x.

d. *A. hypogaea* shoot tip. Callus and shoots; MS NAA 2 mg/liter BAP 0.5 mg/liter, 3.1 x.

Table 59. Responses of cultured tissues and organs in some *Arachis hypogaea* cultivars and two wild *Arachis* species.

Species organs/ tissue	*A.hypogaea*	Wild species
Cotyledons	Callus and shoot buds in A Callus and roots in B, C Swelling of cotyledon and shoot proliferation from nodal ends in A[a]	Not attempted
Gynophore tips	Pod formation in A, E also accompanied by callus formation from peg tissues and shoot formation	*A.pusilla:* As in *A.hypogaea*
Hypocotyl	Callus and roots in B,C	Not attempted
Leaflet segments (Immature)	Callus and plantlets in A Slow growth of callus in C	*A.pusilla:* Callus and plantlets[a]
Root discs from seedlings	Callus and root formation in A	*A.pusilla:* Callus and plantlets[a]
Shoot meristems	Callus and plantlets in A and in D[b]	*A.correntina:* Callus and plantlets[a] Plantlets free from witches' broom disease symptoms

Media MS supplemented with NAA 2ppm, BAP 0.5 except:

a. MS + Kn, 1ppm; GA, 1ppm; IAA, 1ppm.
b. MS + Kn, 2ppm; GA, 1ppm; IAA, 1ppm.

A=cv.Robut 33-1, B= PI No. 259747, C=NC 17, D= *A.hypogaea* x *Arachis* spp PI No. 276233, E= NC Ac 17090.

testa color, and uniformity, and uniform, productive lines were selected for further screening (Table 60).

The rust-resistant selections from this material were handed over to our groundnut pathologists and the most productive rust-resistant lines to our groundnut breeders.

In the 1981 rainy season nine promising bulks and two local checks were sown in a randomized block design, with three replications and three

Table 60. Number of single-plant selections from wild species derivatives.

Parental species	Selections
A.hypogaea, *A.cardenasii*	207
A.hypogaea, *A.batizocoi*	37
A.hypogaea, *A.batizocoi*, *Arachis* sp 10038	148
A.*hypogaea*, *A.duranensis*	11

9-m rows per replication at 75-cm row-to-row and 15-cm plant-to-plant spacing.

The plots were assessed for resistance to rust and leaf spots on a 9-point field scale. The local cultivars were scored susceptible (8) for these diseases, and the wild species derivatives ranked from 4 to 7 for rust, and from 3 to 5 for *C. personatum* and *C. arachidicola.* The best *C. arachidicola* resistant line (3) was resistant to *C. personatum* and moderately susceptible (7) to rust, but the best rust resistant lines (both 4) also scored 4 for *C. arachidicola.* One of these lines and the *C. arachidicola* resistant line had significantly better shelling percentage than the controls, and seven of the lines had highly significant increases in percent bold seed, probably due to retention of leaves.

Seven lines outyielded both local cultivars, despite poor plant stands in some replicates. All nine lines outyielded controls when results were adjusted to allow for the effect of plant population (Table 61).

Table 61. Disease reaction and productivity of selections from *A. hypogaea* x *A. cardenasii* hybrids.

Selection	Disease reaction			Shelling percent	Percent bold seed	Actual yield (kg/ha)	Adjusted yield (kg/ha)
	Rust	*Cercosporidium personatum*	*Cercospora arachidicola*				
1	5	4	5	68	48**	4300	4210
2	5	2	4	68	50**	3610	3660
3	4	3	4	67	47**	2760	3570
4	4	2	4	70*	53**	3440	3040
5	7	2	4	67	42**	2360	2300
6	7	2	3	70*	37	2160	2320
7	7	2	4	67	52**	2160	2570
8	5	4	4	63	48**	3700	3710
9	5	5	5	65	40*	4150	37 20
10 (control)	8	8	8	57	25	2210	1150
11 (control)	8	8	8	62	30	1400	1330

* $P < 0.05$
** $P < 0.01$

Cooperation with National Programs

Coordinated Trials

During the 1980 rainy season, nine yield trials sponsored by the All India Coordinated Research Project on Oilseeds (AICORPO) were conducted on Alfisols at ICRISAT Center under rainfed, nonprotected conditions. Yields were low because of severe attacks by rust, leaf spots, and bud necrosis diseases, and a drought from the 3rd week of September through October. Cultivars that performed well included the Spanish Bunch lines J 1, TG-2E, and X 1-21-B, and the Virginia Bunch lines MK 374 and Robut 33-1.

In the 1981 rainy season seven AICORPO trials were conducted and six ICRISAT lines were included for initial evaluation. Growing conditions were favorable but there was a severe attack of rust and leaf spots. Materials, including ICRISAT lines, that performed well were: Spanish Bunch lines ICGS 1, RG 15, J 2, EC 21137-1, JL 24, and TG 14; Virginia Bunch lines ICGS 5 and ICGS 4; and Virginia Runners MA 14 and M 13.

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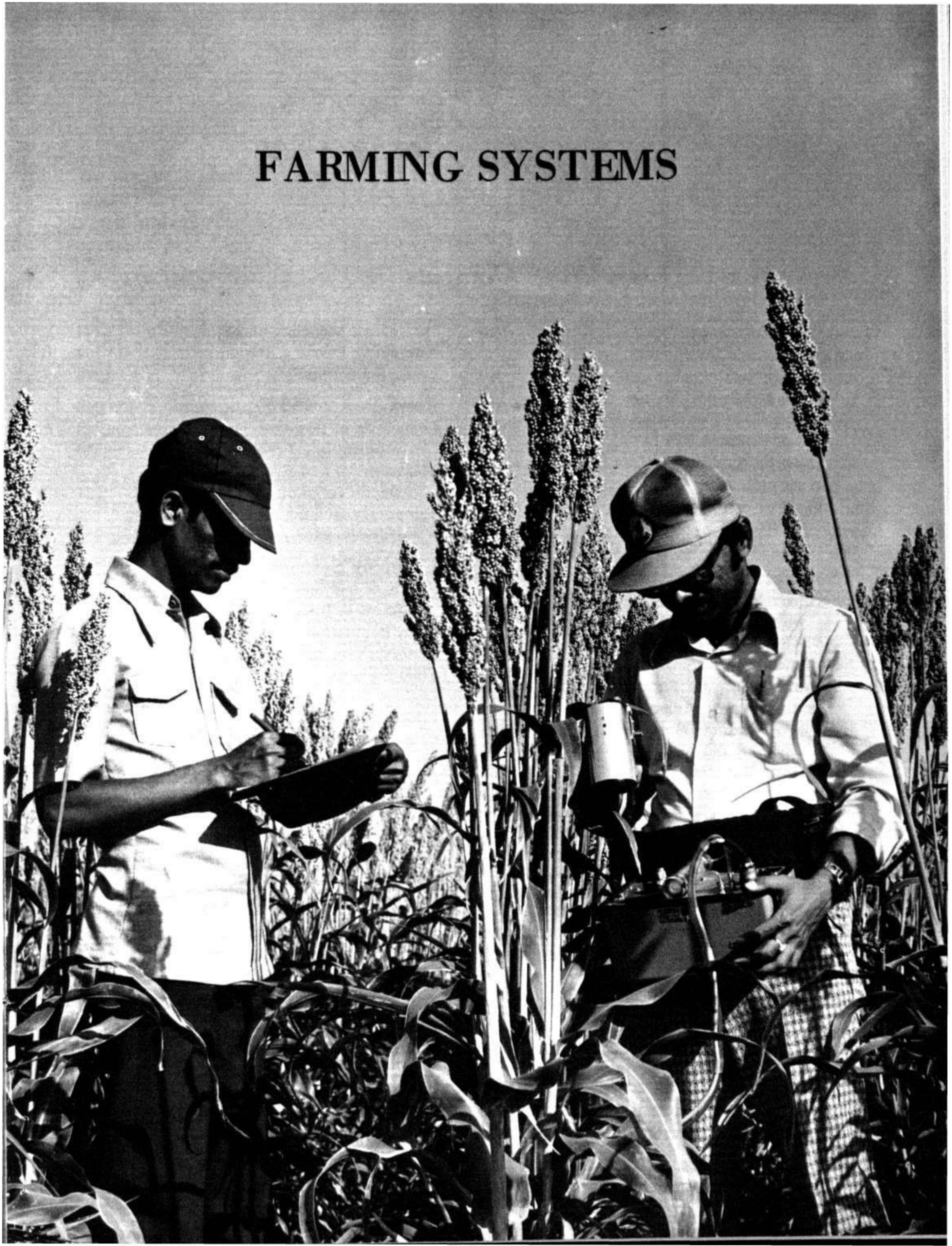
FARMING SYSTEMS



Contents

FARMING SYSTEMS

Agroclimatology

As in previous years, our research during the 1980/81 crop year covered two major areas: (1) collection and interpretation of climatological data from different regions of SAT, and (2) microclimatological and crop-weather modeling studies.

Collection and Interpretation of Agroclimatological Data

Climatic environment of pigeonpea. This study, completed during the report period (Reddy and Virmani 1980 listed in Publications), revealed that the pigeonpea-growing areas of India—where 90% of the world's pigeonpea is grown—fall broadly into three agricultural subdivisions (I, II, and III in Fig. 1). In India's major pigeonpea-growing areas, the mean temperatures vary from 26 to 30°C in the rainy season and 17 to 22°C in the postrainy season. Mean annual rainfall ranges between 600 and 1400 mm, 80 to 90% of which is received during the rainy season. The length of the growing season extends from 120 to 180 days. Our agroclimatic analysis shows that for the states of Uttar Pradesh and Bihar it would be advisable to adopt determinate 120-day pigeonpea types. For the central and southern Indian regions, medium- to long-duration indeterminate types should be suitable.

Revised SAT maps of India, NE Brazil, and Africa. The classification of climate provides a useful index of the ecological conditions, agricultural potentialities, and general environment of a location. Based on Troll's classification (World Maps of Climatology, 1965, Springer-Verlag, Berlin), the semi-arid areas are defined as those with two to seven humid months (months in which mean rainfall exceeds potential evapotranspiration) in the warm season. However Troll's World Maps of Climatology did not show the number of locations on which his global survey was based. These maps place the desert regions of northwest India and the northern parts of West Africa in the semi-arid zone. Therefore, we revised the SAT maps of India, northeast Brazil, and Africa, using an enlarged data base.

This revision, based on data from about 300 locations, places 88% of the geographical area of India in the tropics (Fig. 2). The dry semi-arid tropics cover about 57% of India. The revised SAT map of northeast Brazil is based on data from 180 locations, while the revised map of Africa used data of 300 locations in West Africa and 180 locations in the rest of Africa.

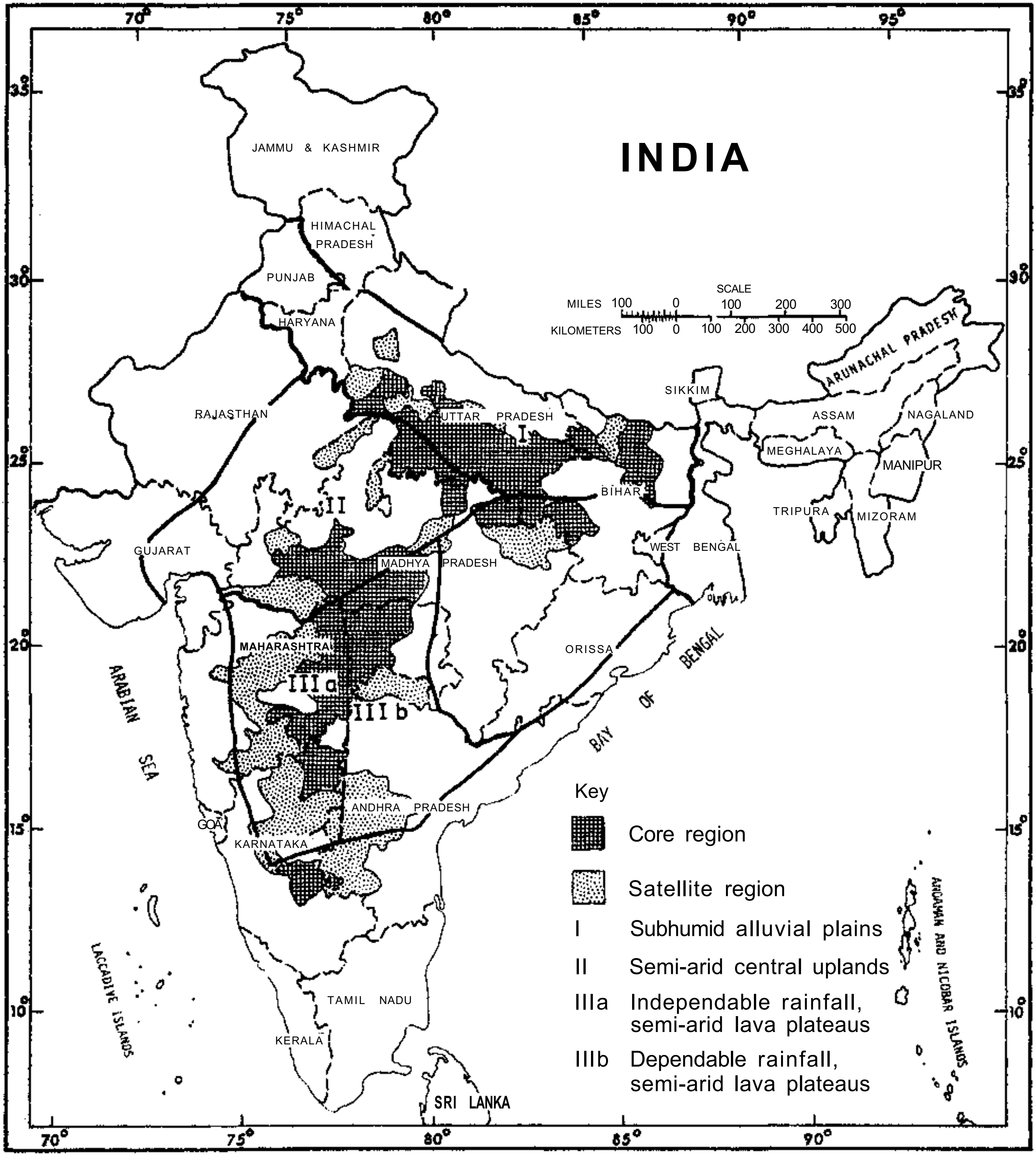
Microclimatological Studies

During 1980/81 our research conceptualization developed over the preceding 3 years-examination of the relationships between intercepted radiation and dry-matter production by sorghum—was extended to cover both the rainy and postrainy seasons. In our experiments this year to quantify crop response to moisture stress, we included millet in addition to sorghum.

Efficiency of Conversion of Intercepted PPFD

Over the past 2 years, we evaluated the productivity of different crops/cropping systems by calculating growth efficiency from the slope of the regression relationship between the cumulative intercepted photosynthetic photon flux density (PPFD) and dry matter and the calorific value of the crop.

During the 1980 rainy season we grew hybrids CSH-1 and CSH-6 on a Vertisol and an



Sources: Easter and Abel (1973), Cropping regions in India; Murthy and Fandey (1978), Delineation of agroecological regions of India.

Figure 1. Agricultural subdivisions of pigeonpea regions of India.

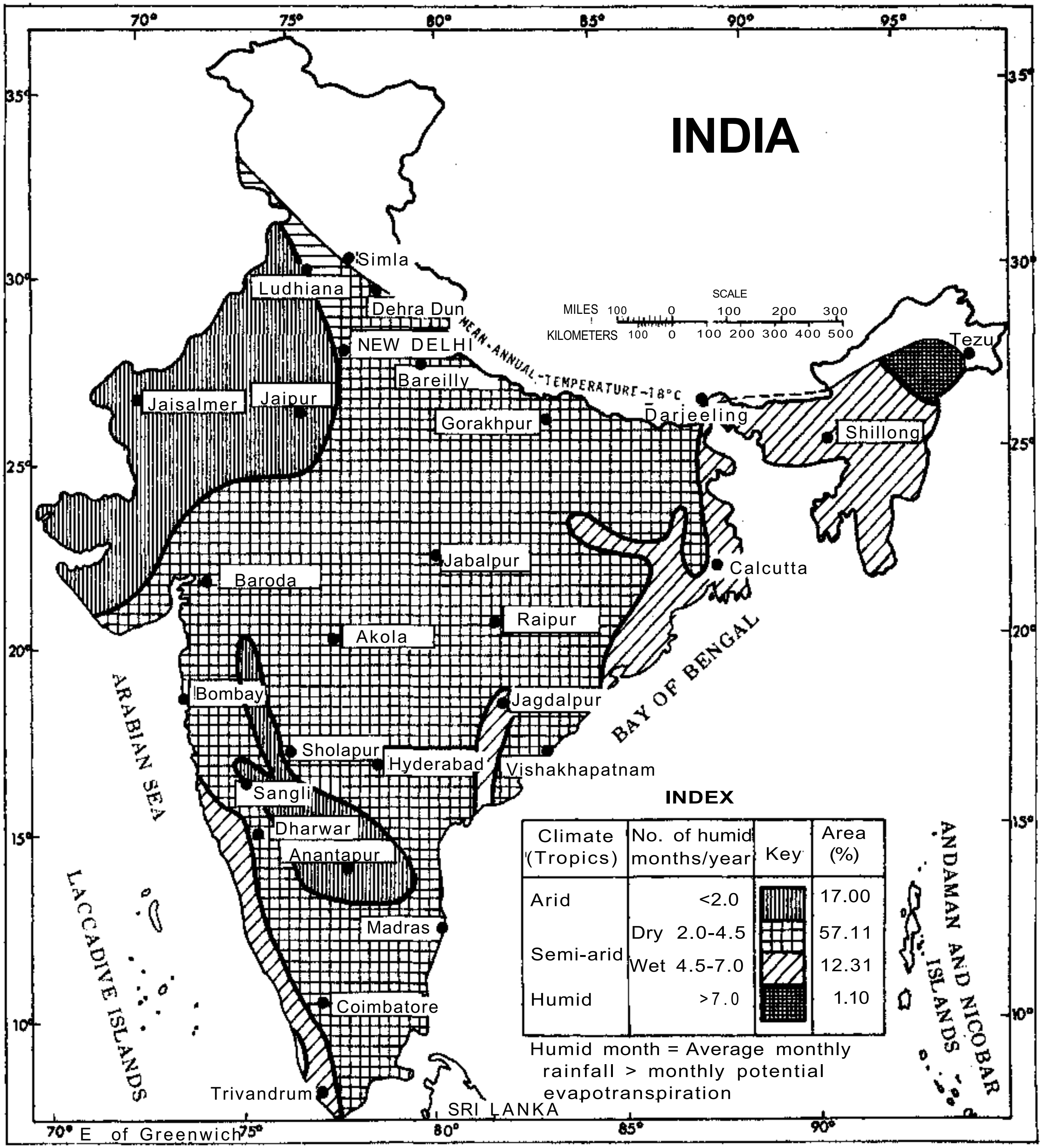


Figure 2. Semi-arid tropics of India (revised using Troll's approach).

Alfisol under uniform management at ICRISAT Center. The experiment on Vertisol also included variety SPV-351, while the trial on the Alfisol included additional irrigation and no-irrigation treatments.

The relationship between the cumulative intercepted PPFD and the dry matter produced for the three sorghums grown on the Vertisol is shown in Figure 3. Calculated growth efficiencies were 5.2% for the two hybrids and 4.5% for SPV-351.

A postrainy-season trial on the Alfisol included hybrid CSH-8 and variety M-35-1 under two irrigation regimes. The slopes of the linear regression through origin showed no significant difference between the two genotypes; hence their data are pooled for the irrigated and non-irrigated treatments. The growth efficiency of the two genotypes was 3.8% with irrigation and 2.4% without irrigation, considerably lower than those observed during the rainy season with CSH-1, CSH-6, and SPV-351.

Quantification of Moisture Stress in Sorghum

We studied the response of sorghum hybrids CSH-6 and CSH-8 and variety M-35-1 to differential profile moisture during the postrainy season of 1980/81. The crops were sown on 10 October 1980 and an 85-mm irrigation was given on 11 October to recharge the profile. Emergence occurred on 13 October. Treatment A received four supplemental irrigations of 75, 78, 71, and 50 mm at 10, 28, 39, and 70 days after emergence (DAE). Treatment B was given only two irrigations: 60 mm at 10 DAE and 85 mm at 39 DAE.

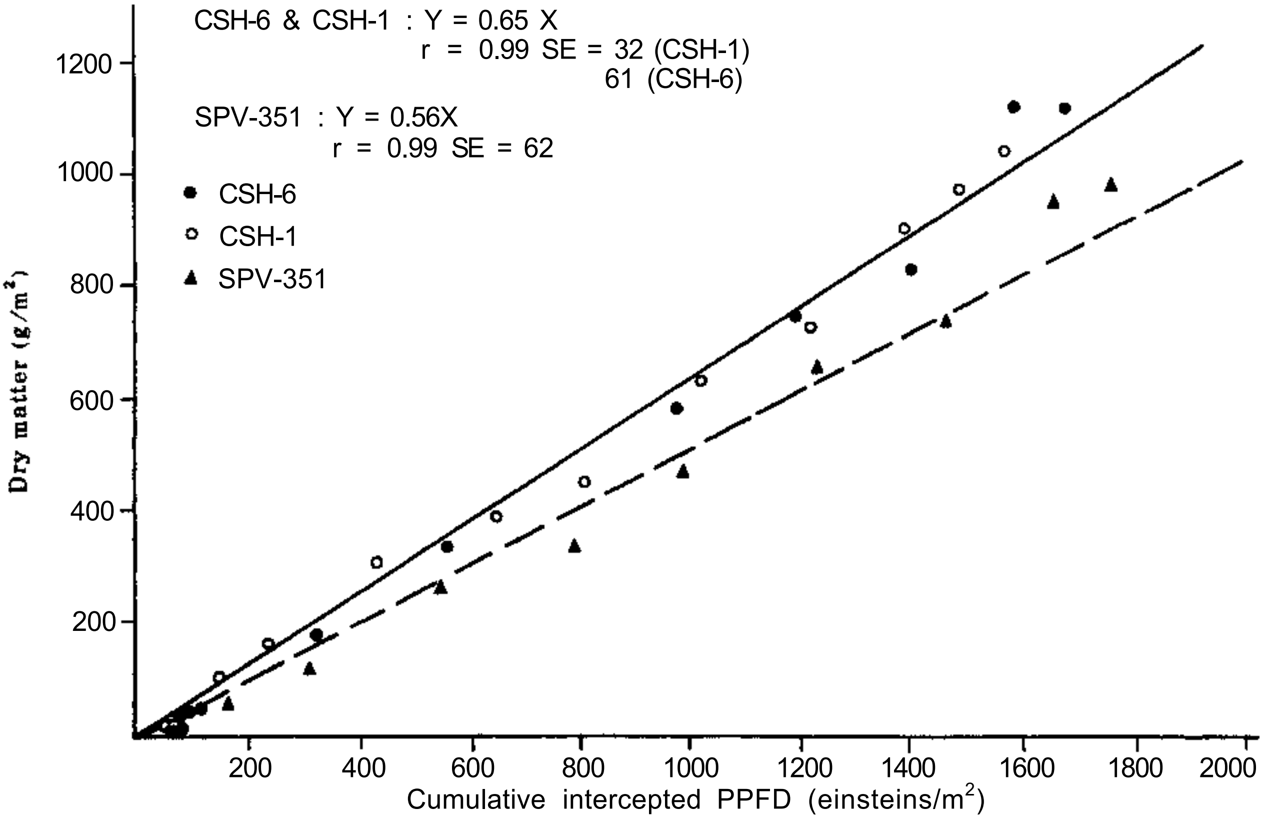


Figure 3. Relationship between cumulative intercepted PPFD and dry matter produced for three sorghum genotypes grown during the 1980 rainy season at ICRISAT Center.

Starting from 40 DAE, daily measurements of stomatal conductance, transpiration, and leaf and air temperatures were taken in all the plots till the crop reached physiological maturity. Leaf-air temperature differential (LATD) was calculated from the difference between leaf and air temperatures measured each day. To facilitate comparison between the treatments, cumulative values were computed from the daily values (all three measures) starting from 40 DAE to physiological maturity.

Cumulative LATD for the three genotypes is shown in Figures 4 and 5. It is notable that although treatment A received 71 mm of additional water prior to the start of the canopy measurements, the treatment effects did not become apparent until 70 DAE when treatment A received an additional irrigation of 50 mm. For the measurement period, the average LATD was -3.81, -4.73, and -4.63°C in treatment A and -3.12, -3.93, and -3.64°C in treatment B for CSH-8, CSH-6, and M-35-1, respectively. These data show that stress-induced increase in leaf temperature, averaged over the measurement period, was the least in CSH-8, followed by M-35-1 and CSH-6.

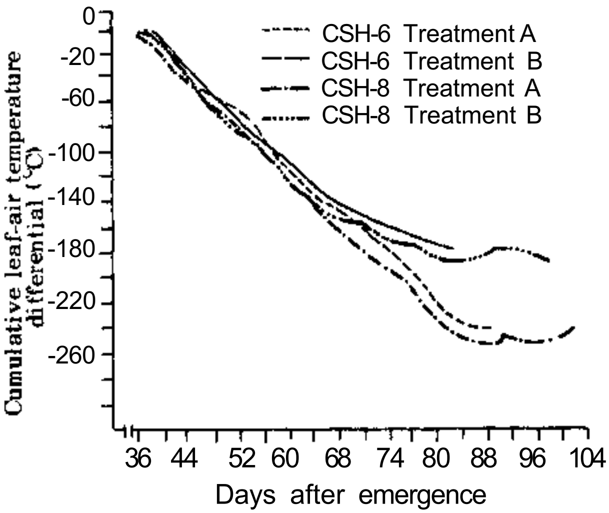


Figure 4. Cumulative leaf-air temperature differential (LATD) for sorghum hybrids CSH-6 and CSH-8 grown under two moisture regimes during the 1980/81 postrainy season at ICRISAT *Center.*

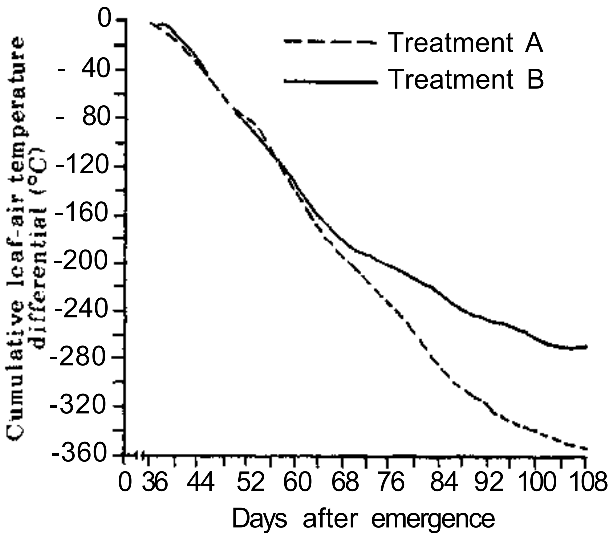


Figure 5. Cumulative leaf-air temperature differential (LATD) for sorghum variety M-35-1 grown under two moisture regimes during the 1980/81 postrainy season at ICRISAT Center.

The order of stomatal adaptation to moisture stress could be given as CSH-8 > CSH-6 > M-35-1, as evidenced by the average daily stomatal conductance levels: 0.81, 0.80, and 0.58 cm/sec in treatment A and 0.51, 0.53, and 0.41 cm/sec in treatment B for CSH-8, CSH-6, and M-35-1, respectively.

The cumulative transpiration rates show important differences in varietal adaptation to moisture stress (Table 1). In treatment A, the highest transpiration rates were recorded in CSH-8. It follows from stomatal adaptation responses discussed above that CSH-8 should show the maximum reduction in transpiration rates under moisture stress, followed by CSH-6 and M-35-1. The average daily transpiration rates shown in Table 1 amply substantiate the stress-induced adaptation ability of CSH-8.

Transpiration efficiencies were calculated from the total dry matter at physiological maturity, final grain yield, and cumulative transpiration. Since the transpiration rates were measured only from 43 DAE, calculated transpiration efficiency values are approximate answers. As shown in Table 1, maximum transpiration efficiency in dry-matter production in

Table 1. Transpiration and transpiration efficiencies of three sorghum genotypes grown under two moisture regimes during the 1980/81 postrainy season at ICRISAT Center.

Parameter	CSH-8 Treatment[a] A	CSH-8 Treatment[a] B	CSH-6 Treatment A	CSH-6 Treatment B	M-35-1 Treatment A	M-35-1 Treatment B
Measurement period (days)	63	59	51	45	76	76
Cumulative transpiration (μ g/cm^2/sec)	685	405	559	346	541	443
Transpiration/day (μ g/cm^2/sec)	10.9	6.9	10.9	7.7	7.1	6.1
Transpiration efficiency (g of dry matter/g/sec)	163	146	166	143	189	140
Transpiration efficiency (g of grain/ g/sec)	89	62	84	*66*	73	38

a. Treatment A = adequate water, treatment B = limited water.

treatment A was observed in M-35-1, while CSH-6 and CSH-8 performed alike. Under stress, however, CSH-8 showed marginally better transpiration efficiency than CSH-6 and M-35-1.

However, for grain yield, the transpiration efficiency of CSH-8 and CSH-6 was higher than that of M-35-1 in treatment A. The differences in transpiration efficiency among the three genotypes under limited water application were still more striking: CSH-8 and CSH-6 showed significantly higher transpiration efficiency than M-35-1

Response of Pearl Millet to Moisture Stress

In order to understand and quantify the effect of timing and duration of stress on the growth, water relations, nitrogen uptake, and yield of millet, we conducted a study during the summer seasons of 1980 and 1981 on a medium-deep Alfisol. The following treatments were given to the crop in a split-plot design in three replications.

Main plot (four moisture regimes after an initial irrigation at time of sowing): M_1—irrigation every 10 days (320 mm); M_2—two irrigations during the early vegetative growth period (80 mm); M_3 —two irrigations at the time of flowering (80 mm); M_4—two irrigations at the time of grain filling (80 mm).

Subplot (three nitrogen levels): N_1— 0 kg N/ha; N_2-40 kg N/ha; N_3—80 kg N/ha.

1980 summer season. Under frequent irrigations (treatment M_1), maximum leaf number per plant was observed at 46 DAE at the highest nitrogen application rate (80 kg/ha). Two supplemental irrigations during early vegetative growth (M_2) resulted in better leaf production than two supplemental irrigations at the time of flowering (M_3) or at grain filling (M_4).

With a nitrogen supply of 80 kg/ha, the crop under treatment M_1 was able to maintain a high leaf-area index till 62 DAE. This was not true however, under the other two nitrogen levels.

The dry-matter distribution pattern in the leaf, leaf sheath, stem, head, and grain components of the millet crop under different treatments in the 1980 growing season is shown in Figure 6 a, b, c, d. Maximum dry-matter accumulation was observed in treatment M_1 at all nitrogen levels. In this treatment the response of millet to nitrogen in terms of increased dry-matter accumulation was evident at both 40 and 80 kg N/ ha. The most significant effects of moisture stress were apparent in treatment M_4 where irrigation was withheld till grain-filling stage. The maximum dry-matter level as well as its distribution among different components indicate, that millet showed little response to added nitrogen under moisture stress.

The mean grain yield for the four moisture regimes over three nitrogen levels showed that irrigating the crop every 10 days gave significantly higher yields than the other three moisture regimes (Table 2). This conclusion is also valid for the comparison of moisture regimes at a given nitrogen level. In terms of the relative yield advantage attainable by two supplemental irrigations at selected physiological stages, mean yields over the nitrogen levels showed irrigating during early vegetative growth or at the time of flowering gave significantly higher yields than irrigating at the time of grain filling.

1981 summer season. On 12, 13, and 14 March, and again on 22 and 23 March a total of 77 mm of rainfall occurred at ICRISAT Center. This rainfall was very unusual, as the probability of even 5 mm rainfall is less than 15% in a 7-day period at this time of the year (Virmani, S.M., Sivakumar, M.V.K., and Reddy, S.J. 1978. ICRISAT Research Bulletin No.1). This unseasonal rainfall occurring during the time of flowering (at 30,31,32,40, and 41 DAE) led to unusual crop responses to stress. However, these results did permit us to draw some generalizations on the response of millet to water stress.

Better moisture environment due to the unusual March rains during the 1981 summer season resulted in higher leaf number than in 1980 summer; maximum leaf number was almost the same in treatments M_1, M_2, and M_3, The leaf-area index (LAI) of millet was also higher during this season. Treatments M_1, M_2, and M_3 were similar, except that in M_3 the decline in LAI occurred a little earlier.

As in the 1980 summer season, maximum accumulation of dry matter occurred in treatment M_1 at all levels of nitrogen. But contrary to the previous year's results, two supplemental irrigations given at the time of flowering (M_3) resulted in higher dry-matter accumulation than in the M_2 and M_4 treatments.

Stomatal conductance and transpiration data of millet under different moisture regimes at 80 kg N/ha for selected days are shown in Table 3. Under significant stress till 50 DAE, millet in treatment M_4 showed significant stomatal closure and reduction in transpiration. The recovery due to supplemental irrigations to this treatment at 58 and 67 DAE was manifested in improved stomatal conductance and transpiration. Similar responses were observed in treatment M_3 after the supplemental irrigations on 39 and 48 DAE. Significant reductions in stomatal conductance and transpiration of millet from 43 DAE till maturity were observed in treatment M_2.

Overall mean yield of millet during the 1981 summer was 2369 kg/ha; in 1980 it was only 1016 kg/ha. Treatment M_1 gave significantly higher grain yield than treatment M_2, but not higher than treatments M_3 and M_4.

Comparison of the results of the 1980 and 1981 summer seasons reveals the following two factors that modulated the response of the millet crop to water and nitrogen stress:

1. A prolonged spell of water stress during both early vegetative and flowering stages reduced the yield of the millet crop substantially. Millet could recover from stress imposed at early growth if supplemental irrigations were provided both at the onset and completion of flowering. Availability of water at this time seems to be crucial for subsequent grain filling.

2. Millet responded to applied nitrogen only when sufficient water was available to promote good vegetative growth and flowering.

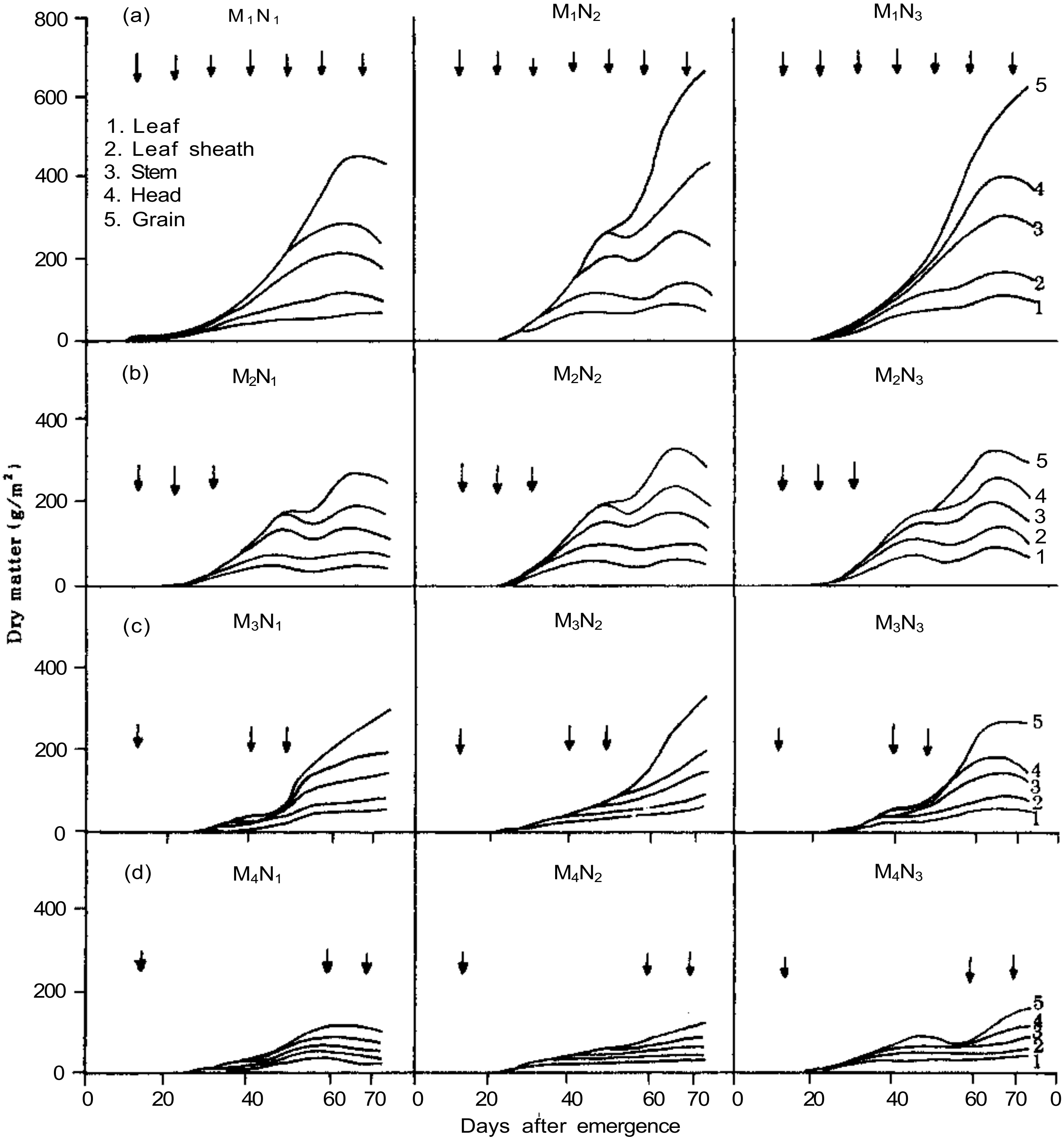


Figure 6. Dry matter distribution pattern in millet grown under different moisture regimes and nitrogen levels during the 1980 summer season at ICRISAT Center.

Table 2. Grain yield response of millet to irrigation and nitrogen levels during 1980 summer on an Alfisol at ICRISAT Center.

Nitrogen levels	Moisture regimes				Means for nitrogen levels
	M_1	M_2	M_3	M_4	
	kg/ha				
	1763	868	827	364	956
N_2	1922	804	945	446	1029
N_3	2173	847	873	363	1064
Means	1953	840	881	391	
CV (%) Whole plot	16				
Subplot	20				

	SE (±)
Nitrogen levels	126
Moisture regimes	176
Nitrogen levels in a moisture regime	251
Moisture regimes in a nitrogen level	270

Crop Weather Modeling: SORGF

Preliminary tests with SORGF, a sorghum growth simulation model (Arkin, et al. 1976. Trans. Am. Soc. Agric. Engr. 19: 622) showed that several of its subroutines needed modification for adaptation to the SAT regions. These subroutines deal with emergence, soil water, leaf-area development, phenology, light interception, and dry-matter partitioning. SORGF-1, the revised SORGF model based on limited data sets (ICRISAT Annual Report 1979/80), showed some improvements in simulating sorghum growth and development.

We used the data collected from our sorghum modeling experiments during the rainy and postrainy seasons of 1979 and 1980 to further examine and improve the SORGF-1 model. This revised model is now referred to as SORGF-2. The revisions and the simulation results from SORGF and SORGF-2 are described here.

Experiments. The crop weather modeling experiments were conducted at ICRISAT Center, Coimbatore, Delhi, Hissar, Parbhani, Pune, Rahuri, and Ludhiana in India and at Khon Kaen in Thailand. At most of these locations, replicated trials involved two sorghum genotypes (CSH-1 and CSH-6) during the 1980 rainy season, and CSH-8 and M-35-1 during the 1979/80 and 1980/81 postrainy seasons. Additional moisture treatments of adequate water and water stress at certain critical stages were included in the postrainy-season experiments. Standard data sets on crop, soil, weather, and management were collected to test the model. (The data and method of collection are described in detail in Agroclimatology Progress Report 4, ICRISAT.)

Summary of weather data. Table 4 gives the rainfall data and seasonal open-pan evaporation at several locations for the 1980 rainy season. The seasonal rainfall at ICRISAT Center was normal and was 28% more than the requirement for potential evapotranspiration (PE). Although rainfall at Khon Kaen was below normal, the PE requirements were adequately met by the seasonal rainfall.

Table 3. Stomatal conductance and transpiration of millet crop grown during 1981 summer under different moisture regimes at 80 kg N/ha at ICRISAT Center.

Days after emergence	Moisture regimes[a]							
	M_1		M_2		M_3		M_4	
	Cond.[b]	Transp.	Cond.	Transp.	Cond.	Transp.	Cond.	Transp.
34	0.53±0.04	14±1.2	0.57±0.04	15±1.1	0.31±0.02	8±0.9	0.43±0.02	11±1.1
43	0.89±0.10	24±1.7	0.50±0.04	13±1.4	0.55±0.03	17±1.2	0.42±0.07	12±1.3
50	0.53±0.03	26±2.0	0.19±0.01	10±1.0	0.69±0.04	24±1.7	0.17±0.05	6±0.8
59	0.29±0.01	14±1.7	0.12±0.01	11±1.0	0.16±0.02	9±0.8	0.30±0.02	16±1.7
69	0.14±0.01	7±0.4	0.00 -	0 -	0.04±0.01	2±0.1	0.29±0.01	15±2.0

a. Days on which treatments were irrigated are indicated on Figure 6.
b. Cond. = stomatal conductance (cm/sec); Transp. = transpiration ($\mu g/cm^2$ per sec).

Table 4. Summary of weather data for different locations of crop weather modeling experiments for the 1980 rainy season.

Location	Seasonal rainfall	Normal rainfall	Open-pan evaporation
		mm	
ICRISAT Center	591	587	658
Delhi	724	617	568
Hissar	200	304	804
Khon Kaen	455	557	392
Parbhani	1050	830	698
Pune	248	516	500
Rahuri	291	538	565
Ludhiana	745	528	528

Phenological events. The data observed during the rainy-season indicate that hybrids CSH-1 and CSH-6 took about 52-56 days after emergence (DAE) to reach anthesis and 85-88 DAE to reach physiological maturity (PM), while SPV-351 (grown only at ICRISAT Center) took about 62-63 DAE to reach anthesis and about 90-95 DAE to reach PM.

In early October plantings during the post-rainy season, CSH-8 reached anthesis by 60-66 DAE and PM by 98-106 DAE, while M-35-1 took about 67-71 DAE to reach anthesis and 105-113 DAE to reach PM. When plantings were delayed till late November on deep Vertisols, days to anthesis and PM were extended for both CSH-8 and M-35-1. Early maturity because of moisture stress was notable for CSH-8 and M-35-1, as well as for CSH-6 (grown only at ICRISAT Center during the post-rainy season). However, the hastening of maturity depends on the degree of moisture stress prevailing during the grain-filling period.

Leaf-area index. Data on leaf-area index (LAI) were collected at 7 to 10-day intervals in all treatments for every crop modeling experiment conducted at ICRISAT Center. Seasonal changes in LAI and days from emergence to anthesis and to physiological maturity for CSH-6 grown in the rainy season are compared with SORGF and SORGF-2 simulation results in Figure 7. It is

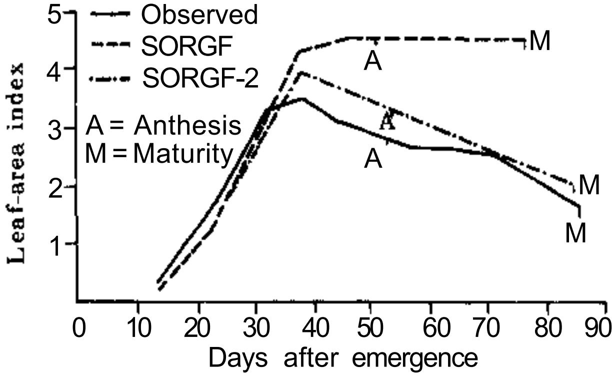


Figure 7. Observed and simulated leaf-area index for sorghum hybrid CSH-6 grown in a rainfed situation during the 1980 rainy season on an Alfisol at ICRISAT Center.

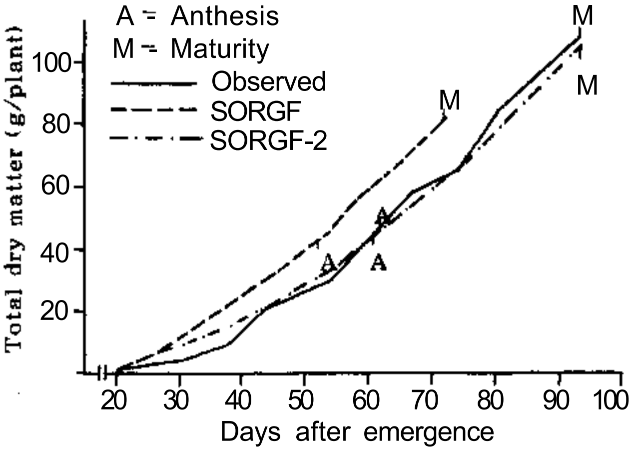


Figure 8. Observed and simulated total dry matter for sorghum variety SPV-351 grown in a rainfed situation on a deep Vertisol at ICRISAT Center.

clear that revisions in the model produced improvement in the computation of LAI and the phenological events.

Dry matter and its partitioning to grain yields. During the rainy season, the total dry matter for SPV-351 was higher than both CSH-1 and CSH-6; however, CSH-6 was superior in grain yields. Reductions in total dry matter and grain yields in CSH-6 compared to CSH-1 in experiments with supplemental irrigations in the 1980 rainy season at ICRISAT Center and at Rahuri indicate that CSH-6 may be susceptible to waterlogging.

In the postrainy season, CSH-8 performed better than M-35-1 under both adequate and limited moisture supply.

Seasonal patterns in observed and simulated dry matter and grain yields for SPV-351 grown in the 1980 rainy season on a deep Vertisol are compared in Figures 8 and 9. Total dry matter and grain yields pooled over all the treatments are given for examination of the degree of correspondence between observed patterns and those simulated by the models. Results indicate that some improvement in simulating dry matter and grain yields was achieved through revisions.

Subroutines revised in SORGF. The computation of phenology, leaf-area index, light interception, soil water, and dry matter and its partitioning has been revised (as described in detail in Agroclimatology Progress Report 5, ICRISAT).

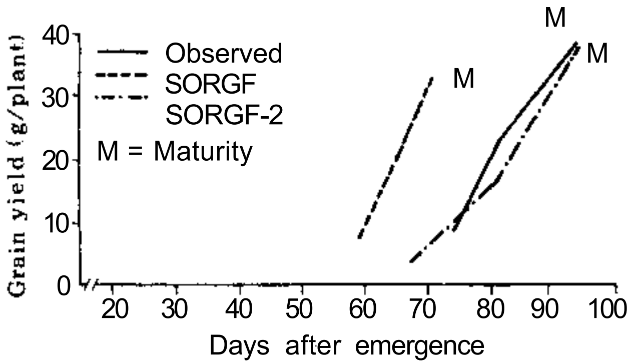


Figure 9. Observed and simulated grain yield for sorghum variety SPV-351 grown in a rainfed situation on a deep Vertisol at ICRISAT Center.

Statistical analysis of simulation results. Crop data pooled over 27 data sets were used to compare the performance of SORGF and SORGF-2 models (Table 5). The observed total dry matter (kg/ha) ranged from 4950 for the genotype M-35-1 grown under moisture stress to 12 510 for CSH-6 grown in the rainy season. Grain yields (kg/ ha) ranged from 1300 for M-35 -1 under moisture stress to 6136 for CSH-8 un-

Table 5. Statistical analysis of simulation results (n = 27)—highest, mean, and lowest response of observed and simulated data.

Crop data	Observed			SORGF			SORGF-2		
	Highest	Mean	Lowest	Highest	Mean	Lowest	Highest	Mean	Lowest
Total dry matter (kg/ha)	12 510	9444	4950	14 548	10 000	5454	14 013	8645	4458
Grain yield (kg/ha)	6 136	3954	1300	7 607	4 687	3183	6 564	3680	1159
Physiological maturity (DAE)	115	97	81	106	85	76	116	98	83
Maximum LAI	3.88	2.89	1.73	4.98	3.68	2.28	4.48	3.2	2.14
Final LAI	2.77	1.24	0.27	4.97	3.65	2.28	2.01	1.12	0.13
Correlation coefficient			SORGF			SORGF-2			
Total dry matter			0.32			0.83			
Grain yield			0.17			0.87			
Root mean square error (RMSE)									
Total dry matter (kg/ha)			2779		1619				
Grain yield (kg/ha)			1886		766				
Physiological maturity (DAE)			13		3				

der adequate moisture supply in the postrainy season. Simulation results show that the SORGF model particularly overestimated the grain yields, while SORGF-2 improved the simulation.

In regard to maturity durations, the SORGF estimates were low, while SORGF-2 estimated closely for the entire range of duration. No major change has yet been made in computing maximum LAI. The effect of moisture stress factors on leaf expansion and senescence should be further examined and incorporated into the model for computing the daily LAI. While the SORGF model overestimated final LAI, SORGF-2 improved the estimations.

The correlation coefficient between observed and simulated results (Table 5) shows that revisions in the model gave improved estimates of total dry matter and grain yield. SORGF could explain only 4% variation associated with grain yields in the present data set, but SORGF-2 could explain 76% variation.

Error analysis of the simulation results indicate that root-mean square error for total dry matter, grain yields, and DAE to PM was reduced by revisions in the model (Table 5).

Soil Fertility and Chemistry

In our continuing emphasis on studies of the behavior of nitrogen in the soil-plant system, our objective is to improve the efficiency of the SAT farmers' use of nitrogen from all sources. This work received substantial impetus in the current year with the commencement of our joint project "Fate and Efficiency of Fertilizer Nitrogen" with the International Fertilizer Development Center (IFDC). This project will complement our work already in progress on the effects of intercropping, interrow spacing, and fertilizer placement on the responses to fertilizer nitrogen.

Our work on other plant nutrients has been concentrated mainly on long-term experiments with phosphorus and potassium; these experiments are continuing.

Fertilizer Nitrogen Efficiency with Cereals

The response of sorghum and pearl millet to fertilizer nitrogen in the rainfed SAT is unclear because of the lack of detailed studies to elucidate both the individual effects of the many factors involved and their interactions. Of these factors, the amount and distribution of seasonal rainfall is particularly important; it determines yield potential, and therefore the requirement of a crop for nitrogen. It also determines the availability of nitrogen to the crop — either directly in terms of accessibility of nitrogen to the plant root, or indirectly because both excessively dry and excessively moist soil conditions may contribute to losses. Therefore we need to know how crop responses to fertilizer nitrogen vary in relation to major agronomic and environmental factors. Our research strategy therefore involves a combination of empirical experiments that include measurements of yield responses over a number of seasons, and detailed studies of the various aspects of the fate and efficiency of fertilizer nitrogen.

^{15}N Balance Experiments

The fate of fertilizer nitrogen is best studied by labelling the fertilizer with ^{15}N, the stable (non-radioactive) isotope of nitrogen. The portion absorbed by the crop or incorporated into the soil can be measured directly, and the deficit from that originally added provides an estimate of the amount of nitrogen lost by leaching and conversion to gases.

We made initial studies on both Vertisols and Alfisols in the 1980 and 1981 seasons. The ^{15}N-labelled fertilizer was used on only selected treatments within larger agronomic experiments that used unlabelled fertilizer. The crop grown on both soils was rainy-season sorghum. Analyses of ^{15}N are still in progress; the results reported here are therefore confined mainly to the effects of agronomic treatments on yield.

Vertisol. Agronomic methods for improving efficiency of fertilizer-nitrogen use involve matching the amounts and timings of applications to crop requirements. The efficiency of uptake may also be increased by placing the fertilizer in a band close to the main axis of the plant. These practices minimize the competition of soil reactions with plant roots for the fertilizer. In our experiment on a Vertisol in 1981 (Table 6), a split application of fertilizer in bands after emergence of the crop was markedly superior to an application at seeding (dry, before rains commenced) by either broadcasting on the soil surface or incorporating into the surface soil (after broadcasting onto the soil surface). This year (1981) was particularly wet; responses to nitrogen were very large, and losses of nitrogen by leaching and denitrification might also have been large relative to other years.

In 1980, maximum yield and response to nitrogen were lower than in 1981 (Table 6); grain yield was not obviously affected by any of the fertilizer-application treatments, with the exception that broadcasting on the soil surface was superior to incorporation into the surface soil. The rainfall during this season was adequate for plant growth on Vertisols.

Alfisol. Both in 1980 and 1981 we used confined microplots approximately 2 m x 1 m in surface area, which were formed by excavating around a block of soil and wrapping several layers of polythene sheet around the block prior to reforming the soil outside the microplot.

Yields were higher than on the Vertisol. Responses to nitrogen were relatively small in 1980, due largely to the already high yield without added nitrogen, but responses in the wet year of 1981 were particularly large (Table 7). Again, split-placement of fertilizer in bands was the superior treatment.

^{15}N recovery. Although the response to fertilizer nitrogen on the Alfisol was small in 1980, the crop was efficient at absorbing it. Recoveries of fertilizer nitrogen in the above-ground crop were greater than 50% (Table 8); this compares well with good recoveries by cereal crops elsewhere in both temperate and tropical climates.

Table 6. Sorghum grain yields in ^{15}N balance experiments on a Vertisol at ICRISAT Center, 1980 and 1981.

Fertilizer-N application		Fertilizer-N rate (kg N/ha)				
Source	Method of application	0	37	74	111	148
		Sorghum grain yield (kg/ha) - 1980				
Nil		3380				
Urea	Incorporated		3900	4420[a]	4910	4880
Urea	Broadcast		4480	4470[a]	4760	4860
Urea	Broadcast—split			4630		
	Band —split			4290		
Urea (DCD)	Incorporated			4420		
Urea	Broadcast			4470		
Sodium nitrate	Broadcast			4480[a]		
SE ± 180						
		Sorghum grain yield (kg/ha) - 1981				
Nil		2720				
Urea	Incorporated			4110[a]		
Urea	Broadcast			4260[a]		
Urea	Band—split		3610	5220[a]	5330	5310
SE ± 220						

a. Fertilizer nitrogen containing 10% atoms-XS ^{15}N was applied to these treatments over the whole plot in 1980 and to microplots located within the plots in 1981.

Table 7. Sorghum grain yields in ^{15}N balance experiments on an Alfisol at ICRISAT Center, 1980 and 1981[a].

Fertilizer-N application		Fertilizer-N rate (kg/ha)				
Source	Method of application	0	40	80	120	160
		Sorghum grain yield (kg/ha) - 1980				
Nil		5230				
Urea	Incorporated			6130		
Urea	Broadcast			6140		
Urea	Band—split			6580		
Urea (DCD)	Incorporated			5890[b]		
SE ± 180						
		Sorghum grain yield (kg/ha) - 1981				
Nil		1590				
Urea	Incorporated		3650	4660	5720	63-50
Urea	Broadcast			5450		
Urea	Band—split			6060		
Urea (SG)	Band			5240		
SE ± 380						

a. All treatments were located within microplots.
b. Fertilizer nitrogen applied to this treatment was not labelled; ^{15}N-labelled fertilizer applied to all others.

Table 8. Comparison of direct (isotopic) and indirect (apparent recovery) methods for estimating recovery of fertilizer urea by sorghum grown on an Alfisol during the 1980 rainy season at ICRISAT Center.

Application of fertilizer-N		Fertilizer-N recovery	
Rate (kg N/ha)	Method	Direct (%)	Indirect (%)
80	Incorporated	55.9±1.5[a]	47.8±3.8
80	Broadcast	56.3±1.3	43.8±6.0
80	Band—split	68.2±0.2	50.3±3.2

a. Standard errors of the particular mean values.

Directly-measured recoveries (by ^{15}N analyses) were substantially greater than the apparent recoveries (as estimated by the increase in total nitrogen content of the plant); this differential, which is not commonly obtained, indicates that the fertilizer nitrogen was taken up preferentially to native soil nitrogen. This preference was increased by the band split application made after emergence of the crop.

Placement. All four of our experiments have confirmed the clear superiority of the placement of fertilizer in bands, with the application split into two times after seeding. However, the interesting finding was that incorporation of urea into the surface soil after broadcasting was never superior to broadcasting alone; it was usually inferior. We had expected that broadcasting urea onto the surface of dry soils would produce losses because volatilization of ammonia could readily occur after the hydrolysis of urea to ammonium carbonate. However, the soil was dry when the urea was applied. There is little information available on the volatilization losses where urea is applied to the surface of dry soils, but our preliminary studies indicate that very little, if any, of the urea hydrolyzes when the soils are air-dry (6-8% moisture) and that ammonia volatilization losses may be sensibly negligible.

Placement and Interrow Spacing Interactions for Sorghum

Widening the distance between rows of cereals is a commonly used agronomic practice to minimize the effects of drought stress on yield. There is, however, very little data on the interactions between interrow distance, the application of nitrogen, and placement of nitrogen in bands. We conducted experiments on both an Alfisol and a Vertisol in 1980, with a constant population (100 000 plants/ha) at all spacings.

Greater interrow spacings usually resulted in markedly lower yields, and usually smaller responses to nitrogen (Table 9). The most marked effect of spacing occurred on the Alfisol; the narrow spacing of 45 cm gave a yield of 5360 kg grain/ha at 80 kg N/ha, whereas the yield was only 3840 kg grain/ha with the 135-cm spacing and the same nitrogen input. Row spacing caused least effect on the Vertisol nil-nitrogen plots, where yields were very low (approx. 1400 kg grain/ha). Recent work elsewhere has indicated that the need for narrower spacing increases with an increase in the yield potential, and that wide spacings are of benefit only when the potential yield is very low, perhaps less than 1000 kg/ha. Our results are in agreement with this finding, including the situation where high potential yield results from nitrogen fertilization. More detailed studies will be made over the next few years.

Placement of fertilizer in bands, rather than broadcast plus incorporation, consistently caused small increases in yield of about 200 kg grain/ha (Table 9). There was no interaction between interrow spacing and placement, indicating that the effects of spacing on yield were not due to accessibility of soil nitrogen to the plant, but rather to an environmental factor, such as poorer utilization of light or soil water, by the crop at greater spacings.

Fertilization of Millet in Millet/Groundnut Intercropping

We continued experiments for another year to obtain further information on the efficiency of

Table 9. Effect of interrow spacing and placement of nitrogen fertilizer on the grain yield of sorghum grown on an Alfisol and a Vertisol at ICRISAT Center in 1980.

Interrow spacing (cm)	Nitrogen application rate (kg N/ha)				
	0	40		80	
		Broadcast	Band	Broadcast	Band
	Sorghum grain yield (kg/ha) - Alfisol				
45	3590	4660	4760	5160	5360
90	3040	4260	4450	4630	4780
135	2720	3220	3460	3710	3840
SE ±			166		
CV (%)			9.0		
	Sorghum grain yield (kg/ha) - Vertisol				
45	1390	3170	3400	4050	4380
90	1350	2820	3090	3660	3910
135	1470	2840	2940	3430	3560
SE ±			100		
CV (%)			6.6		

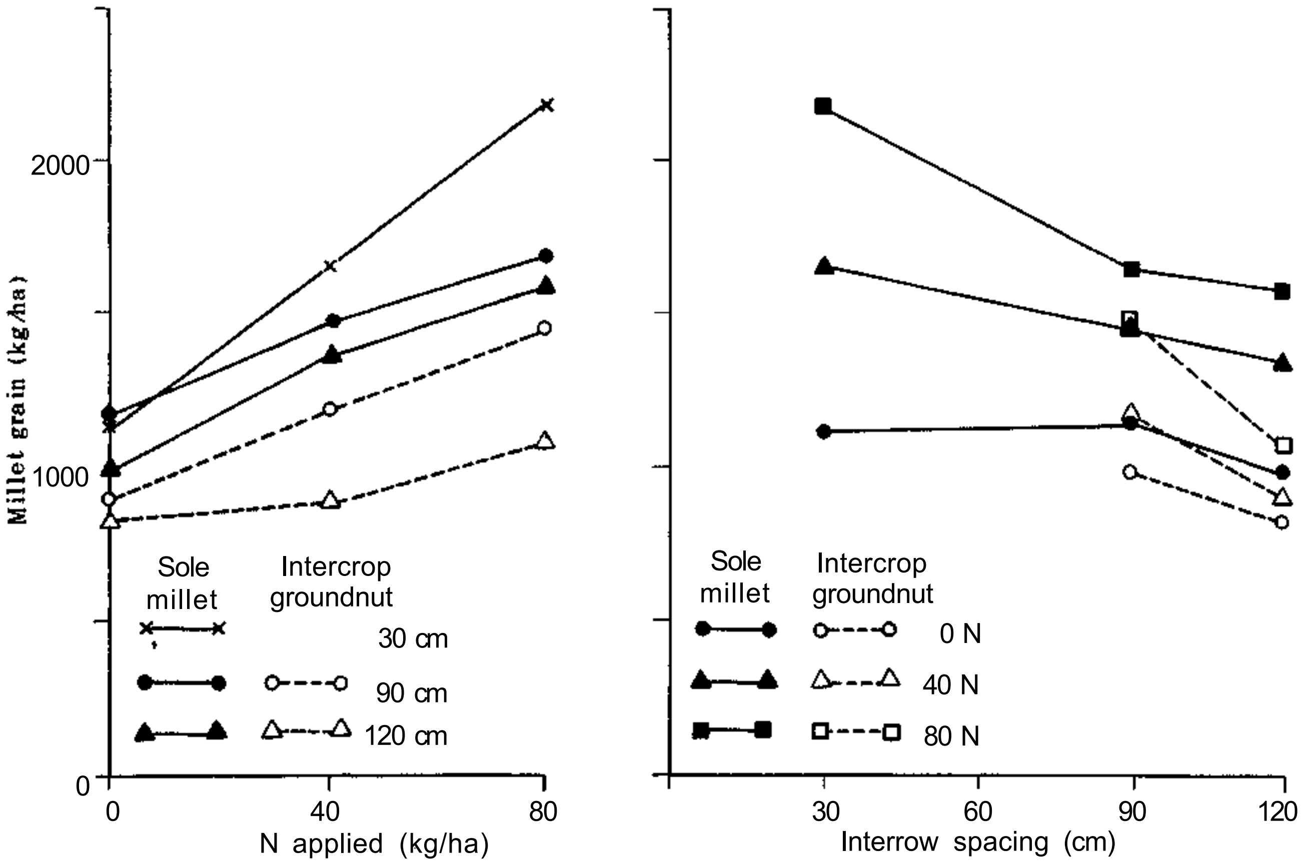


Figure 10. Effect of intercropping with groundnut and of different interrow spacings on the response of millet to fertilizer nitrogen.

fertilizer nitrogen on millet in an intercrop. Millet again responded well to fertilization (Fig. 10), with responses being approximately linear over the range examined (0-80 kg N/ha). But fertilization at the highest rate increased yield in the sole crop (by 1090 kg/ha) much more than in the 1:2 and 1:3 intercrops (increase of 550 and 270 kg/ha, respectively); it also depressed groundnut yield so that the overall advantage of intercropping diminished from a Land Equivalent Ratio (LER) of 1.40 at no nitrogen input to LERs of 1.20 and 1.00 at 40 and 80 kg fertilizer-N/ha (Table 10). Other experiments at ICRISAT Center have also shown a decrease in LER with increase in nitrogen fertilization, but the LER at high nitrogen inputs has usually been greater than unity; in the present experiment, groundnut production was affected in the final stages by the combination of drought stress and leaf diseases.

This year, we also investigated the causes of the decreased LER with increased fertilizer nitrogen in this intercropping system. The responses to fertilizer nitrogen were determined for millet spaced in rows at the same distance as in the 1:2 or 1:3 intercropping system, but both with and without the groundnut intercrop. Results show that the millet responses are substantially lower because of the wider spacing per se (that is, without the groundnut intercrop); addition of the groundnut intercrop further decreased yields. This effect of inter-row spacing is similar to that observed for sorghum; the greater the potential for yield, the greater the reduction in yield when inter-row spacing is increased.

Thus this experiment shows that the lower efficiency of fertilizer-nitrogen in the millet/groundnut intercrop was only partially due to competition between groundnut and millet; the wider spacing between millet rows was a major cause of the lower efficiency.

In two replicates of the experiment, the fertilizer nitrogen applied to the millet was labelled with ^{15}N. Samples are still being analyzed. The results will indicate the extent to which the groundnut rows adjacent to the millet absorbed the fertilizer applied to the millet.

Table 10. Effect of nitrogen fertilization of millet on the Land Equivalent Ratio (LER) of a millet/groundnut intercrop.

Planting pattern	Component	Fertilizer-N applied (kg/ha) 0	40	80
1:2 M:G	Millet	0.81	0.72	0.66
	Groundnut	0.54	0.49	0.36
	Total	1.35	1.21	1.02
1:3 M:G	Millet	0.74	0.54	0.50
	Groundnut	0.70	0.65	0.50
	Total	1 .44	1 .00	1.19

M = millet, G = groundnut.

Cultivation and Nitrogen

Improved cultivation systems may involve a deeper and more thorough disturbance of the soil, which would be expected to promote mineralization of soil organic matter and a greater supply of mineral nitrogen for crop uptake. Preliminary experiments were therefore undertaken on both an Alfisol and a Vertisol; the four treatments consisted of three cultivation intensities (tillage to 0, 5, and 10-cm depths) and the broadbed-and-furrow system. Increasing the intensity of cultivation caused small increases in grain yield and increased nitrogen uptake by the crop (Table 11). Although cultivation resulted in improved accessibility of soil nitrogen to the crop, further studies are needed to determine the mechanisms responsible.

Long-term Experiments

Two long-term experiments were begun in the past few years to provide data on long-term management practices for potassium and phosphorus fertilization. Results of the first full 4-year cycle on the phosphorus experiment were reported in ICRISAT Annual Report 1979/80,p 182; a major feature was the high efficiency of small rates of application of water-soluble phosphorus. This experiment is continuing.

Table 11. Effect of different cultivation systems on yield and uptake of nitrogen by cereals on a Vertisol and Alfisol at ICRISAT Center, 1980.

	Cultivation method					
	Zero	Shallow	Deep	BBF	SE ±	CV (%)
			Vertisol - Yield of sorghum (kg/ha)			
Grain	1820	2000	2090	2060	38	3.8
Straw	5880	6580	6910	6870	119	3.6
(G+S)	7700	8580	9000	8930	122	2.9
			Vertisol - Nitrogen uptake (kg/ha)			
Grain-N	18.5	21.2	23.4	22.5	0.72	6.7
Straw-N	40.5	46.7	54.2	54.1	2.19	9.0
(G+S)-N	59.0	67.9	77.6	76.6	2.41	6.8
			Alfisol - Yield of millet (kg/ha)			
Grain	790	970	1070	1040	41	8.4
Straw	2680	2910	2970	3290	166	11.2
(G+S)	3470	3880	4040	4330	172	8.7
			Alfisol - Nitrogen uptake (kg/ha)			
Grain-N	15.5	18.7	23.5	22.2	1.09	11.0
Straw-N	44.7	47.5	51.5	55.8	2.34	9.4
(G+S)-N	60.2	66.2	75.0	78.0	2.69	7.7

G = grain, S = straw.

Potassium. Our long-term potassium experiment, which has completed its first 2 years, will allow examination of the onset of potassium deficiency as the slowly available reserves in the soil are depleted by exploitive cropping. It will also allow determination of the effects of agronomic practices such as recycling of residues and addition of farmyard manure on delaying the onset of potassium deficiency.

In 1980, the 2nd year of the experiment, some treatments appeared to be marginally deficient in potassium. Treatments 7, 8, and 9 (added potassium) gave significant increases in groundnut pods and stalks and sorghum fodder (compared to treatment 3), but there were no consistent increases in the grain yields of sorghum, millet, or pigeonpea (Table 12). Obviously, the experiment needs to run for another few years for the expression of the effects due to potassium to become clear and distinct from any interseasonal variability due to seasonal weather.

Soil Characterization

Detailed characterization of the soils at ICRISAT Center and off-station sites received little attention until the past few years. A detailed soil survey of the site and surrounding areas is nearing completion by the National Bureau of Soil Survey and Land Use Planning. To complement this, in December 1980 we began a survey of the fertility status of the soils in all fields at ICRISAT Center. The purpose is twofold: to provide a broad inventory of soil characteristics to assist in selection of experimental sites, and to

Table 12. Grain and stalk yields in long-term potassium and residue management experiment at ICRISAT Center, 1980.

Treatment number	Nutrients applied (kg/ha) N	Nutrients applied (kg/ha) K	Other amendments	Sorghum Grain	Sorghum Stalk	Pigeonpea Grain	Pigeonpea Stalk	Millet Grain	Millet Stalk	Groundnut Grain	Groundnut Stalk
1	0	0		2780	1990	320	1170	810	1060	960	1610
2	60	0		3040	2620	310	1140	1060	1300	970	1610
3	120	0		3110	2930	250	1200	1250	1530	890	1510
4	120	0	Fodder returned	3260	3630	330	1090	1380	1890	880	1620
5	120	0	FYM(5 tonne /ha)	3980	3620	320	1570	1550	2060	860	1560
6	0	0	FYM(5 tonne/ha)	3320	3250	360	1670	980	1490	1090	1990
7	120	30		3260	3510	350	1400	1280	1720	880	1680
8	120	60		3240	3230	280	1710	1230	1870	990	1790
9	120	120		3140	3770	270	1180	1130	1700	1010	1840
SE ±				173	164	51	111	89	121	36	60

provide baseline measurements so that large changes in soil properties with time can be assessed.

This survey indicates that most of the low-fertility areas have very low available phosphorus. Over an appreciable area, including almost all of the black soil watersheds, the surface soil contains less than 2.5 ppm available phosphorus, whereas the level usually quoted for sufficiency is at least 10 ppm. The soil is alkaline in most fields; there is only a very small area (all Alfisol) in which the soil reaction is less than pH 6. The survey has defined better the belt of soils known to be marginally or moderately saline in the center and southwest parts of the Center.

We also determined the initial fertility status of the watershed at Taddanpally, used for our transfer of technology studies, by collecting composite samples from each farmer's plot. The soil was low in available phosphorus, with a mean concentration of 0.8 ppm in the surface soil (0-15 cm). The standard "soil-available-zinc" tests indicated that zinc availability was adequate; the average concentration being 2.7 ppm. However, during the 1981 rainy season, visual symptoms of zinc deficiency were particularly evident on maize and were occasionally seen on sorghum. Further investigation into methods for assessing zinc status of soils is merited.

Diagnostic and Predictive Tests

There has been an increasing demand within the Institute for diagnostic and predictive testing of soils and of plant tissue. We have given some attention to chlorosis of groundnut, which appears intermittently but with increasing frequency on Alfisols, and more commonly on the more alkaline Vertisols. The chlorosis appears to be due to iron deficiency. Tissue tests for diagnosing iron deficiency have not been satisfactory in the past, as they were based on the total iron content. It is common for the iron content to be higher in deficient plants than in iron-sufficient plants. However, the o-phenanthroline-extractable iron (an estimate of ferrous-iron) in young groundnut leaves appears to be a satisfactory index of iron deficiency; chlorotic leaves always contained less than 5.5 ppm extractable iron, and healthy leaves greater than 5.0 ppm.

Some preliminary data are emerging from the IFDC/ICRISAT joint project on the nitrogen content of sorghum leaves. By sampling individual leaves at a defined physiological age, e.g., heading, the leaf nitrogen content gives useful information for interpreting the nitrogen status of plants of various nitrogen treatments. We are continuing this work to evaluate the effects of interseasonal weather conditions.

Routine Analytical Laboratory

The purpose of the routine analytical laboratory located in the Soil Fertility and Chemistry subprogram, is to provide a service within the Institute for routine analyses of soil, plant, and water samples. In 1980, over 43 000 analyses were performed, a substantial increase over the 25 000 in each of the previous 2 years.

In addition to performing routine analyses, evaluations and modifications of existing methods are made, where appropriate. One example is the Bal modification to the Kjeldahl method for determining the total nitrogen content of soil. This modification, which was originally proposed from work on Indian soils by Bal in 1925, involves the soaking of subsamples of soil in water for a short period before starting the conventional digestion of the soil with sulfuric acid.

The need for this modification has been rarely reported, although its need for our local soils has been confirmed in two stages. Some years ago, we showed the need for this modification, which was then adopted for all routine analyses of soils in our laboratory. Recent detailed studies in the joint project with IFDC have confirmed the need for this modification, particularly for Vertisols.

Other efforts are directed at improving the output or accuracy of analyses. In one example, we required a method for rapid and accurate determinations of total soil nitrogen. The digestion of soil samples by acid is usually the limiting step, because of the long time required. We therefore examined the block digestor system, in which a large number of digestion tubes can be heated at one time. Alternative systems involve individual heating of each digestion tube or flask, which requires much more equipment and fume-hood space.

The procedure for the semimicro method used for the block digestor was similar to that used for our existing macrodigestion method, but with much smaller quantities. A subsample of finely ground soil (<80 mesh) is placed in a 75-ml tube, and digested (for 2 hr) after clearing with sulfuric acid and the usual amendments (K_2SO_4, $CuSO_4$, Se, and reduced iron). In contrast, the macrodigestion method involves use of 10-20 g soil, and 800-ml capacity digestion flasks.

The technique is simple, rapid, and accurate; values of total nitrogen determined on 31 soil samples were in very close agreement with the values obtained by the standard macro-Kjeldahl method (Table 13). We are able to handle a much larger number of samples (100/day)than with the existing macro-Kjeldahl system (24-30/day), and in a smaller area of digestion space.

Potassium is one of the most convenient elements to determine in plant tissue because it is not combined structurally with plant tissues. A substantial proportion can be leached out with water; the use of a salt solution is sufficient to remove all potassium in the plant. The common solution used is either ammonium acetate or a combination of ammonium and magnesium acetate. However, because other elements in plant tissue commonly need to be determined, it is quite usual for potassium to be determined in an acid digest that was prepared for the determination of either nitrogen or phosphorus. Comparison of the results of analyses of 19 dif-

Table 13. Comparison of total nitrogen content of soils determined using a standard macro and a semimicro-Kjeldahl digestion procedure.

	Vertisol	Alfisol
No. of samples	16	15
Mean total N content (%)		
Macro	0.069	0.061
Micro	0.068	0.061
Mean difference[a]	0.0013±0.00030	0.0003±0.00015

a. Mean of the differences for each sample.

ferent samples of pigeonpea herbage by three methods (conventional acid digestion, extraction with salt solutions, and extraction with 0.5 *N* hydrochloric acid) showed that all three methods gave the same mean value. The coefficient of variation for repeat analyses by the simple hydrochloric extraction method was 2.0%.

Land and Water Management

Land Management Studies on Vertisols

In the 1980/81 crop year we compared the broadbed-and-furrow (BBF) system of cultivation with the flat-on-grade system in field-size plots for the fifth consecutive crop year. The cropping system was maize followed by chickpea. The results obtained were generally in line with those of previous years.

The air-filled-porosity measurements made during late August and early September showed that the 0-15-cm layer in the raised bed zone of the BBF system was better aerated than the corresponding layer in the flat system (Fig. 11). The penetrometer observations during October showed that the penetration resistance was lower in the raised bed zone of the BBF system than in the flat plots (Fig. 12). Since the surface soil was dry at the time of chickpea planting, this lower penetration resistance of the BBF bed zone favored deeper seed placement in relatively moist subsoil, resulting in better crop emergence.

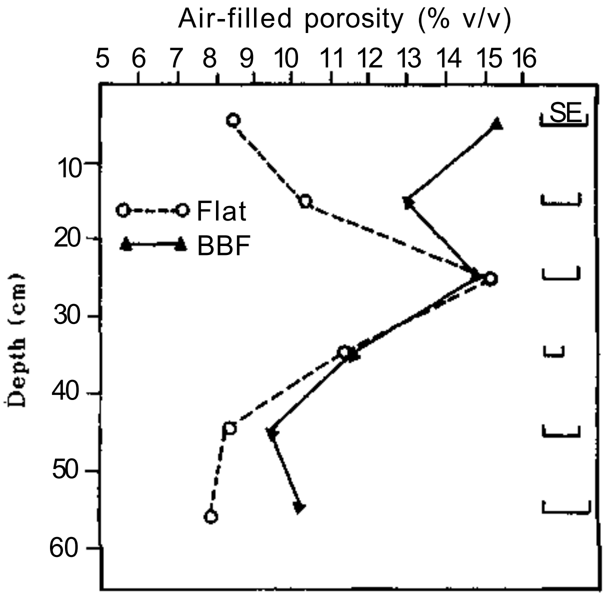


Figure 11. Air-filled porosity during high-moisture period on a Vertisol at ICRISAT Center, 1980/81.

Supplemental Irrigation through BBF Furrows

It has been observed that the application of limited water through furrows becomes difficult where substantial cracking has occurred.We conducted a study during the 1980/81 post-rainy season in a plot that had been under the BBF system for the previous 5 years to evaluate the efficiency of shallow cultivation in furrows to facilitate limited water application to chickpea. The treatments were:

T_1 —No supplemental irrigation (control).

T_2—Uncultivated furrows; one supplemental irrigation through furrows at the chickpea flowering stage.

T_3—Pre-irrigation shallow cultivation (with hand hoes) in furrows; one supplemental irrigation through furrows at the chickpea flowering stage.

We found that the rate of advance was substantially higher in cultivated furrows than in uncultivated furrows (Fig. 13). The study indicated that pre-irrigation cultivation in cracked furrows enhances irrigation efficiency and results in a considerable saving of water without causing any significant difference in chickpea grain yields.

Small-Scale Land Management Studies on Alfisols

We started small-scale studies on Alfisol management in 1979 to devise a land management

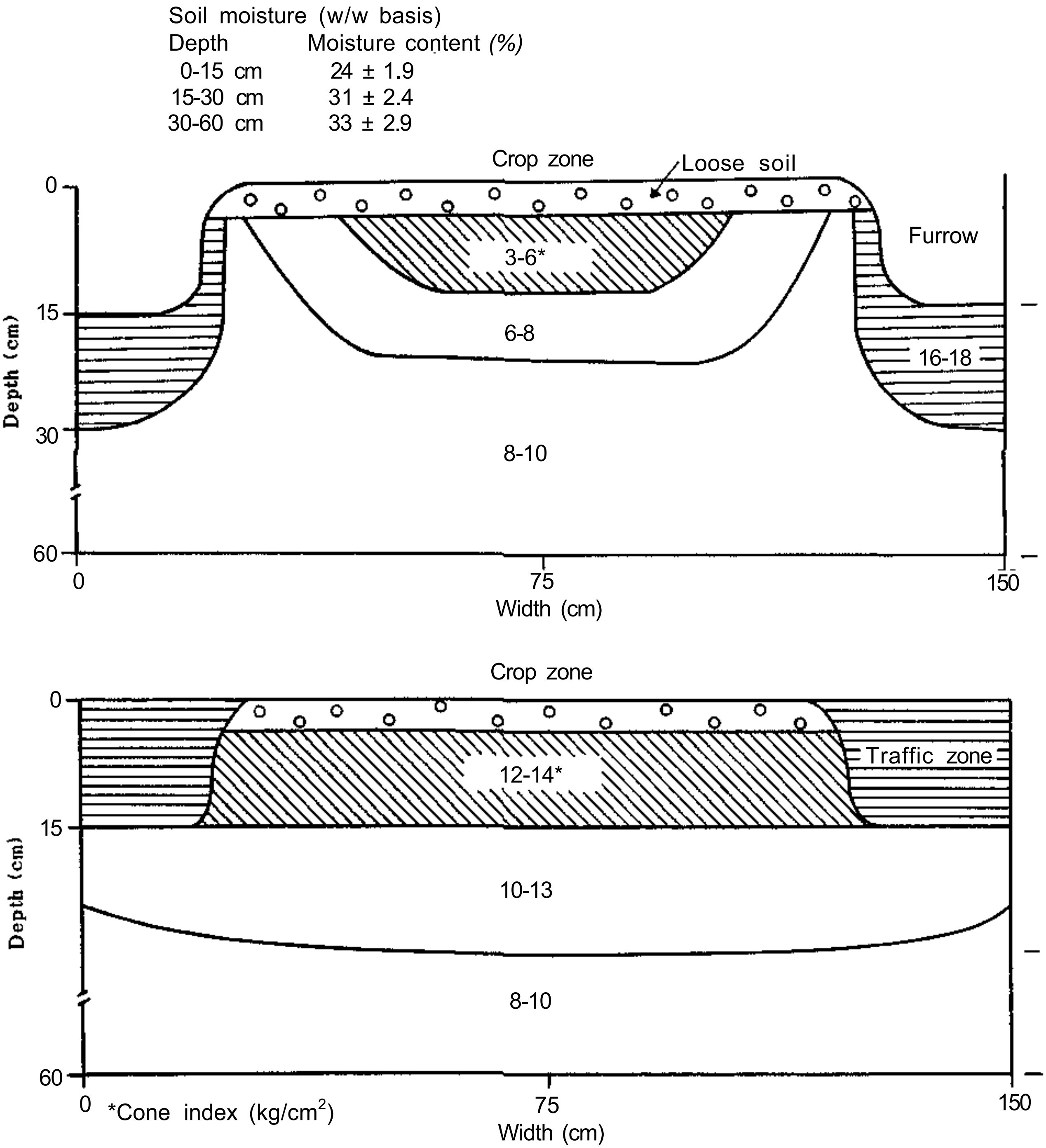


Figure 12. Penetration resistance zones under BBF and improved flat systems of cultivation on Vertisols at ICRISAT Center, 1980/81.

system that would make optimum use of available rainfall and soil resources. Following are some of our conclusions from more than 3 years of study:

The shallow depth of Alfisol profiles and their low water-retention capacity limit the amount of water that can be stored for crop growth. Moreover, the low stability of the topsoil promotes

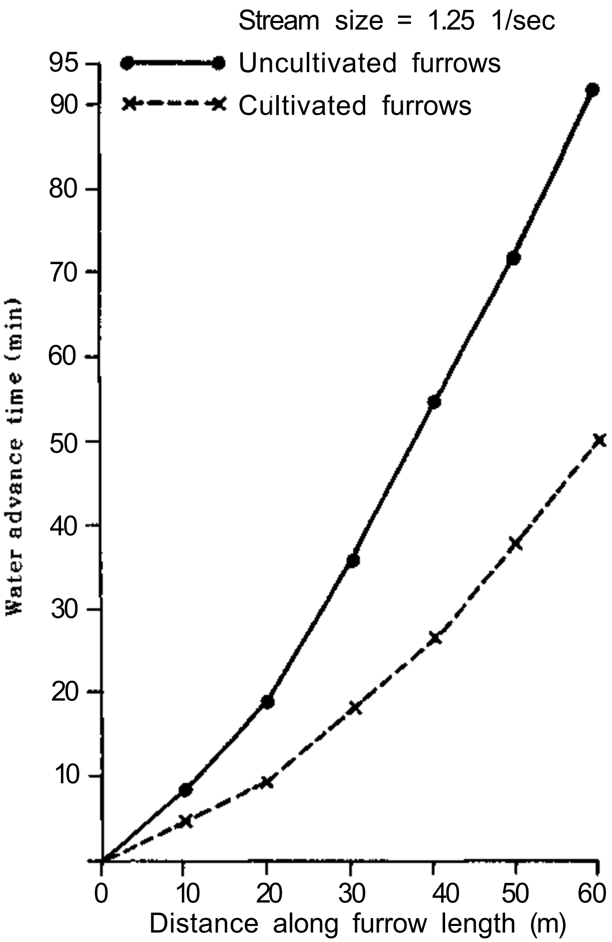


Figure 13. Effects of cultivation in furrows on water advance in a Vertisol at ICRISAT Center.

crust formation after wetting, which considerably reduces infiltration during storms. The B-horizon acts as another barrier to water intake in the soil profile.

During high-intensity rainstorms surface ponding occurs readily, followed quickly by runoff, as depression storage and surface detention tend to be low due to the unstable surface structure. As no preformed drainage paths are available in flat-cultivated fields, the uncontrolled water tends to runoff into natural depressions. Quantities and intensities of runoff can be high. Sheet erosion and rill erosion are very common in these fields, removing considerable topsoil from them.

Since on many occasions rainfall is greater than the profile retention capacity and rainfall intensities frequently exceed the infiltration rate, runoff cannot be avoided. Therefore, apart from techniques to minimize undesirable runoff, a field layout is needed to channel excess water safely to avoid extreme flow concentrations, high velocities, and consequent erosion. Simultaneously, this would enable the collection of runoff water for surface storage and later use. Short-term as well as long-term benefits are envisaged in this approach.

Influence of surface configuration. The aim of this study, run yearly since 1979, was to (1) influence the relationship between infiltration and runoff by manipulating the level of depression storage in the field, and (2) reduce runoff and soil transport by changing the flow patterns at field level.

Small runoff plots (10 m x 4.5 m) were constructed at two locations at ICRISAT Center. Five treatments with the same grade were chosen on the basis of the previous year's experience: (A) flat, (B) standard bed-and-furrow (BBF), (C) wave-type bed-and-furrow, (D) same as C, with tied furrows, (E) same as B, with intensive primary tillage.

During the course of this study in 1980, collected sediment of one replication in each location was analyzed for particle-size distribution per runoff event. The sediment load of the runoff water and rainfall and rainfall intensities were also measured.

The runoff rate from both the flat-cultivated plots (A) and the bedded plots (B) increased with increased rainfall amount. This was also true for increasing rainfall intensity. During moderate rainfall events lower runoff occurs from flat-cultivated plots than from bedded plots: due to the relatively high depression storage capacity in the flat-cultivated plots, part of the runoff water goes into the soil profile, while the compacted furrows of the bedded plots induce early runoff. A higher storm intensity or a longer rainfall duration reduces the relative importance of these initial effects, and runoff from flat-cultivated plots increases due to a reduced infiltration level in general.

A comparison of the soil loss from the standard beds (B) and wave-type beds (C) indicates a higher increase in soil loss in B than in C with increasing rainfall duration and intensity, which could be attributed to the higher flow velocities in the narrow furrows of treatment B.

Properties of eroded material. Finer particles (clay and silt), which can be transported in suspension, are eroded more easily than coarser particles. The coarser particles are dragged along with the streaming water and some of them may settle again wherever flow of velocity is reduced. Part of the more sandy material eroded from the crop environment may never reach the drainage outlet of a field or watershed.

The erosion index of the trapped sediment tends to become well below unity in the cropped plots some time after cultivation. A tillage operation that loosens the surface and enriches the topsoil with clay and silt from deeper layers increases the erosion of finer particles, which elevates the erosion index substantially.

If the soil particles taken along in suspended form are also included, the erosion index becomes much higher. In order to analyze this, we pooled the sediment of a number of water samples. Clay + silt percentages ranged from 60 to 90. Table 14 shows the values of the erosion index of the total soil loss from the runoff plots for a number of storms. These values always exceed unity, which indicates a higher outflow of fine particles. Immediately after cultivation these values tend to rise.

The erosion index increases towards the downstream stretches of the drainage system. Data collected previously for a 4-ha watershed indicate an erosion index of 23 based on the texture of sedimented material at the bottom of the runoff collection tank.

Medium-Scale Land Management Studies on Alfisols

Effects of energy levels of primary tillage. Earlier observations in tillage experiments executed by our Farm Power and Equipment subprogram clearly indicated superior crop performance under a system of intensive primary tillage than under the standard broadbed cultivation. Intensive tillage leaves the bed in a much looser condition. Since it was expected that this would influence the infiltration rate and runoff component, in 1980 we decided to run an unreplicated test to compare two levels of primary

Table 14. Erosion index[a] sediment per storm for two Alfisol locations at ICRISAT Center in the 1980 rainy season.

Location	Storm no.[b] and erosion index										
Watershed A	(7)	(8)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	
Trapped sediment	0.80	1.14	0.72	0.52	0.48		0.35	0.41	0.53	0.89	
Total sediment[c]							1.21	1.16	1.57	4.15	
Watershed B	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(14)	(15)	(16)	(18)
Trapped sediment	1.11	0.89	1.06	1.13	0.87	0.91	0.84	1.60	1.28	0.95	1.41
Total sediment[c]			4.54		1.85		1.35		2.11	2.43	5.04

a. Erosion index = $\frac{\text{(Clay + silt)}}{\text{(Sand + gravel)}}$ Sediment/$\frac{\text{(Clay + silt)}}{\text{(Sand + gravel)}}$ Topsoil

b. Numbers in parentheses are storm number in the season.

c. Includes suspended material in outflowing water.

tillage on a more appropriate scale, measuring differences in crop performance and runoff. The area in which these plots were located has been under permanent broadbed cultivation since 1978. One plot received the normal primary tillage treatment; in the other plot the "split-strip-plow" system was used. All other operations were the same for both treatments.

Table 15 gives the runoff and estimated soil-loss data based on hand-sampling of outflowing water during the runoff event.

A summary of the observations (Table 16) shows the superiority of the intensive system of primary tillage both in yield and bulk density. Although the difference in the quantity of soil loss may be due to an imperfect sampling

Table 15. Effects of level of primary tillage on runoff and soil loss in an unreplicated study on an Alfisol at ICRISAT Center.

		Levels of primary tillage			
		Split-strip plowed		Standard plowed	
Date of storm	Rainfall (mm)	Runoff (mm)	Soil loss (kg/ha)	Runoff (mm)	Soil loss (kg/ha)
July 30	23.6	1.1	13	1.2	8
Aug 14	16.4	2.2	5	3.1	6
19	114.8	0.5		0.8	
		21.6	137	26.6	118
20	72.6	3.4		4.1	
		13.8	172	17.7	87
Sept 3	22.5	1.1		1.2	
		0.3	3	0.3	4
6	31.1	4.4	6	5.2	9
24	14.7	0.3	ND	0.3	ND
Total		48.7	336	60.5	232

ND = Not recorded.

Table 16. Summary of observations on the effect of the intensity of primary tillage on soil moisture, bulk density, and pearl millet yield on an Alfisol at ICRISAT Center.

	Soil moisture at planting (%) DWB			Soil moisture at harvesting (%)					
Treatment	0-10 cm	10-20 cm	20.30 cm	0-10 cm	10-20 cm	20-30 cm	Bulk density (g/cm^3)	Plant height (cm)	Grain yield (kg/ha)
Split-strip plowed	5.2	6.6	11.6	0.4	2.3	7.8	1.48	142	1841
Standard plowed	3.5	5.9	9.8	0.4	1.7	7.3	1.55	133	1503
SE ±	0.22	0.37	0.91	0.06	0.30	0.85	0.017	2.3	105
CV (%)									16.62

method, there is a tendency for higher soil loss in the split-strip-plowed treatment, which may well be due to the looser soils.

Watershed Development in on-Farm Studies

Taddanpally village. An area of 15.42 ha was selected in Medak District for a 1981 rainy-season test and demonstration of the improved soil, water, and crop management technology developed at ICRISAT for the deep Vertisols. This is a cooperative project between ICAR, APAU, Andhra Pradesh State Department of Agriculture, ICRISAT, and the watershed farmers. ICRISAT provided the technical backup, while the Andhra Pradesh State Agriculture Department did the initial contour survey and supervised the construction of the main waterways. The 14 farmers involved used their own animals and labor for land development and subsequent operations.

On the basis of the contour map prepared in March 1981 and visual inspection, localized humps were scraped and depressions filled to create a uniform slope. Then the row direction was determined for each of the plots so that a furrow slope between 0.4% and 0.8% was available in most cases.

Field drains were constructed by the farmers as advised by ICRISAT to direct runoff from the fields. Three cutoff drains in the fields and two main waterways parallel to the road were constructed, so that excess water could flow off freely into natural channels. Figure 14 shows the watershed and adjoining area after full development.

The farmers laid out the broadbeds and furrows with the wheeled tool carrier and their own bullocks. Although the bullocks were not used to walking in straight rows, they learned quickly. Fertilizer application, planting, and intercultivation were carried out with the tool carrier.

The average time for layout and preparation of broadbeds was 16.4 tool carrier hours and 19.3 man hours per ha, while initial land smoothing needed 3.0 tool carrier hours and 6.1 man hours per ha. The construction of field drains, which is extremely important for proper surface drainage, required only 1.6 tool carrier hours and 1.8 man hours per ha. Only about 3 days total time was required to carry out all land development activities.

Hydrologic Modeling and Simulation

RUNMOD testing and verification. We used the parametric model RUNMOD for hydrologic modeling of the 1979 and 1980 rainy seasons. Additional data resulted in further refinements. Using the final version, the runoff from two Vertisol watersheds was also computed for previous years, and some minor differences were observed from earlier predictions. The results from 1974 to 1980 are summarized in Table 17.

We have now gained sufficient experience in modeling the ICRISAT Vertisol watersheds and will apply RUNMOD to our Alfisol watersheds. Later, hydrologic data will be obtained from small watersheds outside ICRISAT and tested with RUNMOD. With such extensive validation, it should be possible to predict runoff for any new location with accuracy and reliability.

Alternative Farming Systems

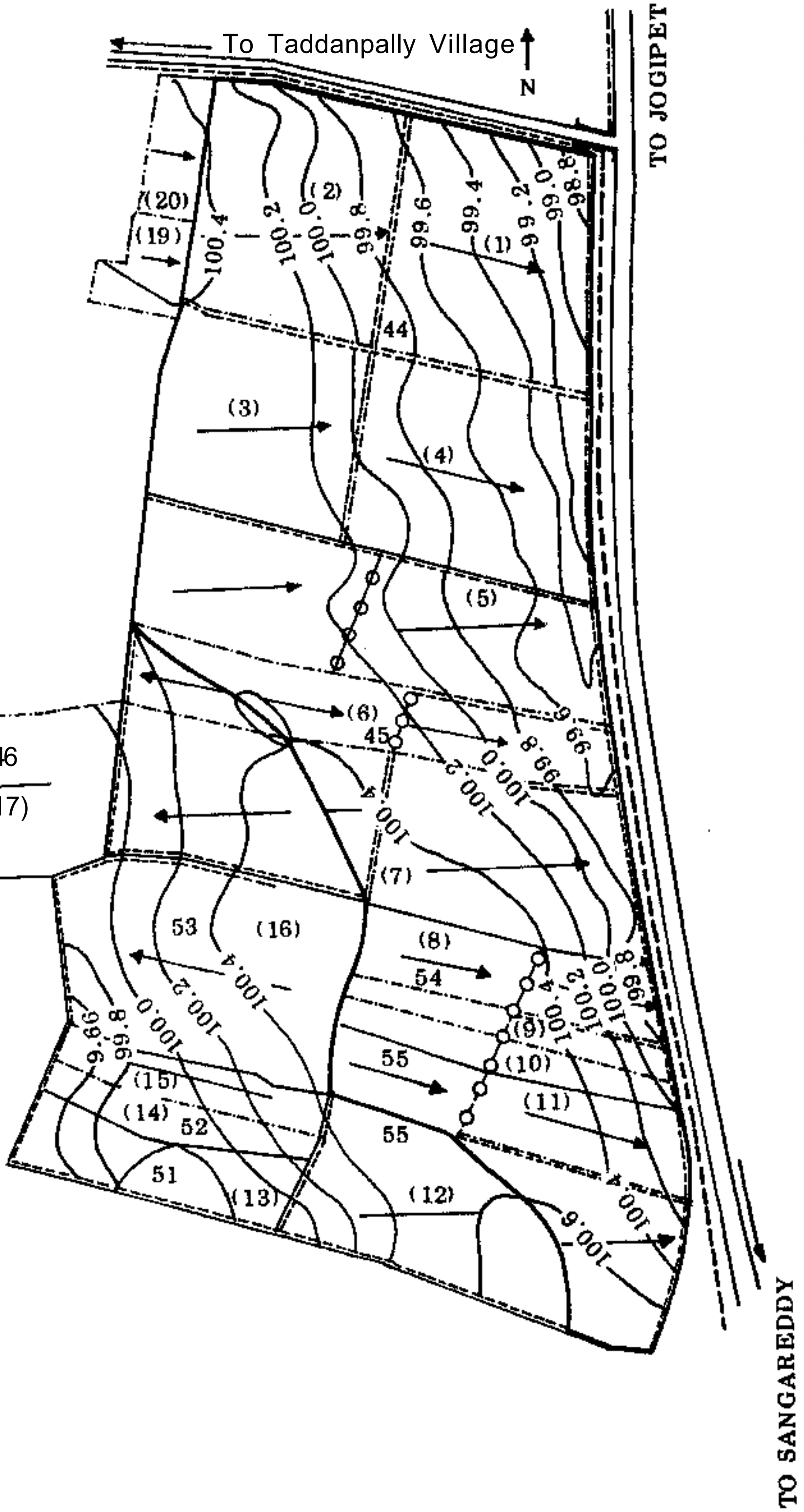
Crop yields and rainfall productivities. The ultimate objective of our watershed-based research is to determine how rainfall can be more effectively utilized. In the 1980/81 season we conducted experiments to determine the levels to which productivity can be increased when improved varieties and crop management (including farm equipment) are combined with land management techniques that promote in situ soil and moisture conservation with and without supplemental irrigation from collected runoff or locally available groundwater.

The yields, gross returns, and the rainfall productivities varied greatly among our main watershed treatments. Under rainfed conditions the crop values on deep Vertisols ranged from Rs 7938/ha for a sequential crop of maize and chickpea to which improved soil and crop

TADDANPALLY WATERSHED

Plot No.	Area (ha)
1	1.24
2	1.20
3	1.03
4	1.23
5	1.50
6	0.83
7	2.18
8	0.52
9	0.25
10	0.29
11	0.63
12	1.52
13	0.49
14	-
15	0.20
16	1.25
17	0.56
18	0.10
19	0.20
20	0.20

Total area = 15.42 ha



Watershed boundary
Field boundary
Field subdivision
44-45 Survey numbers
(1) to (2) Plot numbers
Direction of cultivation
Drain
Cutoff drain
Road
Culvert
100 Contour line

Figure 14. Development of Taddanpally Vertisol watershed, March 1981.

Table 17. Summary of RUNMOD performance (1974-80).

Watershed/year	Rainfall (mm)	Measured runoff (mm)	Computed runoff (mm)	Correlation coefficient
		With broadbed-and-furrow system		
1974	775.9	114.1	112.3	0.972
1975	964.9	156.7	155.4	0.998
1976	648.1	71.6	70.2	0.947
1977	523.5	0.0	0.0	
1978	1062.7	270.6	200.9	0.980
1979	610.1	72.9	78.6	0.992
1980	621.9	121.8	115.7	0.976
		With traditional flat with field bunds, rainy-season fallow		
1974	774.2	210.3	204.1	0.974
1975	966.5	249.7	280.6	0.984
1976	666.2	209.3	190.6	0.956
1977	515.6	52.0	50.5	0.880
1978	1053.6	409.2	405.3	0.987
1979	600.2	178.0	165.7	0.945
1980	595.2	163.5	176.2	0.986

management methods and optimum levels of chemical fertilizer were applied, to Rs 655/ha for sole postrainy-season sorghum grown with local common management and cultivation practices. These two systems attained a rainfall productivity of Rs 111 and Rs 95/cm water, respectively, per hectare. For Alfisols the crop values varied from Rs 3789 for pearl millet/ pigeonpea intercrop with improved practices to Rs 132 for sole sorghum with existing practices. The corresponding rainfall productivities were Rs 51 and Rs 1.80/cm water per hectare, respectively. The highest crop value of Rs 10 184 was obtained with a sequential crop of maize-chickpea in the Vertisel using all improved practices with one supplementary irrigation applied to the chickpea at flowering. The resulting rainfall productivity value was Rs 142/cm per ha.

Economic performance. We determined the net returns for the alternative farming systems by subtracting the production costs from gross returns (crop value/ ha). The production costs included the field operations of primary tillage, sowing, spraying, weeding, intercultivation, and harvesting and material inputs: seeds, fertilizer, insecticides and herbicides. For the deep Vertisols the highest net return Rs 5822/ha was obtained in the sequential crop of maize-chickpea with improved soil and crop management practices, and the lowest net return (Rs 313/ha) in the sole postrainy-season sorghum using traditional practices. For the Alfisols the net returns ranged from Rs 1715 on an intercrop of pearl millet and pigeonpea under flat cultivation with improved crop management practices, to a loss of Rs 250/ha for the traditional soil and crop management practices.

Collaborative Studies

Two cooperative research projects with ICAR through AICRPDA were 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. FS-1 was initiated at seven AICRPDA centers in 1977. Fourteen of the 23 AICRPDA Centre are now participating in FS-1 (Table 18).

General information of the experimental areas under FS-1 at different locations is presented in Table 19.

The results obtained so far in both FS-1 and FS-2 studies have shown some degree of location specificity. With the available research data it is still difficult to generalize results and work out improved land management practices for larger areas, largely due to temporal and spatial variation of conditions at various locations. However, some of the general results and broad indications emerging from the studies as reported by AICRPDA and ICRISAT scientists during the Annual Evaluation Working Group Meeting held from 17 to 19 March 1981 are:

1. The broadbed-and-furrow system performed better than other land treatments on medium to deep black soils (Vertisols) at ICRISAT Center, Indore (for pigeonpea), Akola (for cotton), and Bellary (for sorghum). However, the system was at par with the other land treatments for sorghum and maize at Indore.
2. Flat sowing-on-grade and ridging later at Hyderabad (for maize) and flat sowing as at ICRISAT Center have performed at par with, or better than the broadbed-and-furrow system under light-red soils (Alfisols) and short-duration light rains. However, under prolonged-duration light rains, the broadbed-and-furrow system yielded slightly better results (for crops like pigeonpea).
3. Under medium to shallow black soils (Vertic Inceptisols) as at ICRISAT Center, land treatments did not appear to influence performance of different crops.

Table 18. AICRPDA centers cooperating with ICRISAT in FS-1 studies.

Year initiated	Centers
1977	Akola, Bangalore, Bellary, Hyderabad, Indore, Ranchi, Sholapur
1978	Bijapur, Jodhpur, Jhansi, Rajkot
1979	Udaipur, Dhiansar, Varanasi

Table 19. General information of the experimental areas under FS-1 study at different AICRPDA Centers.

Location	Soil type	General land slope (%)	Experimental area (ha)	Normal annual rainfall (mm)
Indore	Deep black	1.3 - 1.5	3.20	990
Akola	Medium deep black	1 - 2	0.60	784
Jhansi	Medium black	0.7 - 1	0.74	936
Sholapur	Medium black	3	1.20	722
Rajkot	Medium black		1.20	700
Bellary	Medium black	1	0.94	608
Bijapur	Medium black	1	2.57	573
Ranchi	Deep red loam	1 - 2	2.80	1490
Bangalore	Deep red lateritic	2.5	7.00	825
Hyderabad	Shallow red loam	2.5	1.44	760
Dhiansar	Loamy sand		0.48	1180
Jodhpur	Loamy sand		0.18	380
Varanasi	Deep alluvial		0.32	1100
Udaipur	Clayey		0.40	680

4. Performance of pearl millet in the broad-bed-and-furrow system under light soils in the low-rainfall region of Jodhpur was considerably better than other land treatments studied.
5. There was no marked improvement in soil-profile moisture storage through imposition of land treatments. Further, there was less variation in soil moisture due to various land treatments than the variation in soil moisture over time during the crop period.
6. The broadbed-and-furrow system produced less runoff and soil loss on medium-deep to deep black soils at ICRISAT Center and the medium black soils at the AICRPDA stations at Sholapur and Akola. However, there was more runoff in the broadbed-and-furrow system at Jodhpur (loamy sand), Bangalore (red lateritic), Hyderabad (shallow red soils), and at ICRISAT Center (shallow red and black soils) than in the other systems studied.

Due to the seeming site specificity of the results, a more purposeful homogeneous grouping of centers with respect to soils, crops, and rainfall was suggested as necessary to facilitate analysis and interpretation of research results.

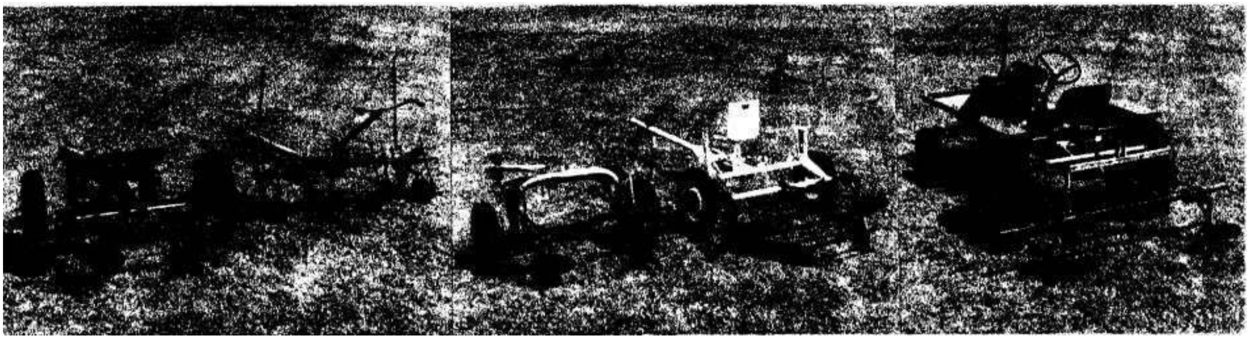
With respect to FS-2 studies, in particular, whose primary purpose is to generalize data on runoff collection and recycling and on operational-scale testing of farming system components, we hope that by 1982/83 the basic information on runoff quantity and rate will become available to determine the feasibility of runoff farming.

Farm Power and Equipment

Evaluation of Low-Cost Tool Carriers

Developed at ICRISAT to ensure the quality and timeliness of farm operations, the animal-drawn wheeled tool carrier, with attachments is an important component in our watershed-based improved farming systems. However, an economic analysis of the improved farming systems using the locally manufactured wheeled tool carriers reveals that many farmers in the SAT areas may not be able to afford the $ 1000 cost of this machine. Therefore, development and evaluation of low-cost tool carriers with comparable versatility is an important activity in this subprogram.

Five machinery systems — the Agribar, Akola cart, low horse-power (Bouyer) tractor, Nikart, and Tropicultor - were compared for their performance on a Vertisol watershed (BW3A) at ICRISAT Center. The Agribar and Akola cart are low-cost tool carriers. The Agribar is a simple T-frame with a beam to which the bullock yoke is attached and a toolbar similar to that used on the other tool carriers. Two small wheels at either end of the toolbar are used to transport the Agribar and also to provide depth adjustment. A lever at both ends of the toolbar is used to raise and lower the implement. The Akola cart was described in the 1978/79 ICRISAT Annual Report and the Nikart in the 1979/80 ICRISAT Annual Report. The tractor



Machinery systems developed at ICRISAT for broadbed-and-furrow cultivation. L to R: Akola cart, Agribar, Tropicultor, Nikart, low-power tractor.

was included because a few Indian SAT farmers own tractors, and other farmers have access to tractor hire services.

In the comparative performance experiment, maize was grown in the rainy season followed by chickpea in the postrainy season. The operations evaluated include plowing, cultivation, bed shaping, ridging, planting, fertilizer application, and interrow cultivation. Observations recorded for each operation include pull force required, operating time in each bed, and turning time. It was not possible to record the pull force for the tractor treatment due to lack of instrumentation.

The average pull required for various operations with the four tool carriers is presented in Table 20. Although there were significant differences between mean pull values for several operations with different tool carriers, there was no definite pattern to suggest that operations with one tool carrier consistently required more draft. The Akola cart had smaller attachments than those of the other tool carriers for plowing and bed shaping, resulting in low pull values for these operations.

Machine hours required per hectare for different operations by the five machinery systems are presented in Table 21. For all operations the tractor required the least time. The animal-drawn tool carriers did not show any significant difference in machine hours required to complete any given operation. It should be mentioned that the figures presented here are valid only for comparing the different types of tool carriers because the plot size in this study was small, and thus no stoppages, due either to human or machine factors, were included.

This study showed that the draft requirement for various operations does not depend upon the size or type of tool carriers. The type of implement attached, its size, and soil conditions are the determining factors. The field capacity of various animal-drawn tool carriers does not differ significantly in the broadbed-and-furrow system of cultivation.

Table 20. Average pull force required for various operations with four tool carriers (ICRISAT Center, 1980).

Operation	Tool carrier type				SE ±	CV (%)
	Akola cart	Agribar	Tropi-cultor	Nikart		
	kg					
Rainy season						
Plowing	180	210	227	206	10.7	10
Cultivation	180	156	131	181	7.2	9
Bed shaping	166	190	192	205	7.3	8
Planting	86	89	87	91	2.3	5
Interrow cultivation I	129	117	126	111	5.5	9
Interrow cultivation II	95	95	89	86	3.5	8
Postrainy season						
Cultivation	170	131	142	145	8.9	12
Ridging	121	125	147	87	5.3	9
Fertilizer application	94	ND	82	81	0.9	2
Planting	114	140	119	109	6.9	11

ND = Data not recorded.

Table 21. Machine hours required per hectare for different operations by five machinery systems (ICRISAT Center, 1980 rainy season).

Machinery system	Plowing & seedbed prep.	Sowing & fert. applic.	Interrow culti- vation	Total
		hr/ha		
Cart-based tool carrier	9.9	4.7	6.0	20.6
Agribar	9.4	2.2	5.5	17.1
Tropicultor	10.7	4.0	5.4	20.1
Tractor	8.4	1.9	4.7	15.0
Nikart	8.7	2.4	6.2	17.3
Mean	9.4	3.0	5.6	
SE ±	0.9	1.2	0.6	

Development of a Fertilizer Drill

Development of a suitable fertilizer metering unit for the wheeled tool carriers began 2 years ago (1978/79 ICRISAT Annual Report). The basic principle involved in the oscillatory metering mechanism, was described in the Farm Power and Equipment section of the 1979/80 Annual Report. During the year under report, we finalized the design of a four-row oscillatory fertilizer drill and used it as an attachment to the Tropicuitor and Nikart to apply a basal dose of ammonium phosphate and side dressing with urea on about a 100-ha area.

A schematic diagram of a four-row fertilizer drill mounted on a Nikart along with unit planters is given in Figure 15. The hopper holds 25 kg of fertilizer, thus requiring four fillings per hectare at a rate of 100 kg/ha.The mounting frame is fabricated from mild steel and has three supporting points on the Nikart. The two ends of this frame at the rear rest in the sockets built on the left and right wheel support legs to receive the cart frame. The mounting frame is held in position through an anchor clamped at the front end of the Nikart.

The power to drive the system is taken from the left wheel of the Nikart through friction contact of a drive wheel on the left tire. The drive wheel supplies power to a drive shaft that has a cam at the other end. The oscillatory motion to the concave is given through a connecting rod. The fertilizer application rate is varied by changing the position of the connecting rod on the concave arm. The concave arm has eight equidistant gradations for calibration of the fertilizer drill. Assuming a bullock walking speed of 1 m/sec, a cam speed of 90 rpm was found to be enough to give a uniform pattern of fertilizer drop along the row.

The oscillatory fertilizer drill was tested for uniformity of metering fertilizer among all four spouts at eight adjustment positions of the connecting rod. Data presented in Table 22 on mean discharge rate of ammonium phosphate show that in most applications the drill could be used at an adjustment between the second and fifth position, which offers a fair range. In adjustment positions 1 through 7 the CV values are generally well within the accepted range of ± 12.5%. At position 8 the fertilizer drill appears to be too sensitive to pick up differences in the discharge rates within the replications as well as between spouts.

The calculated SE values differ greatly among the spouts at any adjustment position. This was partially because spout no. 3 tended to give relatively higher discharge than the others. These variations can be minimized to a

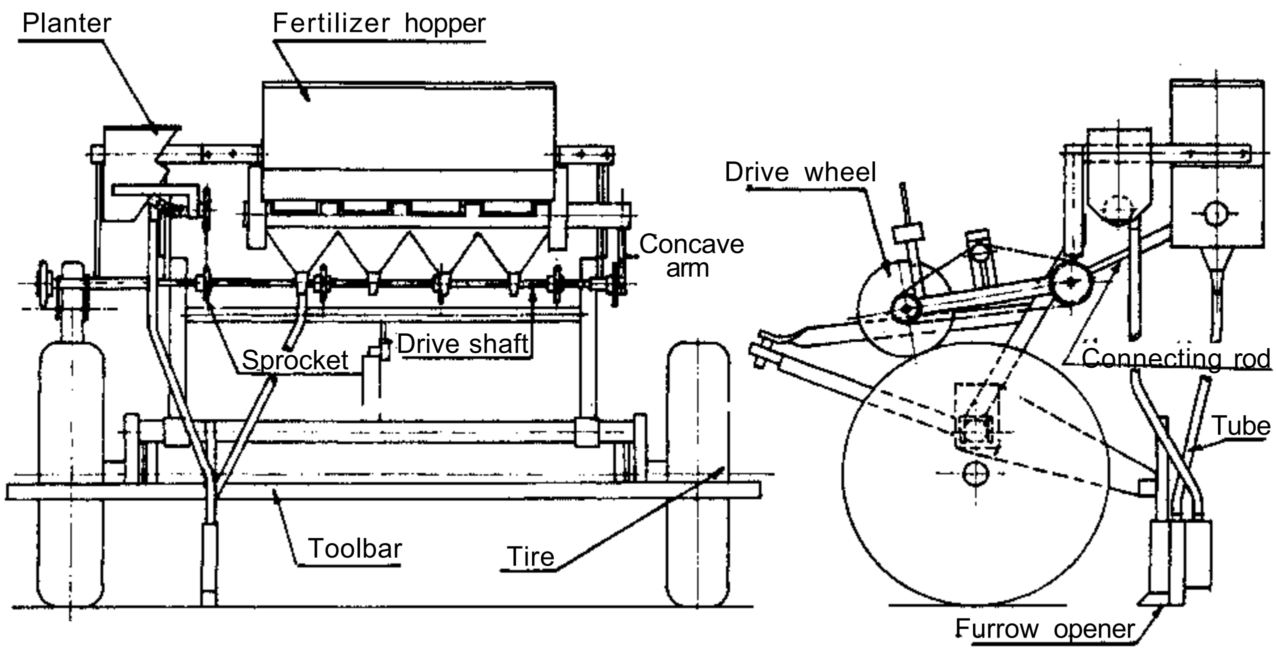


Figure 15. Planter with fertilizer drill mounted on the Nikart tool carrier.

great extent by improving the manufacturing quality. It has been observed that the position of the raker strip with respect to the concave is a major factor in determining the output of the fertilizer.

The actual relationship of the fertilizer discharge (Q) and the adjustment distance(x) is shown in Figure 16. It should be noted that while the design offers the facility of making a continuous adjustment for accuracy in setting, a slight error in the position of the connecting rod at the concave arm will cause wide differences in the application rate. This design appears to be very promising for metering ammonium phosphate, diammonium phosphate, and urea, and a manufacturer in Hyderabad, India, is making a limited number of prototypes for evaluation in the 1981 planting season.

Measurement and Evaluation of Seed Depth Variation

On the Alfisols, plant establishment of sorghum and pearl millet has not always been successful, and improper planting depth is suspected to be an important cause. Fertilizer and seed are placed through the furrow openers attached to the toolbar of the animal-drawn tool carrier, and the furrow openers are set to a required depth. However, once lowered into the working position the furrow openers remain in a fixed position relative to the wheels, which take over depth control. Thus, accuracy of the depth of seed placement in planting will largely depend on the uniformity of the bed height. A tillage experiment was conducted on an Alfisol field (RM16) to measure the effect of planting depth on plant establishment and to use the data to simulate plant establishment. Four primary tillage methods (described in the 1979/80 ICRISAT Annual Report) based on the broadbed-and-furrow system were evaluated. A spring tine harrow mounted between the two ridgers smoothed the soil and gave the seedbed its final shape, This provided a smoother, more uniformly shaped bed than the normal bed shaper. For each treatment an 80-m-long bed was planted. Continuous recording of the soil surface elevation at the press wheel was provided by a linear displacement meter actuated by the vertical movement of the press wheel as it followed the bed contour. The meter, essen-

Table 22. Mean discharge of ammonium phosphate (28-28-0) from four spouts of the oscillatory fertilizer drill at various adjustment positions for 10-m distance (ICRISAT Center, 1980).

Adjustment position no.	Distance, x (cm)	Spout no.	Mean discharge,Q (g)	SE±	cv (%)
1	.4.5.	1	143.0	3.0	6
		2	141.6	1.2	2
		3	174.7	3.0	5
		4	146.1	3.2	6
2	6.0	1	90.0	1.9	6
		2	79.1	1.7	6
		3	89.1	1.7	5
		4	73.2	0.9	4
3	7.5	1	57.1	1.5	7
		2	54.5	1.1	6
		3	58.7	1.1	5
		4	53.3	0.6	3
4	9.0	1	29.7	0.9	9
		2	36.1	0.9	7
		3	40.4	0.6	4
		4	30.4	0.8	7
5	10.5	1	20.0	0.9	12
		2	23.7	0.6	7
		3	32.0	0.8	7
		4	22.5	0.7	8
6	12.0	1	15.3	0.7	14
		2	18.9	0.5	8
		3	22.1	0.7	9
		4	16.9	0.7	12
7	13.5	1	11.4	0.4	10
		2	14.5	0.4	8
		3	16.7	1.0	16
		4	11.2	0.3	9
8	15.0	1	7.0	0.6	26
		2	10.8	0.3	10
		3	14.5	0.6	12
		4	7.8	1.3	48

tially a straight sliding potentiometer, was connected to a strip chart recorder.

Uniformity is expressed as the standard deviation of the average elevation from the same beds, but outside the experimental area a 3-m row of seedlings was excavated per treatment for verification of the actual seed depth.

Of the four sets of elevation data tested for normality and skewness, only one treatment deviated from normality, and in two cases there was noted skewness (Table 23). For planting depth accuracy, the percentages of seeds expected to fall within a specific depth interval around the mean were calculated and compared with the results obtained for direct measurements of excavated seedlings. A high degree of correlation was evident.

Seedlings excavated 14 days after planting showed large individual differences in development (expressed in dry weight of the above-

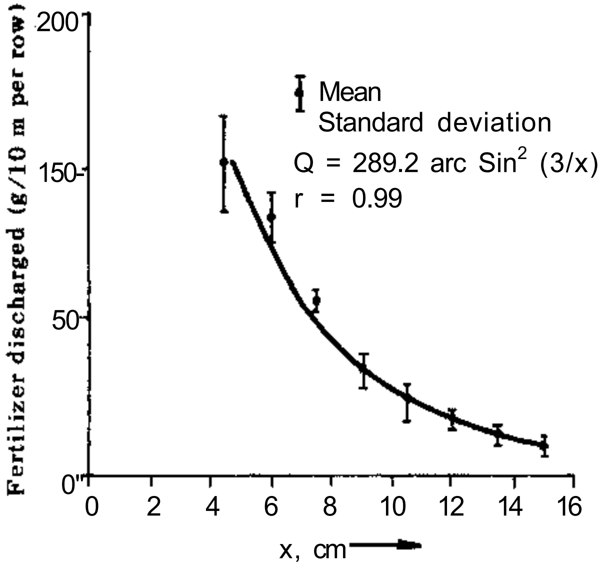


Figure 16. Ammonium phosphate discharge rate as affected by the adjustment position of the cam.

Table 23. Average depth, standard deviation, kurtosis, and skewness of elevation distribution data in seed-depth variation study at ICRISAT Center.

	Tillage method			
	T1	T2	T3	T4
Depth (cm)	6.7	4.1	3.7	4.0
SD (cm)	0.95	0.93	0.81	0.77
SE ±	0.036	0.037	0.033	0.028
Kurtosis	2.58	3.48[a]	3.02	2.75
Skewness	0.04	0.64[b]	0.48[b]	0.11
Number of readings	678	642	787	739

a. Departs from normality.
b. Significantly skewed.
T1 = Split-strip plowing.
T2 = Strip plowing.
T3 = Chiseling.
T4 = Cultivation with sweeps.

ground parts), which were significantly correlated with depth of planting, except for tillage treatment 1 (split-strip tillage).

Simulation. Assuming normality of the distribution of seed depths, the potential emergence was simulated by setting a planting depth (D) and assuming a standard deviation (σ). The probability of seeds falling within a chosen (small) interval starting at D + 3 σ was evaluated. The determined probability was multiplied by the average expected emergence over the interval. These two steps were repeated until the full (greater than 99%) range of planting depths was covered. In Figure 17a the layer-by-layer contribution to emergence and total

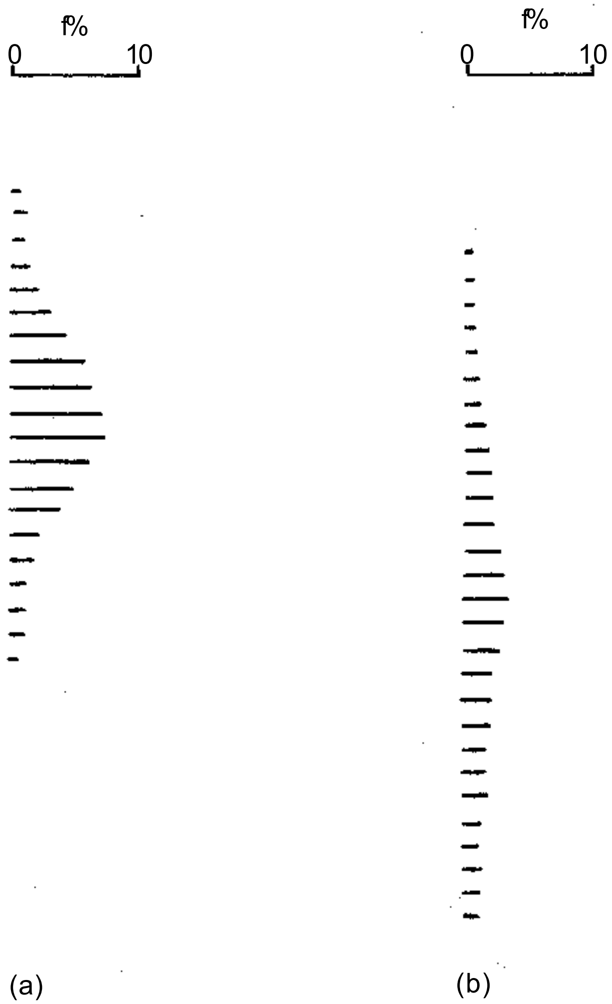


Figure 17. Frequency distribution of simulated plant emergence per 0.2-cm layer: a, planting depth 3 cm, σ= 0.7 cm, total emergence 66%; b, planting depth 5 cm, σ = 1.7 cm, total emergence 49%.

potential emergence are shown. An average planting depth of 3 cm and a standard deviation of 0.7 cm has been assumed. The maximum potential emergence would be 73% if all seeds were planted at 3 cm.

Figure 17b shows the possible planting pattern produced in a rough seedbed or with an incorrectly set planting depth of 5 cm, which could result in a prolonged emergence period with seedlings of various heights. Figure 18, on the effects of a range of planting depths and standard deviations on simulated emergence, shows the drop in total emergence when planting depth is not set accurately and when the expected standard deviation increases. It also becomes clear that the optimum seedling depth shifts as the standard deviation increases.

The seedbed preparation for this study deviated from ICRISAT's standard practice where a bed former shapes the bed by means of deflector boards that redistribute the soil over the bed. Soil and sometimes trash accumulate in front of the collector until the deflectors slip over them. Then the deflectors start accumulating the soil again, and the process is continuously repeated so that a wavy bed shape is formed in the direction of travel. This

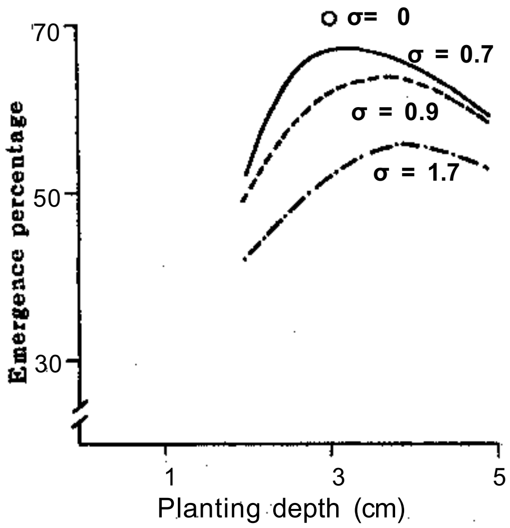


Figure 18. Effect of planting depth on simulated emergence for various assumed seedbed roughness indices.

results in uneven planting depths. The use of a rigidly fixed frame fitting with a spring tooth harrow used in this experiment produces more even soil distribution. No accumulation occurs when the depth is properly set, resulting in a uniform bed in the direction of travel.

Temporary Holding of Rainy-season Harvested Crops

The harvest of rainy-season crops occurs in the months of September and early October, a period of high rainfall probability. Harvest at this time also competes with land preparation and planting of postrainy-season crops. Therefore the farmer needs some means of temporary, safe storage of the harvested crops until they can be threshed.

The use of a natural ventilation system is practical for storing high-moisture maize ears in open cribs after harvest. Husked maize ears at about 20% moisture content can be stored safely in cribs for about 8 weeks even under quite humid conditions, provided the cribs are properly designed. We undertook a study to determine the suitable size of cribs under the weather conditions of Hyderabad and to determine the grain losses during storage between harvest and threshing.

Based on our results with cribs in 1978, we constructed two cribs each of three widths in 1979: 80, 100, 120 cm wide; 600 cm long; and 150 cm high, providing two replications of each size. They were installed perpendicular to the prevailing wind direction.

The cribs were fabricated in panels for easy installation, dismantling, and movement. The crib floor was about 60 cm above the ground so that the ground under the cribs could be kept free from weeds and rat attack could be prevented. One round crib (120-cm dia; 200 cm high) built in 1979 was also filled with maize ears. The sampling locations in these cribs were selected to form the matrices shown in Tables 24 and 25.

The cribs were filled in the 3rd week of September 1980 with maize ears with an initial grain moisture content of 32-35%. Before filling,

Table 24. Sample locations for rectangular cribs.

Crib width			Crib length	Cribheight
80 cm	100 cm	120 cm	600 cm	150 cm
24	30	36	180	45
56	70	84	180	45
24	30	36	420	45
56	70	84	420	45
24	30	36	180	105
56	70	84	180	105
24	30	36	420	105
56	70	84	420	105
21	26	37	300	75
58	74	89	300	75
40	50	60	154	75
40	50	60	446	75
40	50	60	300	39
40	50	60	300	116
40	50	60	300	75

Table 25. Sample locations for round crib (120-cm dia; 200-cm high) tested at ICRISAT Center in 1980.

Crib height (cm)	Sample location (cm)[a]		
30	0	30	60
60	0	30	60
90	0	30	60
120	0	30	60

a. The sampling location is the depth measured from outer surface of the crib to the center of the crib.

the ears were sorted to remove immature, high-moisture, damaged, and unhusked ones. The ears were retained in the cribs till June 1981 to observe the effect of insect attack and change in moisture content, color, and germination percentage. The total quantity of ears stored in the cribs was about 30 tonnes.

Grain samples weighing about 250 g were drawn from each sampling location in the cribs by a sampling probe. Samples were drawn twice a week until the moisture stabilized, after which samples were drawn once a month. The moisture variation in the maize grains is shown in Figure 19. There was no significant difference in moisture content between different locations in the same crib. Similarly the moisture content did not vary significantly with the width of the crib. The moisture content of the stored ears decreased rapidly during the first 60-65 days of storage from 35% to 12%, and then remained constant for the remaining period. The variation in moisture content with duration of storage is significant at the 5% level and was not affected by the intermittent rains during the storage period. The grain moisture content of the stored ears between replications was not significant at the 5% level. It was observed that the moisture content of all the rectangular cribs gave the same pattern of variation with respect to the date of storage after filling.

The quantitative loss due to insect infestation in the grains was calculated by counting the total number of grains and the numbers infested in 50-g samples taken at two locations in each crib at 15-day intervals. The data on insect infestation intensity in the stored ears showed that the maximum insect infestation of 2.5% was observed at the outer surface of the widest rectangular crib (120 cm) after 234 days, while the ears at the center had 1.5% infestation. The ears in the round crib had the least insect infestation at the center as well as at the outer surface of the crib, probably due to good ventilation through the crib.

Data on the effect of storage duration on the percent germination of maize grains showed that those from the surface of the crib decreased faster than those from the center in all the cribs, which may be due to cracking of the exposed grains and possibly heat curing of the inside grains. The average variation in grain germination at the center was between 86 and 90%, while for the outer surface it ranged between 68 and 90%.

It is clear from the results that maize ears can be stored safely for short periods in the 100-cm-wide rectangular cribs. The ears can be stored

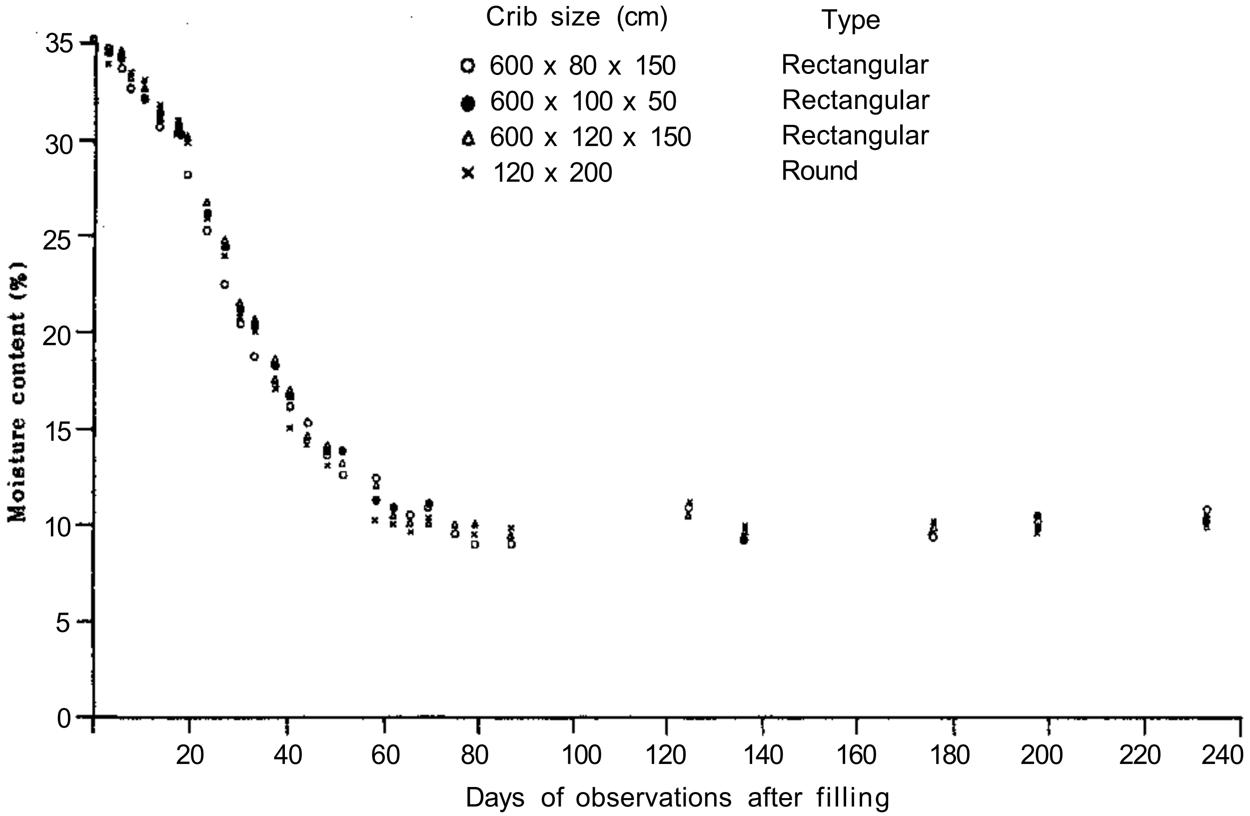


Figure 19. Moisture variation in maize grain on ears under temporary storage in cribs at ICRISAT Center, 1980.

in the 120-cm-diameter round cribs with virtually no damage, but they have the disadvantage of limited capacity.

Cropping Systems

Because of the special importance of intercropping to the poorer farmers of the SAT, our main objective continued to be the development of a better understanding of this system. During 1980/81 our crop physiological studies in intercropping focused on the low-fertility and low-moisture conditions typical of many SAT farms, but work continued on effects of plant population, genotypes, yield stability, and legumes. There has also been an important step forward in developing disease studies in cooperation with pathologists in ICRISAT's crop improvement programs. We continued our work on identifying a wider range of promising systems for both Vertisols and Alfisols.

Effects of Nutrient and Moisture Stress in Intercropping

Nutrients. In 1979 we reported in detail the effects of high or low nitrogen applied to millet in millet/groundnut intercropping at 1:1 and 1:3 row arrangements. These treatments were continued in 1980 as part of a larger experiment, but unfortunately the inherent fertility of the experimental site resulted in only small responses to applied fertilizer. However, growth of the crops was very good, and the experiment afforded a particularly good example of the competitive and complementary effects that can occur between these two crops.

At high fertility (100 kg/ha N and 50 kg/ha P_2O_5 to millet and 50 kg/ha P_2O_5 to groundnut) sole millet yielded 7680 kg/ha dry matter and

2280 kg/ha grain, and sole groundnut yielded 3680 kg/ha dry matter and 2100 kg/ha pods. In the intercrops the greater competitive ability of millet resulted in a marked increase in yield per plant compared with the sole crop (Fig. 20); final yield per plant approximately doubled in the 1:1 row arrangement and approximately tripled in the 1:3 row arrangement. In contrast, the poorer competitive ability of the groundnut resulted in decreased yields per plant during the period of peak millet growth, especially in the 1:1 row arrangement where millet competition was more severe. As the millet neared maturity, and then after millet harvest, the groundnut was able to compensate, and final yield advantages of intercropping for seed and pod yields (as calculated by a land equivalent ratio — LER) were 36% and 28% for the 1:1 and 1:3 row arrangements, respectively. These are in line with the advantages we quoted earlier for this combination, and they represent very worthwhile increases at good yield levels.

Moisture. In 1981 a summer experiment using a line-source sprinkler technique confirmed that with intercropping combinations based on sorghum, millet, and groundnut, relative yield advantages increased with increase in moisture stress. Advantages in the stress situations were not so high as in the previously reported 1980 experiment, however, probably because some rainfall and cloudy weather between 60 and 80 days after sowing reduced the degree of stress.

Considering the treatments across the line source from "no stress" to "maximum stress," and using the same curve-fitting technique as presented last year, we found that the combinations of 1 row sorghum: 2 rows groundnut and 1 row sorghum: 3 rows groundnut gave yield advantages increasing from 17 to 58% and 10 to

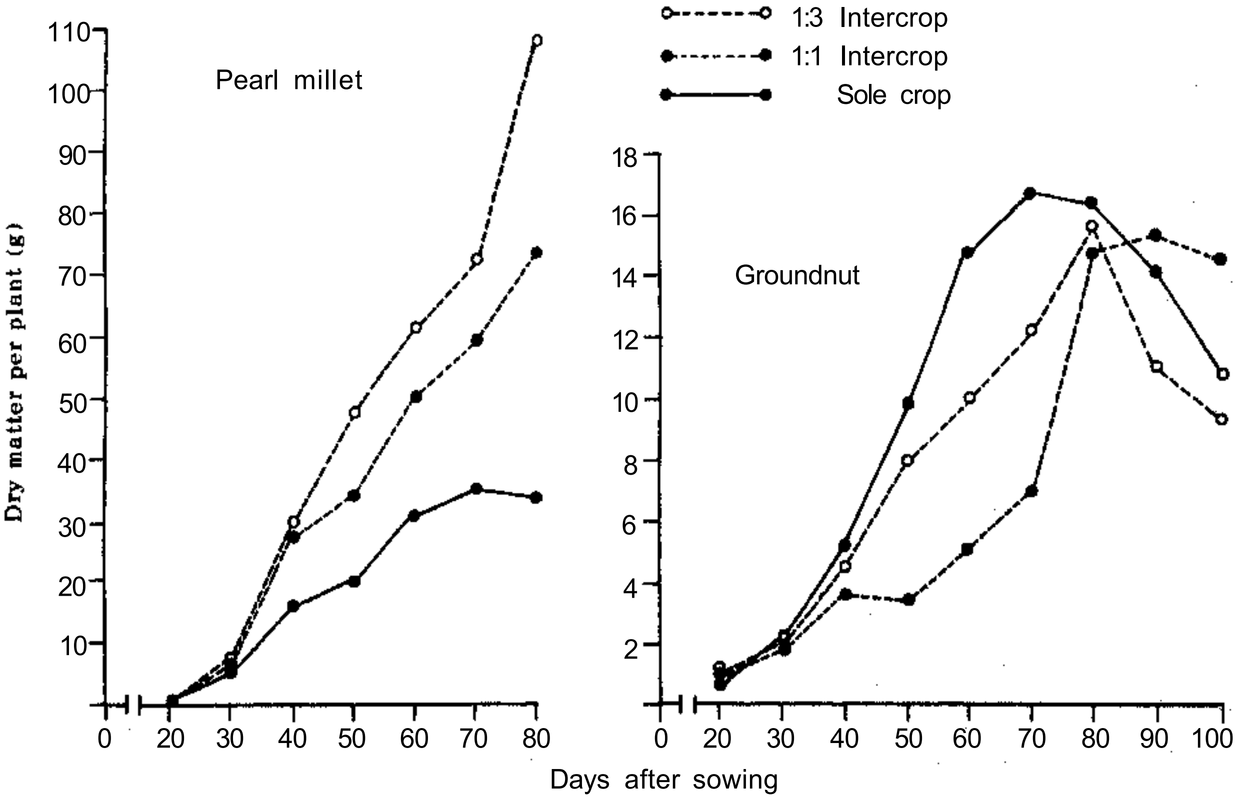


Figure 20. Dry weight per plant of sole and intercropped pearl millet and groundnut at ICRISAT Center in the 1980 rainy season.

45%, respectively. Similarly, the advantages with 1 row sorghum: 1 row millet increased from 10 to 33%, The effects with millet/ groundnut were less pronounced: the 1:1 and 1:2 row arrangements gave increases from 0 to 28% and 21 to 32%, respectively, but 1:3 row arrangement gave its maximum advantage under "no stress" and then slightly decreasing advantages with increasing stress. These data will be presented and discussed in more detail following further experiments in this series.

Nitrogen x water interactions. As outlined above, we have obtained good evidence that intercropping may be particularly beneficial where there is stress for nitrogen or moisture. An important advance this year was to bring these two factors together in a summer experiment so the interaction between them could be examined. An intercrop of 1 row millet: 3 rows groundnut was compared with sole crops on a shallow to medium Alfisol where a low-fertility situation was ensured by growing a previous crop of unfertilized maize. Nitrogen levels were 0 and 100 kg/ha N (applied only to millet), and these were factorially combined with two moisture levels, stress (irrigation every 20 days), and no stress (irrigation every 10 days).

Growth patterns are clearly discernible from the light interception data (Figs. 21a, b, c, d). With stress for both nitrogen and moisture (Fig.21a), the sole crops growth was very slow initially, particularly the millet. A routine irrigation at 63 days, and an unexpected 78 mm of

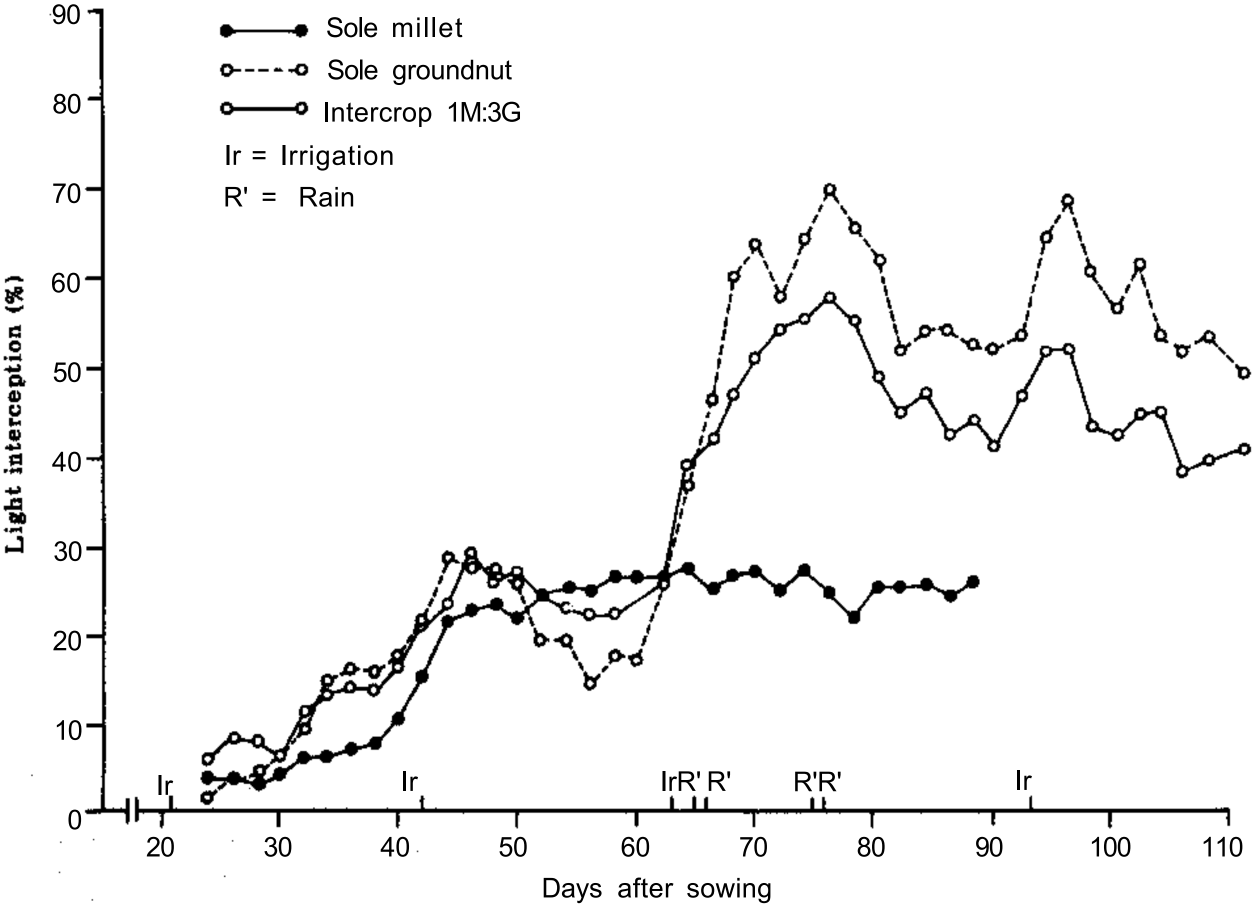


Figure 21a. Light interception by sole crops and intercrop of pearl millet and groundnut under moisture stress and nitrogen stress.

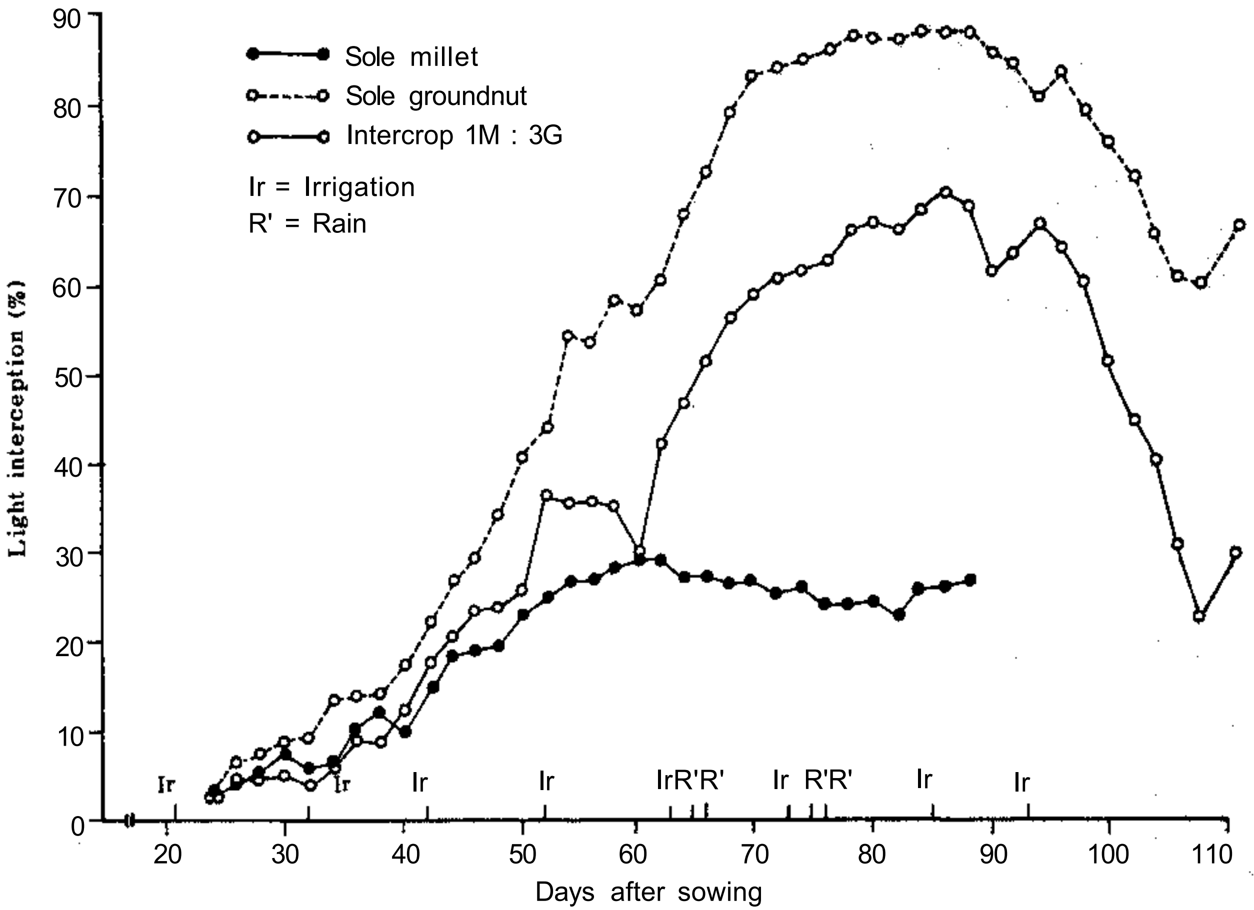


Figure 21b. Light interception by sole crops and intercrop of pearl millet and groundnut under nitrogen stress.

rainfall in the next few days, produced a rapid response in the groundnut but not in the millet, presumably because the millet had already passed its maximum leaf-area index and period of leaf expansion. The rainfall probably increased final yields of both crops, however, because these were higher than anticipated after the initial severe stress. Sole millet yielded 2138(±29) kg/ha dry matter and 939 (±16) kg/ha grain, while sole groundnut yielded 2351 (±32) kg/ha dry matter and 763(±29) kg/ha pods (Fig. 22).

Relieving moisture stress but not nitrogen stress produced a marked increase in light interception (Fig. 21b) and yield (Fig. 22) in groundnut but, very surprisingly, it produced only small responses in millet. In contrast, relieving nitrogen stress but not moisture stress gave substantial responses in both light interception (Fig. 21c) and yield (Fig. 22) of millet. Thus, although the groundnut was limited by moisture availability, the millet was mainly limited by nitrogen availability. As expected, however, when both nitrogen stress and moisture stress were relieved on the millet its light interception was even greater (Fig. 21d) and there was a strong positive interaction on final yield (Fig. 22).

Light- and water-use efficiencies were examined in terms of the amount of dry matter produced per unit of light intercepted or per unit of water transpired. Where there was stress for nitrogen and/or water, the light-use efficiency was 23-31% higher in intercropping than sole cropping and the water-use efficiency was 20-27% higher. Where there was no stress, light-use efficiency was only 12% higher and water-use efficiency only 14% higher. This supports earlier indications that this combination is more likely

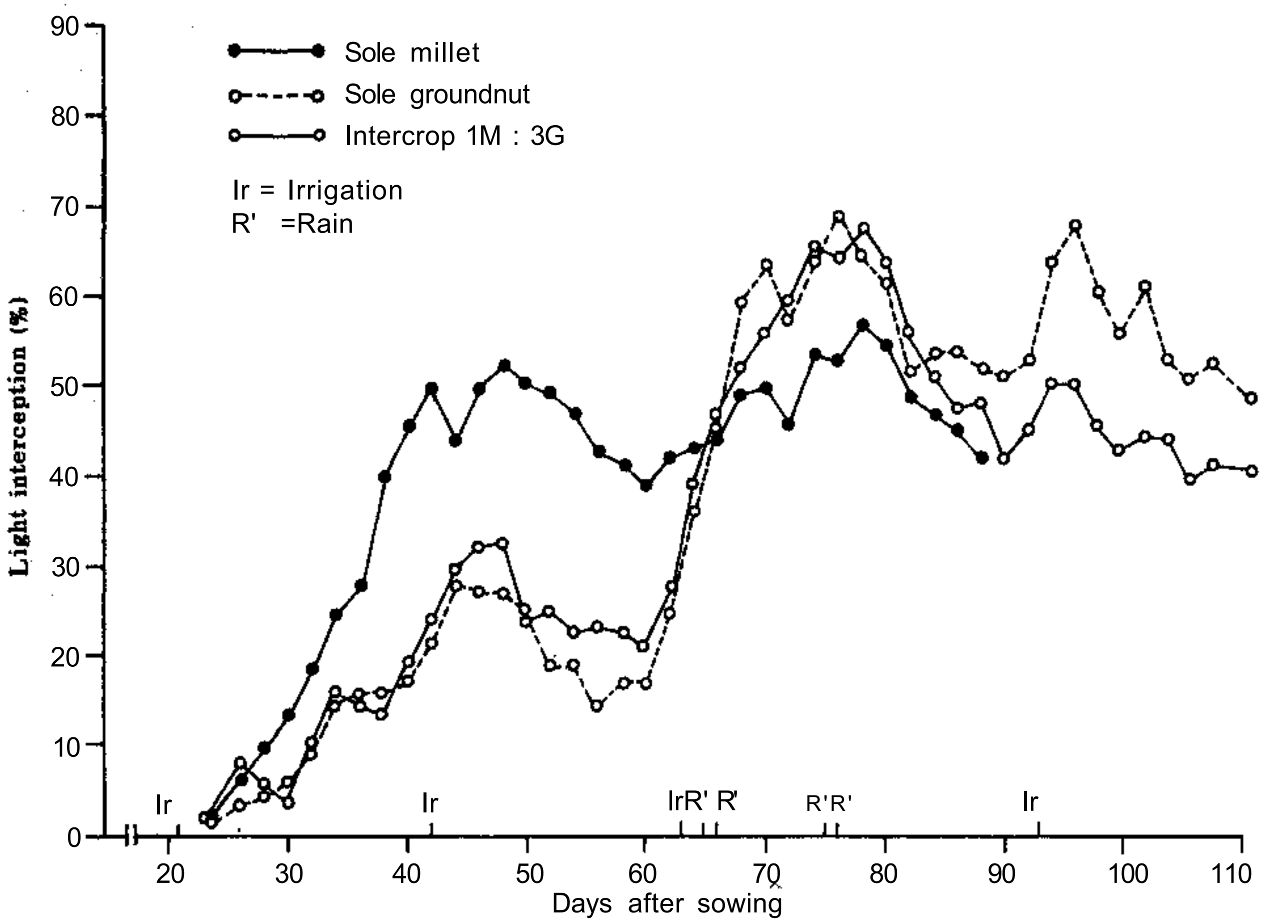


Figure 21c. Light interception by sole crops and intercrop of pearl millet and groudnut under moisture stress.

to give improved resource use, and is thus more likely to produce higher yields, when resources are limiting.

Plant Population in Intercropping

Sorghum/pigeonpea. This year we carried out a third and final experiment to determine the optimum row arrangement and the optimum pigeonpea population for the 150-cm broadbeds on the Vertisols. Row arrangements were the standard 2 sorghum: 1 pigeonpea on 45-cm rows with pigeonpea in the middle of the bed (SPS), and 2 sorghum: 2 pigeonpea on 30-cm rows with either sorghum on the outside of the bed (SPPS) or pigeonpea on the outside of the bed (PSSP)-these last two arrangements differ in practice because of the 60-cm gap between outside rows of adjacent beds. There were five pigeonpea populations ranging from 15 000 to 130 000 plants/ha. Findings have been consistent over the past 3 years and the mean effects are given in Figure 23.

With all row arrangements there was a consistent pigeonpea yield response to increase in pigeonpea population, though this was small above the 40 000 or 70 000 plants/ ha treatments and it was largely offset by a decrease in sorghum yield. A similar compensation between the crops occurred in the row arrangement treatments where the SPPS and PSSP treatments gave higher pigeonpea yield but lower sorghum yield than the standard SPS arrangement. Because of these compensatory effects there was little difference in gross returns between treatments. Maximum gross return was from the SPPS arrangement (Rs 8042/ha), but this was only a little higher than the maximum from the PSSP

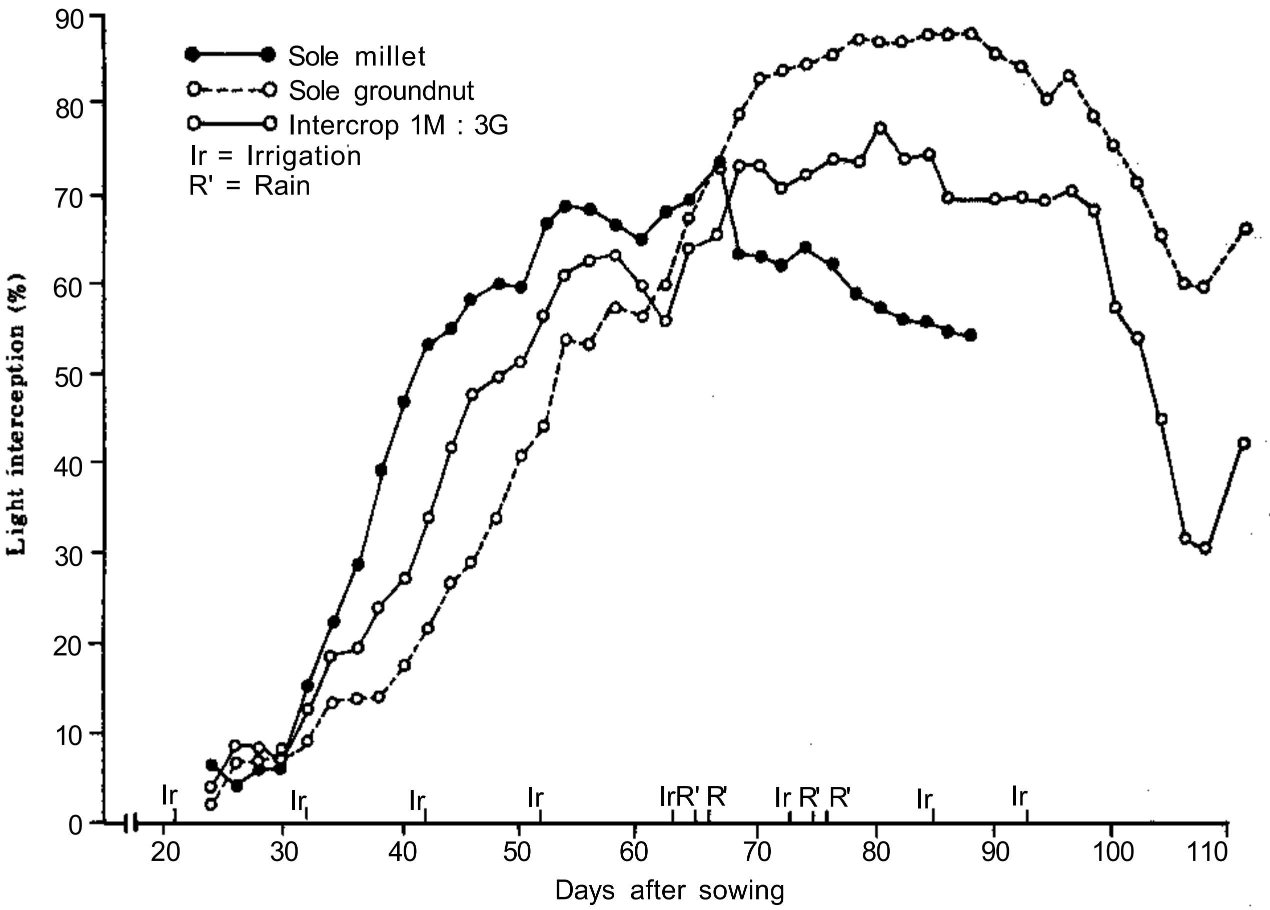


Figure 21d. Light interception by sole crops and intercrop of pearl millet and groundnut under no stress.

arrangement (Rs 7742/ha) or the standard SPS arrangement (Rs 7553/ha). In view of the increased difficulties with interrow cultivations on the 30-cm row arrangements, the standard SPS arrangement is probably the best practical compromise. In confirmation of earlier studies, the results indicate that the pigeonpea population should be at least equivalent to the sole crop optimum of 40 000 plants/ha.

As part of a multilocation trial organized with the All India Coordinated Sorghum Improvement Project, we conducted an experiment this year to determine whether population response in intercropping differed with pigeonpea genotype on a deep Vertisol. The experiment will run for 2 years, so the first year's results are presented very briefly. Pigeonpea genotypes HY3A (compact, harvested at 202 days), BDN-1 (bushy, 178 days), and C-11 (spreading, 188 days) were intercropped with CSH-6 sorghum (108 days). Sorghum yield was good in the sole crop (4181 kg/ha), and only a little less in intercropping with HY3A (94% of sole crop) or C-11 (92%), but it experienced rather more competition from the bushy and early-spreading BDN-1 (87%). Changes in pigeonpea population had no effect on sorghum yield.

The compact HY3A gave a poor yield in sole crop (398 kg/ha) and a poor intercrop performance (249 kg/ha, or 61% of sole crop). The bushy BDN-1 and the spreading C-I 1 gave much better and very similar sole crop yields (1029 and 1030 kg/ha, respectively), but C-11 gave much better intercrop performance (849 kg/ha, or 82% of sole crop) than BDN-1 (704 kg/ha, or 68% of Sole crop). These genotype responses confirm earlier indications that a spreading genotype like C-11 is better adapted to intercropping with

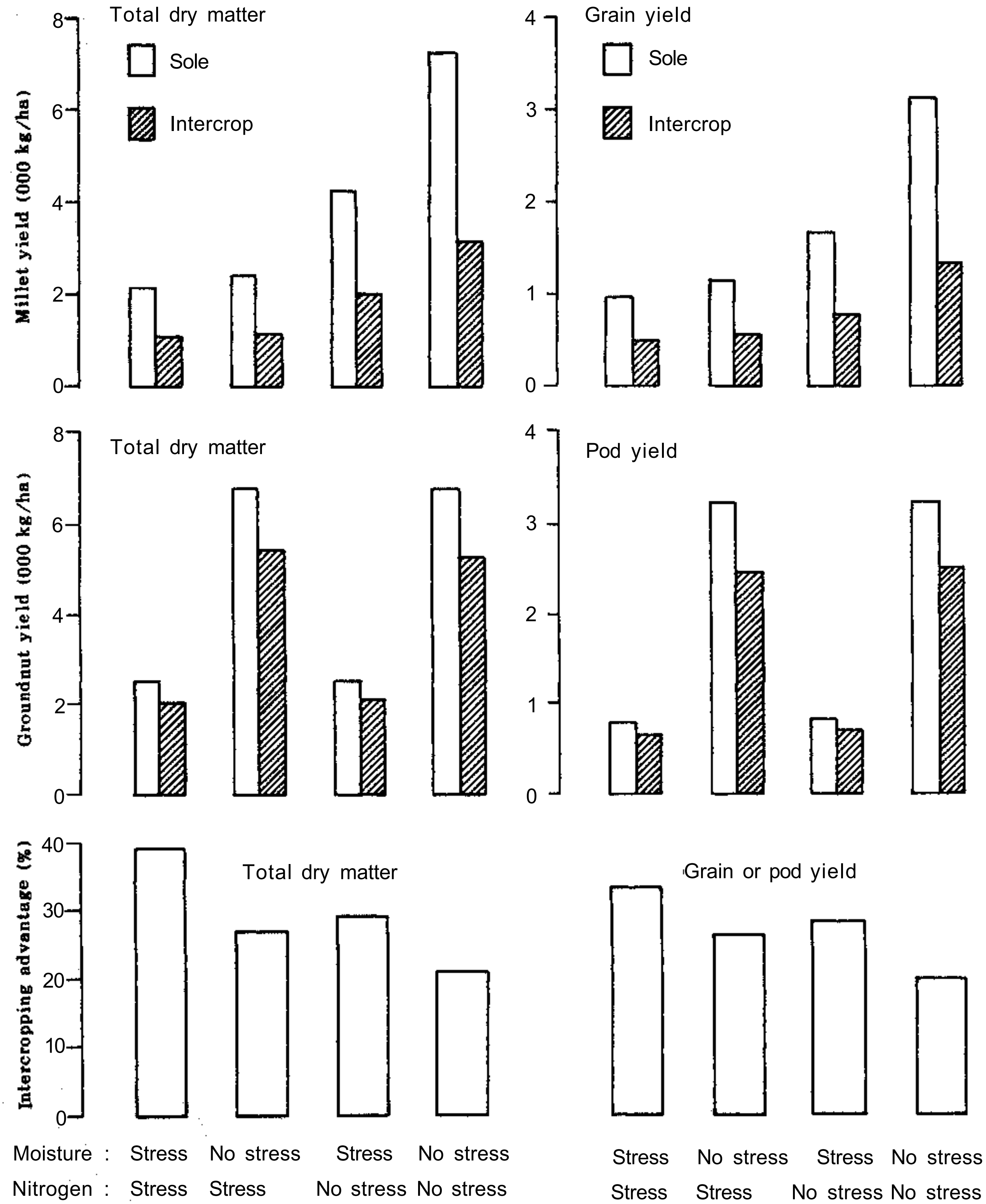


Figure 22. Total dry matter and grain or pod yields of sole crops and a 1 row millet:3 rows groundnut intercrop, and the relative advantage of intercropping under moisture and nitrogen stress, nitrogen stress, moisture stress, or no stress (ICRISAT Center, summer 1981).

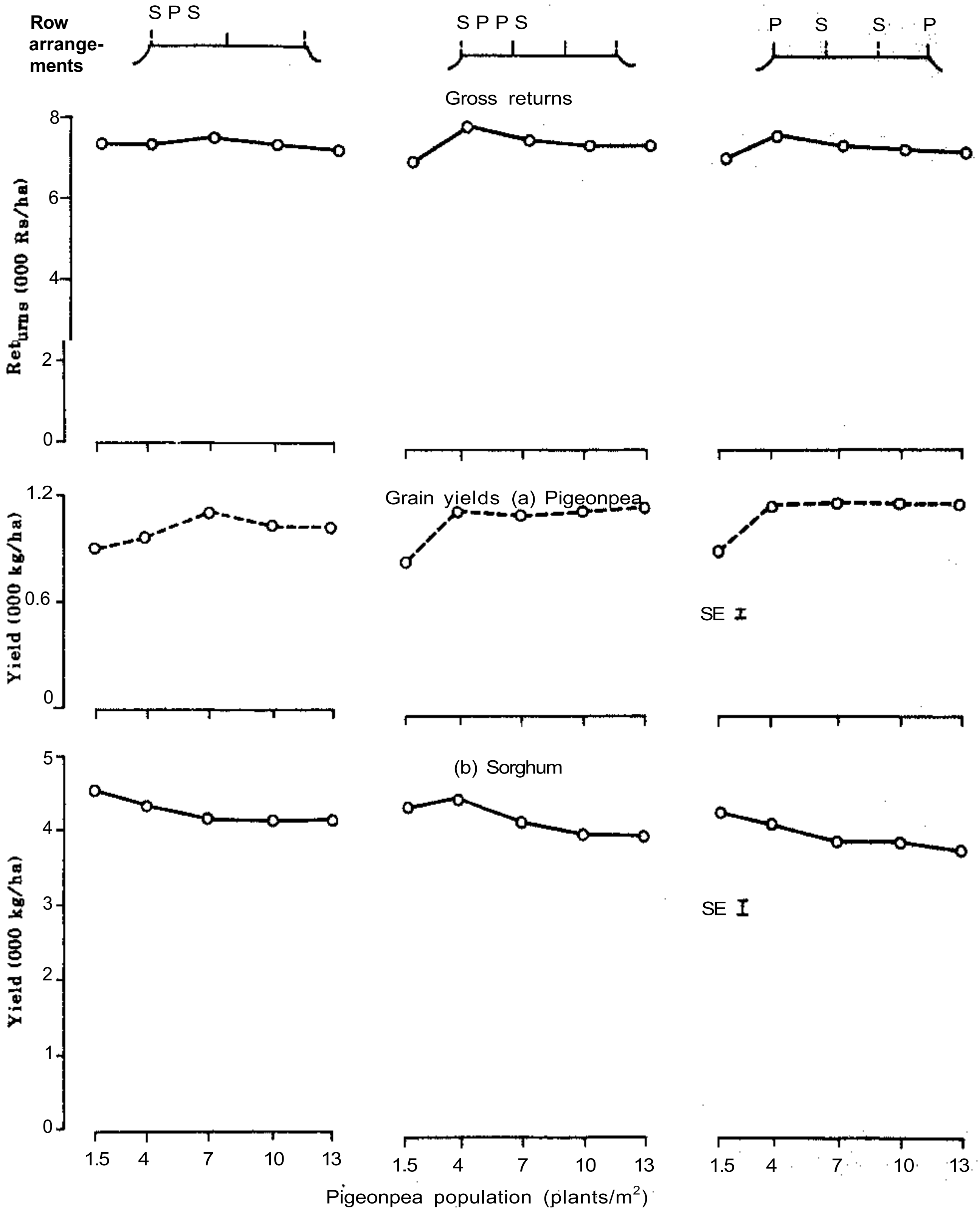


Figure 23. Yields and gross returns of sorghum/pigeonpea intercropping as affected by three row arrangements and five pigeonpea poulations on the broadlead-and-furrow system on deep Vertisols at ICRISAT Center (mean of 3 years, 1978-80).

sorghum than either a compact one like HY3A that is unable to compensate across the sorghum rows, or a bushy, early-spreading one like BDN-1 that produces too much interspecies competition in the early stages. These differences are highlighted by the mean total LERs, which were 1.74 for C-11, 1.56 for HY3A, and 1.55 for BDN-1.

Our preliminary observations indicate that the population response of these genotypes also differs in intercropping, C-11 giving no response above the sole crop optimum of 40000 plants/ha but both BDN-1 and HY3 A giving higher yields at 80 000 plants/ha.

Millet/groundnut. In previous years we used a number of systematic designs to examine plant population and spatial arrangement effects in intercropping. This year a series of experiments was initiated with a millet/groundnut intercrop to examine the efficiency and reliability of some of these designs compared with conventional designs. Millet:groundnut row arrangements 1:1, 1:3, and 1:5 in 30-cm rows were examined at within-row millet spacings of 120, 60, 30, and 15 cm (M1, M2, M3, and M4). These treatments were repeated with the same millet spacings but without the groundnut so the effect of groundnut competition on the millet could be determined. Comparisons of the different designs will be presented in a later report, but some of the competitive effects are presented here.

Observations throughout the season (Fig. 24) showed that tillering in sole and intercropped millet increased as within-row spacing increased. In intercropping, it furher increased at all except the M1 spacing as distance between millet rows increased. The omission of groundnut produced little further increase in tillering at the M4 spacing at any of the intercrop row arrangements, indicating that at this dense within-row spacing of millet the groundnut produced little competitive effect. As within-row spacings of millet increased, however, the omission of groundnut progressively increased tillering, indicating the increasing importance of groundnut competition.

These tillering responses in the millet resulted in marked increases in heads/ plant as the within-

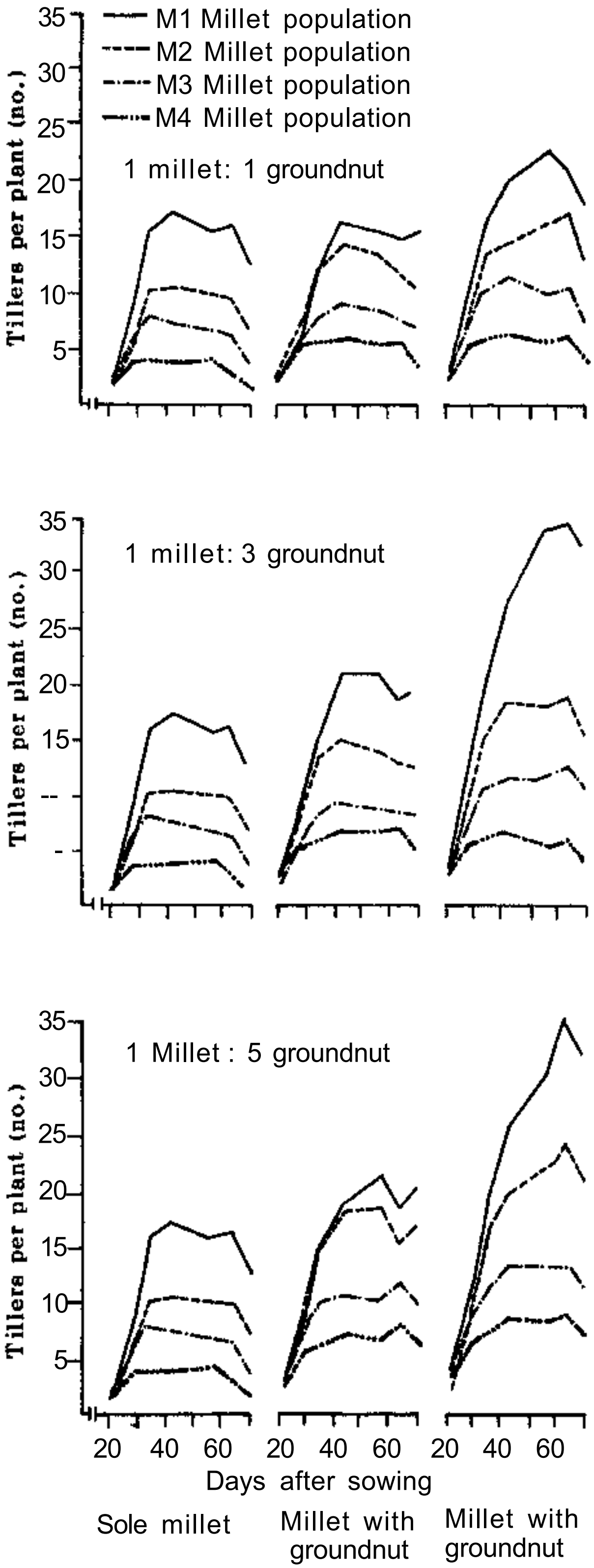


Figure 24. Tillering patterns in millet/groundnut intercropping.

row spacing increased, and to some extent as the distance between millet rows was increased in intercropping (Fig. 25). Mean yield/head showed smaller increases, but both characters contributed to large increases in yield/ plant. The effect of the groundnut competition observed above was largely on heads/ plant. Groundnut yield/plant was decreased both by decrease in millet within-row spacing and in distance between millet rows.

Genotypes for Intercropping

Last year we summarized 3 years of Vertisol experiments in which we have been collaborating with the ICRISAT pigeonpea breeders to evaluate genotypes suitable for intercropping. This year 16 genotypes were evaluated on both Vertisols and Alfisols with a standard GSH-6 sorghum.

Sole sorghum yields were very good and rather higher on the Alfisol (4737 kg/ ha) than on the Vertisol (4120 kg/ha). In intercropping, sorghum yields were depressed more on the Alfisol (mean was 92% of sole crop) than on the Vertisol (96% of sole crop), an effect that was reported in the physiology studies last year. However, absolute sorghum yields in intercropping were still slightly higher on Alfisol (4358 kg/ha) than on Vertisol (3955 kg/ha).

Pigeonpea yields were also higher on the Alfisol, ranging from 353 to 1433 with a mean of 892 kg/ha, compared with 379 to 911 with a mean of 607 kg/ha on the Vertisol. Rather surprisingly, intercrop yield as a proportion of sole crop was also on average higher on the Alfisol (73%) than on the Vertisol (60%), resulting in even bigger differences between absolute intercrop yields (266 to 931 kg/ ha with a mean of 650 kg/ha on the Alfisol, 179 to 523 kg/ha with a mean of 355 kg/ha on the Vertisol). These results highlight the particularly important role that pigeonpea intercropping has on Alfisols because, despite their lower soil-moisture storage, these soils can still produce high pigeonpea yields and, unlike the Vertisols, they rarely provide opportunities for alternative systems of two consecutive crops.

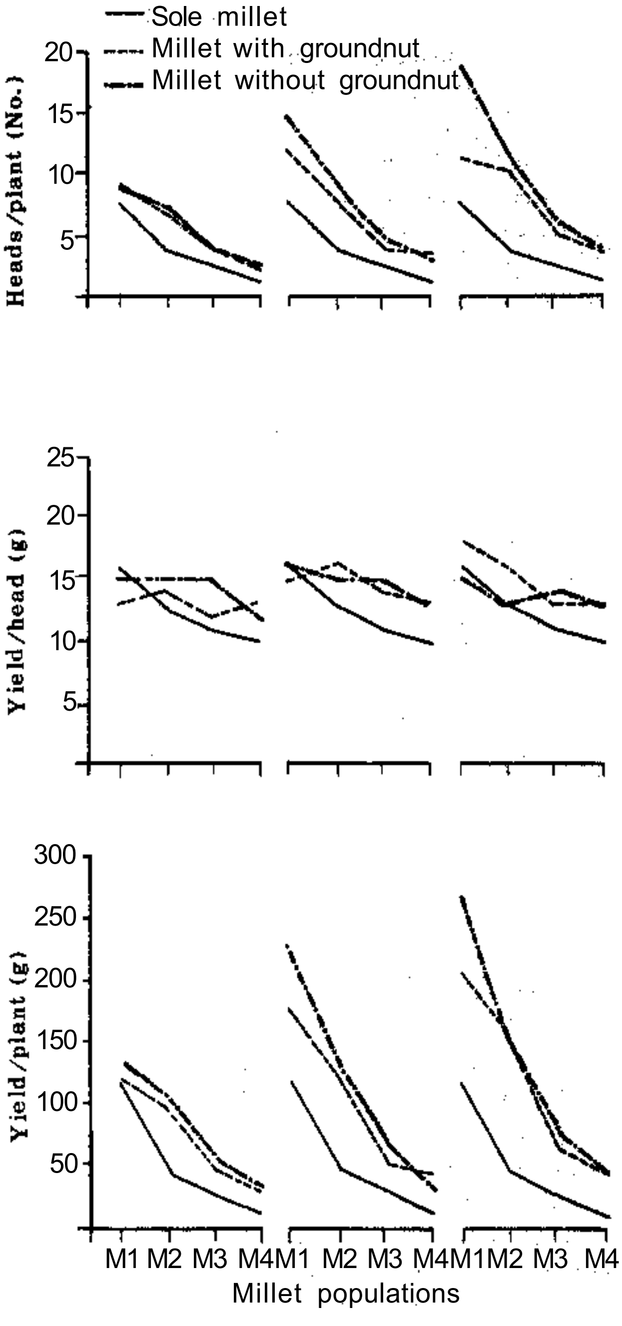


Figure 25. Yield components in millet/groundnut intercropping.

On the Vertisol, genotype response supported our earlier results, some of the poorest sorghum yields and lowest total LERs being associated with the dwarf bushy character, and some of the best pigeonpea performances and highest total

LERs being associated with spreading or semi-compact characters (e.g., Oil, ICPL-100, ICP6982-6). Further, as in most of our previous Vertisol studies, there was no particularly close relationship between intercrop performance and sole crop performance: there was no significant correlation between intercrop yield and sole crop yield, no significant rank correlation between sole cropping and intercropping, and there was a significant genotype x cropping systems interaction. On the Alfisol, however, there was less indication of the required plant type. Also, intercrop performance was more closely related to sole crop performance: there was a significant correlation between intercrop yield and sole crop yield, a significant rank correlation between sole cropping and intercropping, and no significant genotype x cropping system interaction. These preliminary results suggest that for the Alfisols the need for evaluating genotypes specifically in the intercropping situation might not be quite so critical as on the Vertisols; but firm conclusions can be drawn only after further study.

Millet/groundnut. Earlier studies indicated that in millet/ groundnut intercropping the ranking of genotypes of one crop is relatively independent of genotype of the other crop. This suggested that, at least in the early stages of screening, relatively large numbers of genotypes of either crop could be evaluated by growing them with a standard genotype of the other crop. This year the screening of millet genotypes against a standard groundnut genotype (R33-1) was initiated:20 genotypes varying in maturity, height, and tillering ability were grown in sole crop on 30-cm rows (185 000 plants/ha), sole crop on 60-cm rows (92 500 plants/ha), and replacement millet: groundnut intercrops of 1:1 and 1:4 on 30-cm rows. Unfortunately, because of early cessation of rains and severe *Cercospora* attack, the intercropped groundnut yields were poor (average 483 kg/ha), and intercropping advantages were small (only three combinations exceeded 20%). These low groundnut yields also made it impossible to detect the effect of different millet genotypes on groundnut yield, so the main role of the experiment became to evaluate only the millet performance.

Millet yields were very good, the sole crop yields on 30-cm rows ranging from 2409 to 4354 kg/ha. Compared with this treatment, and averaged over all genotypes, yield per plant increased by 60% in the 1:1 intercrop and 105% in the 1:4 intercrop. Useful further information was obtained on the role of tillering in intercropping: in the 1:1 intercrop 50% of the increased yield per plant was attributed to increased yield of the main stem, 15% to increased yield of existing tillers, and 35% to the production of more tillers; comparable figures for the 1:4 intercrop were 42%, 11%, and 47%.

For the individual genotypes, yields in both intercrop situations were largely dependent on sole crop yields, and in all three situations five of the top six genotypes were common (BK560, WC-C75, MBH-110, ICMS7803, and (700250-25) x (2287-3)-3-1-1). This suggests that in this particular experiment intercrop performance could have been predicted reasonably well from sole crop performance. However, a slightly lower correlation between intercrop and sole crop yields for the 1:4 situation (r^2 = 0.54) compared with the 1:1 situation (r^2= 0.68) may indicate that the need for selecting in intercropping could become more crucial as millet becomes a lower proportion of the system and individual genotypic expression becomes more important. It is also of interest that, as in the population experiment reported above, there was little consistent evidence of any groundnut competition with the millet; mean millet yields were 2922 kg/ha in the 60-cm sole crop and 2854 kg/ha in the 1:1 intercrop. This suggests that useful screening might be done simply by growing millet at the same population and spatial arrangement as in intercropping but excluding the groundnut. More definite conclusions on these possible screening procedures must await further research.

Last year we reported in detail the results of a summer-season experiment that examined the performance of six groundnut genotypes under different durations and intensities of cereal petition. This was repeated this year, including an additional genotype (M-13), but findings from this area of research will be summarized and presented in future reports.

Sorghum/millet. We examined a bigger range of genotypes in sorghum/ millet intercropping—nine genotypes of each crop in all combinations on both a Vertisol and an Alfisol. Genotypes were chosen to give a wide range of heights and maturities. On the Alfisol, height differences ranged from a millet 130-cm taller than a sorghum to a sorghum 180-cm taller than a millet, and maturity differences ranged from a millet 10 days later than a sorghum to a sorghum 32 days later than a millet; on the Vertisol, the comparable figures were 118 and 111 cm, and 9 and 31 days. As in previous years all intercrops were grown in alternate 45-cm rows.

On the Alfisol yields of both crops were quite good, sole crops ranging from 1789 to 5884 kg/ha for sorghum and 1366 to 2984 kg/ha for millet. Total LERs ranged from 0.78 to 1.42, with only 15 of the 81 combinations giving a value less than unity. As in last year's experiment, maturity differences had little effect either on competitive ability or total LER. But each component became increasingly competitive as its height increased relative to the other component, and although this meant that the increase in yield in one component was largely offset by the associated decrease in yield of the other component, the total LERs tended to be greater where millet was the taller component.

On the Vertisol the sorghum suffered a fairly severe shoot fly attack, but with the exception of one genotype (E35-1,879 kg/ ha) sole crop yields were still quite good, ranging from 1835 to 4000 kg/ha. Sole millet yields were good, ranging from 1728 to 3252 kg/ha. The range of total LERs (0.79 to 1.39) was very similar to that on the Alfisol, but the average was a little lower and rather more combinations (25) had values less than unity. Again, height differences had a marked effect on competitive ability, but maturity differences had little effect either on competitive ability or total LER. In contrast to the Alfisol, total LERs tended to be greater where sorghum was the more competitive component; this may have been because the situations where millet was more competitive were often those where shoot fly attack had lowered the sorghum contribution and this decreased the total LER.

This year's studies have confirmed the trends that have been emerging over previous seasons, and the work is now terminated.

Chickpea/sorghum. Previous experiments have indicated that the yield benefits of intercropping chickpea with sorghum in the postrainy season are relatively low (10-20%), but no range of chickpea genotypes has been explored. This year five were examined: Annigeri (48 days to 50% flowering), JG-62 (51 days), ICCC-4(56 days), K-850 (60 days), and G-130 (68 days). They were examined in alternate rows with sorghum (our previous studies had indicated this was the optimum row arrangement) at a constant chickpea population (167 000 plants/ha) and with three different sorghum populations (30 000, 60 000, and 90 000 plants/ha). Because of the early cessation of rains, upper soil layers were dry at sowing and the experiment was given a light irrigation for germination and an additional 20 mm after 20 days to facilitate thinning and top dressing.

In sole crop, sorghum yields were good (a maximum of 3121 kg/ ha at 90 000 plants/ ha), as were yields of chickpea (Annigeri, 1232 kg/ha; JG-62,1297 kg/ha; ICCC-4,1051 kg/ha; K-850, 1137 kg/ ha) except for the latest-maturing genotype (G-130,576 kg/ha). However, there was no consistent evidence of any intercropping advantage, and in the above order of genotypes total LER means over the three sorghum populations were 1.02, 1.04, 1.03, 1,01, and 0.99. With all genotypes, increasing the sorghum population increased the sorghum contribution but commensurately reduced the chickpea one; across the five genotypes, the sorghum:chickpea LER means for the 30 000,60 000, and 90 000 plants/ ha sorghum populations were 0.52:0.50, 0.68: 0.34, and 0.75:0,27, respectively.

Yield Stability in Intercropping

Stability studies on sorghum/pigeonpea (2:1

row arrangement), sorghum/millet (1:1), millet/groundnut (1:3), and pigeonpea/groundnut (1:5) were continued in nine situations across ICRISAT Center, ranging from shallow Alfisol to deep Vertisol and incorporating different intensities of weeding and plant protection. Detailed stability analysis will require data from further seasons, but some interesting pointers have already emerged on the behavior of both sole crops and intercrops across the different environments.

Sorghum yielded well as a sole crop at all locations except an unsprayed one where it failed completely because of pest attack. But when intercropped with pigeonpea it suffered quite a marked yield loss in two Alfisol situations (74% and 72% of sole crop), and it was a poor competitor with millet on all Alfisol locations (average was 33% of sole crop). The situation where sorghum failed was a good illustration of the value of the yield compensation that is possible in intercropping because the associated pigeonpea compensated to 96% of its sole crop yield and millet to 76%. The millet was particularly stable as a sole crop over all situations and gave some particularly good intercrop yields with groundnut on Alfisols (a mean of 64% of sole crop over all five locations). Yield levels of both pigeonpea and groundnut tended to be low because of the early cessation of rains. Pigeonpea yields were highest on two Alfisol locations and lowest in a low-lying, waterlogged situation. Groundnut yields were little affected by soil type or depth but were markedly decreased at a low intensity of plant protection or weeding. For Alfisols and Vertisols, respectively (and excluding the treatments where sorghum failed), mean total LERs were 1.56 and 1.76 for pigeonpea/groundnut, 1.57 and 1.64 for sorghum/pigeonpea, 1.31 and 1.15 for millet/groundnut, and 1.09 and 1,01 for sorghum/millet.

Legume Effects in Intercropping

This year saw the end of a 3-year experiment that we conducted to examine the benefits of a groundnut intercrop on an associated maize crop or a subsequent sorghum crop. In the rainy season, sole maize was grown as two rows 90 cm apart on 150-cm broadbeds; intercrops had maize at the same population and spacing as in sole cropping, but two intervening rows of groundnut were added. Phosphate was applied as a basal dressing to all plots, but four levels of nitrogen (0,50,100, and 150 kg/ha) were applied to the maize in both sole and intercrop treatments.

According to the 3-year means, sole maize responded up to 150 kg N/ha, while the intercropped maize reached the same maximum yield value at only 100 kg N/ha (Fig. 26a). However, yield differences between sole and intercropped maize at a given nitrogen level were not significant and it is considered unlikely that the differences in response indicate a transfer of nitrogen from the groundnut to the maize. Intercropping advantages decreased with inreased nitrogen, as has been observed with other intercropping combinations, the values being 1.35 at 0 kg N/ha and 1.13 at 150 (Fig. 26b). It was also evident that if no nitrogen was applied to the maize its yield was poor while the groundnut yield was good; in contrast, if nitrogen was applied to the maize its yield was similar to the sole crop, but the groundnut was then suppressed.

In the postrainy season all treatments were followed by an irrigated test crop of sorghum at four levels of nitrogen (0,40,80, and 120 kg/ha). After sole groundnut there was a residual effect equivalent to about 15 kg/ha of applied nitrogen, and there was also some evidence of a small residual effect after the intercrop to which no nitrogen was applied. It is of interest, however, that these residual effects occurred at all levels of nitrogen applied to the test crop, so factors other than nitrogen may have been involved. Intercrops where nitrogen was applied to the maize left no residual effect, presumably because of the marked suppression of groundnut growth and because fixation in groundnut is much reduced by the presence of a cereal intercrop (see report of Groundnut Microbiology).

A similar series of experiments was initiated this year on sorghum/cowpea as part of a multilocation study in cooperation with the All India Coordinated Sorghum Improvement Project.

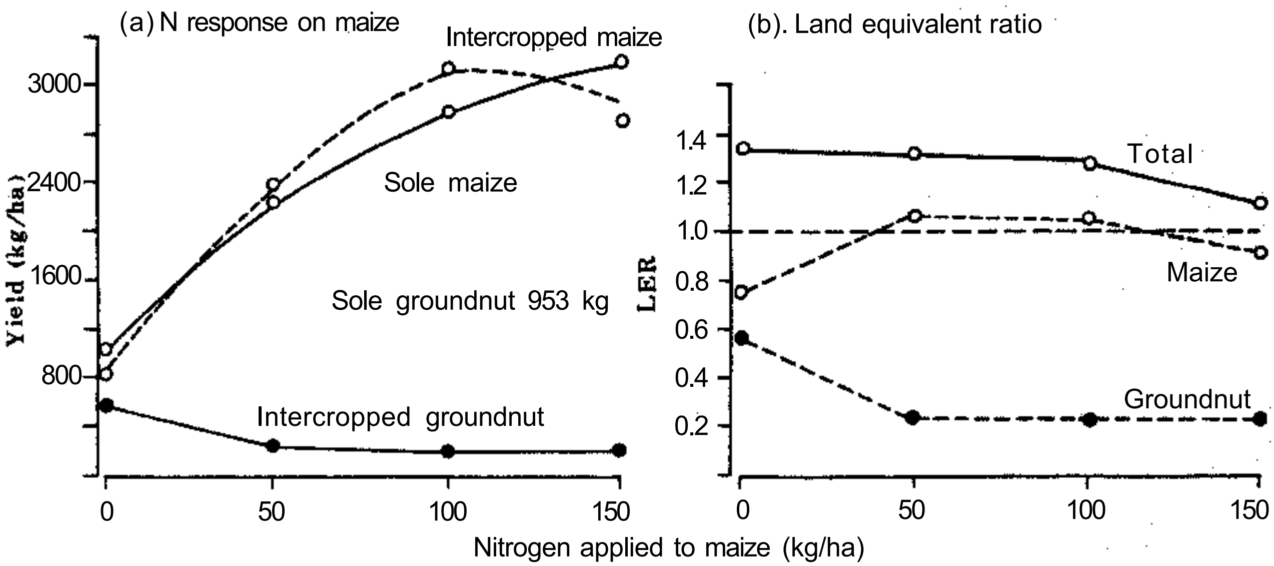


Figure 26. Response of sole maize and intercropped maize to nitrogen and the effect of nitrogen fertility on land equivalent ratios in intercropping (mean of 3 years, 1978-1980).

Intercropped sorghum showed a nitrogen response similar to sole sorghum, but yields were substantially reduced by intercropping (averaging only 73% of the sole crop) and there was no evidence of any beneficial effect from the cowpea. Maize was used as the postrainy-season test crop, but there was no evidence of any residual effect after intercropping. Sole cowpeas gave a rather larger benefit than the groundnut described above, but again factors other than nitrogen were indicated because effects were apparent at all levels of nitrogen applied to the test crop.

Effect of Intercropping on Diseases

Last year we initiated a cooperative experiment with ICRISATs pulse pathologists to study the effect of different cropping systems on the soil-borne *Fusarium* wilt of pigeonpea. It was continued this year, and again there was striking evidence that a sorghum intercrop could decrease wilt incidence (see Pigeonpea Pathology report for details). Two new cooperative experiments have given initial indications that a millet intercrop can be beneficial to groundnut by reducing foliar diseases of *Cercospom* leaf spot and rust and thrip-borne bud necrosis (see Groundnut Program report for details). A point of particular interest in the foliar disease experiment was the effect of disease resistance on LERs; for the susceptible genotypes LERs were 1.24 (TMV-2) and 1.26 (R33-1), for the moderately resistant they were 1.38 (NC Ac 17129) and 1.52 (NC Ac 17135), and for the resistant they were 1.40 (NC Ac 17090) and 1.53 (PI 249747). The higher LERs of the resistant and moderately-resistant genotypes were considered to be due to their better retention of green leaves as they neared maturity. This again emphasizes the importance of good groundnut growth after the period of peak millet growth and after millet harvest, to achieve a good groundnut contribution and a high total LER in this intercropping combination.

Cropping Systems for Vertisols

A 4-year, small-plot study of alternative cropping systems for Vertisols was concluded this year. Results are summarized in Figure 27 as net monetary returns (gross returns less costs of land preparation, labor, seeds, fertilizer, and pesticides, as estimated from adjacent operational-scale watersheds). It was confirmed that,

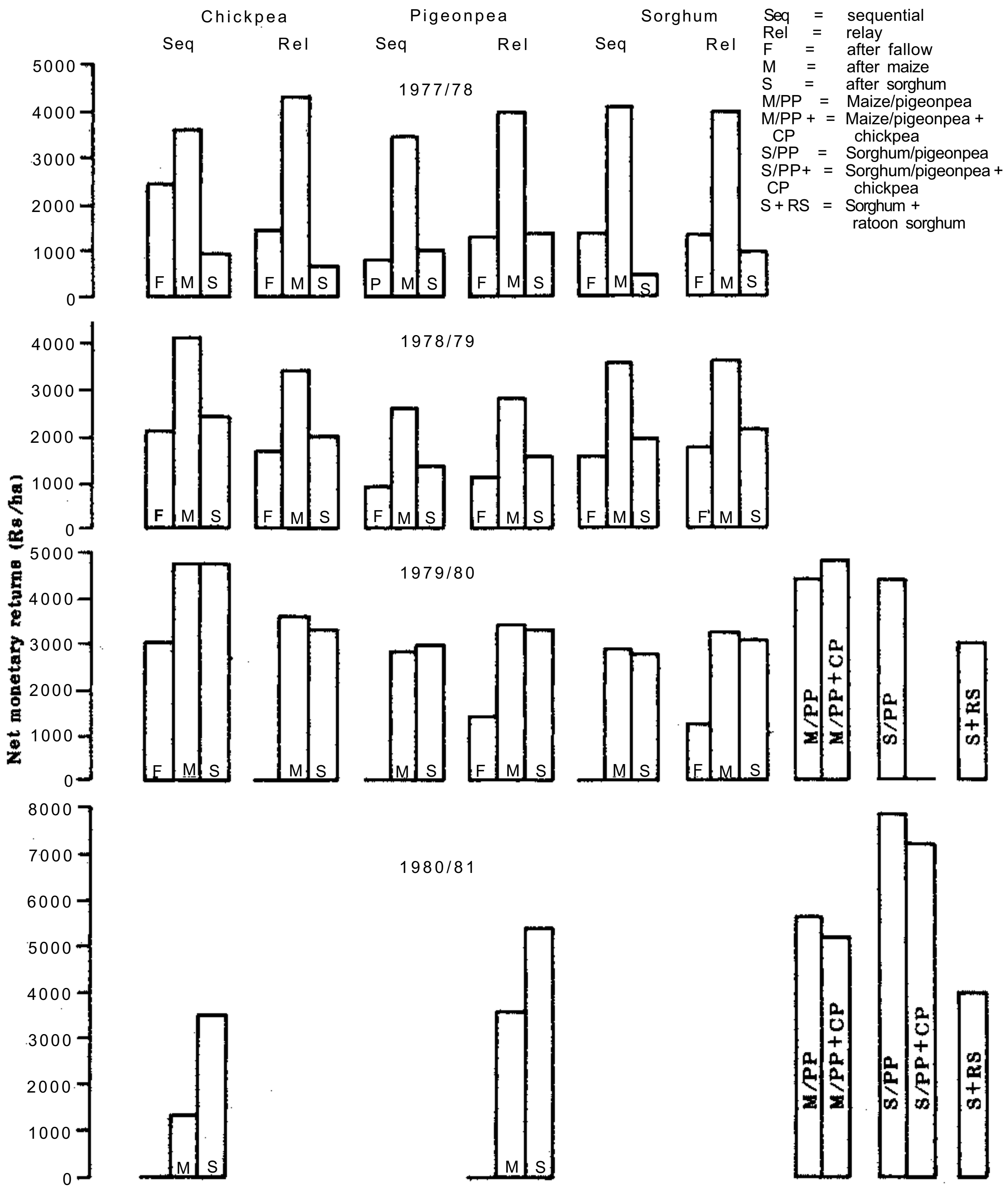


Figure 27. Net monetary returns (Rs/ha) from various promising cropping systems grown on deep Vertisols at ICRISAT Center (1977-1981).

compared with the traditional rainy-season fallow systems, greater net returns can be obtained from a wide range of systems that use both the rainy and postrainy seasons, despite the extra costs of growing the additional crops. Maize proved a good rainy-season crop, though in 1980/81 net returns were much better from the soghum-based systems, largely because of a better price for sorghum. However, there was consistent evidence of slightly lower post-rainy-season yields after sorghum than after maize, and there were drastic yield reductions after sorghum in 1977/78 (see ICRISAT 1978/79 Annual Report). For postrainy-season crops, chickpea was better as a "sequential" crop sown after the harvest of a previous crop but pigeonpea was better as a "relay" crop sown approximately 20 days before the harvest of a first crop.

The cereal/pigeonpea intercrops compared well with the sequential or relay systems. In 1979/80 when September rains were good the latter systems were slightly better, but this was reversed in 1980/81 when the dry September resulted in poor establishment and low yields for the postrainy-season crops; these results typify the potential problems of the sequential and relay systems and the likelihood of greater stability with intercropping systems. These last 2 years' experiments also nicely illustrated the possible role of a three-crop system where a third crop is sown after harvest of the cereal in a cereal/pigeonpea intercrop. In the good moisture year of 1979/80, useful additional chickpea was obtained in maize/pigeonpea, and the net returns were increased; in the drier year of 1980/81 the chickpea could not be established, but the costs of trying to do so reduced net returns. This could be a useful system but it seems important that the third crop should be attempted only in the good years when there is a high probability of success.

Cropping Systems for Alfisols

The results of a 3-year, small-plot study of alternate cropping systems for Alfisols are presented in Figure 28 as net returns (see above). Among the sole crop systems, castor and pigeonpea were good in all years tried, though in 1980/81 net returns were much higher for sorghum or groundnut because of their high prices. Growing a mung bean before the castor gave good additional returns in 2 of the 3 years if the castor was relay-sown. Ratooning the sorghum gave only small increases in net returns. The relatively poor net returns of sole millet were usefully increased by adding a sequential or relay crop of horse gram, though the overall net returns of this system were still rather low. High net returns from the intercropping systems emphasize the great value of these systems under these particular conditions where the moisture may not be fully used by a single sole crop but is insufficient for sequential or relay systems based on full-season crops. In all 3 years, sorghum/pigeonpea intercropping gave higher net returns than millet/groundnut intercropping, and in the 2 years in which it was examined, pigeonpea/groundnut intercropping gave higher net returns than any other system.

Cropping Entomology

Surveys. As in previous years we surveyed the pests and their natural enemies on crops and weeds at ICRISAT Center; at Kanzara—an ICRISAT VLS site in Maharashtra, India; and on local farmers' fields. In the 1980/81 crop season *Heliothis armigera* was abundant on sorghum, millet, and groundnuts in August-September. However, from October to December, when this pest normally reaches peak populations and feeds mainly on pigeonpea and chickpea, our field counts and light trap catches showed lower numbers than those recorded in previous years. This year the rains ceased rather early, and this factor may have been responsible for the low *Heliothis* populations on pulse crops at ICRISAT Center.

In sorghum the pest populations, with the exception of the stem borer *Chilopartellus,* were generally larger at ICRISAT Center than in farmers' fields. Shoot fly (*Atherigona soccata*) and armyworm (*Mythimna separata*) were found in greater populations in pur crops on

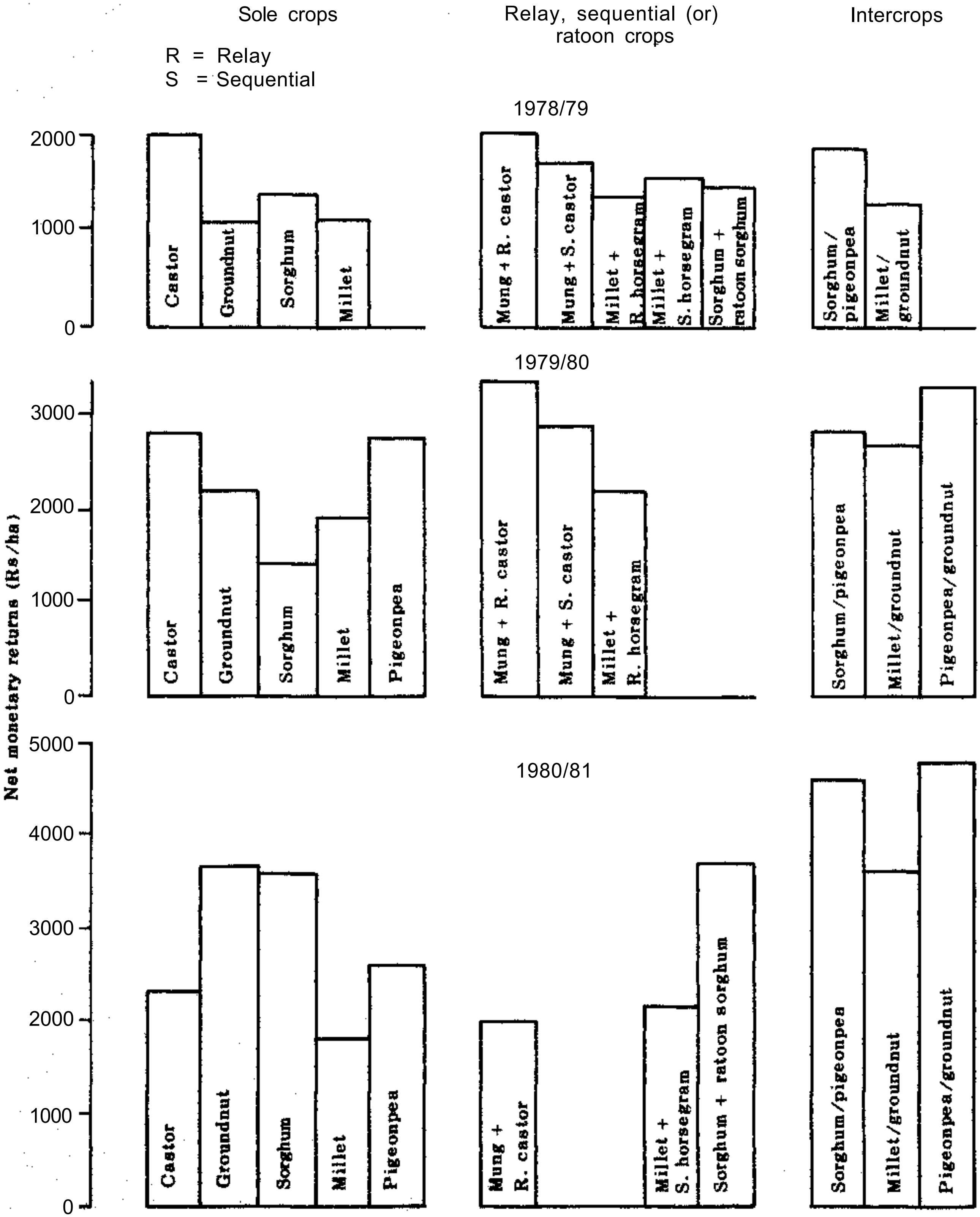


Figure 28. Net monetary returns (Rs/ha) from various promising cropping systems grown on Alflsols at ICRISAT Center (1978-1981).

Alfisols than on Vcrtisols. But aphids (*Rhopalosiphum maidis*), head bug (*Calocoris angustatus*), and earhead caterpillars of *Heliothis armigera* and *Euproctis subnotata* were all more common in the crop on Vertisols.

Catches of *Chilo* moths in our light traps at ICRISAT Center in 1980/81 were greater than in previous years (Table 26), but this pest was not found in large numbers in sorghum at our Center or in nearby farmers' fields. At Kanzara, however, more than 50% of the plants in some sorghum fields developed deadhearts due to *Chilo* feeding, the damage being greater on the early-sown sorghum than on the later sown. This was in contrast to the damage caused by shoot fly, because, as usual, the early-sown sorghum escaped severe damage by this pest.

Spodoptera litura, which is best known as a pest of tobacco, defoliated some of our groundnut fields at ICRISAT Center in March. There is concern that this pest may be extending its host range, for in recent years there have been reports of *S. litura* causing widespread, severe damage to cotton and groundnuts in farmers' fields.

Natural enemies. We continued surveys of the natural enemies of the pests of our mandate crops and collected the various developmental stages of the pests from their host plants at ICRISAT Center, in neighboring farmers' fields, and from farmers' fields in Maharashtra and Karnataka States in India. These insects were reared in our laboratory using the original host-plant material as food. The emerging parasites were identified and recorded.

As in previous years, *Ovomermis albicans,* a mermithid nematode, was commonly found parasitizing *Heliothis* spp larvae from June to October, particularly on crops and weeds on our Alfisols. We recovered this nematode from all three species of *Heliothis* that are found locally: *H.armigera, H. peltigera,* and *H. assulta.* In some collections more than 50% of the larvae were parasitized. After October, as in previous years, this parasite was very rare. Mermithids were also found parasitizing larvae of *S. litura* on groundnuts, S. *exigua* on volunteer chickpeas in July, *Cydia critica* and *C. ptychora* on pigeonpea, and *Chilo partellus, Mythimna separata,* and *Marasmia suspicalis* on sorghum. We consider these nematode parasites to be particularly useful because they are most common early in the season and so can have a greater effect on pest populations than the parasitic insects, most of which build up to large populations later in the season when pest populations are large and crop damage has already occurred.

In 1981 we distributed a report - Arthropod parasitoids of insect pests (excluding *Heliothis* spp) recorded in Andhra Pradesh, India — on

Table 26. The catches of some pest species and their seasonal distribution in a light trap on a Vertisol watershed at ICRISAT Center 1980/81, and their means for 1977-80.

	Percent insects trapped			Total no. trapped
	June-Aug	Sept-Nov	Dec-May	
Heliothis armigera	29.3(12.6)[a]	51.3(36.6)	19.4(50.8)	7653(14953)
Maruca testulalis	5.1 (1.8)	62.5(59.4)	32.4(38.8)	1092(1901)
Adisura stigmatica	5.3(3.2)	19.2(25.3)	75.5(71.5)	1586(2514)
Chilo partellus	4.2(4.5)	70.4(44.5)	25.4(51.0)	18635(8393)
Mythimna separata	42.9(27.6)	56.8(72.2)	0.4(0.2)	280(1985)
Spodoptera litura	6.8(21.5)	15.9(39.7)	77.4(38.8)	10491(3712)
Dysdereus sp.	4.9(2.5)	95.0(79.5)	0.1(18.0)	59345(14272)

a. Figures in parentheses are the means for the 1977-80 seasons.

our studies of the crop-pest-parasite relationships (Cropping Systems Progress Report 7).

We have so far recovered 27 species of parasites from *Heliothis armigera.* In addition we have found 12 species of hyperparasites and 20 species of predatory insects on this pest. As in previous years, we found large differences in the natural-enemy complexes on different crops. For example, parasitism of *Heliothis* eggs was common on sorghum and most other host plants, but rare on pigeonpea and chickpea, similarly, *Campoletis chlorideae,* an ichneumonid parasite, was very common in *Heliothis* larvae collected from most crop and weed hosts but rare in pigeonpea. Such differences (Table 27) partly explain why *Heliothis* is so damaging on our pulse crops, particularly pigeonpea. The dipteran parasites, commonly found in *Heliothis* larvae collected from pigeonpea, are not very helpful in reducing the damage because they are able to kill the larvae only when the larvae are fully grown.

Insect traps. We record the catches of a wide range of insects, both pests and natural enemies, in three light traps at ICRISAT Center. In addition, in cooperation with the Indian Council of Agricultural Research (ICAR) and national universities, we receive data on catches of a limited number of insect pests from a network of traps that we have supplied to them and which are sited across India. This network was expanded this year.

The data on catches of *Heliothis armigera* from light traps confirmed our field observations that during November-December 1980 this pest was less abundant than in previous years, particularly in southern India. Several other pest species were also caught in lower numbers than usual this year, including *Mythimna separata,* but catches of *Chilo partellus, Dysdercus* sp, and *Spodoptera litura* were generally greater than in previous years (see Table 26).

The light traps are also useful in catching some of the pests' natural enemies. We have sent *Enicospilus* spp, caught in the traps, to the British Museum of Natural History, London, for identification. The insects of this ichneumonid genus are parasitic on a wide range of lepidopteran larvae, but little is known of their seasonal incidence. We now have recorded 14 species of *Enicospilus* and have some data on their relative abundance and seasonal incidence.

The data from the light trap network will allow us to determine the seasonal and geographical variations in populations of the pests and some of their natural enemies. However, light traps can be used only in locations with a reliable power supply and where a skilled recorder is available to sort the catches. Therefore, this year we made greater efforts to improve our pheromone traps. We now expect to supplement the light trap network with pheromone traps that will catch the male *Heliothis armigera* and so allow us to record seasonal changes in populations of this pest in situations where electricity and skilled recorders are not available.

Surveys of intercropped sorghum and pigeonpea. In India most pigeonpea is grown as an

Table 27. Parasitism levels recorded from eggs and larvae of *Heliothis armigera* on sorghum (CSH-6) and pigeonpea (ICP-1) in cropping systems trials at ICRISAT Center, 1978-81.

pest stage	Collection period	Crop	No. *H.armigera* examined	Parasitism (%)	
				Diptera	Hymenoptera
Eggs	Aug-Oct	Sorghum	11846	0.0	26.4
	Sept-Feb	Pigeonpea	9250	0.0	0.1
Larvae	Aug-Oct	Sorghum	6098	2.1	24.9
	Sept-Feb	Pigeonpea	14052	10.2	1.1

intercrop, with sorghum as the dominant companion crop. We have been studying the pest and natural enemy populations and the damage caused in sorghum/pigeonpea intercrops in comparison with those in the sole crops both at ICRISAT Center and other areas in India.

In the 1980/81 crop year we studied four treatments: sole crop pigeonpea, sole crop sorghum, and intercrops of these at half and full plant populations. In the intercrops the row arrangement was 2 sorghum : 1 pigeonpea, sown at the same time. The maturities of the cultivars used ensured that the pigeonpea flowered soon after the sorghum was harvested. We sowed large plots (0.35 ha) of each of these treatments in four locations on both Vertisols and Alfisols at our Center. We also made similar studies in farmers' fields.

All of our experimental plots were pesticide-free. Counts of pests and their natural enemies within each plot were recorded throughout the season. As in previous years, the *Heliothis* populations and the damages caused by these were at least as great in intercrops as in the sole crop. We again found that most of the natural enemies that were feeding upon *Heliothis* eggs and larvae in the sorghum heads failed to transfer with their host to the pigeonpea. However, the yield benefit of intercropping was again evident with more than 40% advantage in the land equivalent ratio. Summarized data for 3 crop years (1978-81) from all the plots at ICRISAT Center are presented in Table 28.

Weed Science

During the 1980/81 crop season our weed management research focused mainly on two broad areas: (1) quantification of the effect of several physical, cultural, and biological factors on crop-weed balance, and (2) operational-scale evaluation of different weed management systems.

Effect of Different Factors on Crop-Weed Balance

The 1980 results of three long-term studies initiated in previous years are briefly presented here.

Soil management practices. In 1980 we continued a long-term experiment initiated in 1978 to monitor the trends in weed emergence and weed seed depletion from a Vertisol under traditional and improved management sys-

Table 28. Counts of *Heliothis armigera,* percentage yield loss, and yields of pigeonpea grown as a monocrop and intercropped with sorghum at two spacings (mean data from trials at ICRISAT Center 1978-81).

Crop	*Heliothis* /100 terminals at peak activity		Estimated yield loss(%) to pests	Grain yields (kg/ha)		LER
	Eggs	Larvae		Pigeonpea	Sorghum	
Sorghum monocrop					2544	1.0
Pigeonpea monocrop	85	44	35.9	1043		1.0
Intercrops, wide spaced	111	41	36.6	541	2005	1.4
Intercrops, close spaced	110	46	39.3	575	1800	1.4
SE ±	7.0	3.7	2.35	73.9	181.1	0.11

LER = Land Equivalent Ratio.

tems. During 1978 and 1979 we compared three soil-management practices: flat beds, narrow ridges (75 cm), and broadbeds and furrows (150 cm); after 1979 the narrow-ridge treatment was abandoned.

Soil samples from each soil-management treatment were collected from two depths (0-15 and 15-30 cm) over 3 years. These samples were placed in earthen pots and watered regularly. When the seedlings appeared, they were identified, counted, and removed from the pots.

The 3 years' data on annual weed seedling emergence (Fig. 29) show that weed emergence was greatly influenced by the soil-management treatment and that emergence declined with time. Of the total weed seedlings that emerged, most were from the soil collected from the 0-15 cm depth. Peak seedling emergence was observed in June-July, followed by a lesser peak in November-December.

Time of weed removal. Most of the studies on crop-weed competition reported in literature pertain only to sole crops, so we initiated experiments at ICRISAT Center in 1978 to study the effect of time of weed removal in the major intercropping systems. Results from two of these experiments, conducted during 1980, are briefly reported here.

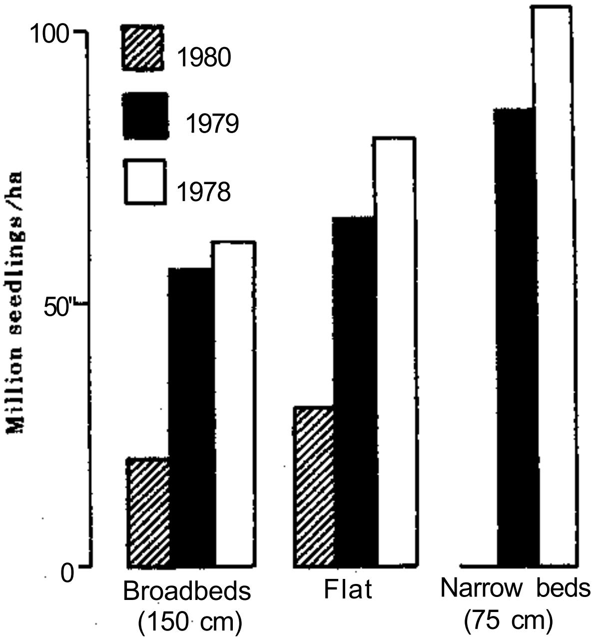


Figure 29. Effects of three soil-management treatments on total annual weed emergence on Vertisois at ICRISAT Center, 1978-80.

In the case of a sorghum/pigeonpea intercrop on a Vertisol we found that if only one hand weeding was possible, the best time to give it was 4 weeks after planting. If two hand weedings could be given, the optimum times for them were 3 and 5 weeks after planting.

The other experiment, on an Alfisol with pearl millet/groundnut intercrop, showed that one hand weeding 4 weeks after planting gave higher yields than keeping the crop weed-free up to 3 weeks after planting. The treatment in which the crop was kept weed-free up to 4 weeks after planting seemed to be quite satisfactory for high yields.

Cultivar effect. Our field experiments with several sole crops over previous years have shown that crop cultivars differ in their weed competitive ability. In some crops we also observed differential herbicide tolerance. During 1980 we continued an experiment initiated in 1978 with different pearl millet cultivars (Ex-Bornu, GK-77-3, BJ-104, and IVS/AX-75) on Alfisols. The results indicated that though the yield potential of all the cultivars was high under weed-free treatments, the tall cultivar Ex-Bornu withstood weed competition in the unweeded check better than a dwarf type GK-77-3. No difference in herbicide tolerance was observed among the four pearl millet cultivars.

Operational-Scale Evaluation of Weed Management Systems

During the past few years we conducted small-plot experiments to develop and evaluate weed management systems for different crops and cropping systems. In 1979 we started testing some of these in the watersheds on an operational scale. In two experiments conducted during the 1980/81 crop season with two cropping systems, three weed management systems based on hand weeding, herbicide, and smother cropping were evaluated in comparison with weed-free and weedy check treatments.

Maize-chickpea sequential cropping. Results from this study (Table 29) showed that the system based on herbicide (Atrazine at the rate of 1.5 kg a.i./ha preemergence) seemed to have good potential for maize-chickpea sequential cropping in deep Vertisols. However, smother cropping showed less potential in this situation because maize suffered competition from the smother crop. These results further confirmed our earlier hypothesis that a herbicide can be an integral part of improved farming systems in deep Vertisol areas with dependable rainfall, where hand weeding is difficult when the soil is wet.

Sorghum/pigeonpea intercropping. We used fluchloralin (at the rate of 1.5 kg a.i./ha) as a preemergence application in this cropping system. The herbicide-based weed management system proved to be effective in this case also (Table 30). Smother cropping also showed potential in this situation. This experiment also demonstrated the operational feasibility of smother cropping; we had little difficulty planting two rows of smother crop per bed between the sorghum and pigeonpea rows using a Tropicultor.

On-Farm Collaborative Research

ICAR and ICRISAT have been involved since 1978 in cooperative on-farm research on farming systems in two villages—Aurepalle (Andhra Pradesh) and Kanzara (Maharashtra)—in two different agroclimatic and socioeconomic subregions of central peninsular India,

Small-scale on-farm experiments were initiated in 1978 as part of ICRISAT's village-level studies (VLS) to obtain preliminary information on the performance of ICRISAT technology. The first 2-year study (the 1979/80 and 1980/81 crop years) has been considered a technology introduction and testing phase. In 1979, one small watershed in each village was developed with an improved soil and water management system, and different inputs of improved technology were tested and evaluated in these

Table 29. Effect of different weed management systems on the net productivity of the maize-chickpea sequential cropping system on Vertisols at ICRISAT Center, 1980/81.

	Rainy season			Postrainy season				
Treatments	Maize yield (kg/ha)	Smother crop yield (kg/ha)	Return (Rs/ha)	Chickpea (kg/ha)	Returns (Rs/ha)	Total returns (Rs/ha)	Operational cost (Rs/ha)	Net returns (Rs/ha)
Weed management systems based on:								
Hand weeding	4142		4349	361	993	5342	320	5022
Herbicide	4321		4537	415	1141	5678	560	5118
Smother cropping								
Mung	3411	132	3978	260	715	4693	360	4333
Cowpea	3583	156	4230	365	1004	5234	360	4874
Weed free	5307		5572	512	1408	6980	640	6340
Weedy check	2869		3012	245	674	3686		3686
SE ±	284			140				
CV (%)	11			55				

Table 30. Effect of different weed management systems on the net productivity of the sorghum/pigeonpea intercropping system on Vertisols at ICRISAT Center 1980/81.

	Rainy season			Postrainy season				
Treatments	Sorghum yield (kg/ha)	Smother crop yield (kg/ha)	Return (Rs/ha)	Pigeonpea (kg/ha)	Return (Rs/ha)	Total returns (Rs/ha)	Operational cost (Rs/ha)	Net returns (Rs/ha)
Weed management system based on:								
Hand weeding	2995		2246	749	1947	4194	320	3874
Herbicide	3080		2310	936	2434	4744	470	4274
Smother cropping								
Mung	2676	105	2322	886	2304	4626	360	4266
Cowpea	2934	171	2714	735	1911	4625	360	4265
Weed free	3841		2881	1143	2972	5853	640	5213
Weedy check	1699		1274	654	1700	2974		2974
SE ±	150			56				
CV (%)	10			13				

watersheds. The test site at Aurepalle is a typical shallow Alfisol (loamy sand), and at Kanzara it is a shallow to medium-deep Vertisol (loam to clay loam). In the 1980/81 cropping season, Aurepalle received 373 mm total rainfall and Kanzara received 673 mm. The rainfall at Aurepalle was more erratic than at Kanzara, and the rainy season ended early at both places.

In 1980/81, we tested improved soil and crop management practices, including high-yielding varieties, optimum fertilizer input, and improved implements. Crop yields in the improved management plots were compared to the yields of the farmers' traditional system in plots outside the watershed. The agronomic performance and resource requirements of the improved and traditional systems were also compared, using similar crops on similar soils.

Aurepalle

The growth of cereals such as sorghum and millet was excellent, but pigeonpea and castor suffered heavily due to early cessation of rains. The sorghum and millet in the watershed substantially outyielded (up to seven times) those under the traditional system. Because of large differences in moisture-storage capacity, with soil depth ranging from 10 to 45 cm, the crop yield levels varied widely across farmers' fields within the watershed.

The suitability of broadbeds and furrows for Alfisols is still in question. Though it appeared that broadbeds are necessary to obtain precision control in seeding and fertilizer application, there were no noticeable differences in yields between the flat-planted and broadbed-and-furrow planted crop (Table 31). The utility of the Tropicultor was noted, particularly in precision planting and fertilizer application. On the flat seedbed, yields of all the crops planted with the Tropicultor were higher than those of crops planted with the local drill. The combined use of standard row spacings (45 cm) and the Tropicultor resulted in higher crop yields than using local spacings (7 to 10 rows of varying row widths of cereals and 1 or 2 rows of pigeonpea) made with the local drill (Table 32).

Kanzara

Because of early cessation of rains, pigeonpea and cotton suffered heavily during the critical

Table 31. Crop yields (kg/ha) of several cropping patterns on flat and broadbed systems of planting at Aurepalle village in 1980/81.

	Sorghum yield		Pigeonpea	
	Grain	Fodder	grain yield	Castor
Sorghum/pigeonpea (flat)[a]	1720	3490	30	
Sorghum/pigeonpea (beds)	1370	2800	32	
Millet/pigeonpea (flat.)	850	1140	50	
Millet/pigeonpea (beds)	1500	1570	30	
Sorghum/castor (2:1) (flat)	1740	3420		20
Sorghum/castor (2:1) (beds)	1210	3050		40
Castor/sorghum (2:1) (flat)	1120	2150		40
Castor/sorghum (2:1) (beds)	930	2240		113
Sole castor (flat)				220
Sole castor (beds)				410
Local technology[b]				
Sorghum/millet/pigeonpea	389[c]	1590[c]		
Sole castor				150

a. Data on flat cultivation presented here are from unreplicated small plots.
b. Data collected from eight farmers' fields — average of 72 samples.
c. Sorghum plus millet yields.

Table 32. Crop yields (kg/ha) for several crops at Aurepalle village watershed under flat cultivation, 1980/81.

Genotype	Planting drill	Row spacing	Cropping system	Cereal grain	Cereal fodder	Pigeonpea	Castor
L	L	L	Sorghum/millet/pigeonpea	520	3260	Nil	
I	L	L	Millet/pigeonpea	580	960	0.6	
I	L	S	Millet/pigeonpea	520	650	0.4	
I	I	S	Millet/pigeonpea	860	1150	0.5	
I	L	L	Sorghum/pigeonpea	960	3070	0.4	
I	L	S	Sorghum/pigeonpea	1250	2710	0.3	
I	I	S	Sorghum/pigeonpea	1410	3500	0.4	
I	I	S	Sole castor				200
I	L	S	Sole castor				350
I	L	S	Sorghum/castor	1510	2900		40
I	I	S	Sorghum/castor	1740	3400		20
I	I	S	Castor/sorghum (2:1)	1120	2150		40
I	L	S	Castor/sorghum	910	1730		20

I = Improved
L = Local
S = Standard (45 cm)

period of their growth. Very heavy showers during July and August resulted in some waterlogging, and in September and October the crops suffered moisture stress. This waterlogging and drought in a single season produced very poor crop growth in general. Erosion early in the season and moisture stress later occurred in both the flat and the broadbed-and-furrow system of cultivation, but broadbeds required good crop canopy cover to maintain their shape. Apparently, groundnuts helped to retain the broadbeds while sole cropping of cotton produced some splash erosion. Some other major observations are:

1. The use of high-yielding cultivars, optimum fertility management, good weed control, and optimum plant protection, etc., in the watersheds produced crop yields far superior to the traditional system of farming (Table 33).
2. Though the broadbed-and-furrow system facilitated drainage, in general there was no significant difference in yields between flat and broadbed-planted crops on shallow to medium-deep Vertisols (Table 33).
3. The use of the Tropicultor seemed to have considerable advantage in planting, fertilizer application, and intercultivation, which was reflected in higher crop yields.
4. When compared to the yields of traditional systems practised by the neighboring farmers, the yields obtained with the watershed management technology were substantially higher than those of the traditional system practised by neighboring farmers.

Looking Ahead

Agroclimatology. We will continue our efforts to provide meaningful climate evaluation for outlining cropping potentials for different regions. Microclimatic studies and crop-weather modeling efforts to give us the scope to assess crop potential at the field scale will also con-

Table 33. Crop yields (kg/ha) of various cropping patterns on flat and broadbed systems of planting at Kanzara village, 1980/81.

Cropping pattern	Sorghum	Sorghum fodder	Pigeonpea	Cotton
Sole sorghum (beds and Trop.[a])	1800	7290		
Sole sorghum (flat and Trop.)	2040	8120		
Cotton/pigeonpea (beds and Trop.)			20	240
Cotton/pigeonpea (flat and Trop.)			70	330
Sorghum/pigeonpea (beds and Trop.)	1450	4670	80	
Sorghum/pigeonpea (flat and Trop.)	950	4580	90	
Cotton/Borghum/pigeonpea (beds and Trop.)	180	830		210
Cotton/sorghum/pigeonpea (flat and Trop.)	240	830		210
Flat with local drill				
Cotton/pigeonpea			20	180
Traditional technology				
Sorghum/pigeonpea	430		40	
Sorghum	450			
Cotton/pigeonpea/sorghum	60		30	130

a. Tropicultor

tinue. Use of collaborative approaches in studying the soil-plant-atmosphere continuum has given us fairly satisfactory ability to predict sorghum growth and development, and we envisage further improvement and extension of our ideas to other crops.

Soil fertility and chemistry. We will give greater emphasis to studies of the behavior of nitrogen in soil, because this will assist in the interpretation of the causes of the variability of crop responses due to season and various agronomic practices. Continuation of the use of ^{15}N-labelled fertilizer will be invaluable because it allows the fertilizer nitrogen to be readily distinguished from the much larger amount of native organic nitrogen in the soil.

Land and water management. Operational testing of the broadbed-and-furrow system of land and water management on experiment stations and in on-farm situations will be intensified in Vertisol areas in the identified dependable rainfall regions in India. At ICRISAT Center, approaches for predicting the suitability of land and water management systems and their adaptation to a given topography, soil, climate, and cropping system will be explored using estimated critical limits of selected soil parameters.

Since we are still obtaining inconsistent research results in land management systems on Alfisols, we will try alternative approaches to surface configurations, with more focus on crust management, mulching, and varying intensities of primary and secondary tillage.

We will continue studies on the use of small tanks for supplemental irrigation and efforts to develop low-cost seepage control methods. Studies will also be initiated on developing suitable water lifting and recycling systems.

Our simulation and modeling efforts will continue, particularly those to define water balances more accurately and to contribute to the generation of better farming practices.

The parametric runoff prediction model RUNMOD, originally developed and extensively tested for Vertisol areas, will now be tested with data from Alfisol watersheds at ICRISAT Center and with data from AICRPDA cooperating centers where watershed-based hydrologic studies are conducted.

Our collaborative work with ICAR through AICRPDA on resource development, conservation, and utilization will now include new studies on suitable tank sealants, lifting of small quantities of water, and water recycling systems for supplementary irrigation.

Farm power and equipment. Increasing attention will be given to determining the planting parameters that affect crop establishment and crop yield.

We also hope to finalize two distinct planter and fertilizer drill designs next year. One will achieve a considerable degree of precision and will be particularly suitable for the wheeled tool carriers. The second design will be much cheaper but will still greatly improve metering and seed placement over most traditional seeding practices.

More emphasis will be given to determining the role of tillage on overall weed control and management.

Cropping systems. In the intercropping studies a major part of the work on plant population and spatial arrangement, genotypes, and legume effects is now concluded. More emphasis will be given to the effects of moisture and nutrient stress and to the role that intercropping may play in giving better control of pests and diseases. The stability studies will continue until there is sufficient data for a meaningful analysis. Comparison of different cropping systems for given soil types will be upgraded from small plot to operational-scale studies.

Weed science. Studies will continue on weed control methods appropriate to the needs of the SAT small farmer and of our crop improvement research programs.

We will design studies to control weeds in a given farming system. In planning operational research at the ICRISAT watersheds, long-term studies on the specific effects of the farming systems on weeds will be considered. Collaborative studies with the Farm Power and Equipment and Land and Water Management subprograms to develop appropriate tools and -cultural operations for weed control will be intensified, Herbicide studies will be confined to improve the overall productivity of farming systems and to control perennial weeds that are difficult to manage.

Weed management studies on farmers' fields will receive greater emphasis in the near future.

On-farm collaborative research. Our on-farm research at Aurepalle, Kanzara, and Shirapur over the past 4 years has yielded baseline data on farming systems under diverse agroecological conditions in the semi-arid tropics. We have also tested some components of the watershed-based improved technologies at these three villages for improving the crop production on Vertisols and Alfisols. This work has now been concluded.

In the coming years, emphasis will be placed on testing and refining the deep Vertisol technology in dependable rainfall areas. The ICRISAT Center experience has been that by cultivating the land immediately after the harvest of the preceding crop, by improving drainage, by dry seeding of crops ahead of onset of rainy season, and by using improved seeds and fertilizers, two crops can be grown on these soils where one is grown at present. A maize/pigeonpea intercrop has given an average of over 3.8 tonnes of foodgrain production per year without the use of irrigation over the past 5 years. We are testing this technology at Taddanpally village on a watershed of about 15.42 hectares in association with the A. P. Department of Agriculture, the All India Coordinated Dryland Agriculture Research Project, the A.P. Agricultural University, and 14 participating farmers.

The Taddanpally experiment will be used not only to verify the experience we have had at ICRISAT with regard to the technology options but also to test the ability of the delivery systems to support the demands which the improved technology will obviously place upon them. It therefore will be a test of technical and economic performance of the options in real farm conditions.

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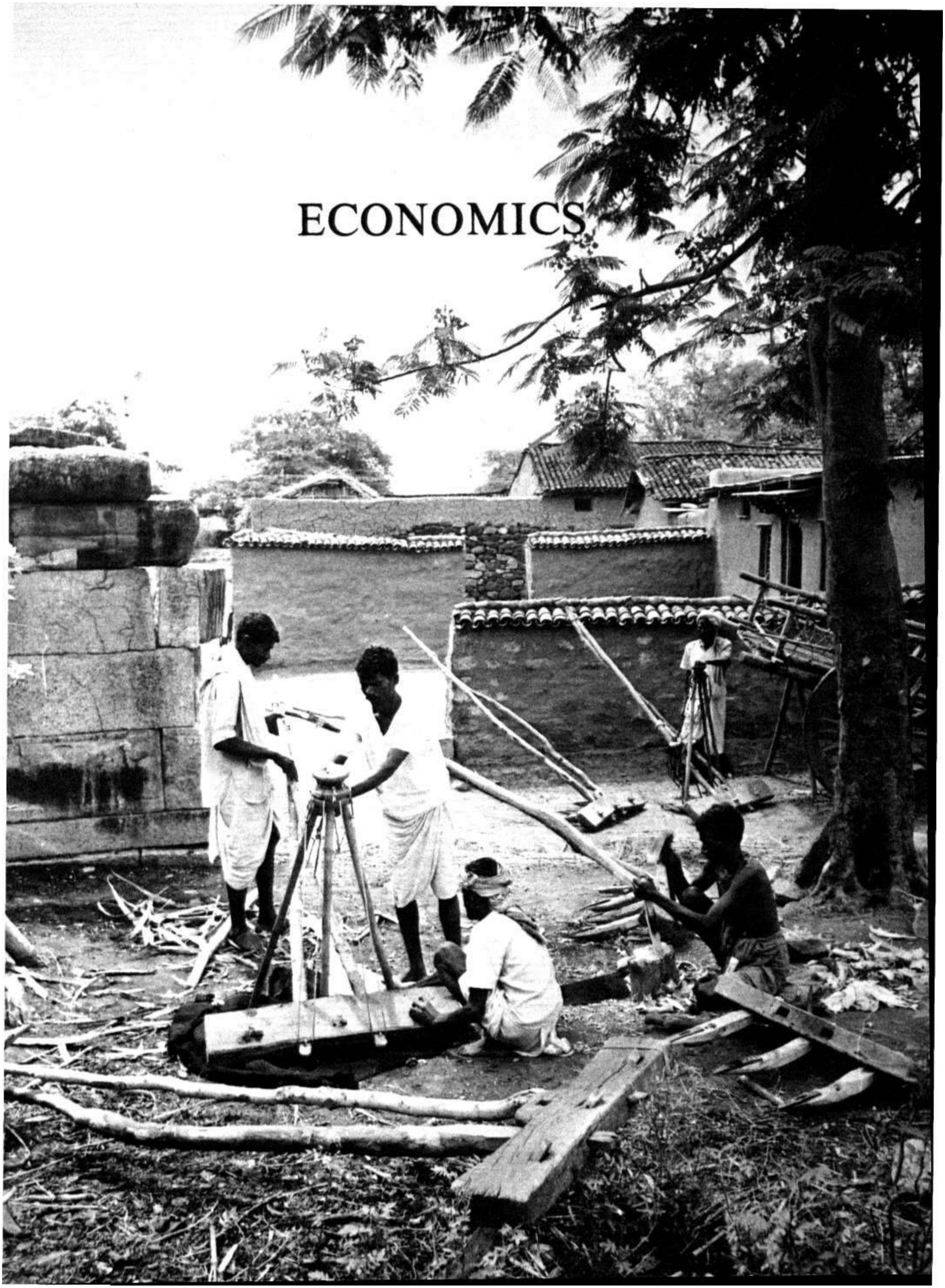
ECONOMICS



Contents

ECONOMICS

Assessment of Prospective Technologies

Review of ICRISAT Research

A comprehensive review of the accumulated evidence from 6 years of research on farming systems at ICRISAT was undertaken jointly this year by the Economics and the Farming Systems Research Programs. The objective was to identify promising components for possible transfer to farmers and/or those requiring further adaptive testing. Attempts were made to derive generalizations where possible and to identify the environments where components were expected to be viable. The results were published in Binswanger et al. (1980; listed in "Publications"), and are summarized below.

Deep Vertisols

In regions of the Indian semi-arid tropics (SAT) with medium-deep to deep Vertisols and a rainfall pattern similar to that at ICRISAT Center, it appears that crops can be successfully grown in both the rainy and the postrainy seasons. Presently, millions of hectares of such soils are left fallow in the rainy season. The important conclusions from field-scale management trials, watershed-based research, and simulation modeling at ICRISAT Center on these types of soils were as follows.

1. Cropping systems

- Intercropping of maize and pigeonpea is more profitable than maize-chickpea sequential cropping.
- Crop cover reduces cumulative and available runoff by at least 10 percentage points and more in low rainfall years; this is true for both flat cultivated and broadbed-and-furrow (BBF) watersheds.
- Crop cover greatly reduces soil erosion, often to less than one-fourth of the fallow treatment. With early vegetative cover, soil losses seem to be well within acceptable limits.

2. Bunding

- Contour bunds lead to losses in the rainy and postrainy-season crops by causing waterlogging near the bund and by loss of cultivated land. They are not necessary if rainy-season crops are grown.
- Under both cropped and fallow conditions, contour bunds reduce watershed runoff by storing it temporarily above the bunds; water may evaporate or add to groundwater recharge (in situ runoff may not be reduced).
- Well-designed and maintained contour bunds reduce watershed erosion (in situ erosion may not be reduced).

3. Broadbeds and furrows

- BBF reduce runoff under fallow conditions.
- Under cropped conditions BBF reduce cumulative and available runoff by at least 30% compared with flat cultivation.
- Under cropped conditions BBF may further reduce soil losses compared with flat cultivation, particularly if high-intensity rainfall occurs early in the rainy season.
- Under cropped conditions BBF give higher gross returns than flat planting (roughly 15%).
- Under cropped conditions BBF give higher profits than flat planting (roughly Rs 600/ha, Rs 9=US$1).
- BBF lead to savings in bullock time required for primary tillage but not in other operations, compared with flat cultivation.
- Operating within field boundaries may not

lead to substantially lower gross returns and profits for either BBF or flat cultivation.

Medium and Shallow Vertisols

There has not been as much research at ICRISAT Center on these soils as on deep Vertisols. However, the following conclusions can be made, a number of which are similar to those made for the deep Vertisols.

1. Cropping systems

• Intercropping of maize and pigeonpea is higher yielding and more profitable than maize-chickpea sequential cropping.
• Successful cropping based on residual moisture in the postrainy season is unlikely.
• Crop cover reduces cumulative and available runoff by at least 10% and by more in low-rainfall years.
• The crop cover probably reduces soil losses to acceptable levels for all soil treatments.

2. Bunding

• Contour bunds lead to substantial waterlogging losses to rainy-season crops, especially on medium Vertisols. This generalization implies that they are not necessary.
• Runoff on ICRISAT Center Vertisols is lower, the shallower the soils.

3. Broad beds and furrows

• BBF do not affect runoff and erosion significantly.
• BBF do not result in substantial yield, gross return, or profit increases.

The key difference between the results above and those for the deep Vertisols is that the BBF on medium and shallow Vertisols do not affect runoff or erosion nor do they substantially increase yields or profits. This seems to be due to the absence of serious surface and subsurface drainage problems on the medium and shallow Vertisols used for these experiments. In poorly-drained situations BBF may enhance performance and profits on the medium and shallow Vertisols. Evidently, more research is necessary to understand the differing effects of BBF on medium to shallow, compared to medium-deep and deep Vertisols.

Alfisols

The conclusions emerging from research on Alfisols at ICRISAT Center are somewhat different from those for Vertisols.

1. Bunding

• Contour bunds reduce watershed runoff (but not in situ runoff), while graded bunds do not.
• Contour bunds reduce watershed soil loss (but not in situ loss).

2. Broadbeds and furrows

• Under cropped conditions, the present BBF system usually increase cumulative or available runoff. Cumulative and available runoff are substantially higher than under flat cultivation for BBF grades between 0.4 and 0.8%.
• The present BBF system may substantially increase soil loss.
• Yields and gross returns are not substantially different for BBF compared to flat cultivation. Therefore profits are not expected to be higher for BBF compared to flat cultivation under rainfed conditions.

Water Harvesting and Supplementary Irrigation

A review of research on storing runoff for supplementary irrigation of upland crops at ICRISAT Center and data from the Sholapur research station of the All India Coordinated Research Project for Dryland Agriculture suggested the following conclusions.

1. Runoff collection

• Watershed runoff increases less than proportionately with size of catchments.
• Alfisols at ICRISAT Center have greater cumulative and available runoff than Vertisols.
• Runoff potential on ICRISAT Center deep Vertisols is higher than on medium to shallow Vertisols at Sholapur.

- On ICRISAT Center Vertisols, runoff potential increases with soil depth.
- Larger catchments have a higher potential for profitable use of runoff water.

2. Irrigation and organization

- Traditional tanks are concentrated on soils with low moisture-retention capacity and in areas with granitic subsoils.
- Traditional tanks are concentrated in low-rainfall areas and especially where postrainy-season rains are substantial.
- Existing tanks in Alfisol areas are more profitable and are better utilized than those in Vertisol areas.
- Tank construction costs per unit of stored water tend to decrease with the size of the tank.
- Gravity flow can be used in larger tanks; small dug tanks require pumping, which may increase costs.
- Larger tanks have larger ratios of settled irrigation command area to submerged area. Therefore, they probably have lower relative evaporation losses.
- Larger tanks and groups of people can be supported by administrative systems, while small ones depend more frequently on spontaneous group action.
- Supplemental irrigation from runoff collection on small watersheds is not profitable on medium and shallow Vertisols in Sholapur for postrainy-season crops.
- Supplemental irrigation from small-scale runoff collected may be profitable on Alfisols, especially if applied to high-value crops.

This study indicates that the potential benefits from storing and using runoff water on shallow Vertisols may be much lower than on medium-deep and deep Vertisols. On the latter soils runoff storage will most likely be more profitable in the postrainy than in the rainy season.

Suggested Systems for Selected Areas

This review of the research conducted by ICRISAT identified the likely components of improved farming systems in selected areas (Table 1). In drought-prone areas such as Sholapur it is doubtful if runoff collection and supplementary irrigation will be viable even on deep Vertisols. However, it may be attractive in higher rainfall zones. Before extrapolating results to the higher rainfall, rainy-season fallow zones, we require a better understanding of what are the basic causes of the extensive areas of rainy-season fallow. A study was conducted in the Economics Program to look at this question and the results are reported below.

Rainy-Season Fallowing on Vertisols

This study found that the greatest extent of rainy-season fallowing (12 million hectares) occurred in the states of Madhya Pradesh, Maharashtra, and Andhra Pradesh (Fig. 1), and most of the fallowed area consisted of deep Vertisols (Michaels 1981; listed in "Publications"). According to this study there are two zones of rainy-season fallows in India: the low-rainfall or "dry" fallow regions, and the high-rainfall or "wet" fallow ones (Fig. 2). For the precarious, low-rainfall areas in southern Maharashtra (e.g., Sholapur) where deep Vertisols have a high moisture-holding capacity, rainy-season fallowing is practiced as a means of avoiding the problems of soil preparation under extremely wet or dry conditions and of avoiding the threat of mid season drought. Where the Vertisol profiles are deep enough, growing postrainy-season crops on residual soil moisture apparently results in a successful crop more frequently than growing rainy-season crops. In northern Maharashtra (e.g., Akola), where rainfall is higher and more assured and soils are not so deep, little rainy-season fallow is practiced. Beyond another rainfall threshold, in the Vertisols of Madhya Pradesh (e.g., Raisen) postrainy-season fallow is again practiced extensively. These areas appear to have too much water for drought-resistant rainy-season crops, such as sorghum and millet, but too little for crops with high water requirements such as rice. Consequently, further along the rainfall axis into higher rainfall areas (e.g., Bastar), the degree of rainy-season fallowing again falls as rainy-season rice becomes climatically feasible.

Table 1. Suggested farming systems for selected regions and soil types.

	Sholapur (low rainfall) Deep Vertisols	Madhya Pradesh (high rainfall) Deep Vertisols	ICRISAT Center (average or medium rainfall) Deep Vertisols	ICRISAT Center (average or medium rainfall) Alfisols	Akola (average or medium rainfall) Medium to shallow Vertisols
Soil- & water-management	Broadbeds and furrows Guide bunds Land smoothing Grassed waterways Emphasis on erosion control and infiltration	Broadbeds and furrows to be tested Guide bunds Land smoothing Grassed waterways Emphasis on drainage	Broadbeds and furrows Guide bunds Land smoothing Grassed waterways	Flat cultivation, except where supplemental water is available Guide bunds Land smoothing	Guide bunds Land smoothing Grassed waterways Cultivation and tillage to be investigated
Cropping system	Rainy-season fallow (possibly short-duration low-input rainy-season crop in some years)	Potential for rainy-season cropping to be investigated	Preferably rainy-season crops with intercrops	Rainy-season crops with intercrops	Rainy-season crop with intercrop
Runoff collection for supplementary irrigation	No	Not for rainy-season crops[a]	Not for rainy-season crops	Promising for high-valued crops	Not for rainy-season crops
Supplementary irrigation from other sources	To be investigated (if water is available)				
Group action	Confined to establishment and maintenance of the soil- and water-management system				

a. Potential may be explored for collecting runoff for supplemental irrigation of postrainy-season crops.

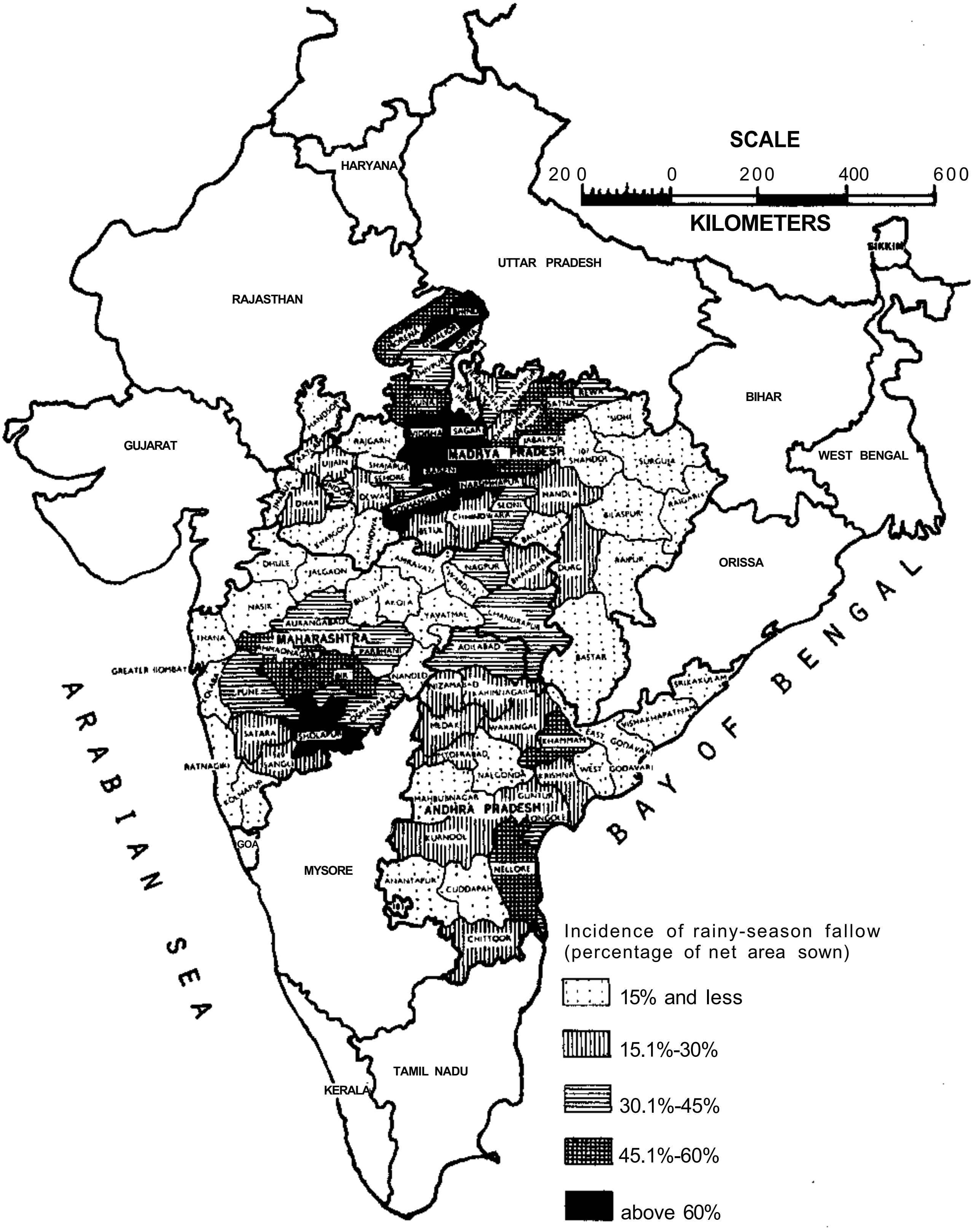


Figure 1. Extent of rainy-season fallows in three of the semi-arid tropical states of India—Andhra Pradesh, Madhya Pradesh, and Maharashtra.

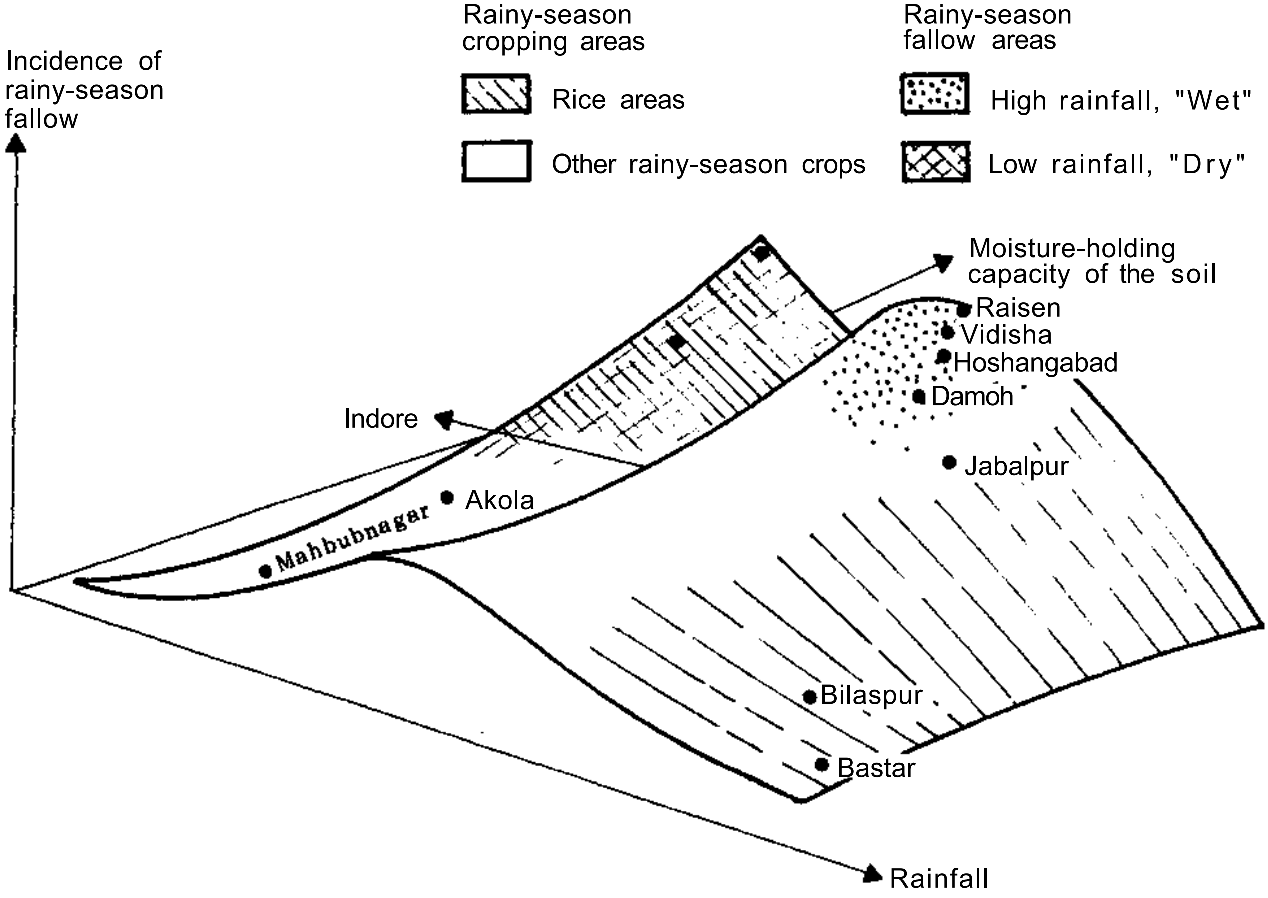


Figure 2. Incidence of rainy-season fallow as a function of moisture-holding capacity of the soil and rainfall, with approximate locations of selected districts.

Multiple-regression analyses at the district, farm, and plot levels were carried out to examine the significance of climatic, agronomic, and economic determinants on the extent of rainy-season fallowing. Analysis of district data for 1 of the 3 years shows that incidence of fallow land increased significantly with the coefficient of rainfall variation (Table 2). Higher May-June rainfall adversely affected the extent of fallowing practiced in 1972/73 (but not in the 1973/74 or 1974/75 regressions, results of which are not shown). Irrigation, soil-moisture-holding capacities, and annual rainfall were the main factors determining the incidence of fallowing. When a range of values for the determinants were substituted into the estimated regression equations and plotted, the predicted patterns were similar to those represented in Figure 2; thus the analysis supported the hypothesized relationships.

A logit model was fitted to plot data from a survey conducted for this study (Michaels 1981) in the "wet" rainy-season fallow districts of Raisen and Hoshangabad, and in the rainy-season cropping district of Dewas in Madhya Pradesh. For an individual farm plot the cropping decision at the outset of the rains is that of a binary choice: the plot will be either left fallow or cropped. The logit model allows estimation of the probabilities of rainy-season fallow, depending on various physical characteristics of the plots, environmental factors, and farm variables. The following explanatory variables were used in the logit: slope, position in the topose-

Table 2. Regression results of district-level determinants of rainy-season fallowing in India, 1972/73.

Variables	Coefficient	t-value
Dependent variable: Percent of net area sown, rainy-season fallow		
Intercept	-695.4	-1.13
Soil-moisture-holding capacity (SOIL)	4.22	1.63
Irrigation intensity (IRRIGATION)	-3.50	-1.17
Population density	-0.131	-0.66
Normal annual rainfall (RAIN)	243.4	1.29
May + June rainfall	-0.01[a]	-2.81
Relative rainy-post-rainy-season prices	0.51	0.15
SOIL x RAIN	-136.3[b]	-1.91
$(\text{RAIN})^2$	-24.59	-1.31
$(\text{RAIN})^3$	75.15	1.25
IRRIGATION x SOIL	0.04[a]	2.30
IRRIGATION x RAIN	0.34	1.21
IRRIGATION x SOIL x RAIN	-0.39[a]	-2.30
SOIL $\times(\text{RAIN})^2$	10.72[a]	2.00
SOIL $\times(\text{RAIN})^3$	-0.00014[b]	-1.80
Coefficient of rainfall variation	0.73[c]	3.30
R^2	0.54	
F	5.33[c]	

a. Significant at 95%.
b. Significant at 90%.
c. Significant at 99%.

quence, soil clay content, soil gravel content, whether irrigated in rainy or postrainy season, rotation followed, May-June rainfall, and the interaction between slope, toposequence, and clay content.

The most consistent results were for the "wet" rainy-season-fallow districts. The coefficients on the slope, clay, gravel, postrainy-season irrigation, rotation, and interaction variables emerged as significant from the asymptotic t-statistics of the logit. Presenting the results in the form of predicted probabilities of rainy-season cropping (Table 3) showed that as the gravel content in the soil increases (given the slope and clay content), the predicted probability of rainy-season cropping also increases. Also, as the percentage slope increases, the predicted probability of rainy-season cropping increases, often substantially, for each clay/gravel combination. Changes in slopes can be sufficiently large to change our expectations for rainy-season cropping on a plot. For example, for a plot with a 0.7% slope, 20 to 25% clay content, and 2 to 17% gravel content, the predicted probabilities of rainy-season cropping are fairly low. We would not expect a plot to be cropped in the rainy season in the Raisen and Hoshangabad districts under these conditions. However, for the same toposequence and clay and gravel conditions, a plot with marginally higher slope (1.2%) would have greater odds of being cropped in the rainy season.

In all cases, the response of the predicted probabilities to change in clay content was not entirely as hypothesized. The expected result was that as clay content is increased, given slope and gravel, the probability of rainy-season cropping would decline. This relationship holds initially, but is shown, by virtue of the interaction term, to turn and increase for higher values of clay content.

The final portion of this research consisted of a normative analysis of the rainy-season cropping decision in Raisen district, using discrete stochastic linear programming. It showed that it would be profitable for farmers in that district to cultivate crops in the rainy season and to even replace wheat with enterprises such as sorghum/pigeonpea intercrop. Wheat prices would have to increase substantially relative to pigeonpeas for the fallow-wheat system to be preferred to sorghum/pigeonpeas. It therefore seems that if drainage could be improved in these "wet" rainy-season-fallow areas, the prospects for replacement of the rainy-season-fallow systems with rainy-season-crop alternatives would be bright

Table 3. Predicted probabilities of rainy-season cropping on individual plots with varying slope, soil clay and gravel contents: Raisen and Hoshangabad "wet" rainy-season fallow areas in India.

Soil/clay content (%)	Soil gravel content (%) 2	7	12	17	22
			SLOPE = 0.70%		
20	0.14	0.22	0.34	0.48	0.62
30	0.12	0.20	0.31	0.45	0.59
40	0.28	0.41	0.55	0.69	0.80
50	0.62	0.75	0.84	0.91	0.95
			SLOPE = 1.20%		
20	0.81	0.88	0.98	0.96	0.98
30	0.42	0.57	0.71	0.81	0.89
40	0.48	0.62	0.75	0.84	0.91
50	0.71	0.81	0.89	0.93	0.96
			SLOPE = 1.70%		
20	0.99	1.00	1.00	1.00	1.00
30	0.80	0.88	0.98	0.96	0.98
40	0.68	0.79	0.87	0.93	0.96
50	0.78	0.86	0.92	0.95	0.97

Technology Options for Deep Vertisols in Assured Rainfall Areas

Joint research by the Farming Systems Research and Economics Programs at ICRISAT Center from 1976 to 1981 (Ryan and Sarin 1981; listed in "Publications"), has shown that an improved watershed-based technology using maize intercropped with pigeonpea can increase profits by about 600%, compared with a traditional system based on rainy-season fallow followed by postrainy-season crops of sorghum and chickpea. This improved system utilizing BBF has generated profits averaging Rs 3650/ha per year compared with a figure of only Rs 500/ha per year from the traditional system over 5 years (Table 4). These profits represent a return to land, capital, and management, as the annual costs of all human and animal labor, fertilizers, seeds, and implements have been deducted. For an extra annual cost of about Rs 1200/ha a farmer changing from the traditional system could earn an additional profit of about Rs 3100/ha. This represents a rate of return on the increased annual expenditure of about 250% — an attractive figure.

On the deep Vertisols at ICRISAT Center the data show that BBF increase profits by about 30% compared with a flat cultivation system using a maize/pigeonpea intercrop. With the maize-chickpea sequential system the BBF have a 20% profit advantage.

The improved technologies do not seem to increase risk compared with the traditional practice if we define risk as the ratio of standard deviation of profits to average profits (CV). Besides being more profitable, the improved maize/pigeonpea intercrop systems are also characterized by a lower level of profit risk (CV 21, 27%) compared with the improved maize-chickpea sequence (CV 50, 57%).

The improved technology results in a greatly increased demand for human and bullock labor. This is desirable because it will allow landless laborers and small cultivators, who rely on wage

Table 4. Economics of improved technology on deep Vertisols at ICRISAT Center: Annual averages 1976-81.

Crops	Soil and crop management	Gross returns	Costs[a] Rs/ha	Gross profits
Maize /pigeonpea intercrop	Broadbeds and furrows, HYVs,[b] chemical fertilizers, wheeled tool carrier, plant protection	5380	1730	3650 (975)[c]
Maize/pigeonpea intercrop	Flat cultivation, HYVs[b], chemical fertilizers, wheeled tool carrier,plant protection	4607	1771	2836 (606)
Maize-chickpea sequential crop	Broadbeds and furrows, HYVs,[b] chemical fertilizers, wheeled tool carrier, plant protection	5304	2241	3063 (1527)
Maize-chickpea sequential crop	Flat cultivation, HYVs[b], chemical fertilizers, wheeled tool carrier, plant protection	4811	2254	2557 (1469)
Rainy-season fallow, postrainy-season sorghum and chickpea	Flat cultivation, local varieties, farmyard manure, local implements	1083	589	494 (270)

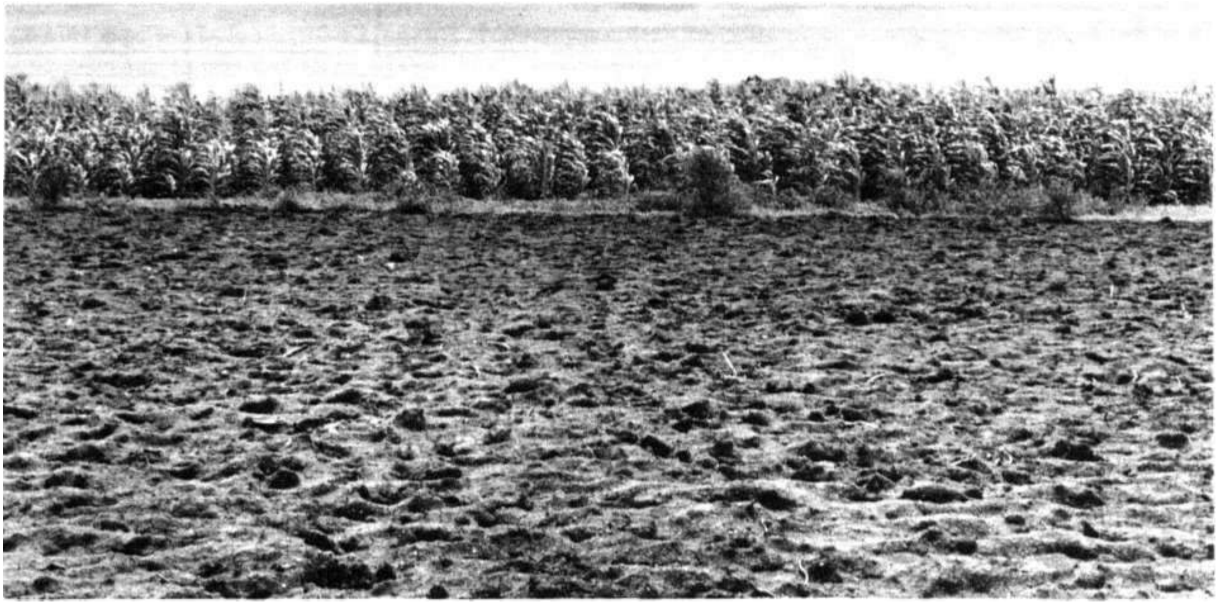
a. Costs include all materials, human and animal labor, and annual costs of implements. Although threshing costs are higher for the BBF treatments, the increased costs of land preparation and intercultivations with the flat system meant that total costs were about the same.

b. A variety of cultivars were used: maize - Deccan Hybrid 101, SB23, 51-54, Vitthal; pigeonpea - Sharada, ICP-1; chickpea - local.

c. Figures in parentheses are the standard deviations of gross profits. They are based on 15 observations for the BBF and 7 for all others.

earnings for a substantial part of their income, to share in the additional income streams that the improved technology can generate. The improved technologies can imply an increase in human labor use of more than 250%. The traditional rainy-season-fallow, postrainy-season-cropped fields at ICRISAT Center used a little more than 300 man-equivalent hours per hectare. This compares well with the figure of 268 derived from our village-level studies in the Sholapur region. The improved intercrop technologies could increase this to more than 1000 man-equivalent hours per hectare. The operations demanding increased human labor would be threshing, harvesting, weeding, and sowing. The substantial labor peaks that could result would tend to put upward pressure on agricultural wages, which could benefit laborers. However, as we have observed in some village-level studies, pressure on wages encourages selective mechanization, such as the use of threshing machines which might dampen the demand peaks.

The improved technology can augment average bullock use by 50% for an intercrop system, and by 70% for a sequential crop system. The main reasons for the increased use of bullocks are (1) the additional land preparation, including initial smoothing of fields, plowing, forming and maintaining BBF, and (2) the sowing of an additional crop in the case of the sequential system.



In foreground a farmer's field lies fallow, while his neighbor's field in background grows an extra season's crops in ICRISAT's on-farm studies. Economic analysis of operational-scale experiments at ICRISAT Center over several years showed profits from sowing an extra season on Vertisols generated more than seven times the profits of the traditional rainy-season fallow, postrainy-season cropping system.

The seasonal pattern of bullock-power utilization is substantially altered with the intercrop or double-crop system. About 70 to 80% of the bullock-power utilization occurs between February and May with the improved BBF, whereas 85% of it occurs after June with the traditional systems. As a result it is likely that the availability of fodder for animals may be more of a constraint with the improved systems, particularly in the hot season from March to May. Nonetheless, the improved systems would eventually generate increased quantities of fodder, so the major problem would occur in the initial year when the watershed is being developed using bullock power, but before additional fodder has been produced.

More on-farm research to verify these results from ICRISAT Center is required, especially in the high-rainfall (> 750 mm) zones in Madhya Pradesh, Maharashtra, and Andhra Pradesh. This research should examine technical aspects of the technology, such as alternative cropping patterns and rotations, and weed, insect, and disease problems. In addition, the capabilities and constraints operating at the farm level and with the delivery systems need to be determined. These include the availability of draft power, credit, input supplies, funds to construct community drains, markets for potential new crops, and training facilities for soil conservation and agriculture officers.

Simulation of Water Harvesting and Supplementary Irrigation Potentials

A simulation model combining rainfall runoff and crop yield/moisture stress relationships was used to evaluate the economic potential of harvesting excess runoff in small tanks for supplementary irrigation of rainy-season sorghum during periods of moisture stress (Ryan et al. 1981, Assessing the economics of water harvesting and supplementary irrigation: A simulation approach. Economics Program mimeographed

Table 5. Average net returns (Rs/ha of catchment) and areas irrigated (ha) from supplementary irrigation of sorghum at different growth stages[a].

Location/soil/land management		Growth stage: Panicle initiation	50% flowering	Green ripening
ICRISAT Center Vertisols BBF 0.4%	Net returns	-120	-53	58
	Area irrigated	0.25	1.39	1.80
ICRISAT Center Alfisols BBF 0.4%	Net returns	-62	77	304
	Area irrigated	0.74	3.58	4.22
Sholapur Vertisols Flat	Net returns	-67	-1	217
	Area irrigated	0.68	2.42	3.76

a. Assumes farmers on the 12-ha watershed share the costs of the tank, pump, and pipes, and a sorghum price of Rs 1.5/kg. It is also assumed that the effect of stress on yield at any stage is independent of stress in other stages.

paper). The model was used for ICRISAT Center Alfisols and Vertisols, and for Sholapur Vertisols assuming a 12-ha watershed and a 20-ha cm sealed tank.

In general, the joint probabilities of stress and availability of stored runoff are likely to be higher at the grain ripening stage for all locations and under various land treatments. Thus, for rainy-season sorghum it may be advisable to save harvested runoff for the later growth stages, thereby irrigating a larger area of crop and also obtaining greater yield and profit increases (Table 5).

Alfisols offer much better prospects of earning profits from this type of technology than Vertisols, although even on Alfisols the net profits from the investments of more than Rs 17 000/ 12-ha watershed are not very attractive. In more than half the years the sorghum crop would be under no stress and could not benefit from irrigation even though the tanks would be almost full (Table 6). In contrast, on Vertisols there would be no stress for more than 2 of every 3 years. In such situations the tank would be more than half full. Averaged out, the frequency of this situation reduces the payoffs obtainable from the occasions when there is stress and stored runoff water is available.

Table 6. Average amount of stored water in the tank in years when stress does not exceed critical levels at ICRISAT Center, using BBF at 0.4%.

Growth stage	Vertisols	Alfisols
Panicle initiation		
Water available (ha cm)	11.2	18.1
% years of no stress	84	89
50% flowering		
Water available (ha cm)	13.6	19.2
% years of no stress	77	63
Grain ripening		
Water available (ha cm)	12.9	19.4
% years of no stress	67	53

These results suggest that it would be difficult to justify water harvesting and supplementary irrigation for rainy-season, low-value upland crops like soghum alone. Consideration will have to be given to changes in cropping patterns along with the introduction of the water harvesting technology so that the water can be used more frequently than only for "life-saving irrigations" of traditional upland crops. More research on these questions is under way.

Impact of Machine Threshing and Implications for Technology Development

Should research institutions in the public sector invest scarce resources in the evaluation and design of threshing technologies for the SAT of India? This multifaceted question was partially addressed in a study on the village-level consequences of mechanical threshing (Walker and Kshirsagar 1981, Economics Program progress report 27). The research focused on the prospects for and impact of mechanically threshing rainfed sorghum.

The study relied on ICRISAT Village-Level Study (VLS) data that are ideally suited for impact analysis because they can furnish a "before and after" evaluation along with a "with and without" comparison. Moreover, the time-series nature of the VLS allows an in-depth monitoring of the employment effects of new technologies.

Because of few confounding effects, Kanzara village in Akola district offered an excellent vantage point to evaluate the impact of mechanical threshing. The first thresher was introduced into the village in 1976. By 1980 five threshers, owned mostly by large farmers, had been purchased. In 1979/80, two threshers operated in Kanzara, and the others did contract work outside the village.

Mechanical threshing rapidly displaced traditional methods in Kanzara (Table 7). By 1979/80, all 30 farm households in the VLS sample had hired mechanical threshers to thresh at least a part of their produce. The data in Table 7 also suggest that mechanical threshing has not completely dominated traditional techniques: many farmers in 1979/80 reverted to traditional techniques.

The most salient feature of mechanical threshing in Kanzara is the rate structure that owners of threshers have adopted to promote increased utilization of thresher capacity. For sorghum and wheat, regardless of the size of output, they retain 4% of production as a payment for threshing.

The results from this study strongly suggest that the introduction and widespread diffusion of machine threshing in Kanzara did not significantly reduce costs, increase cropping intensity, or displace labor. These findings must be placed in perspective, as the results from one impact study in one village cannot be expected to apply to all of SAT India. But they do provide a reference point for analysis of the likely consequences

Table 7. Method of threshing hybrid sorghum (CSH-1) and local sorghum on sample farms in Kanzara.

Method of threshing	Crop year				
	1975/76	1976/77	1977/78	1978/79	1979/80
			% of output		
Hybrid					
Hand	18	1	16	1	0
Bullock	82	29	3	0	7
Machine	0	71	82	99	93
Output (kg)	14 243	20 224	19 867	9412	16 800
Local					
Hand	28	14	14	17	27
Bullock	72	27	4	17	21
Machine	0	59	82	*66*	52
Output (kg)	14 353	12 865	5494	5346	8067

Traditional hand threshing (right) and animal threshing are gradually being replaced by mechanical threshers in VLS villages. However, in one study village they did not significantly reduce costs or increase cropping intensity.

of machine threshing in other socioeconomic and agroclimatic settings.

One major finding that is widely applicable is that a diversified output mix limits the scope for and conditions the impact of mechanical threshing technologies in SAT India. Crop diversity and low production encourage machine hiring, as few farmers have enough produce to afford a large investment like a thresher. Based on our calculations, two machines of current vintage can profitably thresh all the sorghum and wheat produced in the village. Addition of a third thresher makes mechanical threshing a far less attractive investment opportunity—the expected rate of return for each machine owned for custom hiring drops from 30 to 13%.

Although we usually think that mechanical threshing is an apt example of selective mechanization, machine threshing in Kanzara was anything but selective in terms of access to technology. Hiring out and the need for high rates of machine utilization to make ownership profitable made mechanical threshing readily available to all farmers in the village. Under such conditions, mechanical threshing based on custom hiring may respond particularly to the needs of small farmers who do not own bullocks or who have limited access to draft power.

Seasonality in labor demand did not appear to explain the higher use of machine threshing for earlier maturing hybrids. Expectation of postharvest damage from October rainfall probably explained why machine threshing was favored for hybrids, but we could not find convincing evidence that timely machine threshing directly led to reduced postharvest losses.

The marked decrease in labor hiring for threshing between 1975/76 and 1978/79 is yet another indication of the speed with which mechanical harvesting technology diffused throughout the village (Table 8). The number of observations where members of the VLS landless labor and small-farmer households were hired for postharvest work, mainly sorghum

Table 8. Frequency of postharvest labor[a] in the VLS sample in Kanzara from 1975/76 to 1978/79.[b]

Crop year	Labor observations	
	Male	Female
1975/76	30	10
1976/77	33	7
1977/78	17	12
1978/79	2	0

a. Postharvest operations include drying, threshing, winnowing, and cleaning.
b. Data on time allocation by operation were not collected for 1979/80.

threshing, totaled 40 in 1975/76. By 1978/79 only two observations of labor hired for post-harvest threshing were recorded in the VLS sample.

Nonetheless, a buoyant male labor market in Kanzara insulated daily workers from the potential labor-displacing effects of mechanical threshing. Daily agricultural workers who threshed sorghum during the introduction and diffusion of machine threshers in 1976/77 and 1977/78 experienced significantly higher rates of unemployment than in 1975/76, but they were able to find alternative employment in 1978/79. Because cotton is the principal crop in Kanzara, we should not expect that machine threshing of sorghum will cause a high level of labor displacement. This benign expectation may not hold for rainy-season fallow, postrainy-season sorghum areas, nor would it apply to new multicrop machines capable of threshing grain legumes that traditionally require a large amount of female labor in the threshing operation.

Likewise, we could not attribute an increase in cropping intensity to mechanical threshers. Increased sequential cropping is not documented in either before-and-after or with-and-without comparisons. For other areas of the SAT, the argument that machine threshers may break labor bottlenecks that constrain multiple cropping may still apply, but the validity of the argument is diminished by the multiplicity of cropping patterns in dryland agriculture.

Our results show that mechanical threshers have not significantly reduced threshing costs. Certainly, the 4% in-kind fee charged by thresher owners has not been exorbitant, but the spatial oligopsony nature of the village threshing market suggests that the cost-reducing potential of mechanical threshing has only partially been realized. The dynamics of diffusion of mechanical threshers point to the same conclusion. The 4% price of mechanical threshing has not changed—even with the gradual entry of more machines—in the past 6 years in Kanzara.

With present levels of cereal production in SAT India, only a few machines per village are economically feasible. A few machines per village do not lead to competitive pricing. Under these conditions, it is questionable whether potential benefits from reduced costs due to new threshing technologies will be passed on to producers and consumers. There should be less problematic investment alternatives than mechanical threshing research and development to directly increase production in SAT India.

Yield Gap Analysis

Two studies were completed on yield gap analysis using data from the VLS. The first study utilized budgeting techniques on the major cropping systems in three regions (Sarin and Binswanger 1980, Economics Program progress report 12) to examine the value of the IRRI methodology. Our concern was primarily with Gap II—the difference between potential and actual farm yields. Unlike IRRI, we do not deal with one sole crop grown generally under flooded conditions such as rice, but have a number of intercrops grown under uncertain rainfall conditions; therefore yield per se has no meaning. Hence we rely on gross and net returns in Rs/ha to assess performance gaps (Table 9).

Results for Akola, a fairly assured rainfall region oriented to cash crops, show that farmers' costs are substantial but a little less than when improved technology is used. The gap for high-yielding varieties of sorghum is only 20%, while for the intercrop comparisons farmers' returns are two-thirds less than those of the improved system. In both Mahbubnagar and Sholapur, farmers used far less material inputs (mainly fertilizers) than in the improved system, and their output consequently was more than 75% less.

Although the above data were not explicitly derived for undertaking gap analysis, they do suggest that the large gaps between farmers' output levels and those from improved technologies in village fields may be associated with variety and fertilizer differences.

Gap II can be divided into two components: (1) that caused by biological constraints, and (2) that caused by socioeconomic constraints. To endeavor to separate these two determinants, whole-farm linear risk programming was used

Table 9. Gross returns, variable costs, and gross return gaps from different cropping systems under improved and farmers' management.[a]

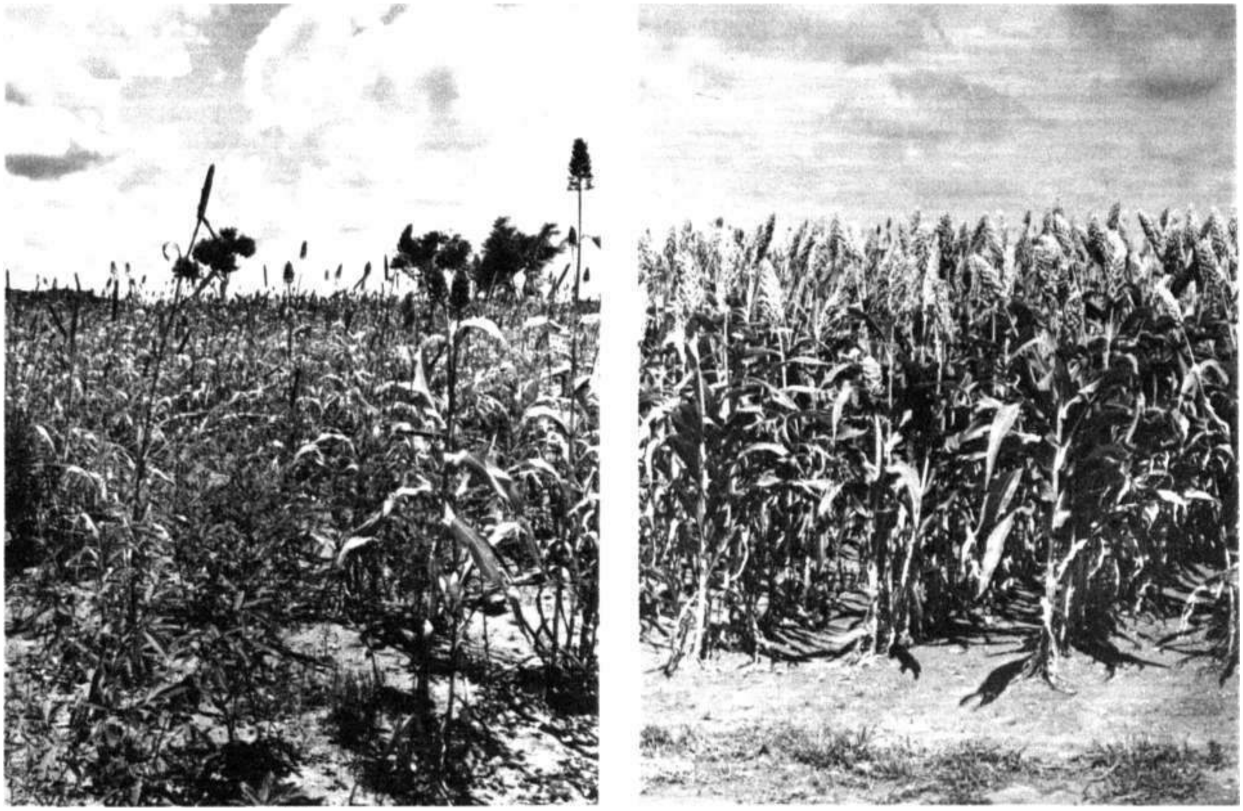
Region/soil	Cropping systems	Gross returns	Total variable cost Rs/ha	Gross returns Gap II
Mahbubnagar (Aurepaile) Alfisols				
Improved village plots[b]	Castor sole (HYV)	1316	773	
Farmers' plots[c]	Castor sole (Local)	326	339	990 (75)[d]
Improved village plots[b]	Pigeonpea intercropped with sorghum (HYV)	3086	775	
Farmers' plots[c]	Sorghum mixtures (Local)	421	248	2665 (88)
Akola (Kanzara) Medium-deep Vertisols				
Improved village plots[b]	Sorghum (HYV)	1788	765	
Farmers' plots[c]	Sorghum (HYV)	1425	562	363 (20)
Improved village plots[b]	Pigeonpea intercropped with sorghum (HYV)	2042	829	
Farmers' plots[c]	Cotton (Local) + sorghum (Local) + pigeonpea (Local)	701	768	1341 (66)
Sholapur (Shirapur) Deep Vertisols				
Improved village plots[b]	Sorghum postrainy season (HYV)	1606	1080	
Farmers' plots[c]	Sorghum postrainy season (Local)	396	260	1210 (75)
Improved village plots[b]	Pigeonpea (HYV)	3806	1123	
Farmers' piots[c]	Pigeonpea (Local)	282	88	3524 (93)

a. Prices are the same for all locations.
b. Improved plot data refer to 1978/79.
c. Farmers' data are from large samples for the years 1975/76 and 1976/77.
d. Figures in parentheses are percentage differences.

(Ghodake 1981; Economics Program progress report 24). This technique is particularly suited to the analysis of yield gaps in rainfed SAT agriculture where risk, intercropping, and rotational complexities lead to numerous production alternatives that are difficult to assess using partial budgeting.

Using data from the VLS village of Kanzara in the Akola district of Maharashtra, 27 possible crop production activities were defined, along with labor-hiring and credit activities. Fourteen constraints were imposed, including land, labor, credit, and risk aversion. The programming routine maximizes profits subject to these constraints. By relaxing these constraints one can evaluate their impact on returns and hence their contribution to "gaps."

The gap between present gross returns per. hectare achieved by farmers in Akola and the potential gross return if farmers were technically and allocatively efficient, had no capital and labor constraints, and were not averse to risk,



Farmers' fields under traditional management, left, and improved technology. Yield-gap analysis in the VLS villages suggested that lack of capital (for fertilizers, pesticides, improved cultivars, etc.) and technical advice were the major constraints preventing farmers from achieving higher and more profitable yields.

was around 75% (Table 10). Capital was the most important single constraint, contributing more than 50% of the gap, particularly on smaller farms. Lack of technical efficiency explains most of the remainder of the gap and is more important on large farms. Risk aversion is only significant on small farms, but it does not explain more than 15% of their gap.

These results suggest that mathematical programming can be used effectively to identify the causes of gaps in output between what is feasible on farms and what is currently practiced. In the case of the farmers in Akola district, our results indicate that capital is the major constraint, along with extension and management expertise required to improve technical efficiency. These support the conclusions of Sarin and Binswanger that fertilizers (which require capital) and varietal improvements (which are technical innovations) were the major contributors to yield gaps in all six VLS villages.

Yield Risk and Genotype Selection

A methodology was developed to evaluate genotype performance in multilocation and multiyear trials, (Binswanger and Barah 1980, listed in "Publications"). This approach is based on the distinction between stability and adaptability. A genotype is said to be "stable" if at a given location its yield varies little from year to year; it is "adaptable" if its yield on average over years varies little across locations. Traditional approaches to stability analysis do not distinguish between time and location dimensions of environmental differences.

Table 10. Partition of yield[a] gap (%) into various components on different size farms in Akola region.

Source of gap	Farm size: Small, Gross returns	Small, Net returns	Medium, Gross returns	Medium, Net returns	Large, Gross returns	Large, Net returns
Technical	31	31	33	34	50	48
Allocative inefficiency	-3[b]	1	6	11	-4[b]	6
Capital constraints	59	53	61	55	48	40
Labor constraints	0	0	0	0	2	2
Risk aversion	13	15	0	0	4	4
Potential percent gap	73	78	75	80	72	78

a. Output gap due to each source is measured as a percentage of the potential gap.
b. Negative sign of gross return gap on small and large farms does not indicate negative contribution of allocative inefficiency; the absolute value indicates allocative inefficiency.

Stability relates to risk, and it can be evaluated through a choice-theoretic framework that can unambiguously rank genotypes by incorporating information on farmers' attitudes towards risk. The two principal features of the choice-theoretic framework are highlighted in Figure 3.

First, it is assumed that a farmer has a preference or utility function that relates his level of satisfaction to the expected yield of a genotype and its variability. Various combinations of expected yield and standard deviation can lead to the same level of satisfaction (utility). In Figure 3 one such combination is P_1R_1. Because individuals display a preference for lower variability and higher yields, the utility level associated with P_4R_4 is the highest among the four iso-utility lines. Farmers attempt to choose the genotype (designated by lettes A to K in Figure 3) that allows them to reach the iso-utility line that lies the farthest in the direction of the arrows to the lower right corner of Figure 3, i.e., the genotype that allows them to obtain the highest yields with least variability.

Secondly, the assumption that farmers are averse to yield variability facilitates the evaluation procedure. One only has to consider those genotypes that lie on the risk-efficiency frontier connecting K, F, C, B, and A. A risk-averse decision maker who hates to lose more than he likes to gain would prefer genotype D over H because it achieves a higher yield with equal standard deviation. A genotype is risk-efficient if no other genotype in the tested set can achieve the same average yield with lower standard deviation or the same standard deviation with higher average yield. Choice among the risk-efficient

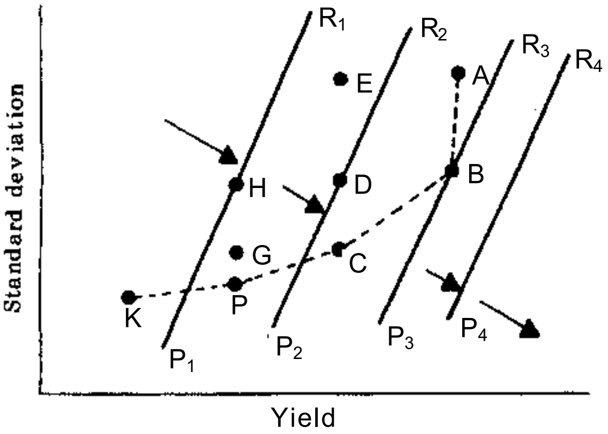


Figure 3. Risk aversion and preference-based choice in genotype selection.

genotypes along the broken line in Figure 3 depends on the slope of the iso-utility lines (the PR lines) that map the tradeoff preferred by the farmer between expected yield and variability.

The slope of the PR lines had earlier been estimated in a series of psychological experiments (Binswanger 1980) where it was found that the slope (Δ standard deviation/Δ yield) lies close to 2.0 for semi-arid tropical farmers of Maharashtra and Andhra Pradesh. For a value of 2.0, genotype B would be the preferred choice in Figure 3.

An additive model of crop yields was used to estimate the components of genotype yield. Variability was partitioned by analysis of variance techniques into stability and adaptability components. The stability component is made up of the variance of average time effects across locations and the variance of the residual x time interaction, after the location-genotype interaction is accounted for.

A similar procedure was used for selecting adaptability-efficient genotypes. The variance of average crop yield (over years) across locations was estimated for the additive model, but, unlike the stability analysis, criteria for choice among genotypes are not proposed in the adaptability-efficient set. Optimal choice can only be arrived at through a comparison of the costs and potential for the success of different breeding strategies.

With these procedures, conclusions about stability and adaptability apply only to agroclimatic zones similar to the ones in which the multilocation trials were initially conducted. Conclusions that are not nursery- or region-specific, should be based on physiological/ structural models in which characteristics, such as drought tolerance, photoperiod insensitivity, or disease and pest resistance are specifically identified. This study recommends regression analysis on plant-independent variables as a suitable approach to such structural identification.

The choice-theoretic framework was tested with data from the All India Coordinated Sorghum Improvement Project (Barah et al. 1981, listed in "Publications"). Trial data from a balanced set of five hybrids and six varieties were chosen over 18 locations from 1971 to 1974. Management practices included a uniform fertilizer dose of 80 kg N, 40 kg P_2O_5, and 40 kg K_2O, early sowing, and plant protection.

For this particular data set, three varieties and two hybrids were risk efficient. Hybrid CSH-5 was the preferred genotype for varying levels of risk aversion, and it was also the highest yielding. Genotype rankings based on risk preferences and yield were highly correlated. Moreover, single-year data predicted adaptability and stability fairly well, and most members of the stability-efficient set also belonged to the adaptability-efficient group. Further analysis is required to determine whether these conclusions hold for genotypes tested in lower fertility and less protected environments.

Organization of Wells for Irrigation

A study of the organization and management of open wells in three of the VLS villages was conducted to test the hypothesis that farmers would prefer individual ownership of small supplementary irrigation sources (Doherty et al. 1981, listed in "Publications").

Seven respondents in Aurepalle, two in Shirapur, and three in Kanzara were found to share,or hold sole ownership of, more than one well. Differences in cropping patterns, soils, and subsurface geology are likely to have influenced the patterns of well ownership in the three villages. The overall high incidence of well ownership in these three villages is striking, reaching 48% of the entire VLS sample in Aurepalle and 43% in Shirapur. At the time of the study, wells were the primary source of irrigation in these villages.

The average numbers of owners per well and the average numbers of active owners per well who irrigated in the postrainy season of 1979/80 suggest that small groups do form themselves around these organizationally independent sources of supplementary water (Table 11). Many wells have been under shared ownership for several generations; most changes in owner-

Table 11. Shared ownership and use of wells among respondents in six SAT Indian villages, 1979/80.

Type of ownership	Aure-palle	Shirapur	Kanzara
Owners per active well	2.4	4.8	1.0
Active owners per active shared well	2.7	4.5	0
Active wells with shared ownership	12	10	0
% of active wells with shared ownership	71	83	0
Owners per active pump	1.4	3.5	0.7

ship seem to occur through inheritance. Pumps are also owned in common.

The natural agricultural environment appears to be a key determinant of common well ownership. The highest average number of owners per active well (4.8), and the highest average number of irrigating farmers per active, shared well (4.5) are found in Shirapur, where rainfall is the least dependable. Shirapur also has the highest shared ownership per pump (3.5). Although Shirapur's deep Vertisols have a high moisture-retention capacity, farmers still want wells and own them in common. The second largest average number of owners per well and of active irrigators are in Aurepalle, where the moisture environment for crops is also rather undependable, due to the rainfall pattern and shallow soils. In Kanzara there are no instances of shared ownership among the 16 sample wells. Among the three villages Kanzara has the highest and most dependable rainfall. Its soils are Vertisols, mostly medium to shallow except along the major water courses. On the shallow soils aquifers are generally poor. Under such conditions there would seem to be less incentive for well construction. One hypothesis in line with these data from the three villages would be that although small groups of owners form and persist around these wells, shared ownership is not easy to handle organizationally and it may be uncommon unless there are no attractive alternatives.

Water control systems and the degrees and kinds of interaction among farmers were also investigated. These systems minimize interaction among the owners. Farmers do not meet to confer together to consider the season as a whole, or to devise ways to increase the productivity of their shared water resources. On the contrary the systems assure that the rights of each individual operate automatically by invariant principles. For example, in Aurepalle there is a de facto upper limit on the area one can irrigate, and in times of drought all pumps must be turned on and off at the same time. In Shirapur rights to water from wells are reckoned in terms of days. For one day's share, one is entitled to as much water as the well will yield from sunset to sunset.

The behavior of the VLS sample farmers who share rights to wells in Aurepalle and in Shirapur contradicts our earlier hypothesis that farmers would prefer individual ownership of small supplementary irrigation sources. The systems of cooperation followed by farmers who share rights to wells in Aurepalle and Shirapur are clearly rule-based. Farmers who obtain access to a well need not worry about what the rules will be. On the other hand, decision-based interaction, in which one person's decisions on cropping pattern or irrigation timing might affect his neighbor's crop, is carefully excluded by custom regarding shared ownership and use of wells. We suggest that such rule-based activity is suitable for small or large groups, even though the larger group ultimately must sustain and sanction it.

Thus, we have revised our hypothesis to state that farmers would prefer small sources of irrigation water such as runoff-collection ponds on small watersheds to be individually owned, unless simple rules for the distribution of water could be specified, such that interaction and common decision-making among owners would be reduced to a minimum.

Pigeonpea Consumption and Marketing

A study of pigeonpea consumption in the six VLS villages revealed that pigeonpea was the preferred pulse (Bidinger and Nag 1981; listed in "Publications*'). For children aged 1 to 6 years pigeonpeas comprised between 43 and 85% of their pulse consumption, the former figure representing Kanzara and the latter Dokur. The dietary protein supplied by pulses in these villages for the 1976-78 period was only 11% of total protein, with a range of 6 to 18%. Pigeonpea supplied between 3.4 and 9.7% of the protein and between 6.2 and 21.7% of the lysine. These results partially confirm the declining trends in the importance of pigeonpea consumption documented in the national statistics, which in 1971-75 showed that pulses contributed only 22% of total protein.

Large farm families generally consumed greater amounts of pigeonpeas per caput than small farm and landless families and, with the exception of Dokur, adults consumed more than children. However, in these villages children tend to be fed more pulses relative to cereals than is the case with adults (Table 12). All cereal:pulse ratios are far in excess of those recommended by the National Institute of Nutrition in India, which encourages a 3:1 ratio for very young children, 5:1 for women, and 6:1 for men. There did not appear to be any seasonal variation in pulse consumption.

Table 12. Relative cereal and pulse consumption by village and age group.

Village	1 to 6-year-olds	7 to 18-year-olds	Adults
	Cereals (g) : pulses (g)		
Aurepalle	31:1	35:1	37:1
Dokur	23:1	31:1	42:1
Shirapur	15:1	14:1	17:1
Kalman	14:1	18:1	20:1
Kanzara	7:1	9:1	10:1
Kinkheda	9:1	10:1	10:1

A study on pigeonpea marketing found that the crop is widely grown and consumed in India, the world's largest producer (von Oppen 1981; listed in "Publications"). In the past two decades there has been a shift in pigeonpea production from the north of India to the north-central and southern states. About 35% of the quantity produced enters primary wholesale markets, while 65% is retained on the farm. Pigeonpea producers and consumers respond to price changes and the grain moves over much longer distances in trade from primary markets than do coarse cereals.

Tenancy, Crop Choice, and Input Use

A study was conducted to determine (1) the effect of household resource endowments on the extent of leasing of land, (2) whether tenants have a greater preference for relatively more risky cropping patterns than owner-operators, and (3) if sharecroppers use lower input intensities compared to owner-operators (Pant, 1981, Economics Program progress report 20).

It was found that households with relatively more bullocks tended to lease in more land. This lends support to earlier conclusions that there is an imperfectly functioning market for bullock-hire services in these SAT Indian villages (Jodha, 1980, Economics Program progress report 17). From the regression analysis the coefficients on the bullock value variable imply that an extra bullock pair valued at Rs 2000 would permit Mahbubnagar households to cultivate an additional 1 ha of land (Table 13). In Sholapur and Akola districts the comparable figure is about 3 ha. Since many households may be leasing out their land because they do not possess adequate draft animal labor, it is likely that land reform measures that provide only land to the landless may not succeed unless supplementary measures to provide inputs such as bullocks are simultaneously introduced.

Households owning more land lease in relatively less land when we hold other factors constant. Thus land leasing brings into closer

Table 13. The effect of resource endowment on tenancy in VLS villages in India: estimated coefficients of the regression equation explaining net leased-in area per household.

	Independent variables					
District	Area of land owned (ha)	Value of bullocks owned (Rs)	No. of workers	Dependent worker ratio	R^2	No. of observations
Mahbubnagar	-0.2	4.0×10^{-4}	9.3×10^{-2}	5.7×10^{-2}	0.23	135
	(-6.5)[a,b]	(3.0)[a]	(1.0)	(0.3)		
Sholapur	-0.3	15.0×10^{-4}	-7.3×10^{-2}	-67.6×10^{-2}	0.20	129
	(-3.2)[a]	(5.3)[a]	(-0.4)	(-1.8)[c]		
Akola	-0.2	12.6×10^{-4}	-3.0×10^{-2}	-17.4×10^{-2}	0.13	121
	(-3.7)[a]	(4.6)[a]	(-0.2)	(-0.7)		

a. Denotes t is significant at 95% level.
b. Numbers in parentheses refer to computed t-values.
c. Denotes t is significant at 90% level.

alignment the household's endowments of land and labor resources. Neither the number of family workers in a household nor the composition of the household in terms of the ratio of dependents to workers was found to influence the extent of land leasing in general.

Analysis of the determinants of cropping patterns showed that there was no tendency for sharecroppers to devote more land to drought-sensitive (risky) crops such as paddy, wheat, maize, groundnut, sesamum, mustard, linseed, cotton, sugarcane, and vegetables. The extent of irrigation available was the major factor explaining the cultivation of these crops, the relationship being positive.

Examination of input use differences on sharecropped and owner-operated plots in the Sholapur villages revealed that there were no significant differences in the use of seeds, irrigation, and manure, but the use of labor (human and bullock) may be greater on owner-operated lands. However, factors other than tenancy, such as the ownership of bullocks, the availability of family labor, or the allocation of land to drought-sensitive crops, seem to be more important determinants of input-use differences.

Since tenancy (particularly sharecropping) does not appear to lead to a less intensive use of inputs compared to owner-operated land in these villages, this argument against tenancy may be invalid. It ignores the wide diversity in the terms and conditions in sharecropping contracts that ensure intensive use of inputs by sharecroppers. Tenancy also has other advantages as mentioned earlier, such as allowing a household to adjust its operated land area to its endowment of draft bullock power in the context of imperfectly functioning draft power markets.

Looking Ahead

We plan to initiate a study of the economics of small upland ponds versus traditional lowland paddy tanks in Alfisol areas of South India. The net effects on production, profits, employment, and equity of diverting runoff into the small upland tanks for supplementary irrigation of upland crops, instead of using it for flood irrigation of paddy, will be studied. A study of the economics of alternative supplementary irrigation decision rules for upland crops, involving choice of crops, timing, frequency, and amounts of irrigation will also be initiated.

We will work with the Farming Systems Research Program on further on-farm verification and testing of the technology options for deep Vertisols in high and assured rainfall areas of India in the coming years. This will be done in collaboration with national programs in selected pilot projects.

Further work on risk will focus on ascertaining farmers' perceptions of the risks they face. Previously we concentrated on measurement of the extent of risk and of risk attitudes. Risk perceptions are important to understand because they have implications for price policies and technology adoption.

We will analyze the level, distribution, and variance of family and per caput incomes using the large body of accumulated time-series and cross-section data from the village studies.

A study of the extent and causes of crop failure will be completed using our village studies data.

A conference on marketing in the semi-arid tropics is being planned, involving the markets for inputs as well as outputs. We also hope to initiate a small in-service training program for economists working in national agricultural research programs in the SAT.

Publications

Institute Publications

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INTERNATIONAL COOPERATION

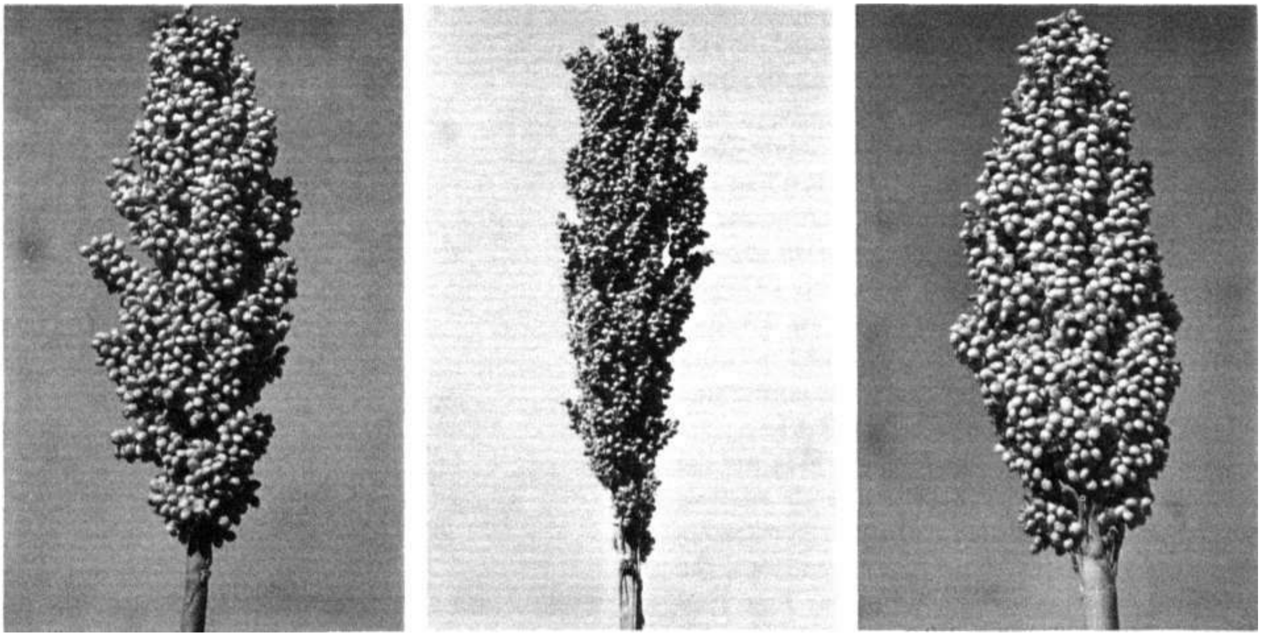
Contents

INTERNATIONAL COOPERATION

Our cooperative program in Africa entered a new phase in the period covered by this Annual Report (June 1980-Dec 1981) with full acknowledgement of the long-term commitment required to ensure continuity in agricultural research by creation of several new core positions in Africa. In the 1980 financial year, four core positions were created and the position of second economist was filled. In 1981, another four core positions were created and the positions of millet pathologist and agronomist were filled.

Considerable progress was made with plans to establish an ICRISAT Sahelian Center at Sadore, near Niamey, in Niger. An agreement was signed between UNDP (on behalf of ICRISAT) and the Government of Niger for the establishment of the Center. With the full support of the Government of Niger a 500-ha site was located and demarcated and preliminary soil, vegetation, and water surveys were carried out. National organizations, including the National Agricultural Research Institute of Niger (INRAN), the Food and Agriculture Organization (FAO), and the International Livestock Center for Africa (ILCA), assisted in the preliminary work. Staff core positions at the Center were filled beginning in the middle of the year, and a preliminary program of research was initiated, mainly on the millet crop.

Phase 11 of the UNDP-funded special project on improvement of the sorghum and millet crops



Two sorghum germplasm lines and a selection (IS-3541, IS-9302, and E 35-1) with good adaptation and high yield potential widely used in sorghum breeding programs in Africa.

was completed in October after a review of the program. Phase III was initiated in November 1981 with a small reduction in the complement of scientists—the cereal entomology position in Senegal and the cereal pathology positions in Nigeria and Upper Volta were phased out. All four positions under the Organization for African Unity/Semi-Arid Food Grain Research and Development (OUA/SAFGRAD) project were filled, and work continued on *Striga* under an agreement with the International Development Research Centre (IDRC).

A new initiative was taken with the appointment of a socioanthropologist to assist the team at Kamboinse in Upper Volta under an agreement with IDRC for strengthening the input into the economics program, with particular reference to socioeconomic constraints to adoption of new technology. In early 1980, the ICRISAT sorghum breeder located in Tanzania under a subcontract with the International Institute of Tropical Agriculture/US Agency for International Development (IITA/ USAID) returned to ICRISAT Center, but continued to assist with consultancy visits. The USAID-funded Mali program was reviewed and approved for continuation of funding.

The in-house review of the African Programs was held at Dakar from 26 to 28 February 1981. Our staff participated in the Annual OAU/ SAFGRAD Workshop held at Gaborone, Botswana, from 16 to 20 March 1981.

We were extremely sorry to lose Claude Charreau who returned to ORSTOM/IRAT in late 1981. He had been the Regional Coordinator for ICRISAT's West African Program on deputation from ORSTOM/IRAT since July 1975 and had contributed immeasurably to the development and functioning of the ICRISAT network in West Africa. We acknowledge the continuing support accorded by ORSTOM/IRAT.

Because of different cropping periods and the need for additional time for research analysis and for communications and other constraints on our scientists in the African countries, the following report covers the crop year June 1980 through May 1981. The crop year in Africa constitutes a single growing season starting around June when the rains begin in most of the countries being reported. The dry season (off season) begins after the rains have ceased.

Upper Volta

Our research team located at Kamboinse in Upper Volta intensified its efforts on sorghum and pearl millet improvement in the 1980 growing season. An important step forward was the multiplication of E-35-1, a cultivar introduced and tested by our sorghum breeding program, by the Upper Volta seed multiplication service for extensive testing in 1981.

Sorghum Breeding

A major focus of our sorghum breeding effort in Upper Volta has been to study the potentials and limitations of locally-adapted lines and the utility of introduced improved lines under local con-

These tall, low-yielding local sorghums leave much room for improvement.

ditions of soil, rainfall, and some degree of improved management. The program's emphasis has so far been on pure-line varieties.

In much of Upper Volta the 1980 growing season was marked by two periods of scant rainfall, one starting around mid-June and lasting nearly a month in some areas, and the other beginning after 10 September, the date of last effective rain at Kamboinse. Though this situation was unfavorable for farmers and devastated some of our research station trials, it gave us a good opportunity to screen experimental and advanced material for natural drought tolerance.

From 776 local sorghum cultivars from Upper Volta, Niger, Mali, and Senegal, which we screened in 1979 for agronomic appearance, yield potential, and resistance to disease and insects, we selected 103 for inclusion in two replicated yield trials in 1980: a long-duration yield trial (cultivars flowering in 110 days) and a medium-duration yield trial (cultivars flowering in less than 100 days). In the long-duration yield trial, Fada 7, Fada 80, and Niger 2573 performed better than the Kamboinse local in terms of yield. Some sections of the medium-duration yield trial plots had been located on drought-prone soil and were affected by drought. Therefore, only agronomic characteristics such as days to flowering and height, and taste acceptance were recorded.

In 1980, 232 untested cultivars in our earlier collections from West Africa were planted in single row, nonreplicated plots, and 53 were selected for further testing. In addition we sowed 42 entries selected from the 776 cultivars screened in 1979 for their resistance to the sorghum midge *Contarinia sorghicola.* The most promising lines against midge were Fada 80, with long glumes that seemed to inhibit oviposition, and Fada 3 and 109 with very dense panicles that seemed to be less attractive to insect pests.

In the segregating generations of various crosses made in 1979 and earlier, 787 panicles were selected from the F2-F4 generations for evaluation in 1981.

In 1980, we grew 130 F_1s from crosses between selected local and elite exotic cultivars and made 369 new crosses between photosensitive lines. We also crossed individual F_2 and F_3-generation progeny of crosses between E-35-1 and photosensitive locals. Nine backcrosses were made with E-35-1 as the recurrent parent, with a view to eliminate its drawbacks of poor germination, unsatisfactory seedling establishment, and poor head exertion under drought conditions.

Trials and nurseries. Several international trials were grown at Kamboinse in 1980:

From the 10-entry 1980 Semi-Arid Food Grains Research for Agricultural Development (SAFGRAD) trial of medium- and short-duration sorghum, C151-186 and SB-722/67/2 are being multiplied for possible inclusion in the 1981 medium-duration yield trials.

Preliminary Sorghum Yield Trial-1 (PSYT-1) consisted of 20 entries, mostly of short duration, including six hybrids. No significant difference was observed between hybrids and pure-line entries, or between the check, E-35-1, and any other entry.

The International Sorghum Preliminary Hybrid Trial (ISPHT) consisted of 23 experimental hybrids developed at ICRISAT Center and two checks. Though the trial was slightly affected by drought, all plots were harvested and yield data were analyzed. No significant difference was found between E-35-1 (the pure-line check) and any hybrid.

A trial of 73 entries selected from the 1979 Sorghum Elite Progeny Observation Nursery (SEPON) and the Sorghum Preliminary Hybrid Nursery (SPHN) were completely devastated by drought.

The top 10 sorghum lines from each of the two International Sorghum Preliminary Yield Trials (ISPYT-1, -2) grown at Kamboinse in 1979 were repeated in unreplicated trials in 1980. Drought severely damaged the trials, but A-3631 and A-3680 appeared to be more resistant to stress throughout the season and are being multiplied for possible inclusion in the 1981 short-duration yield trial.

A sorghum observation nursery of 466 cultivars and experimental lines, consisting of an array of advanced breeding materials, disease-resistant crosses, and segregating lines, was planted late (on 20 July) and was devastated by drought. Yet, three varieties (SPV-43, SPV-102, and SPV-156) and one *Striga*-tolerant experimental line (SPV-103-11-1) were harvested for further observation.

We sent three medium and short-duration varieties, E-35-1, SPV-35, VS-702, to the Organisme Regional de Developpement (ORD) for on-farm testing. Results for E-35-1, a medium-duration variety, were returned from Kamboinse, Ouagadougou, Koudougou, Kaya, and Fada-N'Gourma, but trials of SPV-35 grown near Ouahigouya and VS-702 grown north of Fada-N'Gourma failed because the rains ceased very early.

We conducted on-farm trials of E-35-1 in Upper Volta for the third consecutive year at locations throughout its zone of adaptation (600-850 mm rainfall). A well supervised set of trials in the village of Kamboinse had a mean yield of 2165 kg/ha under good management conditions. The trials of E-35-1 conducted in cooperation with ORD included locations at or beyond the extremes of the adaptation zone and were less well supervised. The overall yield for these trials was 1025 kg/ha, and data obtained in 1980 showed clearly the effect of planting date on yield: yields were significantly lower in fields planted after 30 June.

The advanced yield trial and a trial of tillering lines failed at Kamboinse, but will be repeated. However, excellent medium-duration lines were selected from the intermediate trial, the grain mold resistance trial, the SAFGRAD trial, and

The crop in the foreground is a high yielding cuitivar (E35-1) introduced from ICRISAT; that in the background is a tall local sorghum.

PSYT-2. Some of these lines will be transferred to the advanced trial next year.

In our work on short-duration sorghums, the 1980 season again demonstrated the need for sorghum varieties that can be planted in July and produce a good yield in October.

Sorghum Pathology

Our sorghum pathologist in Upper Volta also covered Mali.

Grain molds. In the 1980 growing season field testing was continued at Farako-Ba, where observations were made on three trials. The International Sorghum Grain Mold Nursery (ISGMN) and the Sorghum Elite Progeny Observation Nursery (SEPON) were also assessed this year. F_2 progenies from 29 crosses between grain mold resistant and West African advanced adapted materials were tested for grain mold resistance.

The ISGMN comprised 28 entries, to which we added 16 promising entries retained from the corresponding trial in 1979. Three criteria were used for superior reaction to grain molds: field head mold rating below 3 on 1-5 scale; threshed grains less than 10% covered by mold; and for the set of 28 entries, threshed grains judged as being among the top 10 in appearance. On the basis of satisfying two of the three criteria, 16 entries were considered satisfactory.

Similar observations were made in the 39-entry SEPON, supplemented by 38 promising entries retained from our previous season's testing, and 12 entries were judged satisfactory. The consistently outstanding performance of IS-8272, N-6065, and N-6125 since 1977 was noteworthy. Two entries tested for the first time in 1980, M-90737 and M-90883, were agronomically superior, as was M-64080, which was first screened in 1979.

Foliar diseases. We have observed consistently high infection pressure of sooty stripe disease at Cinzana (Mali) over several years. Therefore we chose this site for the assessment of the 30-entry International Sorghum Leaf Disease Nursery in 1980. Other major foliar pathogens of sorghum were at insignificant levels, as evidenced by the lack of symptoms on susceptible checks. Sixteen entries appeared resistant to sooty stripe.

Charcoal rot. In 1980 we planted the International Sorghum Charcoal Rot Nursery (ISCRN) at Kamboinse and at Same (Mali) to identify resistance sources. At Kamboinse entries were assessed for lodging, soft stalks, and number of nodes crossed by charcoal rot infections: four entries were found to be free of disease. However, in the absence of uniform infection pressure, the trial will be repeated.

Pearl Millet Breeding

In the 1980 season, we evaluated several trials at Kamboinse, Gorom-Gorom, Farako-Ba, and on farmers' fields.

A set of Togolese lines, 63 entries from Nigeria, 27 from Mali, representative West African lines obtained from an ORSTOM/FAO collection, and 18 IMPS lines were evaluated at Kamboinse; 48 lines were selected for further evaluation. The Togolese lines showed good yield and disease resistance. Another 343 lines in a Germplasm Evaluation Trial from ICRISAT Center were evaluated at Kamboinse and

An ICRISAT millet breeder examines a local pearl millet line characterized by good head and grain size, high tillering ability, and freedom from disease. The line was collected in Upper Volta,

P242, a Souna pearl millet germplasm line from Mali, which has high potential for use in breeding work in West Africa, being shown to visiting scientists at the Kamboinse Station.

Farako-Ba. The germplasm set being diverse, much variation was observed in days to flowering, daylength sensitivity, plant height, tillering, and ear characteristics. Entry P 242, a Souna type, was most promising for several agronomic characters.

Of 12 synthetics and 10 experimental varieties and composites tested in a trial at Kamboinse and Gorom-Gorom, only EBK 79, (a recombined mixture of five top lines from Ex-Bornu composites) appeared satisfactory. The trial at Gorom-Gorom was again attacked by birds, as it matured about 3 weeks earlier than the local variety, so the results were inconclusive. The data on yields and disease ratings of the entries at Kamboinse for the 1979 and 1980 seasons showed that synthetics Nos. 19 and 46 were among the top yielders in both years.

Two multilocational trials from ICRISAT Center, Pearl Millet Synthetics Trial (PMST) and Pearl Millet Initial Synthetics Trial (PMIST), were grown at Kamboinse. The entries showed early flowering, high tillering, synchronous maturity, and heads with low ergot infection. Grain yields of several entries were high but not significantly different at 5% level because of much soil heterogeneity in the experimental block. For five of the entries in PMIST, disease scores were nil for all three major diseases — downy mildew, ergot, and smut, and their grain yields ranged from 1800 to 2600 kg/ha.

Our work on recurrent selection in composite populations continued. For the Ex-Bornu population, recombination between selected lines and testing of full-sib progenies was carried forward. In the 1980 crop season the EBK cycle-2 progenies, EBK cycle-1 progenies, and a local variety check were combined in a trial at Kamboinse. Grain yields were significantly different, and the top ranking entries were from both cycle-1 and cycle-2 populations. The leading lines, EBKC 2-77 and EBKC 2-47, were free of downy mildew and ergot but were slightly affected by smut. The overall mean yields of EBK cycle-1 and cycle-2 progenies were 960 and 870 kg/ha, respectively.

Six sets of advanced-generation lines from crosses obtained from ICRISAT Center and those made at Kamboinse were evaluated in separate trials at Kamboinse in 1980. Most of the F_4 lines were attacked by ergot and smut, yet 23 promising plants were selected from four sets of populations. From the F_3 materials, 19 agronomically superior plants free from diseases were selected. Another 18 disease-free agronomically superior plants were harvested from VCF_3. Early-generation material developed at Kamboinse and that received from ICRISAT Center (F_1 and F_2 progenies and observation lines from various crosses) was also evaluated at Kamboinse and selections were made.

The experimental material evaluated for ergot resistance in 1980 consisted of selections from West African germplasm and from our previous years' crosses. Seven West African lines had low ergot severity. A total of 41 F_3 and 47 F_4 plants with less than 5% ergot were selected from various crosses for further evaluation. Days to flowering and ergot severity scores did not correlate, suggesting that selection for relatively early-maturing resistant lines may be possible.

The 1980 Pearl Millet African Regional Trial (PM ART) consisted of 25 entries contributed by various West African Cooperative Programs and ICRISAT Center for evaluation across locations. At Kamboinse the trial performed very poorly, possibly due to delayed planting (10 July). The Nigerian composites, WC-C75, and

CIVT II had less than 20% ergot, and NBB and Kamboinse local escaped ergot. Other entries had ergot severities exceeding 30%. Scores on downy mildew infection in the sick plot showed that several of the entries had resistance even with late sowing. The performance of subset entries sown on 25 June was relatively better; however, a very high coefficient of variation for grain yield was obtained due to soil heterogeneity and sensitivity of several entries to drought conditions.

We also conducted 14 on-farm trials of Ex-Bornu (original) at four villages close to Ouagadougou. Yields reported from six trials ranged from 500 to 1400 kg/ha. Planting date is critical and to minimize the risk of pollen wash and bird attack, we concluded that Ex-Bornu and similar entries should be planted in the first fortnight of July. In determining the most suitable date for a particular plot within this range, the effect of soil conditions (especially as determined by toposequence) on flowering needs to be considered.

A preliminary test was conducted in 1980 to assess the quality of Ex-Bornu, a Togolese line, and a local variety grown in the vicinity of Kamboinse. The order of acceptability was local, Ex-Bornu, and the Togolese line.

Pearl Millet Pathology

In 1980 our research efforts on pearl millet diseases in Upper Volta progressed from initial empirical screening for resistance/susceptibility to longer term projects aimed at investigating the stability of resistance and the possible use of chemical seed treatment as a control measure. More fundamental studies were carried out on the inheritance of disease resistance in the host and biological specialization in the pathogen.

Downy mildew. Ongoing research emphasizes disease control by exploitation of genetic host-plant resistance and by chemical seed treatment methods. Further samples were collected for studies of biological specialization in the causal pathogen.

A program to develop local sources of resistance was initiated in 1978 and was expanded in cooperation with the ICRISAT team in Mali to include germplasm material of Malian origin and an additional screening site at Baramandougou (mean annual rainfall 750 mm). In 1980,12 lines were selected with zero or very low downy mildew score from among 375 Malian millets tested at Sotuba (Bamako) and at Baramandougou.

In 1980, for the 5th year of testing in a sick plot at Kamboinse, four Ex-Bornu type millet lines (particularly 700651) again showed low downy mildew infection levels.

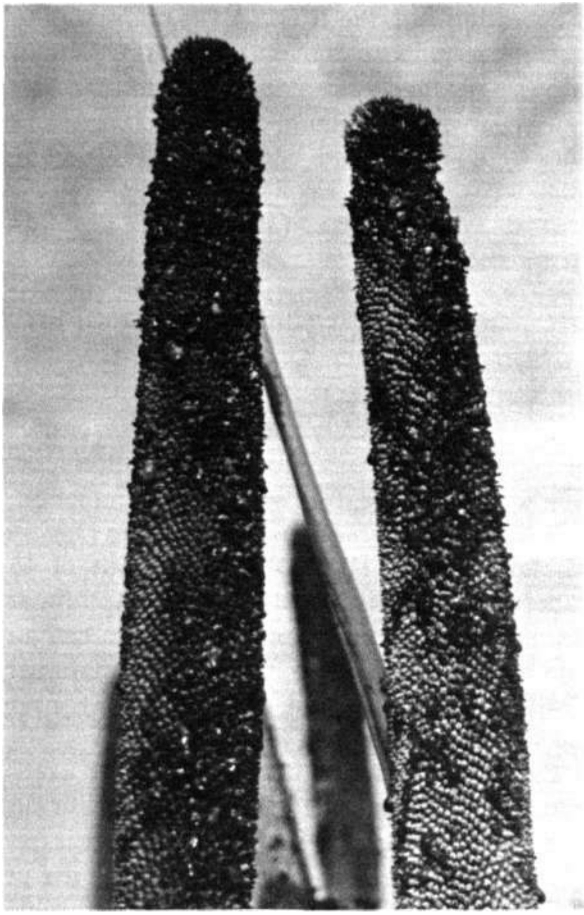
Of 16 agronomically good germplasm entries of Togolese origin tested for downy mildew reaction at Kamboinse, four were free of infection.

In the 1980 International Pearl Millet Downy Mildew Nursery (IPMDMN), five out of 45 experimental entries developed no symptoms at Kamboinse. The local check, Kapelega, had an infection index of 31%. In the International Pearl Millet Adaptation Trial (IPMAT), four entries had an infection index of zero.

Experiments in 1980 indicated that the likelihood of yield increase following seed treatment with Ridomil was small. In regions where infrequent rains hamper zoospore spread, the use of Ridomil might reduce infection in susceptible materials by the elimination of within-crop primary foci.

Increased attention was given to the investigation of biological specialization in *Sclerospora graminicola,* in support of ongoing research at ICRISAT Center and at the University of Reading, U.K.

Ergot. An artificial inoculation method for screening for ergot resistance was perfected during the report period. Using this method, we screened selections with low susceptibility from four sources: (1) West African germplasm,(2) F_3 progenies of crosses involving known low-susceptible sources (e.g., SC 1, SC 2, and SC 3), (3) F_4 progenies of West African materials known to possess reduced susceptibility, and (4) International Pearl Millet Ergot Nursery (IPMEN). From all four sources, 293 heads with less than 5% ergot infection were selected for future testing.



Pearl millet heads infected with ergot.

Smut. Infection caused by *Tolyposporium pennicillariae* (smut) sometimes results in yield losses exceeding those caused by downy mildew. The disease occurs more frequently to the north of the 600-mm isohyet.

The International Pearl Millet Smut Nursery (IPMSN) consisting of 32 entries and 2 checks was sown at Bambey, Senegal. Ten entries had less than 2% of their head surface infected by smut.

Sorghum and Pearl Millet Entomology

Our entomologist in Upper Volta also covered Niger and Nigeria.

In 1980, pest incidence on sorghum and millet was geographically mapped, and the distribution and relative importance of the major insect-pest species were determined. Studies on population fluctuations were initiated on sorghum and millet at Kamboinse and Farako-Ba, and information was obtained on seasonal abundance and frequencies of pest species. Sorghum and millet were extensively sampled in farmers' fields in Upper Volta, Niger, and Northern Nigeria to assess the relative importance of various insect pests.

Sorghum shoot fly. The predominant shoot fly species on sorghum in Upper Volta was *Atherigona soccata* (Rond.), though IRAT entomologists have reported over 17 *Atherigona* species in fish meal traps at Farako-Ba. Although the pest occurred mainly in the south and central regions of Upper Volta, it caused little overall damage. *Atherigona* spp had little economic impact in the northern Sahelian and eastern regions.

Sorghum midge. Distribution of midge, *Contarinia sorghicola* corresponded to about 700 mm isohyet. The adult was found only up to 13°N. Contrary to local farmers' claim, we did not observe this pest at Ouahigouya, Kongoussi, or Kaya. The highest infestations were observed at Fada N'Gourma and Bobo Dioulasso(100%), Reo (80%), Lalgaye (95%), Tenkodogo (75%), Bazega (90%), and Koudougou (75%). Late-planted and late-maturing varieties were usually the worst affected. In the Banfore area, midge infestation was extremely low, apparently because of late flowering.

Stem borers. These are the most widely distributed and potentially damaging pests on sorghum and millet in Upper Volta, Niger, and Nigeria. Their distribution is closely related to rainfall. In the drier regions, there is a reduction both in the number of pest species and severity of attack on the crops.

On young plants of Souna III and local sown at different times, the overall borer damage caused by *Acigona ignefusalis* was not great. No clear relationship was established between planting date, borer infestation, and head production.

Twelve promising millet entries from the Ex-

Bornu full-sib (EBFS) selections and six other varieties were tested against *Acigona* infestation at Kamboinse. Though stem and internode infestations were high in all entries, grain yield differences did not reflect the level of borer damage.

At Samaru, 187 entries in the sorghum leaf spot evaluation trial and 35 promising sorghum lines were scored for borer damage. Borer infestation was caused by *Busseola fusca,* and all entries in both trials were highly susceptible.

Stem borer surveys were carried out in Upper Volta and Nigeria in 1980. *B. fusca* and *A. ignefusalis* were the more important species. Two less common species, *Eldana saccharina* and *Sesamia calamistis,* were found below latitude 12°N in Upper Volta and northern Nigeria. The overall percentage of sorghum stems infested in Upper Volta was relatively low; borer infestation of millet was far higher and more extensive.

Another borer species, *Chilo diffisilineus* was also found on sorghum and millet in Upper Volta. Larvae were recovered in the north (excluding the Sahel), central, and southern regions in August and September.

Entries in Pearl Millet African Regional Trials (PMART) sown at Kamboinse and Gorom-Gorom were also observed for *Acigona* infestation. At Gorom-Gorom, borer infestation was very low and sources were unreliable. At Kamboinse the local variety and ICMS 7803 had low susceptibility to *Acigona* infestation; all other entries were highly susceptible.

Counts were taken on trials that were originally designed for agronomic studies. Entomological results from a trial on crop rotation and crop residue treatment and plowing date at Kamboinse were confounded by high soil variability between plots and severe drought stress in September. Nevertheless it was observed that *Acigona* infestation was less after a legume-cereal-legume rotation than in a continuous cereal crop system. No difference in borer infestation was observed between early or late land preparation and untilled land before planting. Similarly, complete residue removal or conservation did not show any effect on borer infestation.

Millet earhead caterpillar. Adult populations of *Raghuva* were monitored at the Tarna experiment station at Maradi, Niger, using a battery-operated light trap. The first adult was captured on 17 July and two distinct population peaks were observed. Only one generation of *Raghuva* is produced annually.

Raghuva albipunctella occurs within the southern Sahel and the Sudan bioclimatic zones between latitudes 12 and 15°N where rainfall is usually between 400 and 700 mm. In Nigeria, *Raghuva* infestation was observed as far south as Maramara (100 km south of Kano) and as far north as Niger. It extends west from Zinder to Niamey in Niger and into Dori and Gorom-Gorom in Upper Volta. Infestation in Upper Volta mainly occurs in the north. However, two isolated infestations were observed at Koudougou and Tenkodogo. No infestaton was observed between Ouagadougou and Kaya in Upper Volta.

In 1980 we planted the Pearl Millet African Regional Trial (PMART) consisting of 25 entries at Maradi. The level of *Raghuva* infestation was negatively correlated with the number of days to maturity; early-maturing varieties flowering in less than 60 days were more susceptible to infestation than those with longer growth cycles. The low level of head infestation in Souna III, NBB, and the local varieties with longer growth cycles may be attributed to pest evasion. Counts on the Nigerian composites HKP and CIVTII indicate possible existence of true varietal resistance. There is need for a more concentrated search for resistance.

Spittle bug. In Upper Volta, we found two species of spittle bug on sorghum and millet, *Poophilus costalis* and *P. grisescens,* the former being predominant. Two generations of *E. costalis* are produced during the crop season. Adult population peaks occurred in early August and mid-September, with nymphal peaks 1 week before. Direct damage was observed on leaves as pinpoint marks where the stylet was inserted. Spittle bug infestation is more common on sorghum than on millet. Infestation was less severe and widespread in 1980 than in 1979.

Striga Research

In the 1980 season, many of our experiments in both sorghum and pearl millet at Kamboinse were affected by the 2-week drought that followed sowing, and several plots had to be resown. The rains ceased abruptly in September, resulting in heavy *Striga* infestations, and combined *Striga* and drought stress killed plants in many plots.

We confirmed the resistance of lines identified previously and identified new and stronger sources of resistance during the 1980 crop season.

Sorghum

During 1980 several trials were laid down in farmers' *Striga*-infested fields at three locations in Upper Volta. These trials confirmed the stability of resistance of N-13 and IS-8686 on different soil types and rainfall regimes. CE-90 and SPV-103 were also found to have stable *Striga* resistance. N-13 and IS-8686 were also tested for resistance to *Striga* in farmers' fields in Cameroon and Mali, and in Mali resistance of N-13 and IS-8686 in 1979 was confirmed in 1980. N-13 appears to be the best resistance source presently available.

Our advanced *Striga* trial was grown in six countries, including Upper Volta, but results were available only from the Kamboinse station. Apart from IS-8686 and N-13 (checks), four advanced-generation progenies (148 x Framida, H-509, H-548, and Framida) proved to be satisfactory for *Striga* resistance and grain yield.

Striga, a devastating parasitic weed on sorghum. It also infests other cereals—pearl millet and maize.

New sources of resistance. Forty agronomically good lines from our 1979 observation nursery were retested at Kamboinse and Tiebele. At Kamboinse, where *Striga* infestation was high, eight entries were selected as agronomically superior. Of these, IS-119 and IS-10038 were also good yielders. At Tiebele, *Striga* infestation was uneven, so no evaluation was possible.

Low-stimulant lines. Evaluation of these lines was carried out at three locations, and 10 lines were selected for further testing.

Upper Volta collections. Several local landraces thought to be resistant to *Striga* were collected from Upper Volta and two were selected for future testing.

Advanced-generation breeding progenies. Lines tested were derived either from crosses between *Striga*-resistant parents and adapted lines or from crosses between different resistant varieties to combine different resistance mechanisms. In all, 230 F_5 and 309 F_6 progenies were tested at Kamboinse, Mintimbougou in Mali, and Kobo in Ethiopia.

Yields ranging from 2617 to 1217 kg/ha were recorded in a trial of 21 lines at Kamboinse, and the mean *Striga* emergence was lowest (6%) on the highest yielder (80549-5). The second and third highest yielders (80544-2 and 80598) also had low levels of *Striga* emergence and were presumably tolerant of the parasite.

Pot experiments. These were carried out to confirm field resistance of a few selected sorghum cultivars and to determine the stability of *Striga*-resistant lines by exposing them to *Striga* strains collected from diverse ecological zones of Upper Volta. IS-8686 was more stable than N-13 against a range of strains, as reported earlier by the Weed Research Organisation (UK). Low-stimulant lines were more stable than N-13, which is a stimulant-positive type. The low-stimulant mechanism did not appear to offer greater stability when tested against a range of *Striga* strains in the field, as N-13 was better than IS-8686. In the pot experiments, the only variable was the *Striga* strain; the soil, moisture, and temperature factors were standard. It appears that the interaction between different *Striga* strains and environmental factors is also important in the expression of resistance stability of different cultivars. An understanding of these interactions in relation to host resistance is necessary for the development of *Striga*-resistant cultivars.

Pearl Millet

Since our pearl millet *Striga* testing results in 1979 were not very encouraging, in 1980 we launched an intensive search for *Striga* resistance in pearl millet cultivars of West African origin. The testing was done on a heavily infested farmer's field in Aourema (17 km from Ouahigouya), which is primarily a pearl millet growing area. Two trials were conducted.

The first trial consisted of 90 entries, principally local landraces of West African origin and a few elite selections from our 1979 *Striga* observation trial grown at Thiou. Eleven lines were selected. P 2671 and P 2950 had very good agronomic expression despite severe drought towards the end of the season. Serere 2A-9, which was selected in 1979 for its apparent *Striga* resistance, continued to appear promising, though its agronomic expression was poor. SDN 347-1 was also promising. Of our selections from Thiou, four lines performed extremely well under combined *Striga* and moisture stresses, supporting our observation made in the case of sorghum that some lines highly resistant to *Striga* also possess some drought resistance.

The second trial comprised 63 inbred lines and F_3 progenies from ICRISAT Center and several Serere composite derivatives from our research program in Sudan. None of the entries was well adapted to Aourema environment.

A Pearl Millet Adaptation Trial grown by the ICRISAT Genetic Resources Unit in Maradi (Niger) was observed for *Striga* incidence, and 15 lines were selected for further screening.

During the first two cropping seasons (in 1979 and 1980), our efforts in pearl millet *Striga* research in Upper Volta mainly focused on the identification of resistance sources. The exploitation of these sources in the breeding program was initiated in the 1980/81 dry season. A few lines from the material developed at ICRISAT Center by pedigree methods were found useful as elite sources of *Striga* resistance.

The composite approach is well suited to pearl millet improvement. Intercrossing among several selected less *Striga*-susceptible lines is being attempted (which will be followed in the 1981 rainy season by testing of F_2S (S1s) in sick plots); subsequently full-sibs made between *Striga*-free plants within and between F2S will be advanced, tested, and recombined. This would continue till the population is improved for resistance and other agronomic traits.

Pot experiments. Our pot experiments in 1980 at Fada N'Gourma and Koupela (11-12°N) confirmed our 1979 observation that there are two *Striga hermonthica* strains, one specific to sorghum and the other specific to pearl millet. However, the pearl millet *Striga* strain from Zitango was also able to attack sorghum. This will be further investigated in 1981.

A pot experiment to find evidence for both intra- and intercrop *S. hermonthica* strains was also carried out in 1980. Among the sorghum *Striga* strains, STS-9 from the Gassan-Tougan region was the most virulent, and the one from Farako-Ba (STS-3) was the least virulent. Among the pearl millet strains, STP-13 from Tangaye was the most virulent, and the Benena strain (STP-2) was least virulent. There were

Scoring sorghum for Striga *in pot experiments in Upper Volta.*

also significant differences within and between sorghum and millet strigas. Maize was readily attacked by both strains.

International Trials and Nurseries

International Sorghum Shoot Fly Nursery (ISSFN). No data could be collected at Kamboinse as severe drought destroyed this trial in September 1980. At Farako-Ba, shoot fly infestation was lowest on IS-4660, followed by IS-2291 and IS-18361. However, harvest data indicate that CSH-1, IS-18319, IS-18427, and IS-18479, though most heavily infested, outyielded other varieties.

International Sorghum Midge Nursery (ISMN). This trial was planted in July 1980 at Kamboinse, and most varieties (90%) flowered before 20 September. But the midge population peak occurred on 29 September, so the data were unreliable. However, at Farako-Ba where the trial was planted on 2 August, the lowest number of adult midge (2-3 per panicle) was observed on S-Girl-MRI. This variety also registered the lowest floret infestation, though grain yield was low. In terms of grain yield, IS-12666C and the local check performed better than other varieties and also registered comparatively low percentages of infested florets.

Agronomy

Sorghum and Millet Agronomy

In preliminary testing of sorghum varieties in 1980, 940 S, 38-3, and SPV-35, when planted early (25 June), yielded more than the Kamboinse local sorghum. The early cessation of rains in September adversely affected the improved varieties when planted late (10 July), while the local check did relatively well.

In the preliminary tests of millet varieties, seven introduced varieties and the Kamboinse local millet were planted this year. The yields were low due to early cessation of rains, pollen wash on most short-cycle materials, poor plant establishment of the July plantings, bird damage, and a high degree of ergot infestation. None of the introduced varieties was stable.

Last year we reported that for photosensitive millets the optimum plant population might change in relation to the planting date and that no such interaction occurs in the nonphotosensitive millets. To confirm this observation we planted a local photosensitive millet (Kamboinse local) and a nonphotosensitive millet (Ex-Bornu) on three dates in 1980 at three different plant populations on a deep sandy soil. The local material showed a negative response and the Ex-Bornu a positive response to plant density. The highest yields for the local were obtained in an early June planting at only 20 000 plants/ha; the July planting at high density (80 000 plants/ha) showed some promise. Yields for Ex-Bornu varied greatly but were highest (20% more than local) when planted at the end of June at 80 000 plants/ ha. Thus both planting date and a full population appeared more critical for the Ex-Bornu than for the local.

In advanced testing in 1980, we studied crop responses to planting dates and soil characteristics in order to evaluate improved sorghum cultivars for their yield stability and specific adaptation to the major soil types commonly represented in toposequences. The photosensitive local sorghums (both red and white) yielded around 2.5 tonnes grain/ha in early June plantings. Yield differences in the partially photosensitive varieties were nonsignificant.

Significant decreases in sorghum yield resulted from delayed planting. Highly significant interactions were recorded between variety x date of planting, soil type x date of planting, and variety x date of planting x soil type, thus indicating the importance of sorghum varieties of different maturities and of timing management for various soil types.

Legume Agronomy

Cowpea, a common component of West African cropping systems, is well-adapted to SAT conditions and mainly grown as an intercrop with sorghum and millet. Because of insect problems, cowpea yields on local farms are low. Under advanced management with regular insect control and in pure stands, high yields have been obtained.

We planted 12 varieties, both local and improved, on 11 July 1980 in a toposequence to study their plant characteristics and adaptation to the soil. Because of delayed planting and early cessation of rains (in mid-September), the three local varieties did not attain their yield potential. However, the nonphotosensitive varieties (semispreading and erect) benefited from the late planting date and early cessation of rains by maintaining the quality of the early harvested grain and yielded two to three times more than the spreading-type cowpea varieties on both soil types.

Intercropping

In 1980 major emphasis was placed on crop combinations suitable for specific soil conditions within the toposequence.

Cereal/cereal intercropping. The results from our last year's studies indicated that yield gains in cereal/cereal intercropping could be realized by proper choice of planting date and crop varieties. In 1980 we studied two intercropping systems: sorghum/maize and sorghum/millet. For both systems, intercropping responses were significantly greater in early than in late planting. Also, profits rose with the increase in the difference in maturity of the two components. For instance, early maize with postrainy-season photosensitive sorghum was better than with E-35-1 sorghum, which is partially photosensitive and matures 10 days earlier. Likewise, the combinations of various sorghums with early-maturing Ex-Bornu millet were better than with the late-maturing local millet.

Cereal/legume intercropping. Cereal/cowpea intercropping is a widespread farming practice throughout the West African SAT, with two major objectives: (1) the cereal used as a base crop should reach yields about equal to a pure cereal stand, and (2) the cowpea yield should be realized without the use of insecticides. Both objectives necessitate crop combinations of a nearly full cereal stand to which some cowpea plants are added.

During the 1980 cropping season, we evaluated intercropping of both photosensitive and photoinsensitive sorghums with cowpea. Photosensitive sorghum yields were slightly depressed by intercropping. Local spreading cowpea planted at the same time as the sorghum provided good soil coverage; however, cowpea was quickly shaded out when planted a month later than the sorghum crop. In the case of photoinsensitive sorghums and millets intercropped with either cowpea or mungbean, the pereal grain yield was generally maintained or was a little lower than the sole crop yields. Sorghums with dense foliage appeared to depress cowpea and mungbean. Mungbean was most competitive with sorghums; millets suffered less and competed better with legumes.

Economics

The economics program was established in Upper Volta during 1980 with the arrival of an economist in January. A second economist joined the team in June and will eventually work in Niger.

Long-term goals and plan of work. The objective of the economics program in West Africa is to contribute to the identification and development of improved production technologies through: (1) an analysis of current farming systems to identify socioeconomic and other constraints to production among small farmers and (2) an evaluation of improved technologies under farmers' conditions to assess the constraints to and consequences of adoption. These objectives will be fulfilled through village-level studies, essentially of a long-term nature, and farmers' tests of promising technologies.

Objectives and program of work in 1980. The general goals in 1980 were: (1) to develop a qualitative and quantitative understanding of small farm units and systems of production in Upper Volta, (2) to develop, test, and refine on a pilot scale efficient data-collection and data-processing methodologies for later village studies, (3) to demonstrate methods of conducting farmers' tests of promising technologies, and in so doing establish working links with other ICRISAT programs, and (4) to select study villages. These goals were pursued through three principal activities: (1) a pilot study of current farming practices in two villages of central Upper Volta, (2) farmers' tests of the sorghum variety E-35-1, and (3) reconnaissance surveys conducted throughout Upper Volta. Pilot farm surveys were started in two villages near Ouagadougou. Technical and financial budgets were synthesized for major cereals and legumes grown under local management. The use of local

Research assistant recording market study data at a village market in Upper Volta.

ICRISAT buildings used by economics program investigators in a village in Upper Volta.

sorghum and millet varieties and farmers' planting strategies were analyzed across several environments.

The main conclusion of the study on farming practices was that the donkey-drawn *houe manga* traction system under farmers' management significantly increased returns to both land and labor. It permitted more thorough weeding and was found to be labor-saving. Although its major effect is to increase labor efficiency during first weedings, which come at a peak workload period, it was not labor-displacing. Data suggest that area expansion followed adoption of the traction system, increasing the demand for labor during the slack periods.

Evaluation of E-35-1 by on-farm trials showed that it outyielded local white sorghums by 38% under improved management in late plantings. A disadvantage of E-35-1 was planting period inflexibility. Improved management procedures — preplanting soil preparation, chemical fertilizer, and organic manure—gave average yield increases of 200% over local varieties grown under traditional management.

Reconnaissance surveys were conducted in villages representative of the agroclimatic regions of Upper Volta. These provided a description of the different local farming systems, enabled sites to be chosen for 1981 village studies, and contributed to development of hypotheses that will be tested in an expanded village-study program.

Mali

The ICRISAT Mali Cereal Improvement Program was initiated in 1979 with a view to complementing and supporting the ongoing sorghum and millet improvement efforts of the Malian Food Crops Research Service.

Sorghum Breeding

In 1980, we focused our activities on exploitation of the Malian sorghum collection. Based on our 1979 observations on this collection, we placed the best adapted sorghums in three groups: photoperiodsensitive, midseason, and very early sorghums. In 1980 we tested these sorghums in multilocational observational trials at Sotuba, Cinzana, Baramandougou, and Same. Several of these local sorghums were found well adapted to Malian conditions and might be directly introduced as cultivars or used as good breeding stock in the crossing program. A number of them also showed *Striga* resistance and possessed good quality grain.

Sorghum F_1 hybrids involving Malian male parents and the cytoplasmic male-sterile line, ATx623, were tested at several locations. These hybrids exhibited good seedling and plant vigor, prefloral drought tolerance, and clear grain yield advantages over the parents. For instance, the cross A623 x CSM-432 gave a heterosis index of 261%, the highest recorded among the F_1 hybrids. The outstanding performance of these hybrids indicates that Malian sorghums can be exploited in the hybrid breeding program. A large number of B-lines were also discovered among the Malian sorghums. These can be used as parents to make rapid progress in breeding Malian sorghum hybrids. Through our genetic studies we were able to locate several alleles that will be useful in future crossing.

A set of 85 experimental and standard F_1 hybrids received from ICRISAT Center were tested at Sotuba, Cinzana, and Barmandougou. In all the hybrids, seedling stand and vigor were excellent, plant growth and drought tolerance were very good, and panicles were normal with no blasting and seed set was normal at all locations. From our visual observations, the following experimental hybrids appeared the best: CSH-5 (2077A x CS3541), 2077A x MR-380, 2077A x MR-184, 2077A x MR-383, 296A x MR-376, 296A x MR-162, and 296A x MR-183.

Fifty-nine hybrid selections from the 1979 season's Malian nurseries were tested in 1980 as midseason observation trials at four locations. As with the introduced hybrids, the 61x623 hybrids grew very well at all four locations. Seven selections will be advanced to multilocational yield trials in 1981. The average grain weight for the F_1 hybrids was 1.8 times the grain weight of the male parent and 1.3 times that of the female parent (ATx623).

Several composite breeding populations based on genetic male sterility were established. Testing in the 1980 season indicated the tremendous potential of this approach for exploiting Malian sorghum characters. Screening procedures were developed to test for seedling drought resistance and for good quality. A simple laboratory method of testing for *to* quality using a reduced sample size of 20 and less preparation time was developed.

Screening tests for *Striga*-resistant sorghum cultivars indicated that, of the four 1979 selections, only N-13 was promising. The trait was, however, lost in hybrid combination with ATx623, as indicated by the number of *Striga* plants per sorghum plant (Table 1).

Malian women preparing sorghum for making to.

Table 1. Ratio of striga plants to sorghum plants in screening tests of the hybrid ATx623 x N-13 and the parent N-13.

Entry	Striga plants/sorghum plants			
	Rep 1	Rep 2	Rep 3	Rep 4
N-13	2/12	3/14	2/12	7/9
ATx623 xN-13	125/10	56/8	40/5	

Sorghum Agronomy

The major emphasis of our sorghum agronomy research in Mali continues to be on intercropping. Sorghum or millet with cowpea is the principal local system. In the sorghum/cowpea intercrop, farmers almost always use very low cowpea densities and sow the seed of the two species in the same hill.

In 1980 an experiment with local sorghum as the main crop was conducted to examine how production might be maximized in the traditional systems. A local and an introduced cowpea were planted in the same hill with sorghum, as in the traditional system, and in interrows as in most mechanized systems. The cowpea was grown at the densities normally used locally (approximately 6250 plants/ha and multiples thereof).

Sorghum/cowpea interspecific competition was clearly observed in this trial, and there were distinct relationships between cowpea density and both sorghum grain and cowpea hay yields. As the cowpea density increased, cowpea hay yields increased almost linearly (Fig. 1). There was evidence that the lower sorghum grain yields were not compensated for by the increase in cowpea hay yield. Planting arrangements appear to have similar effects.

Sorghum grain yields were relatively unaffected by planting arrangement, but cowpea hay yields were better with interrow planting. These differences appeared to be due to increased interspecific competition. When seed was sown in the same pocket, the species were more competitive and yields were reduced. Location x

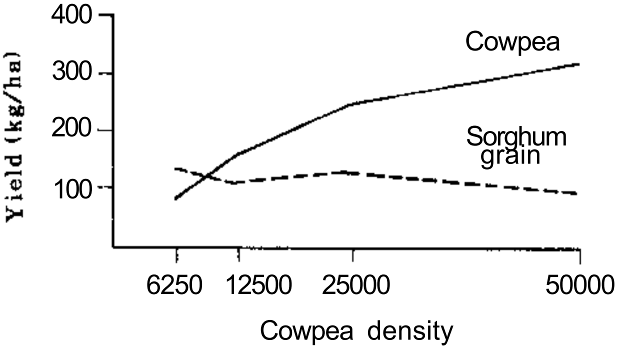


Figure 1. Influence of cowpea planting densities on cowpea hay yield and sorghum grain yield in Mali during the 1980 growing season.

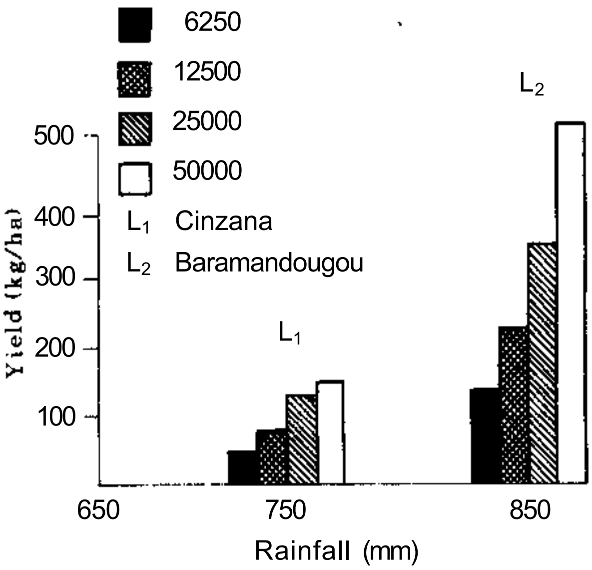


Figure 2. Effect of plant density and location on cowpea hay yield in Mali during the 1980 growing season.

planting arrangement, location x density (Fig. 2), and location x variety interactions were confirmed by working out the land equivalent ratio (LER) relationships.

A second intercropping experiment was carried out at Sotuba, Cinzana, Baramandougou, and Barbe to examine the performance of a range of cultivars in intercropping across sites. With a high density of cowpea in the intercrop, interrow planting resulted in less interspecific competition than planting on the same hill. The effect of interrow planting was a highly significant 35% increase in cowpea hay yields. There was no significant difference in sorghum grain yields, however. The cowpea variety KN-1 significantly outyielded the local by 25%.

The very large cowpea hay yields relative to the sorghum grain yields gave the cowpea hay a dominant role in monetary terms. E-35-1 performed as well as, or better than, the locals across locations. The high-density cowpea plantings used in this experiment generally lowered sorghum yields.

Toposequence studies of several crops. Modeled on the experiments conducted by ICRISAT in Upper Volta, a toposequence study was carried out at Cinzana and Baramandougou, where the topography and soil types were considered typical of large areas of Mali. The purpose of the study was to evaluate the performance of sorghum, millet, pigeonpea, and cowpea under different soil conditions associated with the topographic sequence along the Niger-Bani drainage systems.

Topographic position played a critical role in crop and varietal performance. A cereal-crop x topographic-position interaction was noted. Millet yielded better than sorghum on the upper-slope soils, and sorghum performed better on the heavier soils on the lower aspects of the slope. The yields of local sorghum consistently increased as it was moved down the slope. The introduced material had average yields similar to the local sorghum on the upper and lower slopes.

Cowpea performed best on the soils lower down the toposequence. Results from Baramandougou showed that cowpea did not tolerate waterlogging. In Cinzana where the soil on the lower aspects is as heavy as that at Baramandougou but was subjected to less waterlogging, sorghum yields were comparable to the lower slope yields.

Late planting decreased hay yields on all soil types. Pigeonpea, a new crop being tried out in Mali by us for the past few seasons, tended to yield best on the upper-slope soils. It produced good grain yields on all soils except the waterlogged ones on the bottom lands at Baramandougou.

Fertilizer studies of several crops. Telemsi rock phosphate (TRP) is regarded as a less effective source of phosphatic fertilizer for seedlings than diammonium phosphate (DAP). During the current season, TRP, composted TRP, and DAP were compared as band-applied, starter fertilizer sources. Composting was considered to be a possible, relatively cheap technique for partially acidifying the TRP. Using a range of crops (maize, cowpea, pigeonpea, sorghum, and millet), the experiment established that composted TRP was as good a phosphatic fertilizer source as DAP for total biomass production. In view of the abundance of TRP in Mali, this finding is of great significance, and further experimentation will be carried out in 1981 for confirmation.

Pearl Millet Breeding

Our 1980 reexamination of the Malian millet collection confirmed several generally adapted varieties with good levels of downy mildew resistance, as well as sources of stem borer and *Striga* resistance. Three Tiotoni varieties from Toubakowa (Kolokani), CMM 73, CMM 210, and CMM 305, showed very good resistance to mildew. In collaboration with a Malian entomologist, the entire collection of Malian millets was planted at Sirakorola, a stem borer "hot spot," and 24 entries with less than 5% stems with borer holes were selected. The SAFGRAD/ Mali team collected three millet varieties from Kongola and Siby, which were locally regarded as *Striga*-resistant. Tests revealed that these three millets, Tutuku, Djiko, and Sanyoba, seem to tolerate *Striga* rather than depress the parasite's growth. They will be crossed with a number of contrasting millet types in 1981 with a view to obtaining *Striga* resistance in a diverse range of millets.

Due to the consistently poor adaptation of introduced millets to Mali conditions in previous years, we sowed in our 1980 nurseries only 94 introductions including breeding material from ICRISAT programs in Niger, Nigeria, Sudan, and India. In 1980, as in 1979, the introduced materials were generally too early, were attacked by ergot and smut, and had poor seed set at most locations. Even Souna III performed very poorly in comparison with local Malian varieties. Only one introduced millet—Ankoutess 1/1—showed real promise.

We again demonstrated the phytotoxic action of metalaxyl fungicide on downy mildew on Malian millets. In 1979, metalaxyl treatment resulted in significant grain yield increments by reducing downy mildew infection. In 1980, when mildew infection was later and less severe, no effect of metalaxyl treatment was observed.

Pearl Millet Agronomy

Millet is intercropped with cowpea as frequently as sorghum by the farmers of Mali; therefore our millet agronomy research continued to emphasize intercropping systems.

During the 1980 growing season, contrasting millet and cowpea varieties or cultivars were studied under different agronomic regimes in intercropped systems. Two cowpea densities (local practice, 6250 plants/ha; high density, 50 000 plants/ha) and seeding dates (concurrent with the millet, and 1 month later) were used. The planting date treatment was included because, although most Malian farmers traditionally plant the two crops at the same time, the Dogon on the Seno Plain plant the cowpea about 1 month later as a part of their first weeding operation. The millet and cowpea cultivars used did not improve the systems currently in vogue. However, altering the sowing date or the plant density of cowpea did have a considerable impact. If maximized millet yield is the objective, with some additional cowpea, then traditional practice is superior. If cowpea hay yield or total yield is the aim, changes that improve the cowpea's ability to exploit the environment improve these yields. Total yield increases can be achieved if millet grain yield is sacrificed.

Niger

Pearl Millet Breeding

Our pearl millet breeding program in Niger has been in operation for 3 years, and in this period four of our promising experimental varieties have been selected from the African Regional Trial for testing across countries. Souna III, an improved cultivar introduced from Senegal, was found to be satisfactory in Niger.

National trials and nurseries. Initial evaluation of our 28 experimental varieties at Maradi revealed that IVT 8023 and IVT 8024 performed better than the control, CIVT-II_2. The performance of promising cultivars in this series will be further evaluated. The varieties developed locally were superior to the best experimental varieties and synthetics from ICRISAT Center, indicating the greater value of African material in millet improvement for Africa.

In the breeding program, the interpopulation crosses attempted between improved West African varieties and populations such as Souna III x CIVT II and 3/4 HK x 3/4 Ex-Bornu appeared useful. To examine the general adaptation, composite (Souna III x CIVT II) was submitted to national trials in Niger during 1980. The results show that this population is of value in crop improvement. It will be subjected to recurrent selection in the future.

We completed the second recombination in the four gene pools—African, Indian, Dwarf, and Bristled (developed at Niger) and have derived two composites from each. These composites will be evaluated and improved in the 1981 rainy season. They will be sent to ICRISAT millet breeders in Senegal, Nigeria, and Sudan and given to Niger national breeders for selection. Fourteen trials and nurseries were conducted during the 1980 rainy season in support of the above program.

Regional trials. Four experimental varieties from the breeding program in Niger (ITV 8001, ITV 8002, ITV 8003, and ITV 8004) were included in the 1980 Pearl Millet African Regional Trial (PMART). ITV 8001 and ITV 8004 performed well in Senegal and will be included in Senegal national trials during the 1981 rainy season. ITV 8003 and ITV 8004 appeared of value in Niger and Nigeria. However, all four experimental varieties are heterogeneous and need to be improved.

The Pearl Millet African Regional Trial consisting of 23 entries (from ICRISAT Center, Senegal, Mali, Upper Volta, Niger, Nigeria, and Sudan) and two local checks, was conducted at Maradi, Niger, Entries CIVT and HKP gave the highest grain yields (2217 and 2000 kg/ha, respectively), followed by Maradi local with close spacings (1.0 m x 0.5 m). Among the better entries were two contributed by ICRISAT/Niger—ITV 8004 (the earliest of useful entries, yielding 1733 kg/ha) and composite Souna III x CIVT (yielding 1750 kg/ha), followed by Nigerian Composite. Performance of the entries from ICRISAT Center and the Sudan was not satisfactory.

International trials and nurseries. Thirteen international trials and nurseries from ICRISAT Center were planted during the 1980 season. Some of the more important of these were IPMAT, PMST, EVT, ELVT, BPPT, D_2DVT, and PMHT. The data from these trials were sent to our headquarters at Patancheru, India, for analysis. Most of the entries in these trials were early-maturing, small-headed types especially selected for Indian conditions and were highly susceptible to the insect pest *Raghuva.* Most of the materials, except those with an African background, were ill-adapted to the poor sandy soil of Maradi, Niger.

A trial received from ICRISAT's Genetic Resources Unit with 343 entries and three replications was grown for ICRISAT Center and the data were forwarded.

Nigeria

Pearl Millet Breeding

Crop growth and nursery management in 1980 were good at both Samara and Kano. The amount and distribution of rainfall at both sites during the season was adequate, and no severe drought conditions were experienced.

Two local and one international (Uniform Progeny Nursery, UPN) nurseries were evaluated for use as germplasm. The VCF2 cross 700651 x P 7 (Hyderabad 21) provided many promising downy-mildew-free, semi-dwarf plants for further use in the Nigerian program. The results of the UPN once again confirmed the need to use West African germplasm in the crossing program.

In six local yield trials (PYT-1 to PYT-6) of 210 locally improved entries, 54 were not significantly different from those obtained from Nigerian Composite and Ex-Bornu. These entries will be further tested in 1981.

In 1980 the Pearl Millet African Regional Trial was conducted at Kano. It included 22 entries and three local checks—Nigerian Composite, Ex-Bornu, and a "local farmer" variety obtained from bulk seed purchased at the Samaru market. The farmers' variety was grown at both the researcher's spacing and the farmer's spacing. Four entries—Souna III, ITV 8001, IVS-A78, and ITV 8002—gave yields similar to that of Nigerian Composite and Ex-Bornu, but none outyielded these two improved local checks.

The farmers' local variety (averaged over both spacings) yielded 940 kg/ha lower than the Nigerian Composite and 667 kg/ha less than Ex-Bornu, indicating the advantage that farmers could obtain by adopting these two newly improved varieties. The difference in yield at the two spacings was not significant statistically.

Four international yield trials (IPMAT, D_2DVT, PMIST, EVT) were grown at Samaru. Most entries were poor, both agronomically and in grain yield. Downy mildew, ergot, and smut incidence and severity were much higher in these trials than in the local nurseries in the same field. Entries of interest included ICMS 7704 and ICH 211 from IPMAT-6, and 3/4HK B78 from the D_2DVT nursery.

The overall results from these international nurseries indicate that more effort should be devoted to local and regional genetic material in breeding, selection, and evaluation. The major plants for 1981, therefore, include yield evaluation of all 54 selected local genotypes. Some of the selections will go into regional yield testing, some into international yield testing, and others into local yield trials. International nurseries will be continued on a reduced scale.

Sorghum Pathology

In 1980, the Nigerian quarantine authorities relaxed the requirement that entries from ICRISAT Center should be grown in glasshouses prior to release, enabling quick release of seed samples by the authorities to us. Local cultivars were grown in replicated blocks and were evaluated for disease and pest resistance. Fifteen entries were identified as resistant to the major leaf spot diseases, gray leaf spot, blight, and anthracnose. The 87 leaf spot resistant lines selected previously in Nigeria were retested under artificial epiphytotic conditions, and 25 were selected as possessing good attributes for both leaf spot and shoot fly resistance. Another 283 entries were reevaluated for sorghum downy mildew resistance, and 24 of them were found to be resistant also to major leaf spot diseases and major insect pests.

The Sorghum Elite Progeny Observation Nursery (SEPON) from ICRISAT Center was planted at Samaru. Most of the 37 entries evaluated were free of major leaf spot diseases; however 35 entries were affected by charcoal rot reaching a level of 23.2% in one entry.

Millet Pathology

Our trials in 1980 were sited both at Samaru and Kano to identify disease-resistant entries from local material as well as international entries.

Entries highly resistant to major diseases, besides downy mildew, were selected from the local landraces collected and tested over the last three seasons. Most of them were resistant to more than one major disease and were utilized in crossing with Ex-Bornu and advanced through the F_2 stage.

The Preliminary International Pearl Millet Downy Mildew Nursery (Pre-IPMDMN) was grown in the downy mildew "sick plot" at Samaru. Of 150 test entries, 33 showed high resistance to downy mildew throughout their growth; one entry, P 29, also showed low inci-

Farmer examining a pearl millet head infected with smut.

dence of ergot. Fifty-five entries showed high levels of resistance to smut. Blast disease was not very severe, and thus many entries were only lightly attacked. Most of the entries tested were susceptible to zonate leaf spot. Rust is not currently a problem in Nigeria.

The IPMDMN-4 was grown at Samaru and Kano. Most of the entries did not appear to be of much value under Nigerian conditions. Only 2 of 45 entries tested (E 298-2-1-8 and MPP 7147-2-1), appeared highly resistant to downy mildew till harvest. Considerable differences in downy mildew disease reaction were observed.

The 35-entry International Pearl Millet Ergot Nursery-4 (IPMEN-4) was evaluated at Samaru. Most of the entries were severely affected by downy mildew and were highly susceptible to ergot. Four local entries, IMPS 8010, 8011, 8016, and 8020, showed high resistance to both ergot and downy mildew.

The International Pearl Millet Smut Nursery (IPMSN), containing 32 test entries and three checks, was grown at Samaru and Kano. Many entries from international trials and local origin showed smut resistance. However, most of these were severely affected by downy mildew.

The Experimental Varietal Trial (ExVT), with 27 varieties and five checks, was assessed at Samaru in nonreplicated two-row plots. Only variety NELC 79 showed less than 10% downy mildew up to dough stage, and none of the entries was resistant to ergot. However, many of them were free from smut infection.

The Pearl Millet Elite Varietal Trial (PMEVT) was grown only at Samaru in nonreplicated two-row plots in the downy mildew "sick plot." ICH 226, ICMS 7845, and WC 8015, showed less than 10% downy mildew incidence up to dough stage.

The Pearl Millet Synthetic Trial (PMST) was grown at Samaru in nonreplicated plots. Of 18 entries evaluated, only ICMS 7825 was resistant to downy mildew (under 6.9% of the crop infected) up to dough stage. No entries were resistant to ergot, but several were free of smut.

The International Pearl Millet Adaptation Trial-6 (IPMAT-6), with 20 test entries and one local check, was grown in a nonreplicated block, in the downy mildew "sick plot" at Samaru. ICMS 7845, ICH 165, and IVS-P77 showed high resistance to downy mildew, but none to ergot. Most of the entries were highly resistant to smut.

Among the 20 hybrids and five check entries evaluated in the Pearl Millet Hybrid Trial (PMHT), only ICH 412 (8.7% downy mildew infection) looked promising. Ergot incidence was high in all entries, while ICH 421 and 385 remained free from smut. Stem borer was severe in all entries.

The Disease Observation Nursery for Improvement of Advanced Hybrids (DONIAH) was grown at Samaru in nonreplicated two-row plots. Of 125 entries evaluated, 25 showed high resistance to downy mildew. The progenies of parent line ICH 118 showed promise. All the hybrids were highly susceptible to ergot but not to smut.

Sudan

Sorghum Breeding

The farm at Gezira Research Station (GRS), Wad Medani (Gezira Province), represents irrigated sorghum growing conditions and serves as the center of our research operations in the Sudan. Most of our breeding nursery activities, particularly crossing and early-generation advancement, are conducted here. Evaluations of sorghum lines for drought tolerance, resistance to stem borer, charcoal rot, and *Striga* were undertaken in 1980.

Varietal improvement. In 1980 an increasing effort was made on evaluation of early- and advanced-generation breeding nurseries generated from our local crossing programs. Several groups of sorghum materials were intercrossed with the local types.

Four groups of materials—drought-tolerant selections (6), popular locals (5), elite *Cercospora*-resistant introductions (7), Zerazera types (6)—were used in crossing during summer 1980. F_1, F_2, F_3, and F_4 generations were sown for further selection and advancement.

Introductions of diverse sorghum germplasm and advanced breeding lines, mainly from ICRISAT Center, provided genetic material necessary to diversify the local sorghum germplasm. Many of the recent accessions have been used as parents in both our varietal and hybrid improvement programs. Some of the lines developed showed promise as varieties when compared with appropriate local checks, while others showed good levels of drought tolerance and insect resistance not found in the locals. We are, therefore, encouraged to continue to introduce and exchange sorghum germplasm with other sorghum improvement programs.

During the current crop season, a number of trials and nurseries, again mainly from ICRISAT Center, were evaluated at several test locations in the Sudan.

Sorghum Elite Progeny Observation Nursery (SEPON). This 1980 medium-maturity group SEPON consisted of 60 progenies selected from F_4 and F_5 generations of crosses involving elite lines said to mature in 100-120 days from the ICRISAT Mold-resistant Sorghum Breeding Project. The nursery was planted at Wad Medani (Gezira Province), Gadambalia (Kassula Province), and El Obeid (Northern Kordofan Province). Due to severe moisture stress at the last two sites, many of the entries did not even flower. However, based on both grain yield data and visual agronomic scores, some of the entries were found to be superior to the local check, Dabar 1/1/1/1. The most outstanding entries, M-90344, M-90362, and M-90396, will be advanced for an elite varieties yield trial planned for the 1981 summer season. Additional entries—M-90950, M-91079, M-90110, M-90328, M-90378, M-90874, M-91057, M-90347, M-90362, M-90396, M-91032, and M-90895—were selected as pollinator parents for our hybrid sorghum program.

The 1980 early-maturity SEPON of 39 progenies selected from F_4 and F_5 generations of adapted x mold-resistant crosses was sown at Wad Medani. Many of the entries yielded significantly more than the local check, Dabar 1/1/1/1. Entries M-90950, M-90874, and M-90929 performed particularly well and were selected for inclusion in the proposed elite varieties yield trial in the 1981 season. Entries M-90411, M-91057, M-90118, and M-90926 were selected as pollinator parents for hybrids.

International Sorghum Preliminary Yield Trial-1 (ISPYT-1). ISPYT-1 of 19 early-maturing advanced-generation sorghum lines from ICRISAT Center was grown at Wad Medani under irrigation. Some lines, particularly the cultivar A-3187, yielded significantly more than the standard local check, Dabar 1/1/1/1. A-3187 yielded on par with the hybrid check, CSH-6, and showed excellent adaptation under Wad Medani conditions. This line was selected along with A-6557 and A-3940 for direct advancement into the proposed 1981 elite varieties yield trial. Entries A-3732, A-6352, and A-6425 were advanced for another round of the preliminary yield trial in 1981.

The 1980 ISPYT-II, consisting of 44 advanced-generation lines of medium to medium-late maturity from ICRISAT Center, was also grown at Wad Medani. Entries A-3699, A-6392, A-4041, A-6398, A-3647, A-4028, A-3844, A-6370, and A-2612 wefe found satisfactory on the basis of maturity and agronomic score and will be tested again in 1981.

Regional trials and nurseries. A regional sorghum nursery of 530 entries made up of advanced breeding material, early-generation breeding material, BxB crosses, *Striga*-tolerant selections, charcoal rot resistant selections, F_2 populations, experimental hybrids, selected A and B lines, and F_1-generation-crossed seeds, was organized and sent to us by the ICRISAT sorghum breeder in Nigeria. Many of the entries did not attain their potential in crop expression because of late planting. Several useful selections were made at maturity both for agronomic superiority and tolerance to stem borer.

Hybrid improvement program. The prospects of an accelerated hybrid sorghum program for the Sudan are good.

In the 1980 growing season, activities in the hybrid improvement program included synthesis and evaluation of new experimental hybrids, yield trials of selected experimental hybrids, and evaluation and maintenance of parental lines.

With the assistance of ICRISAT Center and other sorghum improvement programs, we have accumulated an array of male-sterile (A and B) lines, which we continue to evaluate and characterize at our test locations. We also have a pool of several hundred pollinator lines, many of which are producing elite hybrids with excellent adaptation across locations. As our varietal improvement program is developing, advanced-generation material from our local crossing program is beginning to add to the collection of our pollinator parents.

Experimental hybrids: During the 1980 summer, 754 new experimental hybrids resulting from the sorghum crossing program were evaluated at Wad Medani, Gadambalia, and El Obeid. Of these, 70 promising hybrids were advanced as selected experimental hybrids for the multilocational yield trial in summer 1981, Tx-623-A stands out as the most promising female line.

Selected experimental hybrids: An evaluation of several hundred new experimental hybrids in summer 1979 identified 52 promising hybrids for further testing carried out during the 1980 season. On the basis of grain yield and visual adaptation scores, the entries selected in 1980 will be tested as elite experimental hybrids in a multilocational testing program in 1981.

Introduced experimental hybrids: A set of 40 experimental sorghum hybrids was received from ICRISAT Center in 1980. The hybrids were generally tall, possessed good grain quality, and looked well adapted to conditions at Wad Medani. The yields recorded in some of the entries in this trial were among the highest of all entries in nurseries conducted this season at the station. Several entries yielded significantly better than CSH-6, and all except one entry yielded higher than the local variety Dabar 1 /1 /1 / 1 . The hybrid Tx-623-A x MRO 379 recorded the highest yield (4516 kg/ha) against the local check's 1916 kg/ha.

The 23-entry International Sorghum Preliminary Hybrid Trial from ICRISAT Center was also tested at Wad Medani. These entries were well adapted and possessed good grain quality. IS-2219A x A-5032 recorded a yield of 4100 kg/ha, compared with a yield of 3833 kg/ha for CSH-6.

Pearl Millet Breeding

Pearl millet breeding work in the Sudan was carried out at Gezira Research Station, Wad Medani, and Kaba farm, El Obeid. All the international yield evaluation trials and nurseries were tested at Kaba farm. In addition, test locations at Kadugli (Southern Kordofan), El Fasher (Northern Darfur), and Dimsu and Um Rakuba (both Southern Darfur Province) were utilized for conducting multilocational national yield trials.

In January 1981 the Variety Release Committee of the Sudan approved the release of Serere Composite-2 for general cultivation and renamed it "Ugandi." This cultivar had consistently yielded about 13% more than Kordofani and 26% more than Fakiabyad, the two popular local checks, in our national yield evaluation trials during 1977-79.

In the off-season (dry season) of 1979/80, the seed of the 1979 selections was increased and 266 new crosses were made. The full-sib method of recurrent selection was initiated in the intervariety population, and 137 full-sibs were harvested for test in the 1980 rainy season. Two new synthetics were also developed from the selections of Super Serere Composite and Serere Composite-1.

National trials and nurseries. ICMS 7817 again performed well in 1980 in the Pearl Millet National Trial-4 (PMNT-4) at three locations (Table 2). IVS-A78 and ICMS 7705, which were selected from international trials of 1979, also performed well in PMNT-4. In the initial yield evaluation trials, three population progenies, IVS 8206, IVS 7190, and SCI 8003, gave relatively high yields.

Also, 311 new variety crosses, 158 F_2 populations, 1084 F3 progenies, and 91 advanced segregating progenies were evaluated in 1980. The selections will be studied in the 1981 rainy season. Work is in progress to improve the intervariety population by the full-sib method of recurrent selection and to develop a bristled population. Ten entries of the advanced breeding lines were selected for inclusion in the 1981 initial yield evaluation trial. Six entries of the inter-variety population were selected to develop an experimental variety in the off-season of 1980/81.

International trials and nurseries. In the 1980 rainy season, five international varietal trials, five observation nurseries, and one composite progenies trial were carried out. All trials except the last were sown at El Obeid.

Thirty-two entries were selected for multilocational testing in the national trials. These included 13 synthetics, 11 experimental varieties, and 8 population progenies.

Table 2. Yield data of the Pearl Millet National Trial-4 at three locations in the Sudan.[a]

Pedigree	Grain yield (kg/ha) El Obeid	Kadugli	Dimsu
ICMS 7817	477	619	433
IVS-A78	384	984	456
ICMS 7705	475	419	603
SCI-H78	456	356	332
SSC-H76	359	1252	
IVS-A75	257	440	508
Fakiabyad	384	360	522
Kordofani	133	377	309
Mean	313	546	362
SE ±	72.2	182.9	64.4
CV (%)	46	67	35.6

a. Sixteen cultivars were tested in the trial. The top six cultivars in terms of grain yield are reported here (Fakiabyad and Kordofani are local cultivars used as checks).

Regional trials and nurseries. In the 15-entry African Regional Trial, grain yields were not significantly different. Of the 20 entries in the Exchange Nursery, HV 2, HV 6, HV 7, and HV 17 were selected on the basis of head compactness and large grain size for use in the crossing program.

Senegal

Pearl Millet Breeding

The 1980 growing season started late at Bambey, where 5 ha were sown. The rainfall was only 402 mm. At Louga (274 mm) and Nioro (520 mm), 1 ha each was grown. Generally, crop growth was satisfactory.

The best material from the GAM x Indian

crosses, introductions, and our breeding program was evaluated at all three sites. Five varieties from the regional trial were superior to the local check, Souna III, for both grain yield and resistance to downy mildew. IBV 8004 yielded an average of 2445 kg/ha, significantly better than Souna III (1733 kg/ha) at all three sites. IBV 8001 was significantly better than Souna III at Bambey and Nioro. In collaborative trials with the national program, selections were made from GAM x Indian crosses and from 700516, 700651, and 1161. Several other lines were selected for direct use. R 15 and R 16 gave yields of the same order as Souna III; however, their resistance to downy mildew was greater. Nioro proved to be a "hot spot" for downy mildew, producing 100% incidence in the susceptible NHB 3, while Souna III had 42%. Mildew attack was light at Bambey and Louga.

IVS-A78 (2078 kg/ha) and ITV 8001 (2014 kg/ha) were chosen from the African Regional Trial for further testing in Senegal. Both entries are shorter statured than Souna III. Another entry, ITV 8022, was retained for incorporation in trials in late 1981, in view of its yield and agronomic traits.

Work continued on improvement of populations and selection of progeny varieties. Four experimental varieties and seven progeny varieties were selected for further testing. F_1 crosses in the synthetics trials appeared good, but F_2 populations derived from African x Indian crosses were generally unsatisfactory. Thus, overall results from the hybrid trials were not encouraging. Some progress was made in selection for smut, but unfortunately the level of attack in the smut nursery was low. Several other international trials were grown, and in the IPMAT trial, hybrid ICH 162 yielded 2647 kg/ha compared to Souna III, which ranked 10th with a yield of 2127 kg/ha. The overall trial yield was good (2081 kg/ha from the three sites).

Selections were made from 114 genotypes with high yield for use in the second phase of the GAM Corrected Indian Project. These, in general, were susceptible to disease, and the S_2 progenies will be tested at both Bambey and Nioro in the 1981 winter season.

Sorghum and Millet Entomology

Our entomologist in Senegal also covered Mali, Gambia, and some other countries.

During the 1980 growing season, we made a pest assessment on local and improved cultivars of sorghum, and studied the rearing of shoot flies, and the seasonal distribution of shoot flies, stem borers, and midge. International nurseries from ICRISAT Center and West African Regional Trial on multiple resistance of sorghum to pests were sown at Bambey and Nioro du Rip. We also prepared a report of the past 3 years' survey, including a check list of insects attacking sorghum in Senegal. In millet, ICRISAT trials planted at Bambey were evaluated for insect damage.

Both sorghum and millet crops were affected by drought during the vegetative and flowering stages. In general, pest incidence during the season was relatively low.

Surveys on research stations and farmers' fields indicated a wide range of pests attacking sorghum and millet. Armyworms (*Spodoptera* spp) were in abundance at the beginning of the crop season. Millipedes (*Peridontopyge* spp, *Tiliomus* sp, *Haplothysanus chapellei* var. *voltaensis* Marr.) and chafer beetles (*Rhinyptia infuscata*) were noticed for the first time in high numbers. Damage by chafer beetles caused a mean yield loss of 6 g/head in sorghum (CE-90) and 16 g/head in millet (Souna III). Eight hymenopteran and four dipteran parasites were recorded from larvae and pupae of insect pests.

The maximum shoot fly population was recorded in fish-meal traps during August-September, and males constituted a low proportion of the catch (2-12%). Rainfall conditions and host canopy were major factors in shoot fly population fluctuations. Fifteen shoot fly species were identified in Senegal, but only four were common: *Atherigona soccata, A. lineata, A, marginifolia, A. rubricornis. A. soccata* was reared from sorghum, millet, and wild hosts. Sorghum midge was recorded in the 2nd week of May, whereas in 1979 it was not found until the 2nd week of August. The peak adult population was observed during May-July, with low populations during October and mid-December. In 1979, peak infestation was noted between August and November. Absence of flowering heads influenced pest activity. The midge parasites *Tetrastichus* and *Eupelmus* appeared late in the season in very low numbers.

International/regional pest nurseries were evaluated at two locations. In the sorghum shoot fly nursery, a single entry, IS-1028 x R960, was selected for further investigation. The local cultivar, Congossane, was found to be susceptible. Four entries (IS-1151, IS-2205, IS-8844, and 210-P4-1-1-1) were selected from the stem borer nurseries for further use. Among locals, more larvae were found on Congossane and MN-1056. The incidence of midge was low, making evaluation of varietal performance infeasible.

Screening of the regional trial on multiple insect resistance enabled 20 entries to be selected. These entries will be tested again in 1981 for insect resistance.

From seven international/regional pearl millet improvement trials, 14 entries were found relatively tolerant to the attack of earhead caterpillars (*Raghuva* spp, *Masalia* spp). ICH 165 and Souna III were selected for studies on the mechanism of resistance, as they had showed some degree of resistance over the past 2 years.

Other African Countries

Southern Africa

The Southern African Heads of Governments at their Lusaka Summit in April 1980 urged ICRISAT to set up a Regional Center in Botswana to serve the nine Southern African Development Coordination Conference (SADCC) member-countries—Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe. ICRISAT responded in November 1980 by sending a Fact-finding Mission to examine the existing production, production constraints, and status of research and development of the ICRISAT mandate crops (sorghum, pearl millet, groundnut, pigeonpea, and chickpea) and the potential for ICRISAT's input for their improvement. The Mission visited all SADCC countries except Angola, and gathered full information on ICRISAT mandate crops in each country.

The Mission found that there is considerable potential for ICRISAT and other CGIAR Centers to strengthen research on sorghum, pearl millet, groundnut, maize, dry beans, and cassava. ICRISAT could have an immediate role in catalyzing research in SADCC member-countries by providing germplasm, information, and research technology. Initially, this is best done by posting competent staff to SADCC member-countries. It was stressed that a major element in the strategy should be identification and training of national scientists to ensure long-term continuity and follow-through on the crops and systems associated with production. The Mission also recommended development of regional projects on food crops.

Tanzania

Sorghum Improvement

The 1980 rainy season was generally favorable throughout the country, resulting in good performance of the sorghum trials and breeding material at Ilonga and several other key locations.

Local sorghum collection and evaluation. Approximately 119 local sorghum cultivars were collected from areas not previously searched. Most of these are the tall, late-maturing, photoperiodsensitive types with open panicle and good quality grain preferred for food.

A total of 306 local sorghum lines collected in 1978 and 1979 were evaluated at Ilonga. An additional 21 local varieties grown predominantly in the country were evaluated at 10 locations.

National trials. A 24-entry sorghum variety adaptation trial was evaluated at 22 locations in Tanzania. Three varieties, 2KX-17/B/1, 2KX-89, and 2KX-97, which performed well and significantly outyielded Lulu in 1979, gave good and stable yields at most locations. Mean grain yields over locations were 2700 kg/ha for 2KX-17/B/1 and 2800 kg/ha each for 2KX-89 and 2KX-97, compared to 2200 kg/ha for Lulu. The brown-seeded variety in the trial (5DX-135/13/1/3/1) yielded well (2700 kg/ha). In addition to higher yield potential, these three new, white-seeded varieties also have better grain quality, making them more acceptable for food preparation. A sorghum hybrid (ATx-623 x Lulu D) included in the trial was the highest yielder at 3300 kg/ha.

A number of variety and hybrid trials were conducted at four key locations. Promising varieties were identified for further testing.

International trials. A number of international trials from ICRISAT Center and Texas A&M University and Purdue University (USA) were evaluated at Ilonga. Varieties (SC-108-3 x Swarna) x UchV2-6-2 (CS-3541 x 1005)-1, US/R(C1)-398-2-1, and (FLR-101 x IS-1082)-4-5-2, from ICRISAT Center, gave good performance compared to the improved local check varieties. Several other good selections were made from other trials and will be utilized in the breeding program.

Varietal development. The segregating materials derived from adapted x local varieties over the past few years were evaluated at Ilonga and Hombolo. Selected progenies in the F_5 generation appeared to be uniform and stable and will be evaluated in replicated yield trials at two or three locations in 1981. Selected progenies in advanced generations have better grain quality types similar to the local varieties.

Ethiopia

In 1980 we further strengthened our links with the Ethiopian Sorghum Improvement Project. There were exchanges of germplasm, particularly sorghum. The Ethiopian Sorghum Improvement Project participated in testing several of ICRISATs international trials and nurseries. Among them were variety and hybrid yield trials.

Cooperation with CIMMYT

The primary objective of ICRISATs program in Mexico has been to develop high-altitude cold-tolerant sorghum varieties with good grain quality for tortillas. A secondary objective that has emerged in recent years is improvement of genetic material adapted to the low and intermediate elevations of Latin America.

In 1980 the International Cold-Tolerant Sorghum Adaptation Nursery (ICTSAN) was grown in Mexico, Guatemala, Salvador, Ecuador, Bolivia, Canada, Kenya, Lesotho, Rwanda, Ethiopia, Nepal, and China. Results were available only from Mexico and Ecuador at the time of preparation of this report. Of 15 selections tested in Mexico, the highest yielding line was 76BTP51 yielding 5850 kg/ha grain, compared with 3260 kg/ha for the lowest yielding line. In Ecuador, 76BT21 was the highest yielder (2120 kg/ ha), giving over 7 times the yield of the lowest yielding line. A yield trial with selected lines was carried out at El Batan (high elevation) in Mexico to study the adaptation of cold-tolerant lines and to select genotypes for the crossing program and for future on-farm tests in Mexico with the national program. The highest yielding line among the eight entries was 76BTP15, with a yield of 5150 kg/ha, about twice that of the lowest yielding line.

Breeding for early maturity (4 months) is an important aspect of our sorghum improvement program for the highest altitudes (2000 m at latitudes between 30 and 40°N). The pedigree method has been adopted for handling promising top crosses with good agronomic traits. However, to facilitate the best utilization of the material assembled by the project, populations have been created to incorporate a wide range of selected early, cold-tolerant germplasm. The Batan Cold-Tolerant Population (BCTP) has already been despatched to 10 cooperators and will be released to national programs concerned with cold-tolerant work in highland elevations. The population has material tailored for use as human food, with very low frequency of brown, high-tannin grains and a high frequency of vitreous white grains.

Good grain quality for making tortillas is an important consideration in the breeding program. Traits that are considered important to grain quality are mold resistance, sprouting resistance on the panicle, low tannin and phenol content, vitreous seed, and good cooking quality. Pearl white, round, bold seeds are characteristics used for field selection.

There has been excellent cooperation between ICRISAT and Mexico's national program at Institute Nacional de Investigaciones Agricolas (INIA) grain quality laboratory with regard to grain quality work. Food quality sorghum lines suitable for making good tortillas have now been identified and are being further improved with the cooperation of INIA.

Cooperation with ICARDA

The joint ICRISAT/ICARDA chickpea research program continued at Aleppo with the principal objective of improving the kabuli types for west Asia, the Mediterranean region, and South and Central America. The ICRISAT breeder at Aleppo was assisted by a pathologist and an entomologist from ICRISAT Center for the major part of the 1980 growing season.

Major emphasis continued on the development of cold-tolerant cultivars with resistance to ascochyta blight for winter sowing, as such cultivars show substantial yield advantage over spring sown material. Incorporation of ascochyta blight resistance into spring-sown cultivars was also attempted, as our surveys have revealed substantial losses due to this pathogen in the spring crop. Development of all types for mechanical harvesting and increased seed size for southern Europe and South and Central America continued as subsidiary objectives.

International trials. During the 1980/81 crop year, 256 sets of 10 different nurseries were furnished to 25 countries. In the Chickpea International Yield Trial - Winter (CIYT-W), mean seed yields were 60% higher than those in CIYT-Spring at two locations, illustrating the potential for winter sowing in the Mediterranean region. Some entries exceeded the yield of the local check at most locations (Table 3). However, at New Delhi the local check was much superior, indicating poor adaptation of cultivars from the Mediterranean region to North India conditions. The cultivar ILC-482 recorded the highest mean yield (2402 kg/ha), followed by ILC-249 and ILC-484. Tall types produced lower yields than conventional types. Complete data from the international nurseries will be reported separately.

Nineteen cultivars that have been performing well in international trials since 1977/78 are now being tested in on-farm or multilocation trials in eight national programs for their suitability for commercial cultivation.

Resistance to ascochyta blight. Between 1977 and 1981, 3367 kabuli and 6005 desi germplasm accessions from the ICARDA and ICRISAT collections have been screened at Tel Hadya for resistance to ascochyta blight. Twenty-two kabuli and 131 desi accessions have been found resistant.

Most of the kabuli resistant lines originated from the USSR, Turkey, Iran, and Afghanistan, the areas believed to be the center of origin of chickpea. Most of the desi resistant lines originated from Iran, India, Turkey, and Pakistan and were found to be the black seed type.

In international nurseries conducted since 1978/79, five lines (ILC-72, -191, -2380, -2956, and -3279) have shown resistance across locations and years, and others have been resistant at individual locations.

We have also observed that differences in pod damage at Tel Hadya is significant and that it is positively correlated with plant damage in Turkey ($r = 0.92$, $P < 0.01$) and Pakistan ($r = 0.75$, $P < 0.01$), which contradicts the hypothesis of race specificity and suggests the possibility of selecting at Tel Hadya for material resistant in areas where epidemics are more severe.

Breeding for spring sowing. While ascochyta blight appears to be more severe in winter-sown chickpea, surveys indicate that it is also a major cause of crop loss in the spring-sown crop.

F_2 to F_4 populations with resistance to *Asco-*

Table 3. Seed yields (kg/ha) and ranks of selected entries in ICARDA's CIYT-W, 1980/81.

Entry		ILC-72[a]	ILC-202[a]	ILC-249[b]	ILC-482[b]	ILC-484[b]	ILC-3279[a]	Local check	SE ±	Location mean	CV (%)
Cyprus											
Nicosia	Y	218	343	473	546	499	224	385	56.2	394	28.7
	R	20	13	6	2	5	19	11			
Egypt											
Ismailia	Y	861	1035	2167	1792	1306	917	1160	205.3	1244	33.2
	R	18	15	1	2	8	16	14			
India											
New Delhi	Y	1677	1010	1773	1805	1669	1286	2635	203.9	1560	26.3
	R	7	19	6	4	8	15	1			
Lebanon											
AUB	Y	715	634	1226	833	923	619	584	104.2	807	26.0
	R	12	17	1	8	6	18	19			
Terbol	Y	1781	1793	2654	2354	1929	1988	1626	87.6	1864	9.5
	R	12	10	1	2	7	5	17			
Syria											
Jinderis	Y	2344	2348	3762	4302	4011	2777	3473	306.8	2913	21.2
	R	18	17	3	1	2	12	4			
Lattakia	Y	3268	2889	3452	3406	4257	3706	0	209.1	2826	14.9
	R	7	10	5	6	1	3	20			
Tel Hadya	Y	2058	2152	0	2490	3118	2488	0	112.7	2137	10.5
	R	12	9	19	3	1	4	19			
Turkey											
Diyarbakir	Y	3005	2647	3662	3641	3134	2783	2583	111.9	3030	7.4
	R	12	18	1	2	7	17	19			
Jordan											
Marrow	Y	1355	1645	1372	2118	2154	1954	1418	262.0	1731	30.4
	R	19	12	17	4	3	6	16			
Greece											
Larissa	Y	3302	3010	4070	4063	3354	3164	1169	217.5	3359	13.0
	R	14	18	1	2	13	17	20			
Libya											
El-Safsaf	Y	1170	1440	1640	1478	1939	942		126.4	1399	18.2
	R	17	9	3	7	1	18				
Mean	Y	1813	1746	2386	2402	2358	1904				
	R	16	19	2	1	3	10				

a. Tall type.
b. Conventional type.
AUB = American University at Beirut; Y = Yield (kg/ha); R = Rank.

chyta are being advanced for further tests in 1981/82.

In initial evaluation trials, 203 of 2390 F_5 and F_6-generation lines at Tel Hadya, and 110 of 2469 at Terbol, were significantly higher yielding than the best check. The best lines yielded 40% more than the local check. Among 207 lines in replicated tests, two at Tel Hadya and eight at Kfardan gave significantly higher yields than the local check. The highest yielding lines will be included in international trials in 1981/82.

Among 69 lines in preliminary trials at Tel Hadya and 46 in advanced trials at Tel Hadya and Terbol, three were significantly higher yielding than the Syrian Local landrace.

Breeding for seed size. We made 25 crosses to combine extra large seed size (40 g/100 seed) with high yield and resistance to ascochyta blight. Thirty-four F_4 and 46 F_5 progenies were bulked for replicated trials in the 1981/82 season in breeding nurseries of 212 F_3, 122 F_4, and 243 F_5 progenies. Sixteen F3 populations of crosses were identified from the bulked produce for sowing as F_4 bulks in the off-season.

Breeding for winter sowing. In 1980/81, we screened 73 F_1 and 115 F_2 populations, 106 F_3 and 1151 F_4 populations and progenies, and 194 F_5 and 412 F_6 progenies for ascochyta blight resistance at Tel Hadya. Lines damaged by a late frost in the 1st week of April were rejected, as tolerance to frost damage is considered an important attribute in cultivars for winter sowing. We have selected 5990 single plants and 99 bulked progenies for further testing.

In an augmented trial of Ft, Fs, and Fs progenies, many were uniform, resistant to *Ascochyta,* and exceeded the yield of ILC-482 by large margins (Table 4).

Breeding for tall plant types. We have assembled more than 30 tall types, some of which are our best sources of resistance to *Ascochyta,* In a 1980/81 split plot trial of six tall, two midtall, and two conventional types at two population densities (33 and 50 plants/m^2), yields were increased by closer spacing, but differences were small except in the case of midtall types (Table 5). In contrast to the previous year, the yields of the tall and midtall types were lower

Table 4. Seed yields and *Ascochyta* reaction of the best 10 winter-sown progenies at Tel Hadya, 1980/81.

Pedigree	Seed yield kg/ha	Seed yield % increase over ILC-482	Disease reaction[a] Vegetative	Disease reaction[a] Pod
ILC-51 xILC-200	3600	93	3	2
ILC-618xILC-194	3293	66	3	3
ILC-523xILC-183	3333	86	3	2
ILC-1929 x ILC-200	3328	7	3	3
ILC-1929 xILC-200	4848	30	5	5
ILC-72xILC-897	3471	100	3	3
ILC-72xILC-897	3977	17	3	3
ILC-72xILC-897	3502	38	3	3
ILC-201xILC-571	3302	31	3	3
ILC-202xILC-893	3373	23	3	3
Mean	3603	40		

a. 1 = free; 9 = killed.

Note: SE and CV values were not calculated, as large numbers of entries were killed by *Ascochyta.*

Table 5. Seed yields of tall, midtall, and conventional types at normal (33 plants/m^2) and close spacing (50 plants/m^2) at Tel Hadya during the winter season of 1980/81.

	No. of	Yield (kg/ha)	
Growth habit	entries	33 pl/m^2	50 pl/m^2
Tall	6	1804	1950
Midtall	2	1947	2514
Conventional	2	2865	3102

CV (%)	Main plot	18.1
	Subplot	14.1
SE ±	Main plot.	62.7
	Subplot	108.1

than those of the conventional types at both spacings.

Fifty crosses of tall x conventional, tall x tall, and (tall x conventional) x tall were made in an attempt to improve the yield potential of tall types.

On-farm trials. These trials, jointly run by ICARDA and the Directorate of Agricultural Research, Ministry of Agriculture and Agrarian Reform, Syria, continued for a 2nd year in 1980/81. As in 1979/80, ILC-482 maintained its superior performance relative to Syrian Local (Tables 6 and 7).

This coming season ILC-482 will be sown during the winter at 30- and 45-cm-row spacings,

Table 6. Seed yields (kg/ha) of cultivars sown during winter and spring of 1980/81 on farmers' fields and at experiment stations in Syria.

	Winter		Spring	
Location	ILC-482	Syr. Local	ILC-482	Syr. Local
Hama Station[a]	3990	0		3580
Hama	2617	0		1442
Izraa[a]	798	438		
Homs Station[a]	703	0		350
Ibbin	1525	1391	774	897
Ram Hamdan	1534	294	880	686
ROS Alein	493	43	409	293
Kafr Yahmoul	2175	0	1978	728
Tel Tokan	631	561	640	369
Ishkibar	2083	1547	1649	1438
Zeitan Al-Masmia	1132	576	360	401
Qurbe	2698	1464	1242	897
Ataareb	2539	1113	760	727
Deir Qab	832	144	415	283
Alqamieh	1230	1169	1138	1186
Azez	902	0	852	Grazed
Jinderis[a]	2276	804		0
Kafr Antoon[a]	873	512		1177
Breda[a]	534	0		0
Tel Hadya[a]	2337	0	1681	2
Boustan El-Basha	4311	0		1511
Mean	1724	479	983	798

a. Experiment stations.

and this cultivar and Syrian Local will be planted in the spring at 45-cm spacing at 11 research stations and on 10 farmers' fields. Assuming ILC-482 maintains its yield superiority in these trials and that its resistance to ascochyta blight is adequately maintained, it is expected that it may be released by the Syrian Government for commercial cultivation in Syria by the end of the 1981/82 season.

Protein content and cooking time. The protein content of germplasm accessions ranged from 16.0 to 24.8%, and cooking time ranged from 55 to 195 minutes. Desi types took significantly less cooking time than kabuli types, and small-seeded kabuli types took significantly less than intermediate and large-seeded types. The 1981 samples of the same lines took longer to cook than the 1980 samples (60 to 170 min). Whether this was a seasonal or storage effect will be investigated.

The cooking times of seed samples of 20 chickpea lines grown at Terbol were 20% less than those of the same lines from Jinderis, with Tel Hadya lines being intermediate. Protein contents were highest in samples from Tel Hadya (26.5%) and lowest from Jinderis (17.2%).

Fellowships and Training

Training programs provided research opportunities, thesis research problems, and practical experience to agriculturalists who are interested in increased food production in the rainfed semi-arid tropics. During this $1\frac{1}{2}$-year report period, two groups, one of 47 and the other of 63 in-service trainees, completed a 6-month program in crop improvement, crop production, farming systems, research methods, and extension techniques. Fifteen short-term programs were conducted, which included activities in almost all areas of research. A total of 196 scientists and technicians from 42 countries completed individualized training programs (Table 8).

Nine international interns continue to work in our sorghum breeding (Upper Volta), pearl millet breeding, groundnut physiology, pulse virology, groundnut virology, millet microbiol-

Table 7. Mean performance of ILC-482 and Syrian Local during winter and spring on farmers' fields and at experiment stations in Syria, 1979-81.

	Winter		Spring	
Year	ILC-482	Syr. Local	ILC-482	Syr. Local
1979/80	1839[a]	988		973
1980/81	1724[b]	479	983	798
Mean	1782	734	983	886

a. Average of 18 locations,
b. Average of 21 locations.

Table 8. Countries and number of participants who completed ICRISAT's Training Program in 1980/81.

Country	Number trained
Afghanistan	1
Australia	2
Bangladesh	1
Barbados	1
Benin	1
Botswana	3
Brazil	3
Burma	2
China	8
Czechoslovakia	3
El Salvador	1
Ethiopia	7
Gambia	1
Ghana	3
India	34
Indonesia	3
Italy	1
Japan	1
Jordan	1
Kenya	12
Malawi	5
Malaysia	1
Mali	9
Mauritania	3
Mexico	1
Mozambique	2

Continued

Table 8 *Continued*

Country	Number trained
Nepal	1
Netherlands	1
Niger	11
Nigeria	2
Panama	1
Rwanda	1
Senegal	10
Somalia	2
Sri Lanka	18
Sudan	8
Tanzania	5
Thailand	9
Uganda	2
Upper Volta	10
UK	2
USA	2
Zimbabwe	1
Total	196

ogy, farming systems, and pigeonpea breeding programs.

Eight research fellows are associated with sorghum pathology, groundnut pathology and physiology, chickpea breeding, pulse microbiology, and farm machinery.

Six research scholars have thesis research problems in sorghum breeding, millet breeding, pigeonpea breeding and pathology, chickpea breeding, cropping systems, agronomy, land and water management, soil fertility, agroclimatology, socioeconomics, and groundnut microbiology.

Thirteen in-service trainees from seven countries are participating in chickpea, pigeonpea, sorghum, and pearl millet training programs. Also under way is a specialized series of training programs for small groups of scientists from India, who will assist in increasing the amount of rainy-season cropping in deep Vertisol watersheds with assured rainfall.

Followup of former trainees has resulted in increased requests for advice, literature, germplasm, and recommendations for degree training.

Workshops, Conferences, and Seminars

Training/Familiarization Workshop for FAO Project Staff. At the request of FAO, a workshop was designed to familiarize their field project staff with the ICRISAT program and research results. It was felt that this would enable staff to become effective in utilizing practical information for the benefit of countries in which they were posted. Thirty-four participants attended this workshop from 10 to 20 September 1980, at ICRISAT Center.

International Workshop on Groundnuts. The first workshop on groundnuts organized by ICRISAT was held from 13 to 17 October 1980. There were 38 participants from 20 countries. The proceedings of the workshop, as well as the abstracts produced in English and French in a separate volume, are available from Information Services, ICRISAT.

International Workshop on Pigeonpeas. The Indian Council of Agricultural Research (ICAR) and ICRISAT jointly organized this workshop at ICRISAT Center from 15 to 19 December 1980. There were 220 participants from 17 countries. The critique and synthesis, prepared by several eminent scientists in a planning session, will form the basis of future research on pigeonpeas by ICRISAT.

The proceedings were published in two volumes and are available from Information Services, ICRISAT.

International Workshop on Biological Nitrogen Fixation Technology for Tropical Agriculture. This workshop jointly sponsored by CIAT, the University of Hawaii NifTAL Project, and ICRISAT, was held from 9 to 13 March 1981, at the Centro International de Agriculture Tropical (CIAT), Cali, Colombia, and was attended by 190 delegates from 39 countries. The workshop proceedings will be published by CIAT.

Second International *Striga* Workshop. This workshop was jointly sponsored by IDRC and ICRISAT and was held in Ouagadougou, Upper Volta, from 5 to 8 October 1981. It was attended by 30 participants from both developing and developed nations. One day was devoted to a field visit, which helped the participants from the developed nations understand the severity of the problem. The in-house discussions centered around various laboratory- and field-screening techniques to identify the resistant cultivars, breeding to strengthen resistance and to transfer it to elite agronomic backgrounds, and various agronomic practices to alleviate *Striga* damage.

The workshop recommended strengthening of the breeding program, setting up complementary farming systems research to explore alternative ways of controlling *Striga,* and raising the donors' general awareness of the *Striga* problem in all possible ways. The proceedings of the workshop will be published in 1982.

Sorghum Grain Quality Symposium. The USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), ICRISAT, and ICAR jointly sponsored this international symposium at ICRISAT Center, 28-31 October 1981,asacompanion to the Sorghum in the Eighties symposium. Seventy scientists from 18 countries participated. The proceedings of the symposium are available from Information Services, ICRISAT.

SMIC workshop "Meeting the Users' Needs." The Soghum and Millets Information Center (SMIC) at ICRISAT, a special project funded by IDRC, Canada, held this workshop on 31 October 1981. Its objective was to ascertain the usefulness of SMIC to the scientific community it serves and to recommend steps required to improve and augment those services. Proceedings of the workshop are available from SMIC, Library and Documentation Services, ICRISAT.

Sorghum in the Eighties Symposium. This symposium was held at ICRISAT Center, 2-7 November 1981. Jointly sponsored by the Indian Council of Agricultural Research (ICAR), the USAID Title XII Collaborative Research Support Program on Sorghum and Millet (INTSORMIL), and ICRISAT, the symposium was attended by 245 scientists from six continents.

The proceedings, which are in press, will contain reviews of sorghum research during the seventies and projections on research priorities for the eighties, and will be available from Information Services, ICRISAT, in late 1982.

Workshop on Interfaces between Agriculture, Nutrition, and Food Sciences. This workshop jointly sponsored by the United Nations University (UNU), ICRISAT, the National Institute of Nutrition (NIN), and the Central Food Technological Research Institute (CFTRI), was held at Hyderabad, 10-12 November 1981, The inaugural session as well as the scientific sessions for the first two days were held at ICRISAT Center, and the concluding sessions on the last day were held at NIN. About 40 scientists from India, Bangladesh, Nepal, and Sri Lanka drawn from various disciplines, such as agriculture, biochemistry, medicine, food science, nutrition, food technology, administration, voluntary agencies, economics, consumer activities, and education, participated in the deliberations. The proceedings of the workshop will be available in late 1982.

International Workshop on *Heliothis* Management. This workshop was held from 15 to 20 November 1981 at ICRISAT Center, and was attended by 55 scientists from 12 countries. The proceedings of this workshop will be available from Information Services, ICRISAT, in late 1982.

Field days. To provide an opportunity for Indian breeders to see ICRISAT research and select material for further trials, the sorghum and pearl millet programs organize field days every year. In 1980/81, about 50 scientists from all over India and one from Senegal participated in sorghum field days from 29 to 30 September 1980 at ICRISAT Center. The pearl millet program conducted three field days: 24 August 1981 at Bhavanisagar for scientists from southern India, 9-10 September at ICRISAT Center for scientists from APAU and Maharashtra, and 14-16 September at Hissar for scientists from northern India.

About 100 farmers respondents from Aurepalle (Andhra Pradesh) and Shirapur (Maharashtra), where ICRISAT's Village-Level Studies are under way, were brought together during September and December to see research work at ICRISAT Center and other stations in the neighboring area.

Three chickpea breeders from peninsular India attended a consultants' meeting at ICRISAT Center during January/February 1981, while 10 scientists from northern India attended a similar meeting held at Hissar in cooperation with Haryana Agricultural University, 30-31 March 1981. The scientists visited various breeding trials and other experiments at both centers and later held discussions with ICRISAT scientists on ways of mutual cooperation for improvement of chickpeas. The scientists also selected breeding materials for use in local regional stations.

A pigeonpea breeders' meeting organized at ICRISAT Center from 7 to 9 December 1981 was attended by 21 national breeders. At Hissar, ICRISAT and Haryana Agricultural University sponsored another meeting, 19-20 October 1981, attended by 13 scientists. One representative of the University of Queensland, Australia, was at both meetings. The visitors selected materials for their own use and held wide-ranging discussions on problems of mutual interest.

Visitors' Services

During the period June 1980 to December 1981, we attracted 13760 visitors in 832 groups, averaging about 11 groups a week. As before, our biggest number of visitors was of farmers (4384) who came to see our crop improvement experiments and to get first-hand information about the new and improved farming systems technologies being developed by us. On 26 September 1981 we organized a Farmers' Day, when about 1550 farmers from Indian states visited ICRISAT Center.

Prominent visitors to ICRISAT included a European parliamentary delegation and the following officials from Indian government agencies: the Union Minister for Agriculture, New Delhi; The Chief Minister of Andhra Pradesh, along with his ministerial colleagues; the Minister for Agriculture, Madhya Pradesh; the Minister for Agriculture, Haryana; and the Minister for Mines and Geology, Bihar.

Some of the scientific and other administrator visitors to ICRISAT were: the Director General of ILCA; Assistant Director, Science and Technology, USAID; the Director of the Genetic Resources Centre, Ethiopia; a group of college presidents and chancellors, NAFEO, Washington D.C.; the Principal Secretary of Agriculture in Tanzania; the Science Secretary, National Council for Science and Technology, Kenya; the Director of Kenya Agricultural Research Station, Kenya; six Directors of Agricultural Research Stations in N E Brazil; Deputy Secretary, CGIAR, Washington; and the Executive Vice-President of the Ford Foundation. From the donor agencies, representatives came from Germany, Belgium, and ODA, England. In all, about 500 scientists visited from abroad.

A team of radio journalists of West German Radio and All India Radio came to make a documentary on ICRISAT, which was later broadcast in India and West Germany. A reporter of Radio France International also visited us to make a documentary on ICRISAT. Freelance journalists from India and from Switzerland also visited the Institute. Another important group of visitors was a party of journalists from developing countries: Tanzania, Angola, Malawi, Ethiopia, Zambia, Ghana, Bangladesh, Afghanistan, Nepal, Vietnam, etc. Two groups of journalists associated with various newspapers of Rajasthan and Gujarat also came to us to report on the achievements of ICRISAT.

RESEARCH
SUPPORT ACTIVITIES

Contents

RESEARCH SUPPORT ACTIVITIES

Plant Quarantine

Export of Plant Material

During the period under report (June 1980-Dec 1981), 73 796 seed samples of sorghum, pearl millet, pigeonpea, chickpea, groundnut, and minor millets were examined and treated at our Export Certification Quarantine Laboratory. After quarantine clearance by the Government of India phytosanitary authorities, these were despatched to scientists and cooperators in 97 countries (Table 1). Most of the seed material comprised breeding and international yield nurseries, nurseries for screening against pests and diseases, and germplasm accessions. Other crops exported were *Amaranthus, Atylosia* spp, black gram, cowpea, *Euchlaena,* green gram, *Heteropogon,* lentil, maize, safflower, and soybean. Four hundred and fifty unrooted cuttings of *Arachis* spp, 167 samples of freeze-dried sorghum leaf powder, 4 samples of dried pigeonpea flowers and pods, and 86 *Rhizobium* cultures of chickpea, pigeonpea, and groundnut were also examined in our laboratories and exported to 17 countries.

Import of Plant Material

We imported 11 439 samples of our mandate crops and other crops, including minor millets, *Atylosia* spp, *Rhynchosia* spp, *Sesamum indicum, Amaranthus, Coix, Alysecarpus vaginalis, Zea mays, Erisoma* spp, *Phaseolus* spp, from 37 countries (Table 2). These samples were released to us after examinations by the quarantine authorities at the Central Plant Protection Training Institute, Hyderabad, and the National Bureau of Plant Genetic Resources, New Delhi.

Postentry Quarantine

We raised 10 736 imported seed samples of the ICRISAT mandate crops in our Postentry Qua-

Table 1. Plant materials exports from June 1980 to December 1981.

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
AFRICA							
Botswana	581						
Cameroon	659						
Capeverde Islands			1				
Egypt	156		25	364	8		10
Ethiopia	815	21	7	950	105	75	
Gambia	143	150			1		
Ghana	680	8	107	128	49		57
Ivory Coast					7		
Kenya	2 559	202	385	236	55	1120	
Lesotho	11			128	1		3

Continued

Table 1, *Continued.*

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
Liberia			2		6		
Malawi	449	180	88	48	5		
Mali	1 766	248	20		35		
Mauritania	57	60					
Morocco			20				1
Mozambique	293	5	54		10	30	24
Niger	153	922			94		2
Nigeria	1 094	688			24		17
Rep, Du Benin					91		
Rwanda	175		6				
Senegal	1 951	1 487		4	56	29	
Sierre Leone	10		107		46		
Somalia	460	31	97		45	25	
South Africa	126	62	83				
Sudan	897	563	1	377	85		23
Swaziland	2				2		
Tanzania	102		52	64			
Uganda	68	60			148		
Upper Volta	1 749	3 193					
Zaire	15		15				
Zambia	815	135	15	16	104		1
Zimbabwe	714	217	10	10	114		
ASIA							
Bangladesh	185		375	1 749	158	300	1
Burma	207	60		331	260		9
Indonesia			29		120		223
Iraq				364			
Israel		9					
Japan	60		16	48	8		1
Jordan				189			
Kuwait		80					
Malaysia					2		2
Mauritius					43		
Nepal	107	10	280	451			110
Pakistan	717	360	16	4 751	63		332
Peoples' Rep. of China	991		1		271		8
Philippines	989	87	55	292	35		355
Qatar	7						
Saudi Arabia	15	100				60	
Sri Lanka		5		20	229		
Sultanate of Oman		10		24	25		
Syria	78			10 815			42
Taiwan	39				540		
Thailand	1 004		59		159		1003
Turkey			1		24		
Yemen Arab Rep.	168	66	109	246	34		
USSR						199	

Continued

Table 1, *Continued.*

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
THE AMERICAS							
Argentina	863			364	45	25	
Belize	48						
Brazil	717	311	74	129	4		7
Canada	10	2	52	28			208
Chile				643			
Colombia	178						
Dominican Republic			18		49		
El Salvador	704		74	15			
Guatemala	656						
Haiti	42		33				
Honduras	196	10	18	249	38		
Mexico	2 121	292		841		100	1931
Nicaragua	48						
Panama			8				
Peru		39	4	182			
Puerto Rico			1				3
Surinam	53				45		
Uruguay	228						
USA	362	413	81	1 804	325		738
Venezuela	397						
West Indies	121		48		183		
EUROPE							
Austria				2	2		
Belgium		8			3		
Bulgaria				12			
Czechoslavakia					8		
England	56	5	3	12	81	25	19
Federal Rep. of Germany	39	4	18	10	23		8
France		9	8	8			
Greece				65			
Hungary				10			
Italy	112		64	4	10		
Netherlands	2						
Portugal				1			
Romania	1					2	
Spain				197			
Switzerland							8
AUSTRALASIA							
Australia	131	44	112	542	357		15
Fiji			38				
New Zealand					50		
Papua New Guinea		5	95		95		
St.Helena Islands	46			9			
Total	28 198	10 161	2785	26 732	4380	1990	5161

Table 2. Plant materials imports from June 1980 to December 1981.

Country	Sorghum	Pearl Millet	Pigeonpea	Chickpea	Groundnut	Minor Millets	Others
AFRICA							
Botswana	230	45					2
Ethiopia	124						
Gambia	48	16			5		
Ghana	66	308			54		
Kenya	1						
Lesotho	1						
Mali	51	168					
Mozambique	44	28	10		243		
Niger	5	3					
Nigeria	64	9					
Senegal	16	5			551		
South Africa	77	22			1	17	10
Sudan	4	273			1		
Tanzania	417	11		1			
Upper Volta	36	184					
Zambia	217	25	19		82	67	
Zimbabwe		50			52		
ASIA							
Burma	4		5	5	4		
Malaysia					124		
Nepal			30	40		3	
Peoples 'Rep. of China	1				7		
Philippines			50		33	1512	
Sri Lanka			12				19
Syria				1760			
Taiwan	1						
Thailand			30				20
Yemen Arab Republic	4						
THE AMERICAS							
Canada	3						
Chile				2			
Mexico	39	9					
USA	309	649		6	510	329	
West Indies					1		
EUROPE							
England	2	35			967		
France		485					
German Dem. Republic	5	1	1	10		50	
Hungary	4						
Italy	296	137	27	10	11	56	4
AUSTRALASIA							
Australia	63		77				1
Fiji			13				
Total	2132	2463	274	1834	2646	2034	56

Postentry quarantine inspection of imported pearl millet germplasm at ICRISAT Center.

rantine Isolation Area (PEQIA). Seven hundred and three cuttings of *Arachis* spp and hybrids were grown in our quarantine net house and tested for the presence of viruses. Seedlings showing negative results were planted in the PEQIA and inspected twice a week until harvest by a joint team of the Government of India and ICRISAT quarantine staff, for destruction of material infected with exotic diseases. Seeds of healthy plants were released to ICRISAT.

Trips and Visitors

Our Quarantine Officer participated in a meeting of the Working Party on Seed Quarantine for International Agricultural Research Centers at Copenhagen, Denmark, organized by the Danish Government Institute of Seed Pathology and the Food and Agriculture Organization of the United Nations (FAO). The Working Party commended ICRISAT's quarantine facilities and recommended that similar facilities be created at other International Agricultural Research Centers.

A rewarding exchange of information was provided by the visit of the Chief Staff Officer of Plant Quarantine, United States Department of Agriculture, deputed by the FAO to evaluate quarantine facilities at International Agricultural Research Centers.

Statistics Unit

The Statistics Unit is a service unit to all ICRISAT scientists. When the statistician travels to the cooperative programs, he also provides consultancy services to national scientists. The number of requests for advice on field and laboratory experimental designs and data processing from scientists during the year averaged approximately 50 per month and ranged from detailed studies on the efficiency of different designs to reduce variability and hence obtain better estimates of parameters, to assisting with the planning of trials with single and two or more species. With the introduction of the VAX computer and the implementation of statistical packages, more detailed processing has been possible and has increased the number of data processing queries.

Several statistical packages are now in operation at ICRISAT: GENSTAT, a general statistical package for agricultural research from Rothamsted Experimental Station, England; GLIM, a package for fitting generalised linear models; and NEPLOT, a program written by Professor S.C. Pearce of the University of Canterbury, England, to analyse data by the nearest neighbor technique of "papadikas."

The unit also benefitted from a consultancy visit by Prof. Pearce to assist with variability studies, intercropping techniques, and comparison of existing multilocational testing methods. During the course of discussion, a number of practical statistical problems were raised, and the following studies were undertaken:

1. During the 1979 and 1980 postrainy seasons and the 1980 rainy season, a study was conducted with the groundnut breeding unit to investigate different types of experimental designs to eliminate soil variability in large breeding trials. Comparison of 8x8x8 cubic lattice designs with systematic checks at the center of each block of varieties showed little difference between any of the designs in reducing variation.

2. With the pigeonpea physiology unit, a study on the effect of spacing and plot size on variability was carried out on the Alfisol and Vertisol at Patancheru and on an Entisol at Hissar. The

results indicate that there were similar relationships between variance and plot size at the three plant spacings.

3. For the systematic irrigation line-source work on the two-species intercrop, a method of processing results using the bivariate factorial was developed.

4. A bivariate method of analysis was developed with Prof. Pearce for the two-species intercrop factorial design. The method was used to process data from a trial conducted at Patancheru to investigate genotypes, tillage methods, and fertilizer regimes.

During the year, the statistician made visits to the cooperative programs, the Indian Statistical Institutes in Calcutta and Delhi, and the Indian Agricultural Statistics Research Institute in Delhi. He also gave talks to the statistics unit at Osmania University, Hyderabad, and the agricultural staff in Bamako, Mali.

Publications

Conference papers

GILLIVER, B. 1981. Discussion paper on problems associated with multilocaticnal intercropping trials. Presented at the 43rd Session of the International Statistical Institute, 3-11 December 1981, ISI, Buenos Aires, Argentina.

GILLIVER, B. 1981. The design and analysis of intercropping water assessment experiments. Presented at the 35th Annual Conference of the Indian Society of Agricultural Statistics, 28-30 December 1981, Indian Society of Agricultural Statistics, New Delhi, India.

Computer Services

The Computer Services Unit provides timesharing services to ICRISAT personnel through the VAX/VMS (Virtual Address Extension/Virtual Memory Operating System) on a DEC VAX 11/780 computer system and RSTS/E (Resource Sharing Time Sharing/Extended) on a DEC PDP 11/45 computer system. The unit develops interactive software systems, installs software packages, provides data-entry services and conducts seminars on computer usage, in order to integrate the use of the computer into the daily routines of the research, administrative, and service departments of the Institute.

The VAX 111780 computer system was installed at ICRISA T Center in July 1981.

Extended breakdowns of the two disk drives RP04 on the PDP 11/45 added up to a total loss of 8 months of computing. Critical analyses were carried out on the INTEGRA system at Computer Maintenance Corporation, Hyderabad, and a similar PDP system at Bombay.

Installation of the VAX 11 / 780 system in July 1981 is the big news of the period. This has helped catch up with the backlog of work that accumulated during the extended breakdown of the PDP. The unit has carried out conversion of CRISP (Crop Research Integrated Statistical Package) and ECODEP (Economics Data Entry Program). Many additions and modifications have been made to CRISP. A number of statistical packages (BMDP, GENSTAT, GLIM, SHAZAM, and optimization package MINOS) and the CSMP simulation package have been successfully installed on the new system.

A consultant from the University of New Hampshire visited Computer Services for 6 weeks to revise the Positional Index programs and to discuss revision of CRISP to make it more transferable to other systems.

The Computer Center Director of ICARDA visited to discuss ICRISAT-ICARDA cooperation in computer software development.

The Computer Services Head attended the U.S. Fall DECUS Symposium to become acquainted with the VMS operating system. He also visited the International Rice Research Institute, Philippines, as a consultant on computer usage. Two staff members attended the annual meeting of the Computer Society of India at New Delhi in March 1981.

Looking Ahead

A new Data Management and Retrieval System, and Fiscal Accounting, Payroll, Purchase Order, and Inventory Control systems are planned for the coming year.

Library and Documentation Services

Having more or less stabilized document collection and acquisition, the Library and Documentation Services laid more stress on the service aspect during the period under report. Reading room facilities were enlarged to cope with the larger intake of trainees, who are among the most prolific users of the library.

Our library is now well equipped to meet the information needs of its clientele.

Acquisition

The acquisition of documents during the past 1-1/2 years registered a marked increase (see Table below). The figures within parentheses are the number added during the previous year:

Documents	June '80-Dec '81 additions	Total holdings (Dec 1981)
Books and reports	1 519 (837)	15 668
Hound volumes of periodicals	1 666 (664)	9 767
Annual reports	195 (57)	496
Microforms	540 (139)	1 501

This year we reviewed our periodicals subscription list and pruned it from 744 to 722 periodicals.

Reprography

A Central Reprography Unit to serve the copying needs (photocopy, mimeograph, and near-print) of ICRISAT was set up in the Library in July 1980. The average monthly output of photocopies in this unit has increased from 32 000 pages in 1980 to 100 000 in 1981. The cyclostyling/offset output during the same period has increased from 100 000 to 250 000.

With the acquisition of the Ricoh offset copier this year, most in-house reports and seminar papers are printed, collated, and stapled in the Central Reprography Unit.

Sorghum and Millets Information Center (SMIC)

The activities of SMIC have accelerated markedly. The *Sorghum Bibliography, 1970-73* is in press. The *Millets Bibliography, 1970-76* and *Sorghum Bibliography, 1974-76* have been compiled and are being edited, and compilation is nearing completion on the Sorghum and Millets bibliographies for 1977-80. A *Directory of Sorghum and Millets Research Workers* is expected to be published in early 1982. Phase I of the SMIC Project came to an end in March 1982, and a more ambitious Phase II will start in April 1982. Computerization of the SMIC data base is planned in Phase II to provide a quick and efficient service to our clientele. A 1-day workshop "Meeting the Users' Needs" was held on 31 October 1981 to evaluate SMIC's services to sorghum and millet scientists. Workshop participants recommended the continuation and expansion of SMIC services, which were considered very useful. During the past 1-1/2 years, SMIC collected 6000 bibliographical citations and 2000 photocopies on sorghum and 3850 bibliographical citations and 1200 photocopies on millets. SMIC supplied about 600 reprints running to nearly 5000 pages on specific requests from its readers.

The scope of Selective Dissemination of Information (SDI) service was broadened somewhat to include several non-ICRISAT scientists. Thirty issues of SDI service have been provided so far. The service is monthly.

Seven issues of the *SMIC Newsletter* have been brought out so far and distributed to nearly 1200 addresses. From April 1981 (issue No.5) a French version of *SMIC Newsletter* has been published and distributed to nearly 300 addresses in Francophone countries.

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R. Seshadri, Assistant Manager (Purchase & Stores)
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A. Lakshminarayana, Scientific Liaison Officer (Visitors' Services)
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K. K. Sood, Security Officer
K. K. Vij, Executive Assistant (Liaison), Delhi Office
S. Krishnan, Executive Assistant (International Cooperation)
V. Lakshmanan, Executive Assistant
N, Suryaprakasa Rao, Resident Medical Officer

Research Programs

Sorghum

L. R. House, Principal Plant Breeder and Leader
S. Z. Mukuru, Principal Plant Breeder
T. Omori, Principal Sorghum Breeder, Visiting Scientist
L. K. Mughogho, Principal Plant Pathologist
J. M. Peacock, Principal Plant Physiologist
Klaus Leuschner, Principal Cereal Entomologist
J. F. Scheuring, Principal Sorghum/Millet Breeder, Mali
C. M. Pattanayak, Principal Sorghum Breeder/Team Leader (on sabbatic leave)
J. A. Frowd, Plant Pathologist (until Aug 1981)
N. G. P. Rao, Regional Sorghum Breeder, Nigeria
J. H. MacFarlane, Principal Entomologist (Cereals), Nigeria
M. B. Boling, Agronomist (until July 1981)
Gebisa Ejeta, Principal Sorghum Breeder, Sudan
V. Y. Guiragossian, Principal Sorghum Breeder, Mexico
K. F. Nwanze, Principal Cereal Entomologist, and Acting Team Leader, Niger
K. V. Ramaiah, *Striga* Physiologist, Ouagadougou, Upper Volta
N. V. Sundaram, Principal Plant Pathologist, Nigeria (until Oct 1981)
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
N. Seetharama, Plant Physiologist
R. K. Maiti, Plant Physiologist
Suresh Pande, Plant Pathologist
Ranajit Bandopadhyay, Plant Pathologist
Shamlal Taneja, Entomologist
H. C. Sharma, Entomologist
S. P. Jaya Kumar, Administrative Assistant

Pearl Millet

D. J. Andrews, Principal Plant Breeder and Leader

R. J. Williams, Principal Plant Pathologist
F. R. Bidinger, Principal Plant Physiologist
P.J. Dart, Principal Cereal Microbiologist
S. C. Gupta, Principal Millet Breeder, Senegal
R.T. Gahukar, Entomologist, Senegal (until July 1981)
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E. J. Guthrie, Principal Cereals Pathologist, Niger
P. G. Serafini, Agronomist, Bamako, Mali
S.O. Okiror, Principal Millet Breeder, Nigeria
R. P. Jain, Principal Millet Breeder, Sudan
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K. N. Rai, Plant Breeder
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S. D. Singh, Plant Pathologist
R. P. Thakur, Plant Pathologist
S. P. Wani, Microbiologist
K. R. Krishna, Microbiologist
D. B. Godse, Microbiologist
V. Mahalakshmi, Plant Physiologist
Soman Padmanabhan, Plant Physiologist
Pheru Singh, Plant Breeder
Mrs. Nirmala Kumar, Administrative Secretary

Pulses

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D. G. Faris, Principal Plant Breeder, Pigeonpea
J. B. Smithson, Principal Plant Breeder, Chickpea
J. A. Thompson, Principal Pulse Microbiologist
H. Hirata, Principal Plant Physiologist
W. Reed, Principal Entomologist
K. B. Singh, Chickpea Breeder, Aleppo, Syria
M. V. Reddy, Chickpea Pathologist, Aleppo, Syria
D. Sharma, Plant Breeder, Pigeonpea
K. C. Jain, Plant Breeder, Pigeonpea
Onkar Singh, Plant Breeder, Chickpea
C. L. L. Gowda, Plant Breeder, Chickpea
S. C. Sethi, Plant Breeder, Chickpea
Jagdish Kumar, Plant Breeder, Chickpea
K. B. Saxena, Plant Breeder, Pigeonpea
L. J. Reddy, Plant Breeder, Pigeonpea
S. C. Gupta, Plant Breeder, Pigeonpea
N. P. Saxena, Plant Physiologist
Y. S. Chauhan, Plant Physiologist
S. S. Lateef, Entomologist
S. Sithanantham, Entomologist
C. S. Pawar, Entomologist
M. P. Haware, Plant Pathologist
J. Kannaiyan, Plant Pathologist
S. P. S. Beniwal, Plant Pathologist
O. P. Rupela, Microbiologist
J. V. D. K. Kumar Rao, Microbiologist
G. K. Bhatia, Plant Breeder, Pigeonpea

Groundnut

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D. McDonald, Principal Plant Pathologist
D. V. R. Reddy, Principal Plant Virologist
J. H. Williams, Principal Plant Physiologist
Kenji Tanaka, Principal Plant Pathologist, Visiting Scientist
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A. M. Ghanekar, Plant Breeder
P. Subrahmanyam, Plant Pathologist
V. K. Mehan, Plant Pathologist
P. T. C. Nambiar, Microbiologist
P. W. Amin, Entomologist
A. K. Singh, Cytogeneticist
D. C. Sastry, Cytogeneticist
S. L. Dwivedi, Plant Breeder
R. C. Nageswar Rao, Plant Physiologist
A. B. Mohammed, Entomologist
Mohinder Pal, Plant Physiologist

Farming Systems

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R. W. Willey, Principal Agronomist

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G. E. Thierstein, Principal Agricultural Engineer
J. R. Burford, Principal Soil Chemist
S. M. Miranda, Principal Soil and Water Engineer
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E. R. Perrier, Agronomist, Soil and Water Management, Upper Volta
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P. Pathak, Agricultural Engineer
P. N. Sharma, Agricultural Engineer
K. L. Srivastava, Agricultural Engineer
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S. K. Sharma, Senior Research Technician
Siloo Nakra, Executive Assistant

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J. McIntire, Principal Economist, Niger
Helga Vierich, Principal Social Anthropologist, Ouagadougou, Upper Volta
N. S. Jodha, Senior Economist
K. N. Murty, Economist
R. P. Singh, Economist
R. D. Ghodake, Economist
R. S. Aiyer, Administrative Assistant

Support Programs

Biochemistry

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Umaid Singh, Biochemist
V. Subramanian, Biochemist

Genetic Resources

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L. J. G. van der Maesen, Principal Germplasm Botanist
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P. Remanandan, Botanist
V. R. Rao, Botanist

Plant Quarantine

K. K. Nirula, Plant Quarantine Officer (until Aug 1981)

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

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D. V. Subba Rao, Officer in Charge (Warehouse)

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Sudhir Rakhra, Senior Engineer (Civil)
D. Subramanyam, Senior Engineer (Electrical)
S. K. V. K. Chari, Senior Engineer
A. R. Das Gupta, Engineer
D. C. Raizada, Engineer
A. E. Jaikumar, Architect

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